BEFORE THE
PENNSYLVANIA PUBLIC UTIITY COMMISSION

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PA PUBLIC UTILITY COMMISSION
SECRETARY'S BUREAU

INITIAL BRIEF OF JOHN R. STARMANN

TO

ADMISISTRATIVE LAW JUDGE
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A. STATEMENT OF THE CASE

The initial question is whether the Pennsylvania Public Utilities Commission can assist the plaintiff in motivating PECO Energy, through penalties, fines, mandates, directives or other means to force the analysis, review, equipment upgrades, system implementations, and policy changes that appear necessary to provide Power Quality that is not damaging to his equipment and that is within ANSI/IEEE standards. Not having been able to resolve in 18 months an issue that appeared to offer a straight forward engineering approach, an additional concern is whether there may be underlying and systemic issues at PECO Energy that result from a noncompetitive electrical distribution market system, that now require independent oversight and a regulatory shift in focus from Wall Street (Exelon/Constellation Energy merger, energy trading, etc.) to Main Street (or more precisely to London Tract Road).

B. EXHIBITS

A. John R. Starzmann's 8/5/10 complaint to the Commission
B. PECO Energy's 8/24/10 letter
C. PECO Energy 9/1/10 cover letter and response to the 8/5/10 complaint
D. John R. Starzmann's 9/9/10 response to Ms. Williams NEW MATTER OF RESPONDENT
E. The writer's outline for the 9/23/10 conference call with PECO Energy and subsequent 9/23/10 notes
F. The writer's 5/24/10 email to PECO Energy and PECO Energy's 5/28/10 response "we are not able to retrieve your account based on your name, account number, or telephone number you provided".
G. The writer's 5/31/10 email (second request) and PECO Energy's 6/11/10 response.
H. Commission 2010 Customer Service Performance Report that shows "0" for PECO's reported "Number of EDC Residential Disputes That Did Not Receive a Response Within 30 Days".

I. Regulation of Voltage Quality, by Bart Franken, Virendra Ajodhia, Konstantin Petrov, Katja Keller, Christine Muller, Markeets and Regulation, KEMA Consulting GmbH, Bonn, Germany
J. Electrical Power Systems Quality, Second Addition, by Roger C. Dugan/Mark F. McGranaghan/Surya Santoso/H. Wayne Beaty from McGraw-Hill Professional Engineering series, cover page and index
K. Pennsylvania PUC Electric Service Reliability in Pennsylvania 2010
L. 52 Pa. Code § 57.195(g) referenced in Exhibit K (page 2 of 9)
M. 52 Pa. Code § 57.197(a) referenced in Exhibit K (page 2 of 9)
N. ANSI C84.1 Standard Voltage Ranges
O. Power Quality & Voltage Regulation by Allegheny Power
P. IEEE 1547 Voltage and Frequency Tolerance, Interconnection Standards for distributed energy Resources
Q. Industrial Power Systems Handbook, Donald Beeman, Editor, McGraw-Hill Book Company, page 205.
R. Industrial Power Systems Handbook, Donald Beeman, Editor, McGraw-Hill Book Company, Cover Sheet, author index, and pages 114 to 143, Symmetrical Components for Three-phase Systems.
S. Industrial Power Systems Handbook, Donald Beeman, Editor, McGraw-Hill Book Company, pages 374 to 377, System Grounding.
T. Electric Power Research Institute (EPRI) Sections from Volume 8, Station Protection.
U. Single purpose GE IAC time-overcurrent electro-mechanical relay
V. SEL (Schweitzer Engineering Laboratories, Inc.) product feature comparison chart
W. Specification sheets for SEL-351 and SEL-351-5,-6,-7 multifunction relays
X. Photograph of modern switchgear with multifunction GE/Multilin and SEL-351 relays
Y. Photograph of modern switchgear with multifunction GE/Multilin and SEL-351 relays
Z. MPAC (Modular Protection Automation and Control) photograph showing application of multifunction GE/Multilin and SEL relays.

C1. SUMMARY OF ARGUMENT

On multiple occasions, the writer has reported to PECO Energy, that the voltage that is being distributed by PECO Energy is one-half that for which the system is designed. The one-half voltage is for a sustained period of time, and is outside the voltage parameters allowed by the standards. One-half voltage for an extended period of time is detrimental to equipment, particularly motors.

Although a PECO Engineer in the 1980's acknowledged the issue in a phone discussion, and the writer had anticipated that the issue would be corrected, the described low voltage condition remains some 25 years after first being reported. The latest reported incident of sustained low voltage was on 5/24/10. Rather than research and resolve the issue, PECO Energy counsel elected to object under "hearsay" and "statute of limitation". Those objections did not resolve the low voltage issue. The writer offered the background in good faith that PECO Energy would research the past to learn and improve for the future.

Responses from PECO Energy that do not acknowledge culpability are not acceptable and do not meet professional, reasonable, or ordinary criteria.

After reporting the 5/24/10 low voltage incident, PECO Energy closed out the complaint because PECO Energy, despite being provided correct contact information, could not locate the writer.

PECO Energy has not accepted the writer's suggestion on analyzing their distribution system.

PECO Energy has apparently not upgraded their distribution protection system to sense, monitor, relay, trip, record, or enhance their protection and control to preclude similar low voltage conditions.

The writer's position is that the onus for collecting, monitoring, evaluating, and documenting the magnitude of electrical parameters (voltage, current, frequency, etc.) and the duration (time) of electrical disturbances belongs with PECO Energy, not with the customer as PECO Energy suggests.

The writer contends that PECO Energy's position that customers are responsible for disconnecting and isolating motors from PECO Energy's unregulated voltage is unconventional, not practical, and wrong.

PECO Energy's lack of response, both from customer service and engineering, suggests more systemic issues within PECO Energy management that demonstrate a lack of business culture and core values that are embraced by competitive businesses and regulated utilities that have adapted ethical business standards, addressed customer first attitude, and embraced quality standards such as ISO 9000 Quality Standards.

New or revised Pennsylvania Utility Commission Performance Standards are suggested; independent system and performance reviews are recommended.

C2. ARGUMENT

For 31 years following a 9 year career with GE, the writer was with the Quality Control Department of Pacific Gas and Electric Company that is based in San Francisco. As a Senior Quality Engineer with PG&E, I was based back East, and from 1984 until retirement I resided at 515 London Tract Road in Landenberg, PA. My office was in my residence, and for the majority of the work week, I visited manufacturing facilities that were manufacturing and testing equipment for PG&E. I inspected equipment, witnessed tests, interpreted test results, assured that manufacturers were controlling their manufacturing processes, and in short assured that equipment met the specifications and contract requirements. Specifications included those written by PG&E as well as from IEEE, ANSI, IEC, etc. Our inspection work assisted in assuring the quality and reliability of equipment and systems, and in minimizing start up issues.

Our quality control work benefited the end user in the assurance that equipment was tested and met acceptance criteria. Traveling and visiting manufacturing facilities incorporated the majority of my work week, thus when I observed the one-half voltage at my residence, the condition coincided during the 1 or 2 days when I was in my office, observing the condition. I have no knowledge of low voltage conditions that may have existed when I was not home.

In my 40 years as an engineer in the power industry, I cannot recall having engineering or technical issues, such as the sustained one-half voltage condition that I have experienced on various occasions, where the seriousness of the event was not understood or a commitment was not made to analyze and resolve the issue through an engineered solution. Finding and implementing a solution was the right thing to do.

In the beginning of my utility career, the majority of the inspections were at domestic facilities. PG&E in those days was primarily a "buy American" company. As times changed and products became more difficult to obtain in the USA, the "buy American" changed to "purchase primarily in America". Today, PG&E purchases equipment worldwide, and many inspection assignments have included equipment that was manufactured in Finland, Norway, Sweden, Germany, Switzerland, Austria, France, Holland, England, and Scotland. There are some high quality power industry technical products that are no longer offered in the USA (thus my many inspection trips to Europe and Scandinavia). Also a GE colleague pointed out many years ago, in some respects the electrical transmission and distribution systems in Europe are more advanced than those in the USA because Europe had the advantage of starting over after WWII since the majority of the infrastructure had been destroyed. Systems were designed from scratch as to the voltage and type of equipment that would be implemented in the rebuilding effort. My general assessments of inspections in Europe and Scandinavia have been favorable, not only for the quality of the products, but for the engineering analysis that was provided when required.

Many manufacturers and I suspect many electric utilities, have problems and issues. What separates one manufacturer from another is the way a company understands, accepts, and proceeds to address and resolve the issues. Those that acknowledged and are determined to solve the problem are the winners.

Unfortunately, PECO Energy has been unwilling to analyze and resolve the low voltage issue, and PECO Energy's denial of a voltage issue, and the arrogant and condescending approach to have the petitioner drop the case, may be more telling of problematic issues. This opinion is based on 31 years of evaluating test results, reviewing business philosophy, observing production methods, visiting facilities, inspecting products, interviewing personnel, evaluating responses to questions, analyzing systems, and reviewing policies. It is not always what is said when the responder answers, but it is often more telling on how the responder replies or what is left out of the response.

The majority of my quality work at PG&E was with regard to inspecting equipment. A small portion of my work, perhaps less than 5%, was assigned to evaluate suppliers who were not on the approved suppliers list. This evaluation included a visit to the facility, review of how the manufacturer controls their manufacturing process, review of procedures and processes, and discussions with design, production, and quality engineers. Since PG&E would not have a dedicated product going through their system prior to the manufacturer being on an approved supplier list, our assessment work would be more along the lines of a Quality Assurance

Engineer, rather than a hands-on Quality Control Engineer. In such a function, we needed at times to make an informed evaluation based on wisdom acquired from our past experiences.

It was surprising how often a company looked good on paper, only to discover that the presentation on paper was not representative of that observed from a factory visit or firsthand observations. That is one reason why in the qualifying of safety related equipment for nuclear power plants, it is not enough to review certified test reports, but a visit to the source is required to assure the authenticity of the data.

No doubt, PECO Energy will present the Commission with statistics, charts, grafts that show how wonderful PECO Energy's reliability and service has been during the past year. I suspect that PECO may look acceptable on paper. PECO may even present a listing of the "Number of EDC Residential Disputes That Did Not Receive a Response Within 30 Days". The 2010 Performance Report showed zero for 2010, which is interesting since PECO did NOT respond to my 5/24/10 complaint because PECO could NOT locate me (see exhibit F). Eighteen months after my complaint, we are no closer to resolving the voltage issue.

An argument outlined follows:

- Background of the sustained low voltage issues
- Customer service response
- PECO Energy response shows lack of acceptable business culture or core values
- Matrix used for performance measurement
- Quality of performance data
- Who is responsible for protection of equipment and personnel against low voltage issue?
- Why low voltage is bad
- Why uncontrolled utility monopolies and lack of completion in electrical distribution require regulation

- Engineering approach starts with 1-line and 3-line diagrams
- Symmetrical components
- Analysis
- Limitation of single function archaic electro mechanical relays
- Modern multifunction micro processor based relays
- Ethics

i. Background of the sustained low voltage issues

On May 24 and May 31 2010, I reported a sustained low voltage issue with PECO's service supply. Details are provided in Exhibit A.

On 8/24/10, PECO Regulatory Assessor Patricia Batchelor sent the writer a letter [Exhibit B] that stated that a Power Quality technician had provided an explanation of the recent events that affected my circuit and explained "what systems are in place to ensure reliable power to our customers". The letter went on to state that I was "satisfied with our efforts to resolve your complaint". I telephoned Ms. Batchelor on 8/24/10 and advised that while I had spoken to a PECO representative, I was provided no details that would lead me to believe that "systems [were] in place to ensure reliable power to [PECO's] customers". Furthermore, I advised Ms. Batchelor that I was NOT "satisfied with [PECO's] efforts to resolve [my] complaint".

In the beginning of September 2010, I received a 9/1/10 document from Ms. Tishekia Williams, Counsel for PECO Energy Company [Exhibit C]. The document was addressed to the Pennsylvania Public Utility Commission and referenced John R. Starzmann v. PECO Energy Company, PUC Docket no. C-2010-2192759.

The writer's 9/9/10 response [Exhibit D] was submitted to the PUC and a copy of the 9/9/10 response was forwarded to Ms. Williams. The writer trusts that Exhibit D, and all Exhibits referenced in this Brief, will be incorporated into the record.

A 9/23/10 telephone conference between the writer and PECO Energy concluded with no resolution. The telephone conference had been suggested by the PPUC who had encouraged the parties to negotiate a settlement outside of legal proceedings. The writer's pre-telephone general outline and subsequent notes from the conference are included with this Brief [Exhibit E]. The call ended after Ms. Williams advised the writer that PECO would NOT do anything [to satisfy his complaint]. The writer responded to the effect that he recognize that he was only one person attempting to right a wrong, and he acknowledged that he did not have the leverage of a large corporation, but that PECO Energy advising that they would not do anything would not stop him from attempting to have the issue correctly resolved.

On 12/2/11 the writer discussed the general voltage concerns and customer service issues with Scott Newmann, Senior Engineer for PECO Energy. The writer replied to Mr.Newmann on 12/5/11 through Ms. Williams.

The writer's 12/5/11 correspondence that was forwarded to Mr. Newmann included the following:

> *PECO may have a system design issue. I do not believe this is an operation issue.*

PECO should review the 3-line and 1-line diagrams of the distribution system. These diagrams should show the impedance and reactance on a per unit basis. Examine diagram to determine what external disturbances could result in 0.5 per unit (50% voltage) on London Tract Road line. As a minimum, review the 4 kV and 34 kV system.

Calculate positive, negative, and zero sequence impedances, voltages, and currents. In addition to external line disturbances, examine diagram to determine what equipment malfunctions or circumstances (internal and external to the equipment) could result in 0.5 per unit voltage on London Tract Road line. For example, if a 3-phase switch was to close but one phase would remain open (mechanical failure), this may result in single phasing. Could single phasing on the 34 kV side result in 0.5 per unit voltage on 4 kV system (and 0.5 per unit at the 120 Volt panel board)?

The writer does not believe that the voltage issue is a voltage drop issue (i.e. $IR\ \mathrm{Cos}\ \varphi + IX\ \mathrm{Sin}\ \varphi$*).*

Review 34 kV and 4 kV circuit protection and relaying. Why didn't the 34 kV breaker trip during the 5/24/10 incident?

From the 9/23/10 phone conversation that writer had with PECO, the writer understood that the 4 kV breaker was an air blast type. Perhaps this type is similar to the GE Magnablast medium voltage breaker, although the writer is not familiar with the term "air blast" type of 5 kV (nominal) breaker. The writer began his power system work with GE in 1968 (GE manufactured Magnablast breakers at that time). Subsequent to the 9/23/10 PECO phone discussion, the writer consulted with ...a company that he is very familiar with and a company that has recently been supplying PG&E with switchgear. From that discussion the writer understood that the air blast breakers may have predated 1968. If in fact the switchgear predates 1968, unless the relaying has been up-dated, the protective relays are assumed to be electro-mechanical. The electro-mechanical relays are individually limited in function.

If PECO can determine through review of the 3-line and 1-line diagrams that there are circumstances under which the voltage can be 0.5 per unit, then as a minimum, SEL or GE/Multilin (or similar) multi-function relays should be installed and set to trip the line under conditions that are detrimental to the power system and residential service. These multi-functional relays are extremely flexible in function and can be set to trip under adverse voltage, current, phase

> *sequence, frequency, power flow, etc. conditions. The writer assumes that CTs and PTs necessary for the relay detection are in place.*
>
> *The operation engineers at PECO, specifically Russ, have been available and cooperative in providing details of the 5/24/10 disturbance and in describing some of the electrical equipment. The writer understands that the event of 5/24/10 that caused the low voltage was a unique event. From the writer's perspective, PECO need not focus on the specific event of 5/24/10 other that to use that event as an example, in reviewing the system design, of one condition that resulted in the 0.5 per unit voltage. As explained in the filing, there have been other similar observations of sustained 0.5 per unit voltage, caused by other events at other times that the writer observed starting in the 1980's. The writer cannot provide details or dates of these events that caused similar sustained low voltage conditions. The writer anticipates that in PECO's review of the electrical distribution system, the details of the cause and timing of these earlier issues will become a mute point in that PECO will be able, through a system analysis, to determine and predict in the future, system or equipment events that would product a similar sustained low voltage. After this review and analysis, it would only be a matter of installing the proper relay and protective equipment.*

Ms. Williams acknowledged having read the correspondence and responded "I have also reviewed the information you provided. Unfortunately, it doesn't appear that a resolution will be reach[ed] in this matter. It seems that the parties have a fundamental difference in opinion in that you believe PECO's system design is flawed, and of course PECO Energy disagrees. I am not sure a compromise can be reached on that issue" [Exhibit G].

ii. Customer service response

See Exhibit F (PECO Energy 5/28/10 response to 5/24/10 query): PECO Energy stated that they were unable to retrieve account based on name, account number, or telephone number. PECO did not call the telephone number provided. Name provided was accurate. A second request dated 5/31/10 received a 6/11/10 reply from PECO Energy [Exhibit G].

The overall customer service and response from PECO Energy is unacceptable. The fact that I provided information on 5/28/10 which was not acted on displays incompetence and a culture of not having the courtesy to follow up to obtain additional information if necessary. The inaction demonstrates a lack of a core value of taking responsibility.

A conversation from a recent power outage also displays inefficiency. A few months ago I reported a power outage, but there was no information available from PECO Energy other than to assure the writer that approximately 5000 houses were without power. I called back approximately one hour later because a home renovation construction crew had arrived without generators, and I was anxious to obtain an update as to the predicted restoration time. My return call required that I answer on the key pad the usual (name, location, telephone number, etc.). A PECO Energy spokesman then came on the phone and asked the same questions that I had punched in on the key pad. Then the PECO Energy spokesman repeated each answer to the questions that I had just punched into the key pad and had just answered to his query, and required that I acknowledge each answer that had just been submitted twice!

A more efficient customer service system would have identified the information that was already provided and been able to update outage report and direct the issue to the proper department.

iii. PECO Energy response shows lack of acceptable business culture and disappointing core values

The writer has been fortunate to work for two employers during his 40 year career that have professed and implemented core values and business culture that have reflected and included continuous improvement, professionalism, flexibility, excellence (disclosure: the writer was the recipient of PG&E's first ECON --Engineering and Construction—Excellence Award), efficiency, trustworthiness, respect, responsibility, and fairness. The PG&E culture – the organization, the operation, the respect for consumers, and the attitudes—were vastly different than that demonstrated by PECO Energy. While this culture was a reflection of management, to some extent the California Public Utilities Commission may have provided an influence on how PG&E conducted business. For *instance the CPUC encouraged PG&E to purchase from minority owned and woman* owned business. Other California regulatory agencies were influential in the installation or modification of equipment, for example the installation of variable speed drives for use on condenser water circulating pump motors to protect small fish or the installation of an Archimedes screw pump for use as a fish ladder. The writer appreciates the services that regulatory agencies provide in the protection of people, animals, and the environment.

iv. Matrix used for performance measurement

PECO Energy has been provided 18 months to analysis and resolve the one-half voltage issue but has clearly expressed no interest in a resolution. The writer is not aware that he has had any discussion with PECO Energy Substation Engineering since correspondence has either been with operations, Scott Newmann (regulatory affairs?) and PECO Energy counsel Ms. Williams. In a Pennsylvania Public Utility Commission "Customer Service Performance Report 2010" (Exhibit H) the writer observed that for 2010 (and 2009) the "Number of EDC Residential Disputes That Did Not Receive a Response Within 30 Days" was "0". This is interesting based on my reporting of the one-half voltage issue on 5/24/10. The response for my 5/24/10 dispute resulted in PECO Energy closing out the complaint because despite the fact that I provided my name, account number, and phone number, PECO Energy could not locate me. PECO Energy was able, however, to locate me during the month of May 2010 to send me a bill. My 5/24/10 complaint did not prevent PECO Energy from providing themselves a perfect grade in the residential dispute response time category, because within 30 days PECO Energy closed out the complaint after allegedly not being able to locate me! Yet, eighteen months after my complaint, we are no closer to resolving the voltage issue.

Performance monitoring is a more meaningful tool in the evaluation of power quality than the response time of disputes, the results of which the writer has already suggested are suspect.

Exhibit I is a paper entitled *Regulation of Voltage Quality* that was presented at the 9th International Conference, Electrical Power Quality and Utilization conference. The Abstract and Introduction include the following:

> *This paper provides an appraisal of what regulators need to consider in establishing an effective voltage quality regulatory framework for distribution networks. In particular, the paper considers the regulation of five voltage quality dimensions: short interruptions, voltage dips, flicker, supply voltage variation, and harmonic distortions. The paper assesses the most appropriate regulatory control method and presents practical experiences through a number of case studies.*

> *Complementary to price, quality is an important feature of the electricity service provided to customers. Price and quality together define the value that customers derive from consuming electricity. However, electricity utilities may not necessarily be provided with a balanced set of incentives to provide both good price and quality. Strong incentives for higher efficiency and cost awareness may potentially lead to reduction of quality. Therefore, quality regulation is becoming a crucial requirement in the light of the widespread regulatory policy of (incentive based) price regulation. Quality regulation is important to provide incentives to network operators to not only become more efficient, but also to maintain or improve the quality level offered to customers.*
>
> *Until now, the main focus of quality regulation has been on the reliability and commercial dimensions of quality. In contrast, there is far less experience with the issue of voltage quality regulation. Voltage quality is however becoming increasingly important to customers due to increasingly sensitive electronic devices. At the same time, voltage quality levels are in turn affected by the increased use of such devices. Thus, voltage quality deserves particular attention although being notably more complex to implement than the conventional measures of quality regulation. This is mainly due to the multi-dimensional nature of voltage quality and the inherent difficulties in measurement. Nevertheless, there is a trend of regulators becoming more aware of the need for voltage quality regulation. Steps have already been taken into that direction. This paper pursues this path and assesses the issue of what regulators should consider when establishing a voltage quality regulatory framework for distribution networks.*

Excerpts from Roger Dugan's *Electric Power Systems Quality 2nd Edition* [Exhibit J] include the following from the introduction:

> *Both electric utilities and end users of electric power are becoming increasingly concerned about the quality of electric power. The term "power quality" has become one of the most prolific buzzwords in the power industry since the late 1980's. It is an umbrella concept for a multitude of individual types of power system disturbances. The issues that fall under this umbrella are not necessarily new. What is new is that engineers are now attempting to deal with these issues using a system approach rather than handling them as individual problems.*
>
> *Since the first edition of this book was published, there have been some developments that have had an impact on power quality:*
>
> 1. *Throughout the world, many governments have revised their laws regulating electric utilities with the intent of achieving more cost-competitive sources of electric energy. Deregulation of utilities has complicated the power quality problem. In many geographic areas there is no longer tightly coordinated*

> *control of the power from generation through end-use load. While regulatory agencies can change the laws regarding the flow of money, the physical laws of power flow cannot be altered. In order to avoid deterioration of the quality of power supplied to customers, regulators are going to have to expand their thinking beyond traditional reliability indices and address the need for power quality reporting and incentives for the transmission and distribution companies.*

4. Indices have been developed to help benchmark the various aspects of power quality. Regulatory agencies have become involved in performance-based rate-making (PBR) which addresses a particular aspect, reliability, which is associated with interruptions. Some customers have established contracts with utilities for meeting a certain quality of power delivery. We have added a new chapter on this subject.

What is power quality? There can be completely different definitions for power quality, depending on one's frame of reference. For example, a utility may define power quality as reliability and show statistics demonstrating that its system is 99.98 percent reliable. Criteria established by regulatory agencies are usually in this vein. A manufacturer of load equipment may define power quality as those characteristics of the power supply that enable the equipment to work properly. These characteristics can be very different for different criteria.

Power quality is ultimately a consumer-driven issue, and the end user's point of reference takes precedence. Therefore, the following definition of a power quality problem is used in the book: "Any power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipment."

When there is a power problem with a piece of equipment, end users may be quick to complain to the utility of an "outage" or "glitch" that has caused the problem. However, the utility records may indicate no abnormal events on the feed to the customer. We recently investigated a case where the end-use equipment was knocked off line 30 times in 9 months, but there were only five operations on the utility substation breaker .... but the utility will have no indication that anything was amiss on the feeder unless it has a power quality monitor installed.

In response to this growing concern for power quality, electric utilities have programs that help them respond to customer concerns. The philosophy of these programs ranges from reactive, where the utility responds to customer complaints, to proactive, where the utility is involved in educating the customer and promoting services that can help develop solutions to power quality

> *problems. The regulatory issues facing utilities may play an important role in how their programs are structured. Since power quality problems often involve interactions between the supply system and the customer facility and equipment, regulators should make sure that distribution companies have incentives to work with customers and help customers solve these problems.*
>
> *Power quality, like quality in other goods and services, is difficult to quantify. There is no single accepted definition of quality power. There are standards for voltage and other technical criteria that may be measured, but the ultimate measure of power quality is determined by the performance and productivity of the end-user equipment. If the electric power is inadequate for those needs, then the "quality" is lacking.*
>
> *Power Quality = Voltage Quality. The common term for describing the subject of this book is "power" quality; however, it is actually the quality of the voltage that is being addressed in most cases. Technically, in engineering terms, power is the rate of energy delivery and is proportional to the product of the voltage and current. It would be difficult to define the quality of this quantity in any meaningful manner. The power supply system can only control the quality of the voltage; it has no control over the currents that particular loads might draw. Therefore, the standards in the power quality area are devoted to maintaining the supply voltage within certain limits.*

v. Quality of performance data

The writer suggests a review of the benefit of the 30 Day Dispute Matrix. Data collected in this matrix appears to allow PECO Energy to immediately close out a dispute on the fabricated ground that they cannot locate the source. Why not have goals of analyzing resolving disputes? Why not have goals that are case based and would allow the replacement of aging equipment and goals that mitigate repeatable problems such as one-half voltage conditions. Equipment is assumed to be the source of the largest cause of PECO outages (Exhibit K); why not require PECO Energy to provide a list of equipment that document age, type, and manufacturer, and mandate an accelerated replacement program that would modernize their distribution system and include new technologies?

Why not provide independently monitored accountability standards that would compliment customers' requests to analyze and fix outdated systems?

Exhibit K includes the following:

> *If any electric distribution company's reliability performance does not meet Commission standards, the Commission may require a report discussing the reasons for not meeting the standard and the corrective measures the company is taking to improve performance [Exhibit L]. In addition, Commission staff may initiate an investigation to determine whether an electric distribution company is providing reliable service [Exhibit M].*

In the writer's role in evaluating companies before he retired, it was surprising how often a company looked good on paper, only to discover that the presentation on paper was not representative of that observed from a factory visit or firsthand observations.

Most likely, PECO Energy will present the Commission with statistics, charts, grafts that show how wonderful PECO Energy's reliability and service has been during the past year. I suspect that PECO may look okay on paper. PECO may appear satisfactory on paper in the category of "Number of EDC Residential Disputes That Did Not Receive a Response Within 30 Day".

This perfect record for residential disputes is an example on how meaningless the parameter may be in identifying and resolving a serious one-half voltage dispute. There does not appear to be any independent enforcement that would provide the Commission with documented evidence to the contrary.

The existing performance matrixes do not provide justice for the serious issue of repeated sustained low voltage. Exhibit K Figure 15, *PECO Customer Average Interruption*

Duration Index (minutes), does not attempt to differentiate the "0" voltage outage (disruptive but not damaging due to what could have been a one-half voltage conditions) from one-half voltage (potentially damaging conditions).

It is not clear how the Pennsylvania Public Utility Commission investigates, monitors, inspects, and otherwise assures the accuracy of the data that is associated with the documented results, but the writer suggests that an independent quality review may be required to separate the shaft from the wheat.

vi. Who is responsible for protection of equipment and personnel from sustained low voltage issues?

The writer disagrees with the position that PECO Energy has taken: that the customer is responsible for protecting motors during sustained low voltage conditions. The 6 or 7 neighbors that live on London Tract Road between the intersection of Good Hope/Broad Run and Glen Road are not electrical engineers and may not understand how to recognize 50% voltage (other than to observe low lumens from the light bulbs), how to measure the voltage, how low voltage damages equipment (especially motors), nor are they necessarily home to observe low voltage incidences if they are away at work.

PECO Energy has taken the position that the customer, the end user of their service, needs to take protective action to protect motors if the power quality to the residence (or industry?) is outside the ANSI/IEEE limits and may cause harm to equipment. PECO Energy apparently takes this position even when voltage is outside the standards. The writer has not been able to resolve the low voltage issue directly with

PECO Energy, even after offering an incentive carrot in his suggestion on how PECO Energy may analyze and resolve the issue. The carrot is no longer on the table, but the writer appeals to the Commission to use a stick (monetary or other penalty) if necessary to force PECO Energy to meet industry standards. The writer's position is that when power quality conditions cannot meet standards, instrumentation and relays should interrupt the circuit to preclude damage to equipment and unsafe conditions. Damage to equipment includes a reduction to the expected life of the equipment.

Exhibit N is a summary of the allowed voltage ranges that are established in ANSI C84.1 Standard. Exhibit O is information from Allegheny Power on Power Quality & Voltage Regulation. Exhibit P summarizes IEEE 1547 Voltage and Frequency Tolerances.

vii. Why low voltage is bad

Among the many reasons for the need for regulations and standards for electrical equipment is the necessity to ensure the electrical safety of personnel (workers, consumers and the general public), provide consumer protection, ensure a safe supply of electricity, and to establish minimum and consistent standards for equipment and power systems to assure compatibility.

Voltage and current both need to be considered in the design of electrical equipment. There are various conditions in which electrical parameters outside of nominal parameters can have deleterious effects on equipment, safety, and personnel. Sustained low voltage is one of these conditions.

The writer has various motors in his residence, including a well pump motor, multiple water circulators for a heating system, HVAC fan circulating motors, exhaust fan, refrigerator compressor motors, and air conditioner compressor motors.

Electrical equipment is designed to operate within nominal electrical design parameters that are established by ANSI/IEEE (American National Standards Institute, Institute of Electrical and Electronic Engineers), or in some cases IEC (International Electrotechnical Commission).

System and component design are based on an assumption that various electrical parameters that include voltage and frequency will fall within the guidelines established by IEEE, ANSI, IEC, or other standards..

In the Industrial Power Systems Handbook (Exhibit Q) the general effect of voltage spread on utilization equipment is described as follows:

Whenever the voltage at the terminals of a utilization device varies from name-plate rating of the device, something is sacrificed either in life or performance of the equipment. The effect may be minor or serious, depending upon the characteristics of the device, how the device is applied, and the amount the voltage deviates from the device rating.

Principal Effects of Low Voltage on Induction Motors.
The most significant effects of too low voltage are reduction in starting torque and increased full-load temperature rise. The reduction of starting torque may be significant in motor applications driving high-inertia equipment. The lower torque will result in longer acceleration periods. Torque motors are also very materially affected by reduced

voltage as the torque decreases as the square of the voltage; thus at 10 percent below normal voltage, the torque is reduced 19 percent.

The increased heating at low voltage and full load reduces the life of the insulation.

At 50 percent below normal voltage, the percentage of under voltage that is the basis of this complaint, the torque is reduced 75 percent.

The 50% voltage that the writer has experienced over the years is lower than that allowed in ANSI C84.1 Standard.

viii. Why monopolies and lack of completion in electrical distribution are bad

When PECO Energy decrees that they will not analyze the system, will not provide under voltage relaying, will not upgrade their system, will not structure their distribution system to preclude sustained low voltage conditions, then that is a sign of a monopoly who understands that the writer has no choice other than to disconnect from the grid and generate his own power. If there were competition and choice in the selection of who distributes power to my residence, the writer submits that PECO Energy may find that a change in attitude would be required to retain customers.

The writer has proposed that regulation changes focus from Wall Street (Energy Trading, Exelon/Constellation Energy merger) to Main Street (or more specific electrical distribution system to London Tract Road). Exhibit I referenced above in section iv includes a discussion on how Europe is addressing the regulation of voltage quality.

ix. Engineering approach starts with 1-line and 3-line diagrams

The writer had the privilege of working with 5 of the authors of the Industrial Power Systems Handbook, a portion of which is attached in Exhibits Q, R, and S. It may be helpful if the Commission understands the basic concepts of relaying and circuit protection. The analysis starts with 1-line and 3-line diagrams of the system. These diagrams have information such as impedance, voltage, transformer rating (e.g. 500 MVA), transformer connection (e.g. delta-wye), etc. In Exhibit R, an example of a 1-line diagram is shown on the top of page 141; an example of a portion of a 3-line diagram is shown on page 143. Three-line diagrams are called 3-line, because the three lines of a 3-phase power system are shown.

x. Symmetrical components

From the 1-line and 3-line diagrams that are outlined above, through a system that separates electrical vectors into components to simplify calculations, an electrical system can be analyzed. Pages 114 through 143 of Exhibit R provide additional information on symmetrical components.

Exhibit T includes a few introductory pages from Electric Power Research Institute (EPRI) Station Protection section (Volume 8) from a Power Plant Electrical Reference Series. Included in EPRI volume 8 is the following:

> *Application of protective relaying is a complex field that requires a broad knowledge of power system equipment and its behavior during both normal and abnormal conditions. The purpose of protective relaying is to promptly remove equipment from the system during abnormal conditions while ensuring its availability during normal operation.*

The application of protective relaying for a power plant is better understood once the basic logic is defined. It is necessary to know complex equations and rotating vectors in order to master the field of study.

Apart from the overcurrent devices described earlier, undervotage relays play an equally important role in the overall protection and availability of the auxiliary power system. A three-phase negative-sequence (phase-balance) relay provides blown-fuse protection for the voltage transformers used for these relays. A blown fuse creates enough negative-sequence voltage to be sensed by these relays. The presence of negative-sequence voltage is also possible due to certain external faults; therefore, output from these relays is used in logic.

xi. Analysis

The writer has been unsuccessful in having PECO Energy analyze their system. In his conclusion with requested relief, the writer will recommend that the Commission mandate that PECO Energy have an independent source study and analyze their system to the types of system disturbances that may produce one-half voltage conditions. This proposed report should conclude with recommended relaying and upgrades to the PECO Energy distribution system.

The writer anticipates that the requested study will determine scenarios or conditions when one-half voltage exists, and the analysis should be able to recommend protective relays that will protect the circuit. As an example of an analysis, in the middle of page 376 in Exhibit S is a vector diagram that shows a situation where the voltage from an electrical neutral to any point on the winding is between 50% and 100% and the vector diagram demonstrates where the internal voltage can be 50%.

The cause of the reported sustain one-half voltage may be as simple as a single-phase condition on a 3-phase line, or an ineffective ground, or an internal winding failure.

The study should find the cause; the analysis should be able to provide recommendations for protective relays.

xii. Limitation of single function archaic electro mechanical relays

Although PECO Energy has not provided details on the type and age of the relays on the distribution system that feed the writer's service panel, the writer has inferred from general PECO Energy comments that the relays are time overcurrent electro-mechanical relays, similar to a GE IAC relay shown in Exhibit U. Electro-mechanical relays were common prior to the modern electronic relays. Electro-mechanical relays still remain in operation and provide protection for circuits, but the relays are generally single function relays, do not have the flexibility of modern relays, may not operate as quickly as modern relays, do not have the communication interface, and do not have the data collection and display abilities. And time-overcurrent relays do NOT provide undervoltage protection!

xiii. Modern multifunction processor based relays

The first electronic overcurrent relay was developed in the 1970's, but the recent advent of micro processors has brought a new generation of flexible (in function) multipurpose relays. Modern relays are essentially microprocessors or computers.

The typical modern switchgear (electrical equipment that includes relays and circuit breakers) that the writer has been inspecting includes redundant multifunction relays (one set from Schweitzer Engineering Laboratories and the other from GE/Multilin). These relays are integrated into a relay and control system that includes an Arbiter satellite clock to provide a time stamp, an HMI (Human Machine Interface), SCADA (Supervisory Control and Data Acquisition system), and communication system. A Digital Fault Recorder (DFR) can also be incorporated to collect additional data. A summary of the multiple functions of SEL relays is shown in Exhibit V. The multiple functions of the SEL-351 that was suggested by the writer are outlined in Exhibit W. Note that the SEL-351 includes undervoltage protection. These modern relays also have the ability to collect and provide PECO Energy with details (voltage and time) on undervoltages and trip breakers to isolate distribution lines when damaging undervoltage (and other) conditions exist.

Exhibit X is a photograph of modern switchgear with GE/Multlin and SEL-351-6 relays. On the three cabinets on the left, the top device is a GE/Multilin multifunctional F35 or F60. Under the GE/Multilin relays are two rows of test switches, followed by a SEL-351-6 multifunctional relay, followed by two rows of test switches. Exhibit Y shows more multifunction GE/Multilin and SEL relays mounted in modern switchgear. Exhibit Z shows similar relays in a MPAC (Modular Protection Automation Control) building.

The application of a modern relay similar to the SEL-351 is not a straight forward process of removing an old GE IAC relay to be replaced (in kind) with a modern relay. The modern multifunctional relays need to be programmed and integrated into a modern protective and control system, which would require capital investment as well as a trained staff to engineer, program, and maintain the equipment. Perhaps this is the reason that PECO Energy has not been cooperative in analyzing their low voltage issues.

If the staff is not available to analyze and implement a modernization program, the writer suggests that a portion of the work could be contracted. In 1970 the writer worked in the Energy Systems Operation in Building 6 in Schenectady, and at that time a similar Electric Utility Sales Operation was in Building 2. If GE still offers these services, that may be a place to start for a system analysis. Schweitzer Engineering Laboratories may also be able to assist. More recently before retiring, the writer was a quality advisor on a MPAC (Modular Protection and Control) committee. Many of the MPAC projects were purchased under an EPC (Engineer, Procure, Construct) contract with Black and Veatch. B&V engineers are familiar with the programming and installation of SEL (and other) relays.

xiv. Ethics

In the years prior to my retirement, PG&E business culture and core values were reflected in required annual training and refresher classes that included safety and ethics. Based on PECO Energy's lack of culpability, the writer suggests that the Pennsylvania Public Utility Commission consider mandating that all PECO Energy employees receive ethics training.

The writer recalls that in our first ethics training session the instructor asked the class how they would define *ethics*. After a lively class discussion, *Ethics* was subsequently defined and clarified as not doing what you were required to do, not doing what you needed to do by contract, not doing only what you were obligated legally to do. *Ethics* was about doing the *right* thing. The writer proposes that PECO Energy has not done the *right* thing as demonstrated by their response to the low voltage issue.

C. CONCLUSION

The writer has been unsuccessful in having PECO Energy analyze their system and recommends that the Commission mandate that PECO Energy have an independent source, study and analyzes their system to the types of system disturbances that may produce one-half voltage conditions. This proposed report should conclude with recommended relaying and upgrades to the PECO Energy distribution system.
The writer anticipates that the requested study will determine scenarios or conditions when one-half voltage exists, and the analysis should be able to recommend protective relays that will protect the circuit.

The single function time overcurrent electro-mechanical relays that the writer understands are typical of the relays that are on PECO Energy's distribution lines that connect the writer to the grid, are archaic and reflect technologies that predate the 1970's. A new generation of modern multifunctional relays provides many added capabilities, including under voltage protection, communication, and data collection. PECO Energy should upgrade their distribution, and transmission lines if required, with these modern high technology devices.

If PECO Energy does not have a professional staff available to analyze and implement a modernization program, the writer suggests that all or a portion of the work be subcontracted. As noted below, there may be another reason other than lack of staff for this analysis to be subcontracted to someone other than PECO Energy.

Developing the diagrams, calculating the results, analyzing the data, engineering a solution, implementing the relaying and circuit protective devices needed to provide quality power may be the easy part. Gleaned from 18 months of correspondence with PECO Energy is the writer's opinion of more sinister issues.

The follies with PECO Energy customer service would be humorous if not for the serious fact that damaging one-half voltage was being reported. PECO Energy through instrumentation, relays, and SCADA should have been aware of the low voltage condition and immediately taken action.

PECO Energy purporting that the writer refused access to a PECO technician is simply not true. Ms. Batchelor's 8/24/10 letter stating that I was "satisfied with our efforts to resolve your complaint" was also not accurate. PECO Energy, despite having my name, phone number, and account number stating that they were unable to contact me was a similar scenario. PECO Energy providing the Commission with information that suggests a perfect grade in the 2010 residential dispute response time category may also be misleading.

PECO Energy has shown a credibility gap, and because of this PECO Energy's statement that there is nothing wrong with their system design cannot be validated unless there is a review by independent professional engineers.

PECO Energy does not accept culpability when advised that I measure one-half voltage for an extended period of time. PECO Energy does not accept a responsibility to analyze their system, to provide quality power that meets ANSI Standard C84.1. Had PECO Energy recognized their culpability, PECO Energy would have researched who the writer may have spoken to in the 1980's, PECO Energy would have reviewed what conditions existed in the 1980's that exist today that may cause the low voltage condition, and PECO Energy would have honored, if not humored, the writer by proceeding with an engineering evaluation. The issue was not solved because PECO Energy does not accept culpability with the one-half voltage issue.

The carrot approach for a resolution has not worked, and the stick that is probably needed for motivation and improvement is most likely a penalty that costs PECO Energy money. PECO Energy customer service needs massive improvement, according to PECO Energy's statistics the equipment failures is the largest cause of outages so modernization and upgrades appear to be required to improve power quality, core values need to be assessed, a new mind set needs to be instilled and a new culture established. There seems to be room for improvement on the parameters that have been established for electric service reliability. An independent review of the supporting data that PECO Energy provides for the reliability report may be required. Similarly an independent analysis of

PECO Energy's distribution system, including a review of the type and age of installed equipment appear to be also necessary in order to improve power quality and reliability.

While the writer does not propose that the Commission can mandate morality, if the Commission agrees that ethics is about "doing the right thing", then the writer suggests that PECO Energy has demonstrated a general disregard for ethics in the manner in which this dispute has been conducted. PECO Energy has not accepted culpability in the low voltage issue. These deficiencies may be more difficult to regulate, although after further review, a mandate on ethics training or monetary penalty may be appropriate.

The writer has come away from these issues with one positive feeling: that there is a regulatory body that is dedicated to hearing and resolving disputes. I appreciate the forum, for without the Commission, the petitioner would have nowhere to review the issues since PECO Energy has not been willing to resolve the issue directly.

Respectfully submitted,

John R. Starzmann, P.E.
515 London Tract Road
Landenberg, PA 19350
Phone: 610-274-8557
E-mail: mcstarz@aol.com

January 2, 2012

August 5, 2010

John Starzmann
515 London Tract Road
Landenberg, PA 19350
phone: 610-274-8557
mcstarz@aol.com

Secretary
Pennsylvania Utility Commission
PO Box 3265
Harrisburg, PA 17105-3265

On May 24 and May 31 2010, I reported a sustained low voltage issue with PECO's service supply as follows:

"On occasion for 25 years, I have had sustained low voltage. I measure 65 volts on my 120 volt circuits. This was reported and discussed with a PECO engineer in the mid-1980's and the situation was apparently understood but not resolved. On 5/24/10 I again reported a one-half voltage issue that required that I disconnect the main [circuit breaker] at the panel to preclude damage to well pump and refrigeration compressor motors... With SEL351 and GE/Multin F60 multi-function relays common place in modern distribution systems, why cannot PECO apply protective relays and switchgear to preclude sustained damaging low voltage and other damaging power conditions? I would like to have details on the latest low voltage problem and [be advised] what is being done to permanently correct the situation. "

The one-half voltage issue that I am referencing is a condition that lasts for hour(s), not seconds or minutes.

My timely 5/24/10 emergency report to PECO (within several minutes) and PECO's SCADA and report documentation should provide the Pennsylvania Utilities Commission with specific timeline and detailed voltages. My voltage measurements were determined with an analog Amprobe.

The complaint should be resolved a follows:

A. PECO shall install protective relays and switchgear or circuit breakers on the distribution system to preclude low voltage, single phase, and frequency issues and to insure reliable and quality power. In addition, a distribution system that allows selective transfer, preferably automatic transfer, to an alternate firm and reliable power source should be incorporated into the system design.
B. PECO shall establish operating and maintenance/repair procedures to preclude low voltage, single phase, and frequency issues when PECO or their contractors are working on distribution and transmission lines.
C. PECO shall establish procedures that will resolve described issues promptly, including follow-up contact with the complaint source.

EXHIBIT A
1 OF 2

As of August 5, 2010 the limit of PECO's response has been the following:

A. First response (5-28-10 response to 5-25-10 query): PECO stated that they were unable to retrieve account based on name, account number, or telephone number. PECO did not call the telephone number provided. Name provided was accurate.

B. Second response (6-11-10 response to 5-31-10 second request): "We have processed an emergency request to have your voltage issue investigated …Moving forward, please contact our Emergency Services Department regarding this issue at 1-800-841-4141 …Have a nice day!"

Suggestion: A Pennsylvania Utility Commission representative should call and audit the 1-800-841-4141 number to see if they are able to reach a person. My experience has been that this phone number generally has an automatic response to push phone telephone buttons in answer to prerecorded standard questions; not to follow-up with a discussion with a PECO representative.

This complaint is not about light flickering or intermittent voltage surges of short duration such as when PECO is switching or operating transformer tap changers. For a consumer to experience sustained low voltage conditions 25 years after a similar issue was reported is unacceptable. Motors and other equipment are designed to operate within IEEE/ANSI power quality standards. A voltage supply of one-half voltage for hour(s) does not meet those standards. PECO's power quality, procedures and response are unacceptable.

John R. Starzmann

A
2 OF 2

PECO.
An Exelon Company

PECO Energy
2301 Market St.
Philadelphia, PA 19101

John R. Starzmann
515 London Tract Rd
Landenberg PA 19350

August 24, 2010

RE: Account # 45123-01701

Dear Mr. Starzmann:

Regarding your Formal Complaint filed with the Public Utility Commission (PUC) at Docket #C-2010-2192759. The following information may help to resolve your complaint:

- A Power Quality technician spoke with you on 8/23/10 regarding the low voltage concerns you expressed were occurring at your property.
- The Power Quality technician provided an explanation of the recent events that affected your circuit and explained what systems are in place to ensure reliable power to our customers.
- You agreed that there was no need to set a meter to record/monitor the voltage at your home due to the nature of the events and were satisfied with our efforts to resolve your complaint.

If you are satisfied with this resolution, and there is no need to further pursue this matter please contact me at (215) 841-5856 or the attorney of record, Tishekia Williams at (215) 841-6841.

Cordially,

Patricia Batchelor

Patricia Batchelor
Regulatory Assessor

EXHIBIT
B

Exelon.

Legal Department

Exelon Business Services Company
2301 Market Street/S23-1
P.O. Box 8699
Philadelphia, PA 19101-8699

Telephone 215.841.4000
Fax 215.568.3389
www.exeloncorp.com

Business Services Company

Direct Dial: 215.841-6841

September 1, 2010

John R. Starzmann
515 London Tract Road
Landenberg, PA 19350

Re: **John R. Starzmann v. PECO Energy Company**
PUC Docket No. C-2010-2192759

Dear Mr. Starzmann:

Enclosed is a copy of PECO Energy Company's response to the formal complaint filed in the above-referenced docket. The law requires PECO Energy to file an answer to your Public Utility Commission complaint. Keep these papers for your records. This is not a decision on your complaint. If there is a "Notice to Plead" attached to this Answer, you should review the Notice to Plead for information on how to respond to a New Matter, Motion or Preliminary Objection that may have been included with the Answer. Please note that if you do not respond to a New Matter, Motion, or Preliminary Objection an unfavorable decision may be rendered against you.

Soon, the Public Utility Commission will schedule either a settlement conference or a hearing on your complaint. The Commission will let you know by mail whether there will be a conference or a hearing and will include instructions on what to do next. If the matter is set for hearing, the notice will provide you with information about the date, time and place of the hearing. If we are unable to resolve your complaint and have to proceed with a hearing, a judge will be at the hearing and will decide your complaint. You must call the Public Utility Commission if you have any questions about the hearing or if you cannot attend the hearing.

If you have any questions or concerns at any time, please do not hesitate to contact me at the above listed number.

Very truly yours,

Tishekia Williams
Counsel for PECO Energy Company
TW/adz
Enc.

EXHIBIT
C

Exelon.

Legal Department

Exelon Business Services Company
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Business Services
Company

Direct Dial: 215.841.6841

September 1, 2010

Rosemary Chiavetta, Secretary
Pennsylvania Public Utility Commission
Commonwealth Keystone Building
400 North Street, Second Floor
Harrisburg, PA 17120

Re: **John R. Starzmann v. PECO Energy Company**
PUC Docket No. C-2010-2192759

Dear Ms. Chiavetta:

Enclosed for filing with the Commission are the following documents and copies in the matter referenced above.

X	Answer and New Matter (1 original)
	Motion for Continuance (1 original)
	Motion for Judgment on the Pleadings (1 original)
	Preliminary Objection (1 original)
	Exceptions (1 original)
	Reply Exceptions (1 original)
	Brief (1 original)
	Reply Brief (1 original)

I have enclosed a Certificate of Service showing that a copy of the above document was served on the interested parties. Thank you for your time and attention on this matter.

Very truly yours,

Tishekia Williams
Counsel for PECO Energy Company

TW/adz
Enc.

Scheduling recommendation: CALL OF THE DOCKET: ___ NON-CALL OF THE DOCKET: X

BEFORE THE
PENNSYLVANIA PUBLIC UTILITY COMMISSION

JOHN R. STARZMANN :
:
v. : **DOCKET NO. C-2010-2192759**
:
PECO ENERGY COMPANY :

ANSWER & NEW MATTER OF RESPONDENT, PECO ENERGY COMPANY

PECO Energy Company ("PECO"), pursuant to 52 Pa. Code § 5.61, responds to the Complaint and states:

1. Admitted.
2. Admitted.
3. Admitted.
4. Denied. PECO denies that there is a service reliability issue at Complainant's property. PECO also denies that Complainant has had a voltage issue at his property "on occasion" for 25 years. Complainant claims that he notified PECO on two occasions over these 25 years of a voltage concern. The first notification was in the 1980's. Therefore, according to the specific facts laid out in the Complaint, this was the first time Complainant alleges to have had a voltage issue.

The next notifications were on May 24, 2010 and June 11, 2010. Therefore, according to the specific facts laid out in the Complainant, this was the second time in 25 years that Complainant claims to have had voltage concerns.

PECO specifically denies that Complainant notified a PECO engineer in the 1980's of a voltage problem that was not fixed and resurfaced 25 years later. The alleged event in the 1980's (it is difficult to say with certainty if it actually occurred because it was so long ago) and the events in 2010 are completely separate events. There is too long of a period in between without incident to argue that the events are related. If Complainant experienced low voltage in the 1980's, Complainant definitely has not had a continuous voltage issue leading into 2010.

PECO records indicate that May 2010 was the first time Complainant ever notified PECO of his voltage concern. Complainant contacted PECO on May 24, 2010 and on June 11, 2010 regarding his voltage issues. Therefore, PECO denies that Complainant has been notifying it of any long term or on going voltage concern. Because the first alleged incident occurred so long ago and because Complainant's claims are limited to a three year statutory period, this Complainant should be limited to the 2010 voltage issue only.

By way of further response, PECO alleges that, on May 24, 2010, it experienced a burnt 3 phase tap. The equipment was fixed that day. PECO also alleges that on June 11, 2010, an 1100 line was taken out of configuration to fix an issue with a recloser that needed repairs. Therefore, the alleged voltage issue on June 1, 2010 was related to system maintenance. Again, the issue was resolved the same day. There are no other reliability issues with equipment serving Complainant's property. Complainant also has not reported any voltage concerns to PECO since June 11, 2010.

PECO avers that the relief measures requested, based on two events that were quickly and permanently remedied, are not warranted. The measures that Complainant requests are too costly to fix a problem that does not exist.

PECO notes that Complainant claims to have used his own voltage recording device to arrive at his conclusion that his voltage was low. However, Complainant refused to allow PECO to place its own voltage recording device at the property. Without allowing PECO to perform its own investigation, using its equipment that is regularly calibrated, PECO cannot be certain that

Complainant sustained the low voltage he claims. PECO will be happy to thoroughly investigate Complainant's voltage concerns if he allows PECO to perform its investigation according to established procedures, which includes setting a PECO voltage recorder at the meter.

5. This paragraph is a request for relief and no answer is required.
6. PECO Energy is without sufficient information to confirm or deny this statement.
7. Admitted.

NEW MATTER[1] OF RESPONDENT

PECO Energy, pursuant to 52 Pa. Code § 5.62(b), further responds to the Complaint and states:

1. Complainant claims that he has experienced low voltage, on occasion since the mid-1980's. Complainant therefore wishes to bring a Complainant that covers a 25 year period.

2. Complainant should not be allowed to bring an action dating back that far. There is sound logic for this approach because evidence, witnesses and their memories begin to become scarce after a three year period. The Pennsylvania Legislature understands the difficulty in bringing an action 25 years after the fact. 66 Pa.C.S. §3314 (a) states:

> No action for the recovery of any penalties or forfeitures incurred under the provisions of this part, and no prosecutions on account of any matter or thing mentioned in this part, shall be maintained unless brought within three years from the date at which the liability therefore arose.

3. According to 66 Pa.C.S. §3314 (a), all actions must be brought before the Commission within three years after their occurrence or the Complainant will not be allowed to bring such an action.

---

[1] Complainant is advised that a response to the New Matter is required within 20 days of service. The response shall be filed with the Commission, with a copy to PECO Energy at the address provided in this Answer.

4. Because Complainant did not bring a Complainant about his voltage concern in the 1980's within three years after the alleged incident occurred, Complainant should not be allowed to raise this issue before the Commission.

5. Instead, this action should be limited to the alleged voltage incidents that occurred in 2010.

WHEREFORE, PECO Energy Company requests that the Honorable Commission dismiss this complaint.

Respectfully Submitted,

Tishekia Williams
Counsel for PECO Energy Company
2301 Market Street, S23-1
P.O. Box 8699
Philadelphia, PA 19101-8699
(215) 841-6841
Fax: 215.568.3389
tishekia.williams@exeloncorp.com

BEFORE THE
PENNSYLVANIA PUBLIC UTILITY COMMISSION

JOHN R. STARZMANN	:	
	:	
v.	:	**DOCKET NO. C-2010-2192759**
	:	
PECO ENERGY COMPANY	:	

VERIFICATION

I, Tishekia Williams, hereby declare that I am counsel for PECO Energy Company; that as such I am authorized to make this verification on its behalf; that the facts set forth in the foregoing Pleading are true to the best of my knowledge, information and belief, and that I make this verification subject to the penalties of 18 Pa. C.S. § 4904 pertaining to false statements to authorities.

Date: September 1, 2010

Tishekia Williams

BEFORE THE
PENNSYLVANIA PUBLIC UTILITY COMMISSION

JOHN R. STARZMANN :
:
v. : **DOCKET NO. C-2010-2192759**
:
PECO ENERGY COMPANY :

CERTIFICATE OF SERVICE

I, Tishekia Williams, hereby certify that I have this day served a copy of PECO Energy Company's Answer in the above matter upon all interested parties by mailing a copy, properly addressed and postage prepaid to:

John R. Starzman
515 London Tract Road
Landenberg, PA 19350

Dated at Philadelphia, Pennsylvania, September 1, 2010.

Tishekia Williams
Counsel for PECO Energy Company
2301 Market Street, S23-1
P.O. Box 8699
Philadelphia, PA 19101-8699
(215) 841-6841
Fax: 215.568.3389
tishekia.williams@exeloncorp.com

September 9, 2010

John Starzmann
515 London Tract Road
Landenberg, PA 19350
phone: 610-274-8557
mcstarz@aol.com

Rosemary Chiavetta, Secretary
Pennsylvania Utility Commission
Commonwealth Keystone Building
400 North Street, Second Floor
Harrisburg, PA 17120

Reference: John R. Starzmann v. PECO Energy Company
PUC Docket No. C-2010-2192759

Dear Ms. Chiavetta:

The following comments are offered on the NEW MATTER OF RESPONDENT that was provided in Ms. Tishekia Williams/PECO's 9/01/2010 documents:

The background voltage information from an incident in the 1980's was provided to assist PECO in their review of power system disturbances that affect the voltage at my residence. The voltage in the earlier incident (post January 1984) was also a sustained 50% of nominal (65 volts were measure on my 120 volt system). A common issue to the 5/24/10 voltage event is that the grid design allowed a similar sustained under voltage (an hour or longer, not seconds or minutes) with a similar voltage (50% of rated). While PECO "specifically denies that Complainant notified a PECO engineer in the 1980's of a voltage problem that was not fixed and resurfaced 25 years later", PECO's position suggests that they accept no culpability for, and no interest in, determining the source and permanently resolving the low voltage issues that are reported. PECO should review the one-line and three-line electrical diagrams of the transmission and distribution system. A review of these circuits should provide PECO with a clue as to why there was a sustained low voltage at my residence, and most likely, on the distribution line on London Tract Road. A key may be the fact that the sustained voltage is one-half, which may suggest a transformer turns ratio issue; perhaps a result of a single phase condition or lost neutral.

Concurrent with a design review to determine scenarios during which the distribution system could sustain a prolonged undervoltage, PECO should review and provide the Commission with a list of equipment on the system, including the age, equipment average life, maintenance, and forced and planned outage report records, so that it may be determined if worn out or obsolete equipment, or insufficient maintenance, may be resulting in the reliability issues. A list of equipment and associated ages, in conjunction with a three-line diagram that includes impedances, may determine the scenarios that cause the one-half voltage issues. If the only protections for the low voltage condition are switch and fuse equipment, the installed switch and fuse equipment is not sufficient to provide voltage protection (fuses are primarily over current devices). Modern electrical

EXHIBIT D
1 of 6

distribution systems utilize vacuum or SF6 swtichgear or circuit breakers, and multipurpose relays, to provide over current protection and line protection for various conditions, including low voltage, over voltage, under frequency, phase sequence, etc. Multifunction relays also provide data acquisition.

Pacific Gas and Electric Company in California, for instance, use various techniques to anticipate and prevent forced outages. Corona detection in generator windings, gas in oil sampling in transformers and oil circuit breakers, statistical failure data both in house and through utility forums, are among those techniques that can be useful to predict imminent failures, mandate preventive action, initiate the purchase of new replacement equipment, and increase system reliability. In a proactive approach to system reliability, SF6 or vacuum breakers are replacing oil breakers; line post insulators are replacing cap and pin insulators.

PECO should evaluate the use of cap and pin insulators in our service area. In California a cap and pin replacement program was initiated to improve reliability. If a PECO burnt 3-phase tap was the source of the 5/24/10 extended low voltage condition, PECO should evaluate if a failed cap and pin insulator may also result in a prolonged low voltage condition where adequate relaying and circuit protective devices are not installed to isolate low voltage (and potentially other adverse) conditions that can damage equipment or pose a safety concern. Equipment should be monitored and older equipment replaced. Outages should be anticipated and minimized.

On the procedural side, review of the low voltage incident should include a review of temporary maintenance switching during equipment repair or replacement that may result in one-half voltage being distributed. A thorough review of operation procedures in conjunction with system diagrams, should confirm through analysis if systems maintenance work may be temporarily affecting voltage, or identify equipment and modes of failure that cause the voltage issues. System line repair procedures may need to be reviewed and revised to prevent future sustained low voltage occurrences due to repair or replacement. New equipment may be required to prevent future low voltage occurrences.

PECO should provide the Commission with the call log into the 1-800-841-4141 so that a review of the dates and times, and the root cause analysis of the issues that initiated the call from 610-274-8330, can be reviewed. While the majority of the calls from 610-274-8330 were a result of no power (no voltage; line tripped), there were several calls *initiated because of one-half voltage. If the system call-in report system cannot provide* this information, the system should be modified to provide the information.

In the 1980's, electro-mechanical single function relays were common. In today's modern distribution systems, multifunction electronic relays (SEL and GE/Multilin are two popular manufacturers) not only provide sensing to trip switchgear or circuit breakers to limit system disturbances, but they also provide fault and system condition (voltage, current, frequency, phase sequence, timeline) information. SCADA also provides similar data.

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The 1980 incident was offered in good faith to assist PECO with a review of their distribution system. If the 1980's incident had been adequately reviewed, analyzed, and resolved with equipment installed (or procedures implemented) to prevent a similar adverse condition, the incident may have been avoided or at least better understood by PECO in 2010.

Review of PECO's equipment (including age and failure rate), forced outage reports, mode of failure, etc. may find a common thread between similar outages. A detailed outage report review commencing with 1984 may in fact, discover that there were indeed equipment failures or unplanned outages during which the circuit was not protected from the adverse voltage condition and identify that upgrading the system is overdue.

The following comments are offered on the ANSWER & NEW MATTER OF RESPONDENT, PECO ENERGY COMPANY that was provided in Ms. Tishekia Williams/PECO's 9/01/2010 documents:

Until one-line and three-line diagrams, including circuit impedances, are reviewed so that the distribution system can be evaluated, one cannot conclude that "there is too long of a period in between without incident to argue that the events are related". The Complainant does not maintain that he has had a continuous voltage issue leading into 2010. He does attest that there was a similar voltage condition in the 1980's; a condition similar to that which was reported on 5/24/10. Regardless, the 5/24/10 sustained low voltage condition should have been prevented and PECO should have instrumentation, relays, and switchgear or circuit breakers in place to either transfer to a separate circuit that had reliable power, or should have tripped the service to the residence. Required equipment was not in place as evident that the circuit neither transferred nor tripped from the burnt 3-phase tap on 5/24/10.

The writer's only recent low voltage complaint was regarding the 5/24/10 incident. There were references in the PECO document regarding June 11, 2010 and June 1, 2010 issues, but the writer (Complainant) was not aware of, nor did he report, a power quality issue on those June dates. The writer did eventually tender a formal written complaint to the Commission, only after not having been able to resolve the issue directly with PECO. After the first written request to PECO that included my name and telephone number, PECO closed the complaint because they could not locate me. A duplicate complaint regarding the same 5/24/10 issue was acknowledged but later closed out; the writer was advised to call 1-800-841-4141 if information were needed. The writer suggested in his complaint that PECO's lack of response was totally unacceptable. Only after writing the Commission with the complaint, did the writer have an informative discussion with Russ Brocato (sp?) who provided information (from a line operations point of view) on 5/24/10 events. There has only been one recent voltage event that the writer reported: the

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5/24/10 event, and therefore it is not clear why PECO has responded "Complainant also has not reported any voltage concerns to PECO since June 11, 2020".

The writer requests that substantial PECO procedural changes be incorporated and evaluated by the Commission to up-grade customer service. Rate increases should be contingent upon satisfactory implementation of PECO customer service as well as an upgrade in system design and equipment that would increase grid reliability.

"PECO avers that the relief measures requested, based on two events that were quickly and permanently remedied, are not warranted." A 50% under voltage condition that was sustained for more than one hour neither is considered "quickly" by national standards (including IEEE and ANSI) nor is it considered "quickly" by the writer. Motors energized at one-half voltage for sustained periods are specifically prone to damage.

There have been additional one-half voltage experiences that the writer has not reported in the subject complaint. These other sustained low voltage experiences were reported to PECO through 1-800-841-4141 together with the typical reporting of no voltage, line tripped incidences.

"PECO notes that Complainant claims to have used his own voltage recording device to arrive at his conclusion that his voltage was low. However, Complainant refused to allow PECO to place its own voltage recording device at the property. Without allowing PECO to perform its own investigation, using its equipment that is regularly calibrated, PECO cannot be certain that Complainant sustained the low voltage he claims. PECO will be happy to thoroughly investigate Complainant's voltage concerns if he allows PECO to perform its investigation according to established procedures, which includes setting a PECO voltage recorder at the meter."

In a brief conversation with PECO when called to be informed that PECO was proposing that a recording voltage meter be installed, the writer suggested that it would not matter if the voltage meter were installed today, or tomorrow, or yesterday ... on days that he did not have a low voltage ...but that the recording voltage meter would have needed to have been installed on 5/24/10 when there was a voltage issue. The writer also commented that if the recording meter were to be installed, that he wanted to be present and to be called before installing the meter. If the recording meter would be installed at the writer's meter box, he would need to assist the installer with access similar to the assistance provided when the new meter was installed.

The writer subsequently had a phone call from Russ Brocato (sp?). I advised Mr. Brocato that the voltage event was not in August as he had understood, but extended back to 5/24/10. He asked to have time to do additional research. He called back a few hours later, providing a few general details and mentioned a phase B flashover. Mr. Brocato indicated that there were several operating and line issues on the morning of 5/24/10. From Mr. Brocato's review of the PECO problem reports, Mr. Brocato was satisfied (in the writer's opinion from Mr. Brocato's operations or trouble shooting point of view) that there was enough going on the morning of 5/24/10 that in fact he would not have been

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surprised if I had an issue. I received another phone call from Mr. Brocato, who had been contacted from headquarters regarding my complaint, and I clarified that I had spoken to no additional PECO representative subsequent to our two phone discussions, nor had I issued an additional complaint subsequent to our two phone discussions. On the Friday that PECO had scheduled to install the recording voltage meter, I called Mr. Brocato and left a message on his phone late in the morning that I had waited for someone from PECO to call to inform what time the meter would be installed, but that I had to leave the house for a few hours and would be back by 1 PM. I returned home to have the following message from Mr. Brocato: "Hey Mr. Starzmann. Sorry I missed your call. Russ Brocato . I closed that job out as soon as I found out the explanation for the voltage situation at you house. I closed that job out. There is no need for me to come out there to set a voltage recording meter. I am in agreement with you there so there will not be anybody out there and we will see what happens next time. Thanks a lot."

The writer would emphasize to the Commission that Russ Brocato was the one highlight in this entire scenario. Russ communicated on a timely basis, was professional and courteous, and appeared knowledgeable for a lineman or supervisor responsible for daily operations on the sections in distribution lines that were in question. However the writer anticipates that the voltage issue is systemic of larger design and equipment issues. The Complainant did not refuse to allow PECO to place its own voltage recording device at the property.

The Complainant is a current Registered Professional Engineer (Electrical, Delaware) who was as an engineer for GE for nine years in various positions associated with electrical power distribution and was employed as a Senior Quality Engineer by Pacific Gas and Electric Company for 31 years. The Complainant is a graduate from the University of Delaware (Engineering).

At the bottom of page 2 and beginning of page 3 in Ms. Tishekia Williams/PECO's 9/01/2010 document there is question of the accuracy of the Complainant's volt meter. Having been employed as a Senior Quality Engineer with Pacific Gas and Electric Company for 31 years, the writer appreciates the suggestion that his voltmeter may have not been included on a calibration schedule (it was not). The PECO SCADA, substation meters, and multifunction instrumentation on the PECO system should be calibrated and should provide the Commission with calibrated voltage and time parameters. PECO should provide 5/24/10 calibrated information from SCADA and relays to the Commission. If the equipment was not installed, they should be. The calibration accuracy of the Complainant's meter is not an issue since it is not relevant if 59 Volts or 71 Volts were actually fed to the panelboard circuits that should have been 120 Volts. For the record, when new, the Amprobe AM-1 had an AC accuracy of +/- 4% of full scale. Review of the system and outage details will demonstrate why and how the one-half voltage was applied to the residence. Hopefully PECO and the Commission can move forward and get to the system design and equipment inadequacies that most likely caused the sustained low voltage. It should be PECO who is responsible for supplying the Commission with 5/24/10 calibrated voltage and time information. There was no question that the Complainant had a low voltage before he measured the voltage because

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the lights were dimmed, and the refrigerator motor was growling. The writer's subsequent measurements of the voltage confirmed his suspicions. If the accuracy of the Complainant's voltmeter can be shown to be relevant to the discussion (but the accuracy should not be an issue since root/cause analysis should clarify the issue) the voltmeter may be checked against a calibrated instrument and voltage source.

The Ms. Tishekia Williams/PECO 9/01/10 letter appears to acknowledge that PECO actually does not know what the voltage was at my service entrance panel or on the high side of the pole bolted transformer that feeds the residential service during the time of the incident. Otherwise, PECO could provide the Commission with the line voltage on London Tract Road at 8:45 AM on 5/24/10. The writer did clarify with Russ Brocato that the source of the low voltage was deemed by the Complainant to be on the line side of the pole bolted transformer and that no PECO crews were observed working on the lines in the immediate neighborhood.

The writer thanks the Commission for following up on the Complaint. It is the Complainant's hope that after a thorough review if the system designs, the installed equipment, and the operating procedures in place at the time of incident, the system can be modernized to preclude future similar voltage issues. At the same time, if improvements are developed, implemented, and evaluated with PECO's customer service department to encourage customer dialog, sharing of information and resolution directly with the applicable PECO departments, issues could more efficiently be resolved without involving the Commission. Thank you for following-up with the complaint, your assistance, and your service.

John R. Starzmann

CC: Tishekia Williams, Councel for PECO Energy Company
Exelon Business Services Company
2301 Market Street/S23-1
PO Box 8699
Philadelphia, PA 19101-8699

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September 9, 2010 JRS letter to PUC
September 23, 2010 PECO phone conference

JRS and PECO to understand why 50% under voltage was on line
PECO take responsibility
Understand what changes to be incorporated to prevent a similar occurrence
As backup, install devices to prevent unregulated power conditions
PECO customer service changes

Review reasons for ½ voltage, 5/24/10 & earlier	
Related to flicker also observed approximately 7:45 AM?	
One line and three line diagrams reviewed by PECO?	
List of equipment, age, average life, maintenance, forced/planned outages	
Protection for distribution system	
Replacement of oil circuit breakers with vacuum or SF6	
Replacement of cap & pin insulators	
Maintenance switching or operation procedures	
New equipment	
Log call from 610-274-8557 to 1-800-841-4141	
SEL and GE/Multilin relays	
SCADA	
PECO customer service	
50% under voltage for 1-hour is not an event resolved “quickly”	
PECO calibrated instrumentation records of voltage	
Does PECO know voltage?	
PECO to modernize systems	

9/23/1010 Summary

On the phone from PECO was Ms. Williams, Harry Shultz, Pat Bachelor

EXHIBIT E
1 OF 2

The service is fed from a unit substation on Mercer Mill Road. The distribution transformer is 34 kV delta to 4 kV grounded wye. There is a single feed. The circuit is protected by a circuit breaker that was thought to be an air blast type. Details on the types of relays installed were not provided.

The event on 5/24/2010 was on the 34 kV B phase tap that was clarified to be a B phase connection (not a de-energized tap changer on the transformer).

PECO will look into the equipment, and calibrate if necessary. May not be able to take the line out of service until heat conditions mitigate. Calibration and further investigation may be to be delayed.

JRS suggested that they call back in 3 weeks with an up-date.

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From: PECOConvCenterOnline@exeloncorp.com
To: mcstarz@aol.com
Subject: RE: Online Contact:= CU5731524201038226079
Date: Fri, May 28, 2010 2:41 pm

Mr. Starzmann,

Thanks for your email.

We are not able to retrieve your account based on your name, account number, or telephone number you provided.

Please contact our Emergency Services Department directly at 1-800-841-4141; they are available 24 hours a day/ 7 days a week.

Have a nice day!
PECO Online Convenience Center
Customer Service

-----Original Message-----
From: mcstarz@aol.com [mailto:mcstarz@aol.com]
Sent: Monday, May 24, 2010 10:28 AM
To: PECO Online Convenience Center
Subject: Online Contact:= CU5731524201038226079

Customer Name: John Starzmann

Customer Account Number (optional): 45123--0170

Telephone: (610) 274-8557

Subject: Online Technical Issue

Message:

On occassion for 25 years, I have had sustained low voltage. I measure 65 volts on my 120 system. This was reported and discussed with a PECO engineer in the mid-1980''s and the situation was apparently understood but not resolved. Today (5/24/10) as reported, I again had a sustained 65 volts on my system, which required that I disconnect the main at the panel to preclude damage to well pump and refrigeration compressor motors. With SEL351 and GE/Mutilin F60 multi-function relays common place in modern distribution systems, why can not PECO apply protective relays and switchgear to preclude sustained damaging low voltage and other damaging power conditions? I would like to have details on the latest low voltage problem and what is being done to permanently correct the situation. If it is a question of funding, give me the details and I''ll contact the PA Utility Commision.

EXHIBIT F

From: PECOConvCenterOnline@exeloncorp.com
To: mcstarz@aol.com
Subject: RE: Online Contact:= CU9526531201037564504
Date: Fri, Jun 11, 2010 4:10 pm

J.R. Starzmann,

Thanks for the email.

We have processed an emergency request to have your voltage issue investigated.

This email address is intended for customers having problems with our website. Moving forward, please contact our Emergency Services Department regarding this issue at 1-800-841-4141; they are available 24 hours a day/ 7 days a week.

Have a nice day!
PECO Online Convenience Center
Customer Service

-----Original Message-----
From: mcstarz@aol.com [mailto:mcstarz@aol.com]
Sent: Monday, May 31, 2010 3:28 PM
To: PECO Online Convenience Center
Subject: Online Contact:= CU9526531201037564504

Customer Name: J. R. Starzmann

Customer Account Number (optional): 45123-01701

Telephone: (610) 274-8557

Subject: Online Technical Issue

Message:

THIS IS A SECOND REQUEST
On occassion for 25 years, I have had sustained low voltage. I measure 65 volts on my 120 volt circuits. This was reported and discussed with a PECO engineer in the mid-19890''s and the situation was apparently understood but not resolved. On 5/24/10 I again reported a one-half voltage issue that required that I disconnect the main at the panel to preclude damage to well pump anmd refrigeration compressor motors... With SEL351 and GE/Multin F60 multi-function relays common place in modern distribution systems, why can not PECO apply protective relays and switchgear to preclude sustained damaging low voltage and other damaging power condition? I would like to have details on the latest low voltge problem and what is being done to permanently correct the situation.

I have provided you a phone number and name. You closed out the first request without calling or discussing the issue. The first request was assigned CU5731524201038226079 and was submitted 5/24/10

EXHIBIT
G

Customer Service Performance Report

EXHIBIT 14
1 OF 2

Number of EDC Residential Disputes That Did Not Receive a Response Within 30 Days

Company	2008	2009	2010
Allegheny	15	15	14
Duquesne	27	12	13
Met-Ed	2	2	11
PECO	35	0	0
Penelec	2	1	12
Penn Power	2	1	5
PPL	145	72	99
UGI-Electric	0	4	0

Two of the eight EDCs reported a decrease in the number of disputes not responded to within 30 days, and one reported the same number from 2009 to 2010. PECO and UGI-Electric reported zero disputes not answered within 30 days in 2010.

Five companies reported an increase in disputes not responded to within 30 days. PPL indicates that the reason for the increase is due to a high volume of calls and a delay in re-billing both caused by the expiration of the rate cap and a significant increase in customers shopping for suppliers.

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9th International
Conference.
Electrical Power
Quality and Utilisation.
Barcelona, 9-11
October 2007

Regulation of Voltage Quality

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Abstract— **This paper provides an appraisal of what regulators need to consider in establishing an effective voltage quality regulatory framework for distribution networks. In particular, the paper considers the regulation of five voltage quality dimensions: short interruptions, voltage dips, flicker, supply voltage variation, and harmonic distortions. The paper assesses the most appropriate regulatory control method and presents practical experiences through a number of case studies.**

Keywords-voltage quality; power qualty; regulation; electricity

I. INTRODUCTION

Complementary to price, quality is an important feature of the electricity service provided to customers. Price and quality together define the value that customers derive from consuming electricity. However, electricity utilities may not necessarily be provided with a balanced set of incentives to provide both good price and quality. Strong incentives for higher efficiency and cost awareness may potentially lead to reduction of quality. Therefore, quality regulation is becoming a crucial requirement in the light of the widespread regulatory policy of (incentive based) price regulation. Quality regulation is important to provide incentives to network operators to not only become more efficient, but also to maintain or improve the quality level offered to customers.

Until now, the main focus of quality regulation has been on the reliability and commercial dimensions of quality. In contrast, there is far less experience with the issue of voltage quality regulation. Voltage quality is however becoming increasingly important to customers due to increasingly sensitive electronic devices. At the same time, voltage quality levels are in turn affected by the increased use of such devices. Thus, voltage quality deserves particular attention although being notably more complex to implement than the conventional measures of quality regulation. This is mainly due to the multi-dimensional nature of voltage quality and the inherent difficulties in measurement. Nevertheless, there is a trend of regulators becoming more aware of the need for voltage quality regulation. Steps have already been taken into that direction. This paper pursues this path and assesses the issue of what regulators should consider when establishing a voltage quality regulatory framework for distribution networks.

In a first step (section II) the paper develops a general set of guidelines that regulators should take into account when specifying the voltage quality regulation objective and the means through which to achieve this. Section III delves into five main voltage quality dimensions namely (1) short interruptions, (2) voltage dips, (3) flicker, (4) supply voltage variation, and (5) harmonic distortion. Subsequently a feasibility assessment is made, identifying the most appropriate regulatory control method. After a short excursion to existing voltage quality regulation in Europe (section IV) the conclusions of this paper are drawn in section V.

II. GENERAL GUIDELINES FOR INTRODUCING VOLTAGE QUALITY

When setting up a quality regulation framework, there are a number of crucial preconditions that need to be considered in order to make the right choices to design an effective voltage quality regulatory system. Basically it is recommended to accomplish the following three steps.

A. *Quality definition and measurements*

The first step is to clearly define voltage quality and to develop a suitable set of indicators for its measurement. It is of utmost importance that the data that feeds into the quality control is accurate since it forms the basis for the subsequent regulatory process. For this reason, also the measurement methodology needs to be defined unambiguously. Regulators can make use of existing documents such as EN5160 and the UNIPEDE "Measurement Guide for Voltage characteristics" although they will feel the need for making standards more specific.

EXHIBIT I
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B. Clarify the objective of voltage quality regulation

The second step consists of a clarification of the objective of voltage quality regulation. This can be subdivided into two intermediate steps. The first one is to quantify the existing level of performance and if possible to compare it against international best practice. The second and more challenging one is then to define a target quality level. As a matter of fact the underlying challenge is to figure out a quality level that provides highest net economic benefits since the intrinsic features of such a target are its dynamic nature (changing circumstances and customer preferences) and the trade-off between the magic triangle of costs, benefits and quality. Against this background the optimal quality level can theoretically be defined as the point at which the additional costs of providing high voltage quality are equal to the reduction in costs that customers experience due to receiving better quality.

Practically speaking, one would need to have information about the costs and benefits of quality. Notwithstanding the difficulty to obtain this information, insights can be acquired from benchmarking voltage quality levels of one network company against others or from discussions with relevant parties to identify the perceived difference between the actual and the target level of voltage quality. As a result of these assessments the regulatory objective will be to bridge the gap between the actual and the target voltage quality level. This can be achieved by pursuing either the following two policies: Improve voltage quality in case the agreed quality level is too low, or maintain the existing level in case the identified quality level sails close to the optimum.

C. Choose suitable regulatory control method

Once the regulator has identified the appropriate quality indicator, has robust means of measurement, and has an idea of what performance level should be achieved, the third step is to choose a suitable regulatory control method appropriate to reach that objective. To this end two crucial preconditions should be fulfilled against which the different control methods will be assessed: Firstly, the control method must lead to the achievement of the identified regulatory objective and secondly, the former must be feasible to implement. Against this background the regulator may choose from three regulatory measures:

- Performance Monitoring

The basic idea of this tool is to require the network operator to report on his voltage quality to the regulator. Subsequently this information is made available to the general public by publishing the performance of several network companies. This "naming and shaming" approach is considered as a measure to provide incentives to perform better than others due to the underlying reputation concern of the network company. The advantage of this measure is its simplicity and limited regulatory involvement. Moreover, in terms of data requirements, it can be limited to an appropriate number of strategic locations within the network thus limiting the need for extensive measuring points. The drawback of this tool however is that performance monitoring by itself does not guarantee an appropriate voltage quality as it is does not provide any concrete guidance on what voltage quality level the network operator should aim at. In case the regulator aims at maintaining existing performance levels, performance monitoring can be useful. Starting from existing levels, a decrease in performance over time will be noticed by both the regulator and customers. This can put pressure on the company to assure no further deterioration and realign quality performance with past experience.

- Minimum standards

Minimum standards dictate a minimum level (e.g. geared to EN 50160 [a] which is considered a reasonable starting point for voltage quality regulation) to be achieved for a certain performance aspect. A minimum standard provides a clear boundary on what is "good" and what is "bad" performance. In case of not meeting this standard, the utility can be penalized financially or otherwise. If the regulator aims at increasing performance, minimum standards provide clear guidelines about what quality network operators should aim at. They set quantitative targets for the companies to achieve. If combined with financial incentives for not meeting the standards, minimum standards can be very effective quality controls. In case the regulator wants quality levels to remain at existing levels, it can set the minimum standard on that basis. This again provides clear quantitative guidance in what network operators are expected to achieve. As suggested by ERGEG [7] this approach may even go further than implied by industry standards. For instance some regulators imposed quality norms based on the definitions of EN 50160 albeit with more ambitious performance targets. Moreover, so-called power quality contracts can be a solution for specific consumers who require a very high voltage quality. In this contract, customer and distributor agree on a certain performance level and additional adjustments needed to ensure that level. These costs are generally borne by the customer. In case of non-compliance, the distributor then has to pay a penalty to the latter.

- Incentive scheme

An incentive scheme can be considered as an extended minimum standard which imposes a more continuous relation between price and quality by making the financial incentive (penalty or reward) a direct function of actual performance. This makes the incentive scheme conceptually more appealing. If the regulatory objective is to improve quality, then an incentive scheme is most suitable. The gap in performance – being defined as the difference between actual and targeted performance – can be translated into a financial incentive. The better the company performs in terms of reducing the difference between actual performance and voltage quality targets, the better this is financially. By strategically configuring the level of the incentive (being the penalty or reward), incentives can be given to provide an optimal level of quality. This can be achieved by basing the incentive level on the costs that customers incur as a result of quality not being perfect. In theory, this will lead to the optimal level

I

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of quality and thus the socio-economic optimum. Incentive schemes are also very useful if one is aiming at maintaining existing levels of performance. The quality target can then be set on the basis of existing performance. But even though theoretically superior, incentive schemes have serious practical limitations. These mainly arise from two sources. First, it is difficult to exactly measure often heterogeneous customer costs due to lack of quality. In order to arrive at a sensible figure, considerable research needs to be conducted first. The second problem of incentive schemes is even more challenging: the collection of adequate and high-quality data. If actual performance is not known to a high degree of accuracy, the scheme may not be effective as the resulting financial incentive will be flawed. Good and reliable data is thus a precondition for implementing an effective incentive scheme. In order to comply with this, voltage quality meters would need to be installed – in the extreme case at the premises of each individual customer. This will clearly involve come at significant costs.

III. REGULATION OF VOLTAGE QUALITY PARAMETERS

The general set of guidelines developed in the previous section are now applied to a feasibility assessment identifying the most appropriate regulatory control method for short interruptions, voltage dips, flicker, supply voltage variation and harmonic distortions.

A. *Short interruptions*

Short interruptions are defined by the European standard EN 50160 as interruptions of electricity supply with a duration ranging from few tenths of seconds up to 3 minutes. These interruptions are basically accidental, and caused by a transient fault. The voltage level during a short interruption is considered to be close to zero (usually lower than 1% of nominal voltage) as indicated in Figure 1 below.

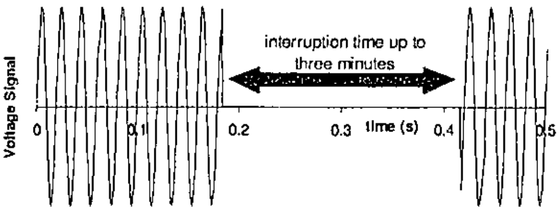

Figure 1. Example of short interruptions

An indicator which is used for reporting the frequency of short interruption is the Momentary Average Interruption Frequency Index (MAIFI), which is comparable to the System Average Interruption Frequency Index (SAIFI), but only takes into account short interruptions with duration of less than 3 minutes. MAIFI is therefore defined as:

$$MAIFI = \frac{\sum_{i} N_i}{N_t} \qquad (1)$$

Where:

N_i: N° of interrupted customers for interruption I (up to 3 minutes)

N_t: Total number of customers served.

The effects of a short interruption to customers are primarily perceived immediately, e.g. through immediate discontinuation of (industrial or manufactory) processes. Due to several studies on Value of Lost Load (VOLL) the interruption costs at customers increase significantly during the first seconds/minutes of a short interruption. The *monitoring* of *longer* short interruptions (1 to 3 minutes) is very much feasible, e.g. by means of manual reporting and/ or SCADA systems. However, interruptions merely lasting up to several seconds may require specific measurement systems. For these "true" short interruptions, *minimum standards* regulating the frequency of such interruptions seem to be the most appropriate quality control.

Since short interruptions are considered as one of the most important quality indicators for power supply, it is worth to consider the possibility of *incentive regulation*. For instance the approach of the Dutch regulator DTe, who included short interruptions of 1 to 3 minutes in its incentive regulation on quality, by applying SAIDI and SAIFI definitions for all interruptions with a duration of more than 1 minute has been proven feasible in the Netherlands. For interruptions lasting less than one minute this approach is however not recommended.

B. *Voltage dips*

Voltage dips seem somewhat similar to short interruptions, but there is one important difference. Whereas short interruptions are characterized by a voltage level close to zero i.e. less than 1% of the nominal level, voltage dips occur when voltage levels could still be relatively high i.e. typically between 1% and 90% of the nominal level, which is shown in Figure 2. Both network operators and customers can be responsible for voltage dips.

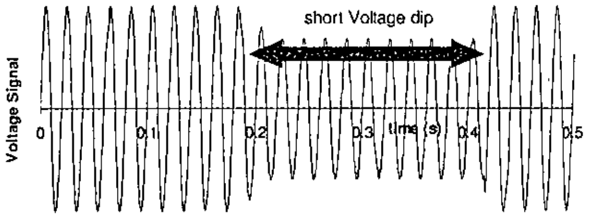

Figure 2. Example of voltage dips

The severity of both voltage dips and short interruptions is measured in terms of the duration of the event. For voltage dips, there is an additional measure needed, namely the extent of the voltage reduction.

As regards the impact on customers, the consequences of voltage dips range from 'no damage at all' to 'similar damage as (short) interruptions' depending on the depth and duration of the voltage dips and connected equipment. Short and shallow voltage dips do normally occur and in principle cannot be avoided. Deep voltage dips are very much comparable to short voltage interruptions. This implies that the damage caused by them very much depends on the duration while it grows exponentially during the first seconds/minutes.

Studies reveal that medium voltage customers are particularly sensitive to voltage dips hence regulatory control measures may be applied. *Monitoring* several classes of voltage dips should be feasible in case a voltage quality monitoring scheme will be implemented. A *minimum standard* is deemed appropriate to define the frequency of periods with a number of short and shallow voltage dips which are acceptable for both the network operator and the customer. The introduction of an *incentive scheme* may be feasible for long and deep voltage dips, but involves voltage quality measurement equipment and statistical techniques for getting a global picture of the entire network. Hence, although theoretically not impossible, incentive regulation for long and deep voltage dips suffers from some practical limitations.

C. Flicker

Flicker is the visual phenomenon which causes changes in the luminance of lamps and could be annoying to people above a certain threshold. Flicker is caused by rapid voltage changes and is dependent on both the amplitude of the fluctuation and the repetition rates as shown in Figure 3 below. Flicker can be characterized by the flicker severity indicators P_{LT} and P_{ST}. The indicator P_{ST} is measured over a period of 10 minutes and characterizes the likelihood that voltage fluctuations result in perceptible light flicker. The indicator P_{ST} having a value of 1.0 represents the level at which 50% of people would perceive flicker in a 60 Watt incandescent bulb. P_{LT} is calculated out of 12 successive P_{ST} values. Flicker is mainly caused by electrical equipment connected to the network by customers. However, network design and operation can reduce the effects of the distortion on the flicker perceived by (other) customers. Flicker could therefore be considered a joined responsibility of both network operators and connected customers.

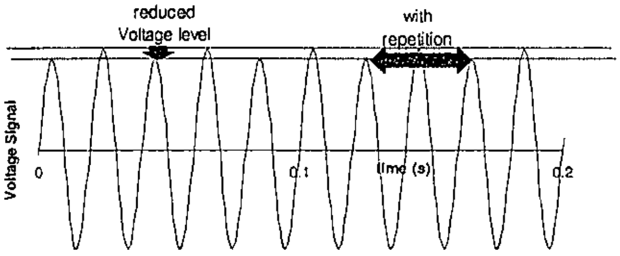

Figure 3. Example of flicker

Unlike the voltage quality parameters discussed above, flicker focuses on the impression of people rather than on malfunctioning of equipment. For this reason, flicker is mainly interfering low voltage customers. By introducing *minimum standards* for flicker severity, network operators are becoming responsible for keeping flicker within certain limits. However, at the same time, network operators should have the possibility to make disturbing customers take measures in case their disturbance leads to a non-acceptable contribution to flicker.

A first step could be *monitoring* of flicker and publication of the results. This can be realized by firstly considering the share of customers for which the minimum flicker severity standards are not met and who hence face serious discomfort due to flicker. Secondly one could introduce compensation payments on not meeting the minimum standards for P_{ST} and/or P_{LT} for which individual customer groups may apply facing a severe discomfort from flicker. Moreover regulation could oblige the network operator to reduce the flicker level. If an *incentive mechanism* is introduced, it should be based on a decentralized, i.e. local voltage quality measure or indicator rather than a system wide measure. One could possibly consider introducing an incentive mechanism which provides incentives for reducing the number of customers for which the flicker severity standards are not met, probably using different classes of flicker severity.

D. Supply voltage variations

Supply voltage variations cover the variation in the voltage level under normal operating conditions. This means that they are mainly caused by changing load and generation patterns in the networks. EN 50160 defines that 95% of the 10-minutes average values of the voltage measured during a week should be within the range of ± 10% of the nominal voltage and that all 10-minutes average values should be within the range of +10%/-15% of the nominal voltage (cf. Figure 4).

Network operators can mitigate supply voltage variations by proper design and operation of the networks. Supply voltage levels are different for every node in the network. Measurement however is relatively easy. Modern voltage quality measurement devices are usually able to capture the average values for the voltage during a predefined period of time.

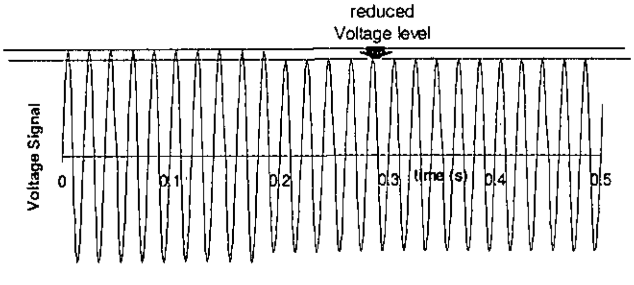

Figure 4. Example of supply voltage variation

If the standard for supply voltage variation is properly defined, the quality of 'supply voltage variation' level is either 'sufficient' or 'non-sufficient'. That is, a customer with 'sufficient' quality is most probably not prepared to pay additionally for even better quality. This is similar to flicker. As a result, *minimum standards* are widely introduced within Europe, sometimes with some adaptations from the EN 50160.

However, the introduction of a minimum standard with associated compensation payments has similar disadvantages as for flicker. The reason is that supply voltage variations could only be sensibly monitored by voltage quality monitoring devices which are not available on every connection point. Similar to the solution for flicker, we therefore suggest a solution whereby customers apply for *monitoring* if they face supply voltage variation problems. In case the voltage does not comply with the standards, network operators should pay a compensation payment and be obliged to solve the local problems. If the supply voltage meets the standards, it should be considered 'good enough'. Against this background it is redundant to introduce an *incentive mechanism* for making 'good enough' quality even better.

E. Harmonic distortion

The electricity wave in Europe is based on a 50 Hz signal. Harmonic distortions come on top of the normal 50 Hz signal and are a multiple of the original frequency as illustrated by Figure 5. The individual elements of harmonic distortion are named after their multiplier. For example, the second harmonic has a frequency of 100 Hz, the third of 150 Hz and so on. The total set of harmonics is usually also summarized in the value for the Total Harmonic Distortion factor (THD), which is determined from the 2nd up to the 40th harmonic.

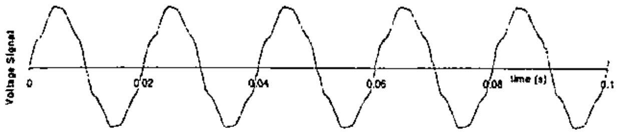

Figure 5. Example of harmonic distortion

Harmonics of the supply voltage are caused mainly by customers' equipment. The main sources of harmonics are so-called non-linear loads which could be connected to all voltage levels of the supply system, e.g. rectifiers which are ranging from cell phone battery chargers up to railways and AC/DC converters in electricity networks. Due to the increase in non-linear loads, harmonic distortion has become increasingly significant in the last few years. In practice, most equipment is designed in such a way that it can withstand harmonic distortions as specified in EN 50160. This means that equipment will continue to operate well, will not be damaged and will be reasonably efficient. It can therefore be concluded that costs due to harmonic distortion mainly arise from harmonic distortion outside of this band. Hence *minimum standards* have been widely introduced within Europe.

Keeping these standards might not be an easy job since harmonic distortion is largely caused by customers themselves and are only influenced by network operators. However, the network operator is the only party that can coordinate the level of harmonic distortion in its network. Therefore regulation should push the network operator to keep its customers within sensible limits of harmonic distortion. In terms of *monitoring* harmonic distortion a sound monitoring program on sensibly selected nodes should be installed monitoring the share of time and/or locations where the standard has not been met. Similar to flicker and supply voltage variation this can be supplemented by compensation payments assuming that those customer groups are considered which face severe problems due to harmonic distortion.

Moreover one could think of introducing an *incentive mechanism* on a global level by applying a THD. However, since the cost curve for harmonic distortion is very asymmetric, a customer is probably not willing to pay for a better THD if his THD is only 2%, while reducing a THD of 10% could save him a lot of money. For this reason, it is probably not sensible to consider the average harmonic distortion level in a network. An incentive mechanism could therefore better focus on situation in which improvements of THD do have a value. Such an incentive scheme could concentrate on the share of time and/or locations where the standard has not been met.

IV. EXISTING VOLATAGE QUALITY REGULATION IN EUROPE

This section assesses the progress made in Norway, Italy and the Netherlands with regard to voltage quality regulation in order to obtain more practical insights into how this issue is dealt with in Europe.

A. Norway

The power industry regulator in Norway NVE put into force a new Directive on quality of supply as of 1st January 2005. The issue of voltage quality regulation is anchored in this directive in order to ensure that the quality of the electricity to customers in Norway is satisfactory, strengthens customer's rights, and provides a better basis for handling disputes between the parties in this regard. The voltage quality regulations are set up in the form of minimum standards and are supplemented by rules for handling enquiries from connected parties to the network companies regarding quality of supply. Moreover NVE has included a provision about deviations from the standard voltage quality regulations providing for the option of bilateral agreements on voltage quality that allows for a voltage quality deviating from the minimum requirements stipulated by NVE.

The set of regulations imposed by NVE go further than the requirements on the EN 50160. E.g. the transmission system operator shall in areas that temporarily have no synchronous connections to an interconnected system, ensure that the voltage frequency is normally kept within 50 Hz ± 2 %. Moreover, network companies have to ensure that *variations in the stationary voltage RMS value* are within an interval of ± 10 % of the nominal voltage, measured as a mean value over one minute, in points of connection in the low voltage network. Furthermore, network companies have to ensure that *rapid voltage changes* do not exceed defined threshold values in points of connection,. In terms of *flicker* network companies have to guarantee that flicker severity does not exceed the predefined values. Network companies have to ensure that the degree of *voltage unbalance* does not exceed 2 % in points of connection. *Harmonic distortions* of the voltage waveform are not allowed to exceed a percentage of 8% and 5 % in points of connection with nominal voltage from and including 230 V up to and including 35 kV. Notably, for some phenomena NVE has decided not (yet) to introduce minimum standards, viz short interruptions, long interruptions, temporary overvoltages,

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voltage dips, interharmonic voltages, mains signalling voltage on the supply voltage and transient overvoltages.

B. *Italy*

Up to now the Italian energy regulator Autorità only set in place minimum quality standards e.g. for continuity of supply in order to ensure adequate service quality standards. Notwithstanding that there currently is no regulation system for voltage quality in place, the Autorità undertakes steps to establish such a system in the future. To this end the regulator's strategy is to first get a better understanding of existing voltage quality levels and to collect reliable and robust voltage quality data. As part of this the Autorità launched a voltage quality measurement campaign in early 2006 including the following main activities: installation of voltage quality meters at strategic locations and submission of data on voltage quality performance to the Autorità. As part of this effort, 400 voltage quality meters have been installed on MV busbars of HV/MV substations and 200 meters at deliver points to customers. The specifications of the meters have been developed by the Autorità on the basis of the IEC 61000-4-30 "Testing and measuring techniques – Power quality measurement methods".

The following voltage quality aspects need to be monitored and reported: Supply voltage variations, supply voltage dips and swells, voltage interruptions, voltage harmonics, flicker, supply voltage unbalance and rapid voltage changes. Moreover utilities are henceforth obliged to install voltage quality meters at the request of customers, whereas the costs of these meters are borne by the latter. Eventually customers and utilities have the possibility to enter into a voltage quality contract. The campaign will last for two years, i.e. till early 2008.

C. *The Netherlands*

Similar to Norway, the Dutch regulator DTe regulates different dimensions of voltage quality. *Flicker* is under regulatory control by imposing a minimum standard. For both medium voltage and low voltage networks P_{LT} limits are defined. Since network operators are obviously not the only parties who can influence flicker, the Grid Code also defines requirements on flicker for the customers connected to low voltage networks. This requirement specifies that the contribution to rapid voltage changes by a connected party on the connection point will not exceed $\Delta P_{ST} \leq 1.0$ en $\Delta P_{LT} \leq 0.8$. For *harmonic distortion* the Netherlands adopted EN 50160 limits, but added that $THD \leq 12\%$ for 99.9% of time. In addition to these requirements Dutch Grid Code refers to requirements for 'producers' of harmonic disturbance.

V. CONCLUSION

Voltage quality is an important aspect of the electricity service and customers are becoming increasingly sensitive to disturbances in voltage quality. This issue is particularly important to take into account in new regulatory frameworks which put strong emphasis on cost reduction thereby potentially jeopardizing quality. Against this background the aim of this paper was to explore the issues that regulators need to consider when establishing a voltage quality regulatory framework for distribution networks.

The outcome of this paper is a set of guidelines with respect to the development of a voltage quality regulatory framework. In order to bridge the gap between the perceived and the target quality level regulators could employ different control methods to achieve their objectives, viz performance monitoring, minimum standards and incentive schemes. In theory, an incentive scheme is the most effective control as it imposes a direct link between performance and financial incentives. Although often limited by practical concerns, it still may be an interesting option for regulating especially short interruptions and voltage dips and to a lower degree flicker, supply voltage variations and harmonic distortion. In contrast, performance monitoring is practically simple to implement but lacks true incentives for increasing voltage quality. Therefore minimum standards seem to strike a good balance between performance monitoring and incentive schemes since the degree of measurement data is more restricted than under incentive schemes. At the same time, minimum standards also provide financial incentives for good voltage quality. They dictate a minimum performance and set a clear boundary of what is acceptable quality and what is not.

Voltage quality regulation is at this point in time less advanced and detailed when compared with for example regulation of continuity of supply. This can be attributed to the higher degree of complexity involved in regulating voltage quality. Nevertheless, the importance of voltage quality and therefore the need for regulation is increasing. Analysis of the issues at stake can surely contribute to a better understanding and therefore lead to effective regulatory systems. This paper can be considered as an effort in pursuing this path.

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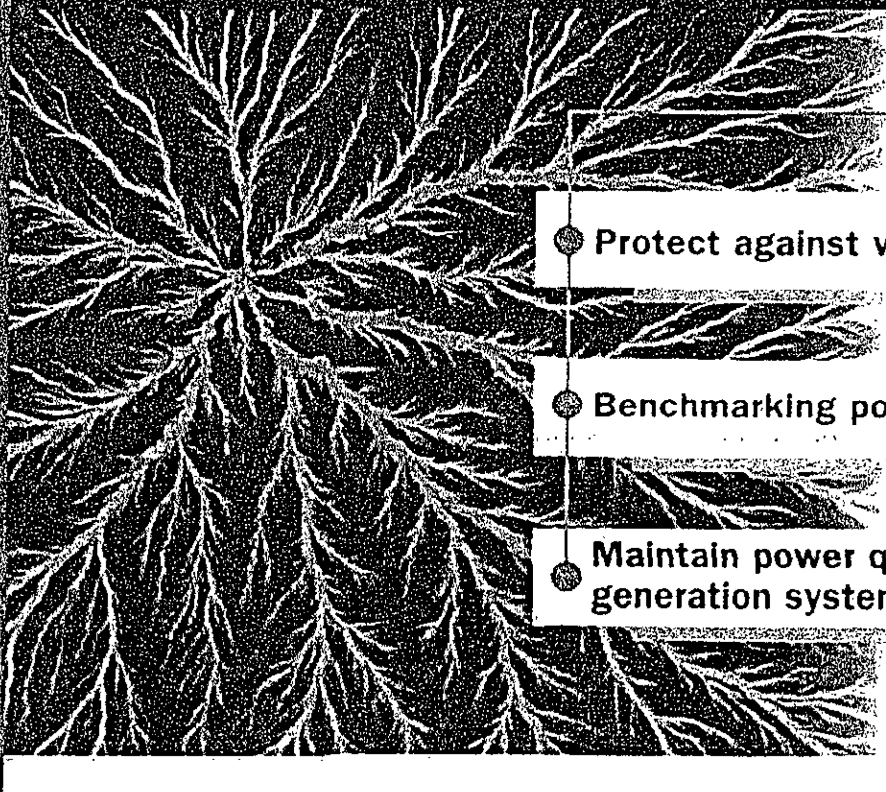
PROFESSIONAL ENGINEERING



- Protect against voltage sags and interruptions
- Benchmarking power quality
- Maintain power quality in distributed generation systems

Electrical Power Systems Quality

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SECOND EDITION

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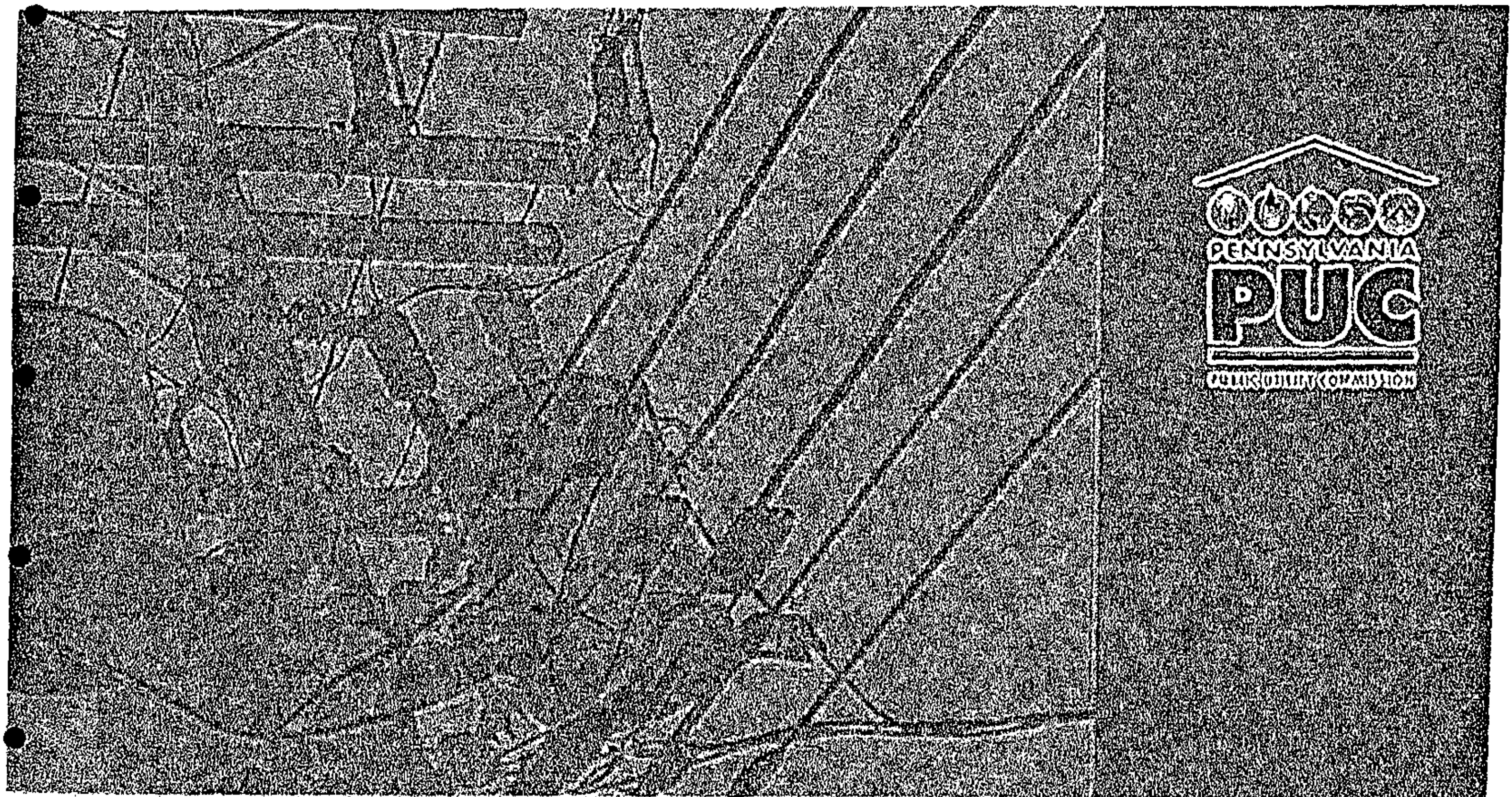

Electric Service Reliability in Pennsylvania

2010

EXHIBIT K
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Pennsylvania Public Utility Commission

The rolling **12-month standard** is 120 percent of the benchmark for the large EDCs and 135 percent for the small EDCs.[19] A greater degree of short-term latitude recognizes that small EDCs have fewer customers and fewer circuits than large EDCs, potentially allowing a single event to have a more significant impact on the reliability performance of the small EDCs' distribution systems.

The rolling **three-year standard** is 110 percent of the benchmark for all EDCs. This performance standard was set at 10 percent above the historical benchmark to ensure that the standard is no higher than the worst annual performance experienced during the years prior to restructuring. The three-year average performance is measured against the standard at the end of each calendar year. The rolling three-year standard analysis, contained in this report, utilizes 2008, 2009 and 2010 calendar year data.

It is noted that a lower number for any index indicates better reliability performance; i.e., a lower frequency of outages or shorter outage duration. A higher number indicates worse performance. For example, if an EDC has a CAIDI benchmark of 130 minutes, a rolling 12-month CAIDI standard of 156 minutes and an actual CAIDI for a particular year of 143 minutes, its performance is considered to be adequate. If CAIDI is 120 minutes, the performance is better than the historical average performance. A CAIDI of 180 minutes, on the other hand, indicates a failure to meet the reliability performance standard.

If any electric distribution company's reliability performance does not meet Commission standards, the Commission may require a report discussing the reasons for not meeting the standard and the corrective measures the company is taking to improve performance.[20] In addition, Commission staff may initiate an investigation to determine whether an electric distribution company is providing reliable service.[21]

Benchmarks and standards for EDC reliability performance and average reliability indices for 2010 are listed in Appendix A.

Inspection and Maintenance

The Act also addressed the promulgation of regulations for the establishment of standards for the inspection and maintenance of transmission and distribution systems. Specifically, 66 Pa. C.S. §2802(20) provides:

> (20) Since continuing and ensuring the reliability of electric service depends on adequate generation and on conscientious inspection and maintenance of transmission and distribution systems, the independent system operator or its functional equivalent should set, and the Commission shall set through regulations, inspection, maintenance, repair and replacement standards and enforce those standards.

On May 22, 2008, the Commission entered a Final Rulemaking Order implementing minimum I&M standards for EDCs operating in Pennsylvania. This created a new Section 57.198 in Title 52 of the

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[19] Large EDCs currently include: Duquesne Light, Met-Ed, Penelec, Penn Power, PECO, PPL and West Penn. Small EDCs include: UGI, Citizens', Pike County and Wellsboro.

[20] 52 Pa. Code § 57.195(g).

[21] 52 Pa. Code § 57.197(a).

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Pennsylvania Code, effective Sep. 27, 2008.[22] Section 57.198(a) states that initial I&M plans are due by Oct. 1, 2009, for Compliance Group 1 and Oct. 1, 2010, for Compliance Group 2, as determined by the Commission.[23] The plans cover the two calendar years beginning 15 months following the Oct. 1 filing, and must be filed biennially.

The I&M plans must detail a program for the inspection and maintenance of electric distribution facilities including: poles, conductors, transformers, switching devices, protective devices, regulators, capacitors and substations, necessary for the distribution of electric current, and owned, operated, managed or controlled by the company and for vegetation management. The plans must comply with the minimum inspection and maintenance intervals set forth in Section 57.198(n) and include a justification for the time frames selected. The plans are subject to acceptance or rejection by the Commission or the Director of the Bureau of CEEP if they are found to be deficient. See Table 1.

Table 1 Inspection and maintenance intervals

Program	*Interval*
Vegetation Management	*4-6 years*
Pole Inspections	*10-12 years*
Overhead Distribution Line Inspections	*1-2 years*
Overhead Transformer Inspections	*1-2 years*
Above-Ground Pad-Mounted Transformer Inspections	*5 years*
Below-Ground Transformer Inspections	*8 years*
Recloser Inspections	*8 years*
Substation Inspections	*5 weeks*

Each EDC has filed its Biennial Inspection, Maintenance, Repair and Replacement Plan, pursuant to 52 Pa. Code § 57.198(a). Most EDCs proposed modifications to the standards for some programs or parts of programs. The exemptions requested involved pole loading calculations and the intervals for overhead line and transformer inspections and substations inspections.

The Commission's regulations provide the following relating to inspection and maintenance time frames:

> (c) *Time frames.* The plan must comply with the inspection and maintenance standards in subsection (n). A justification for the inspection and maintenance time frames selected shall be provided, even if the time frame falls within the intervals prescribed in subsection (n). However, an EDC may propose a plan that, for a given standard, uses intervals outside the Commission standard, provided that the deviation can be justified by the EDC's unique circumstances or a cost/benefit analysis to support an alternative approach that will still support the level of reliability required by law.

52. Pa. Code § 57.198(c).

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[22] Docket No. L-00040167, 38 *Pa.B.* 5273; Docket No. M-2009-2094773.

[23] Compliance Group 1 includes Met-Ed, Penelec, Penn Power, West Penn and UGI. Compliance Group 2 consists of Duquesne Light, PECO, PPL, Citizens', Pike County and Wellsboro.

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The Bureau of CEEP has now accepted all I&M plans. These approvals are contingent upon the possibility that subsequent audits, reviews and inquiries, in any Commission proceeding, may be conducted pursuant to 52 Pa. Code § 57.197(a). Plan revisions must be submitted as an addendum to the EDC's quarterly reliability report.

Appendix B describes the exemptions which were requested by the EDCs and provides a summary of the justification for said exemptions.

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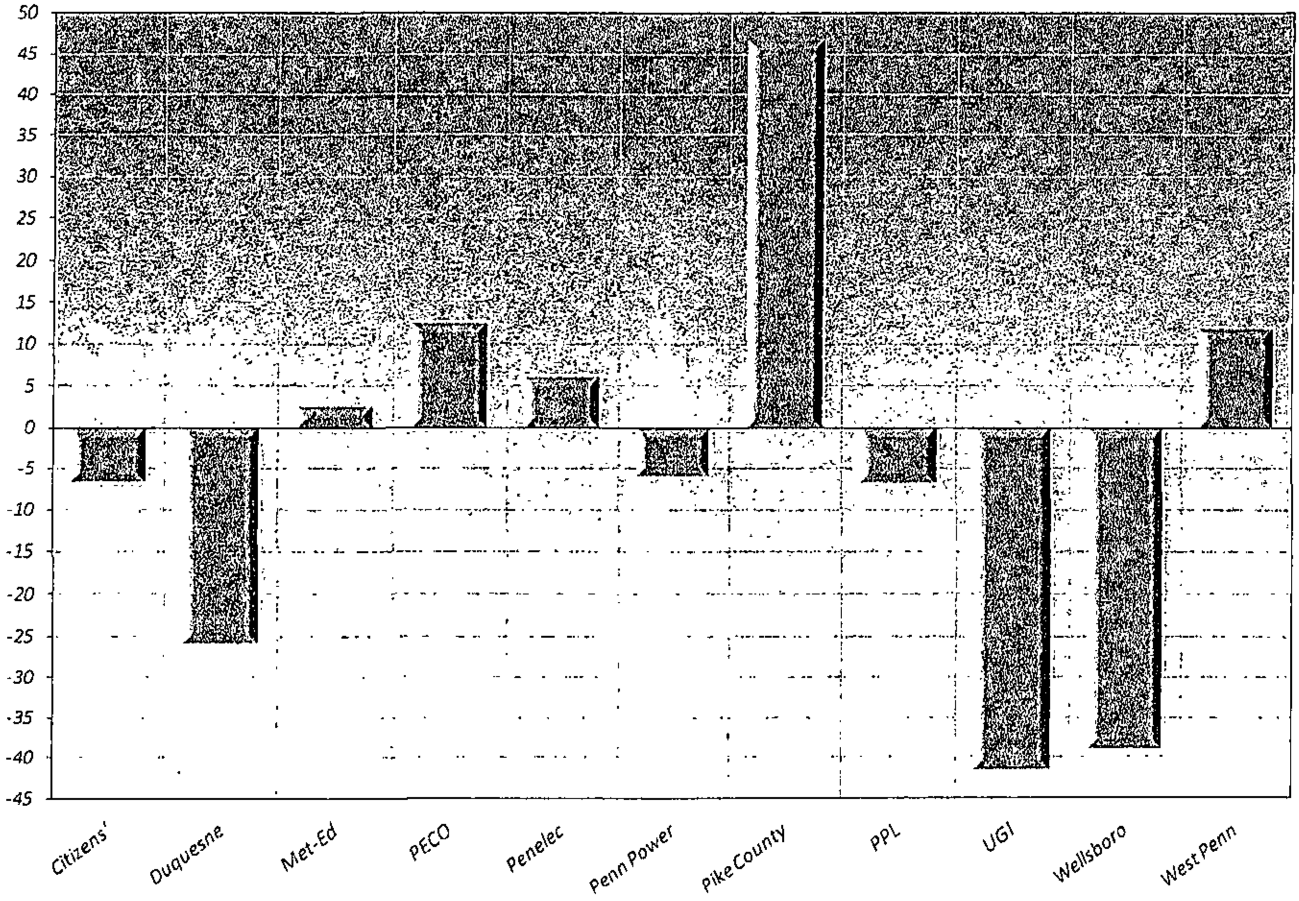
Statewide Summary

The 2010 reliability data submitted by the EDCs indicates that 10 of the 11 EDCs achieved compliance with the 12-month CAIDI performance standards for duration of service outages. Also, six of the EDCs performed better than their CAIDI benchmarks, at an average reduction in outage duration of 21.0 percent or 28 minutes. Six of the 11 EDCs had SAIDIs better than the benchmark.

Ten of the EDCs met their rolling 12-month SAIFI performance standard for the average frequency of service outages per customer. Eight EDCs performed better than their 12-month SAIFI performance benchmarks, at an average reduction in outage frequency of 12.7 percent or 0.12.

Figures 1 and 2 compare the 2010 CAIDI and SAIFI performance against benchmarks for all EDCs.

Figure 1 CAIDI 2010 comparison (percent above or below benchmark)



Note: In Figures 1 and 2, the bars below the zero line indicate performance better than the benchmarks.

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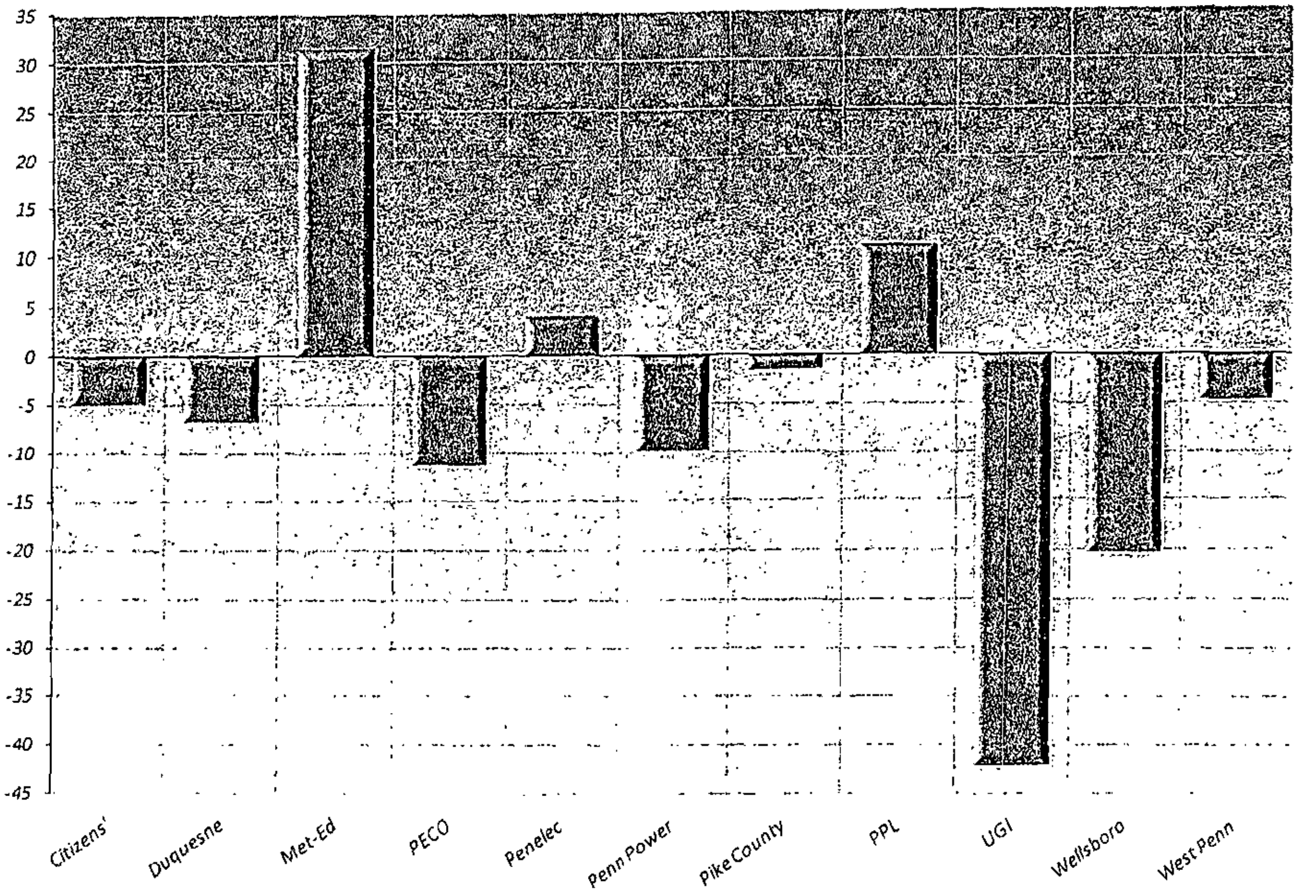
Figure 2 SAIFI 2010 comparison (percent above or below benchmark)



Appendix A provides the actual 2010 reliability performance for each EDC and the benchmarks and standards for each reliability index.

We also have assessed the average reliability performance of EDCs for a three-year period, utilizing data from 2008, 2009 and 2010. Overall, the three-year average performance has improved. One EDC (Pike County) failed to meet its rolling three-year CAIDI performance standard by 31 minutes. One EDC (Met-Ed) failed to meet its rolling three-year SAIFI performance standard by 0.09, as compared to three EDCs in the previous year's comparison. No EDC exceeded the SAIDI standards, and all EDCs have shown an improvement in their three-year SAIDI averages.

The actual 2008, 2009 and 2010 performance for each EDC and the results of the three-year performance analysis also are displayed in Appendix A.

During 2010, 23 requests for exclusion of major events were filed by the EDCs. All of these requests were approved, with the exception of one partial approval. A major event exclusion request may be denied for a variety of reasons, including such things as the event not meeting the 10 percent threshold of customers interrupted or the failure of equipment without supporting maintenance records. A brief description of each major event is provided in the individual EDC sections.

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PECO Energy Company

In 2010, PECO's customers experienced 1,823,663 service interruptions with a total duration of 230.2 million minutes, which was 7.1 percent higher than the 2009 outage minutes. Two major events occurred in PECO's service territory during 2010. The calculation of the reliability indices excludes outage data relating to these events, which were approved by the Commission.[28]

- Feb. 9-15, 2010 – Heavy snow, ice and high winds caused trees and tree limbs to fall across electric distribution equipment; 186,720 customers were affected (11.1 percent).
- June 24-30, 2010 – Lightning, rain and high winds caused trees and tree limbs to fall across electric distribution equipment; 337,351 customers were affected (20.1 percent).

PECO's CAIDI increased from 106 minutes in 2009 to 126 minutes in 2010, which was 18.9 percent higher than the previous year and 6.0 percent below the standard of 134 minutes. CAIDI has been near the standard since December 2009. The CAIDI three-year average was 3.5 percent below the standard of 123 minutes. For the 12-month average ending March 31, 2011, CAIDI was 127 minutes, or 5.2 percent below the standard. SAIDI increased from 103 minutes in 2009 to 137 minutes in 2010, or 0.7 percent below the benchmark. Figure 15 depicts the trend in the duration of customer interruptions for the PECO system from March 2004 through March 2011, compared to the established benchmark and standard for CAIDI.

PECO's SAIFI increased from 0.98 interruptions in 2009 to 1.09 in 2010, which was an 11.2 percent increase in outage frequency and 11.4 percent better than the benchmark of 1.23. SAIFI has remained below the benchmark for most of the past 10 years. The SAIFI three-year average was 23.2 percent below the standard of 1.35. For the 12-month average ending March 31, 2011, SAIFI was 1.18, or 4.1 percent below the benchmark. Figure 16 depicts the trend in the frequency of service interruptions for the PECO system from March 2004 through March 2011, compared to the established benchmark and standard for SAIFI.

In 2010, equipment failure was responsible for 36.5 percent of the incidents, 39.7 percent of customers affected and 33.1 percent of interruption minutes. Tree-related outages involving broken branches and tree trunks or uprooted trees caused 15.6 percent of the incidents, 21.6 percent of customers affected and 31.2 percent of interruption minutes. Vegetation in-growth caused 10.2 percent of outages, 7.5 percent of customers affected and 13.4 percent of interruption minutes. Of the total number of incidents, 17.7 percent were categorized as "other." Figure 17 shows the distribution of causes of service outages occurring during 2010 as a percentage of total outages. The trend in the number of outages by the top four major causes is shown in Figure 18.

PECO completed installation of a new mobile dispatch system in 2009. This new technology provides the capability to transfer outage information directly from centrally located computers to computers in the vehicles of workers in the field for more efficient operations in outage restoration.

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[28] Docket Nos. M-2010-2166572 and M-2010-2187142.

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Figure 15 PECO Customer Average Interruption Duration Index (minutes)

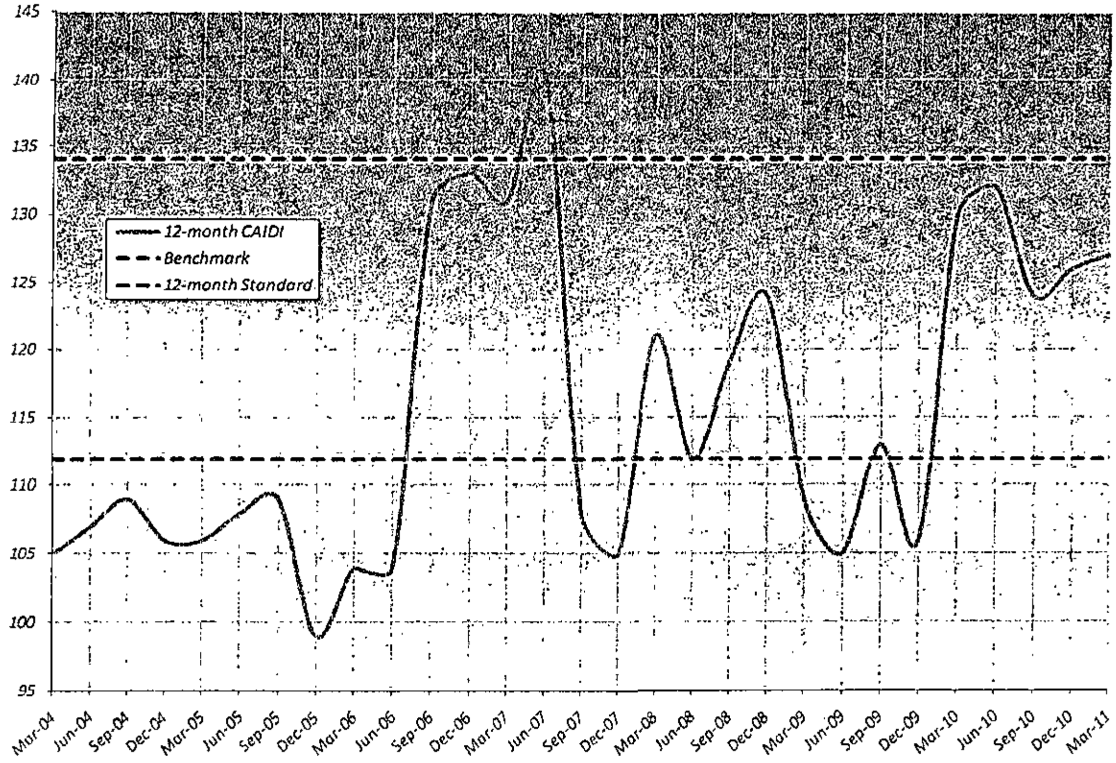

Figure 16 PECO System Average Interruption Frequency Index (interruptions per customer)

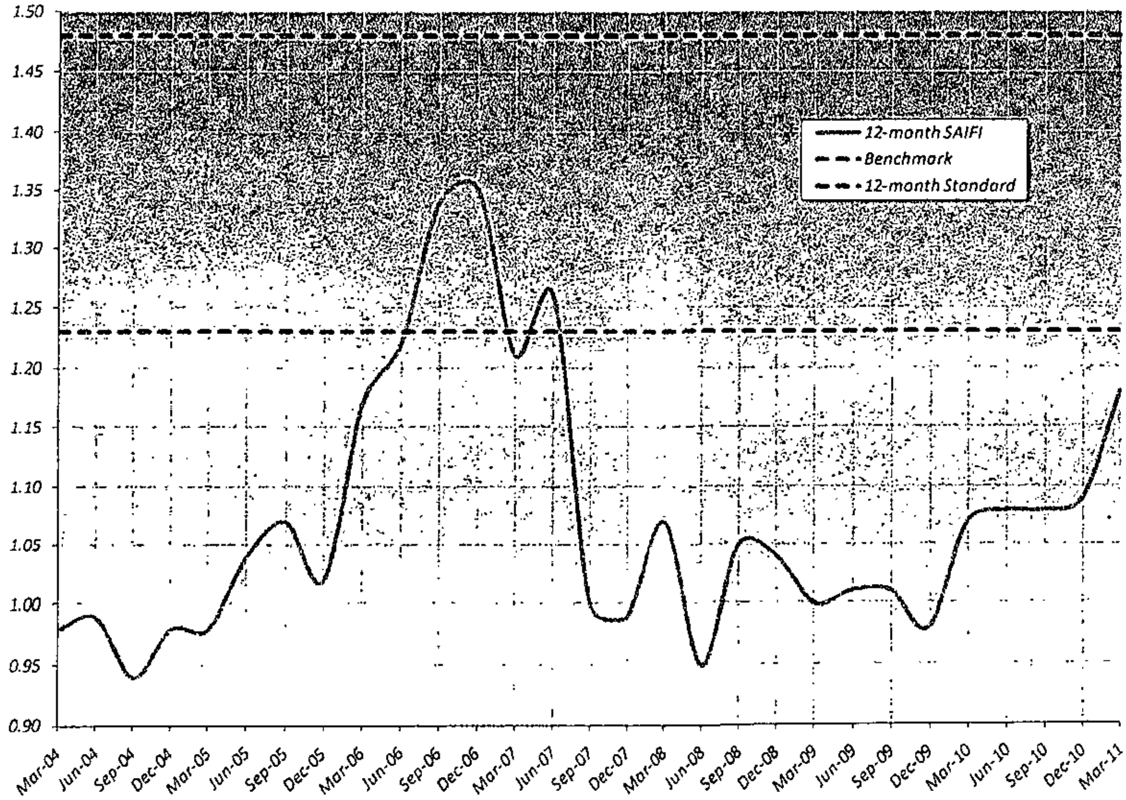

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Figure 17 PECO outage causes (percent of total outages)

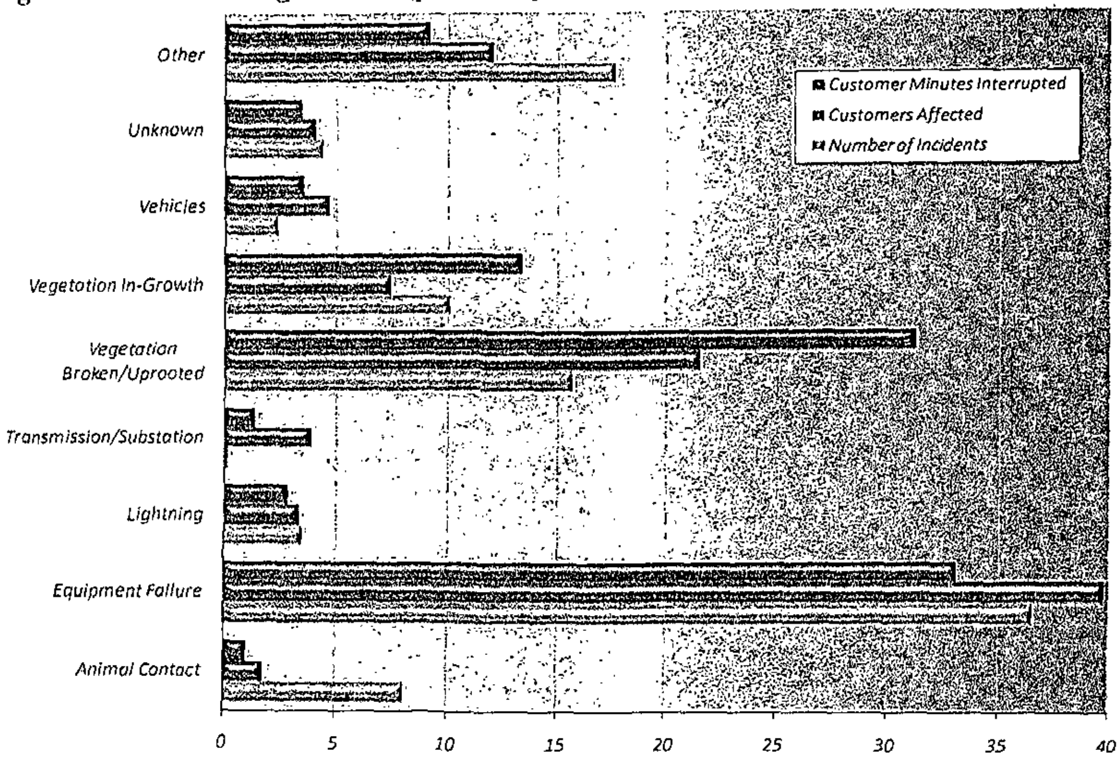
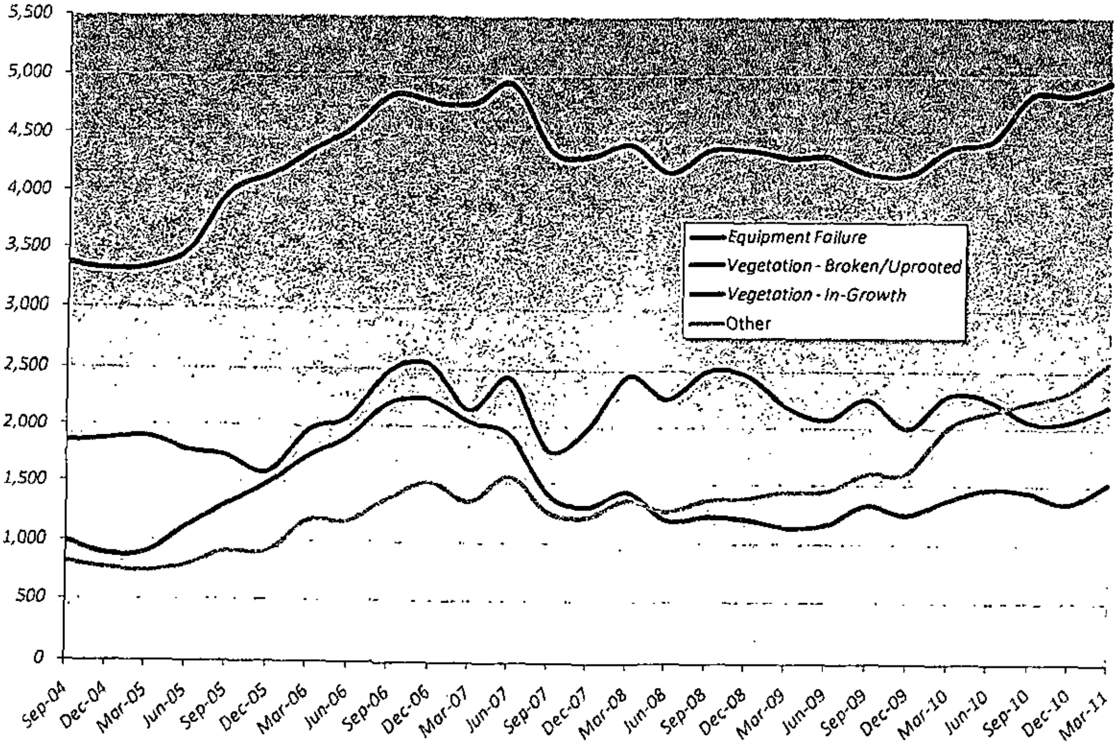


Figure 18 PECO outage tracking (number of incidents)



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VOLTAGE RANGES

Electric service voltages vary slightly during the day. This is because almost every customer draws different amounts of power from hour to hour and day to day. To counter the problem, utilities have operating and design standards which limit the range of service voltage variance. The American National Standard Institute (ANSI) has developed Standard C84.1 which recommends the following voltage ranges for utilities and their customers:

VOLTAGE RANGES
(ANSI C84.1 Standard)

Nominal Service Voltage	[1] Minimum Utilization Voltage	[2] Favorable Service Voltage (Range A)	[3] Tolerable Service Voltage (Range B)
120	108	114-126	110-127
208	187	197-218	191-220
240	216	228-252	220-254
277	249	263-291	254-293
480	432	456-504	440-508

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[1] *American National Standard Institute's C84.1 for comparison. This represents the minimum root mean squared (rms) voltage at the line terminals of the utilization equipment for circuits not supplying lighting loads.*

[2] *Favorable Voltage - The preferred range of voltage operation includes a range 5% below and 5% above nominal. Both this and the tolerable voltage range at right are rms voltages at the service entrance, outside the customer's facility.*

[3] *Tolerable Voltage - The service voltage falls outside the favorable range and includes a range of 8.33% below and 5.83% above nominal. This is considered an undesirable voltage but not low enough to cause equipment damage. Efforts should be initiated to move the voltage into the favorable range in the near future. If the voltage falls outside the tolerable range, this condition is assigned a very high priority and efforts should begin immediately to correct the voltage to an improved range.*

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Power Quality & Reliability

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Power Quality & Voltage Regulation

Understanding the Standard

ANSI C84.1 Standard

The American National Standard Institute (ANSI) has developed the Standard C84.1 which is designed to establish nominal voltage ratings and operating tolerances for 60-hertz electric power systems between 100 volts and 230 kilovolts.

The purposes of the ANSI C84.1 standard are to :

1. Promote a better understanding of the voltages associated with power systems and utilization equipment to achieve overall practical and *economical design and operation.*
2. Establish uniform nomenclature in the field of voltages
3. Promote standardization of nominal system voltages and ranges of voltage variations for operating systems
4. Promote standardization of equipment voltage ratings and tolerances
5. Promote coordination of relationships between system and equipment voltage ratings and tolerances
6. Provide a guide for future development and design of equipment to achieve the best possible conformance with the needs of the users
7. Provide a guide, with respect to choice of voltages, for new power system undertakings and for changes in old ones.

The standard defines voltage classes as :

Low voltage	A Class of nominal voltages 1000 volts or less
Medium Voltage	A Class of nominal voltages greater than 1000 volts and less than 100,000 volts.
High voltage	A Class of nominal voltages equal to or greater

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	than 100,000 volts and to or less than 230,000 volts.

The standard defines preferred* nominal system voltages as :

Class	Three Wire	Four Wire
Low voltage		
	120 / 240	208 Y / 120
	480	480 Y / 277
Medium Voltage		
	4,160	12,000 Y / 6,930
	13,800	12,470 Y / 7,200
	69,000	24,490 Y / 14,400
		34,500 Y / 19,920
High voltage		
	115,000	
	138,000	
	230,000	
Extra High Voltage		
	345,000	
	500,000	
	765,000	

* ANSI C84.1 Table 1 - Standard nominal system voltages and voltage ranges, should be referenced for a complete listing of all voltages available across all voltage classes.

The medium voltage three-wire systems, 4,160, 6,900 and 13,800 volts, are particularly suited for industrial systems that supply predominantly polyphase loads, including large motors, for these voltages correspond to standard motor ratings of 4000 volts, 6600 volts, and 13 200 volts. It is not intended to recommend the use of these system voltages for utility primary distribution, for which four-wire voltages of 12 470Y / 7200 volts or higher should be used.

Furthermore, the standard continues to define as to what acceptable operating voltage ranges are to be for electrical supply and utilization systems. The standard defines these ranges in two categories: Range A and Range B.

Range A :

Service Voltage : Electric supply systems shall be so designed and operated that most service voltages will be within the limits specified for Range A. The occurrence of service voltages outside of these limits should be infrequent.

Utilization Voltage : Electrical systems shall be designed and operated within the voltage range defined as Range A; which most utilization voltages being specified within this range.

Utilization equipment shall be designed and rated to give fully satisfactory performance throughout range A.

Range B :

Service and Utilization Voltage : Range B includes voltages above and below Range A limits that necessarily result from practical design and operating conditions on supply or user systems, or both. Although such conditions are a part of practical operations, they shall be limited in extent, frequency, and duration. When they occur, corrective measures shall be undertaken within a reasonable time to improve voltages to meet Range A requirements.

Insofar as practicable, utilization equipment shall be designed to give acceptable performance in the extremes of the range of utilization voltages, although not necessarily as good performance as in Range A.

It should be recognized that because of conditions beyond the control of the supplier or user, or both, there will be infrequent and limited periods when sustained voltages outside Range B limits will occur. Utilization equipment may not operate satisfactorily under these conditions, and protective devices may operate to protect the equipment.

When voltages occur outside the limits of Range B, prompt, corrective action shall be taken. The urgency for such action will depend upon many factors, such as the location and nature of the load or circuits involved, and the magnitude and duration of the deviation beyond Range B limits.

The following is a summary of the standard showing voltage ranges for Range A and B, along with a table that depicts the standard on a 120-volt base.

The table shows the following range for nominal voltage :

Range A	Utilization Voltage	- 5 to + 5 %
	Service Voltage	- 5 to + 5 %
	Service Voltage (Greater than 600 V)	- 2.5 % to + 5 %
Range B	Utilization Voltage	- 13 to + 6 %

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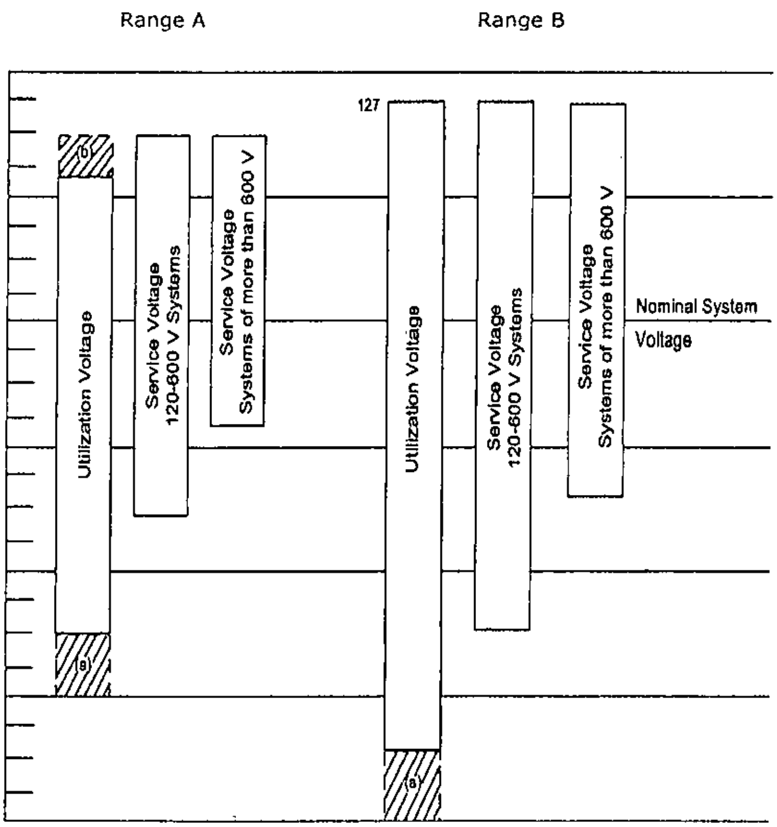
	Service Voltage	– 10 to + 6 %
	Service Voltage (Greater than 600 V)	– 5 % to + 6 %



Voltage Ranges, ANSI C84.1

Notes :

a. These shaded portions of the ranges do not apply to circuits supplying lighting loads

b. This shaded portion of the range does not apply to 120-600-volt systems.

c. The difference between minimum service and minimum utilization voltages is intended to allow for voltage drop in the customer's wiring system. This difference is greater for service at more than 600 volts to allow for additional voltage drop in transformations between service voltage and utilization equipment.

d. The Range B utilization voltage limits in table 1 for 6900-volt and 13800-volt systems are 90% and 110% of the voltage ratings of the standard motors used in these systems and deviate slightly from this figure.

ANSI C84 does establish nominal voltage ratings and operating tolerances, for 60-

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hertz electric power systems above 100 volts and through 230 kilovolts that apply to sustained voltage levels only, this standard doe not include momentary disturbances, which may be the result of, but not limited to, utility switching operations, fault clearing, large motor starts, lightning strikes, and similar occurrences.

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Interconnection Standards for Distributed Energy Resources

- IEEE 1547 Voltage and Frequency Tolerance

Voltage Range (% Nominal)	Max. Clearing Time (sec) *
V < 50%	0.16
50% ≤ V < 88%	2.0
110% < V < 120%	1.0
V ≥ 120%	0.16

(*) Maximum clearing times for DER ≤ 30 kW; Default clearing times for DER > 30 kW

Frequency Range (Hz)	Max. Clearing Time (sec)
f > 60.5	0.16
f < 57.0 *	0.16
59.8 < f < 57.0 **	Adjustable (0.16 and 300)

(*) 59.3 Hz if DER ≤ 30 kW

(**) For DER > 30 KW

- Additional disconnection requirements
  - Cease to energize for faults on the Area EPS circuit
  - Cease to energize prior to circuit reclosure
  - Detect island condition and cease to energize within 2 seconds of the formation of an island ("anti-islanding")

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EFFECT OF VOLTAGE SPREAD ON UTILIZATION EQUIPMENT

General Effects. Whenever the voltage at the terminals of a utilization device varies from name-plate rating of the device, something is sacrificed either in life or performance of the equipment. The effect may be minor or serious, depending upon the characteristics of the device, how the device is applied, and the amount the voltage deviates from the device rating. NEMA Standards provide for certain tolerances which may be taken advantage of without seriously affecting the performance of the apparatus. However, with usage of electric power for precise operations, there is often a major sacrifice in production for voltage variations of considerably less than given in the NEMA Standards.

So that the plant engineer can better judge the effect of voltage variation on the electric equipment in his plant, the characteristics of many commonly used devices are given here. It is these characteristics which have been used as a starting point for establishing the desired voltage spread of Tables 4.8 and 4.9.

Effect on Induction Motors. Induction motors are the most common utilization devices in industrial plants. The variation in characteristics as a function of voltage for the widely used induction motors is shown in Table 4.6. The material in this section deals only with the effect on motor characteristics of changes in voltage magnitude. The effect of unbalanced voltages is also very important and should be considered. The current may become excessive for only a small voltage unbalance. The NEMA Standards should be consulted for detailed information on this subject.

Principal Effects of Low Voltage on Induction Motors. The most significant effects of too low voltage are reduction in starting torque and increased full-load temperature rise. The reduction of starting torque may be significant in motor applications driving high-inertia equipment. The lower torque will result in longer acceleration periods. Torque motors are also very materially affected by reduced voltage as the torque decreases as the square of the voltage; thus at 10 per cent below normal voltage, the torque is reduced 19 per cent.

The increased heating at low voltage and full load reduces the life of the insulation.

Principal Effects of High Voltage on Induction Motors. The most significant effects of too high voltage are increased torque, increased starting current, and decreased power factor.

The increased torque may cause couplings to shear off or damage to driven equipment. Increased starting current causes greater voltage drop in the power system, hence increases light flicker. Decreased power factor is particularly disadvantageous where power-factor penalty clauses

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Industrial Power Systems Handbook

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Chapter 2 by R. H. Kaufmann

Symmetrical Components as Applied to Short-circuit-current Calculation on Three-phase Systems

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The unbalanced circuit problems encountered in short-circuit analysis can be resolved by using symmetrical-component analysis. This analysis technique is used extensively by power-system investigators and authors. Developed in this chapter are concepts and procedures for the application of symmetrical-component analysis to the determination of short-circuit currents. While this procedure is built up from base fundamentals, it is aimed expressly at the solution of electrical-system short-circuit problems. For other possible applications of symmetrical-component analysis such as the determination of unbalanced currents in certain circuits or machines, it is suggested that reference be made to a more elaborate textbook* which explores the full field of application more completely.

THE USE OF COMPONENTS

The separation of an electrical vector quantity into components to simplify computation procedure is familiar to all. It has been common practice to consider an alternating voltage or alternating current to be composed of two components at right angles to each other. It should be evident that the process is not limited to two quantities, nor is it necessary that the components be 90° apart.

---

* Edith Clarke, "Circuit Analysis of A. C. Power Systems," vol. 1, John Wiley & Sons, Inc., New York, 1943.

For example, take the expression

$$E = IZ$$

It is entirely valid to express this as

$$E = (I_1 + I_2)Z = I_1Z + I_2Z$$

provided that

$$I_1 + I_2 = I$$

or as

$$E = (I_1 + I_2 + I_3)Z = I_1Z + I_2Z + I_3Z$$

provided that

$$I_1 + I_2 + I_3 = I$$

Thus there is no mystery about the use of components. It is applicable so long as the equations are linear (as they will be in electrical-circuit work).

$E = IZ$, $I = EY$, [illegible] $Z_1 I_a$ etc.

[illegible]

SYMMETRICAL COMPONENTS

If the Z per phase as illustrated in Fig. 2.1 could be represented as a firm fixed value, the circuit analysis would be simple. Since the conductors of the three phases are magnetically coupled, the voltage drop in the A phase depends not only on the current in the A phase but on the current in the other two phases as well.

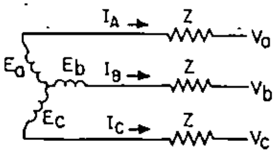

FIG. 2.1 A simple symmetrical three-phase system.

Consider the induction-motor impedance diagram of Fig. 2.2. Assume the rotor to be turning at normal speed in the direction produced by an impressed voltage of sequence ABC. What IZ drop will be produced in the A phase because of a current I_A alone? That is a tough one; although there are some relationships of which we are sure.

Under the conditions of balanced currents of sequence ABC there will be balanced terminal voltages of sequence ABC. With normal rated voltage and light load the current will be of the order of one-fourth or one-third rated value. Under this condition all three phases appear to have identical impedances of 1/0.25 or 1/0.333 or three or four per-unit (300 or 400 per cent).

On the other hand, had the impressed voltage been applied with opposite sequence (ACB), it is evident that this would be equivalent to

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plugging. There would be a balanced set of currents, but this time the application of rated voltage would cause currents of about six times rated value. In other words, the impedance appears to be the same in all three phases, but its value is now $\frac{1}{6} = 0.16$ per-unit, or 16 per cent. The effect of mutual winding coupling alone may make the effective impedance per phase as low as 16 per cent or as high as 300 or 400 per cent.

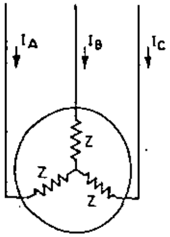


FIG. 2.2 Induction-motor impedance diagram.

There is one significant observation. So long as the three currents are equal and separated by the same angular displacement, the effect of currents I_B and I_C on the voltage drop in phase A will be identical with the effect of currents I_C and I_A on the voltage drop in phase B and also with the effect of currents I_A and I_B on the voltage drop in phase C. Thus the effective impedance will appear to be identical in all three phases; that is, the impedance voltage drop in the A phase will bear the same relationship to the current in the A phase as the impedance drop in phase B bears to the current in phase B and as the impedance drop in phase C bears to the current in phase C. Or expressing this symbolically,

$$\frac{I_A Z_A}{I_A} = \frac{I_B Z_B}{I_B} = \frac{I_C Z_C}{I_C}$$

Thus $Z_A = Z_B = Z_C$.

This also identifies the fact that the impedance voltage drops $I_A Z_A$, $I_B Z_B$, and $I_C Z_C$ are separated by the same angles as I_A, I_B, and I_C.

These are two very important facts which emphasize the value of *symmetrical* components.

POSSIBLE SYMMETRICAL COMBINATIONS

There are but three possible symmetrical combinations in a three-phase system in which the three phase quantities are equal and separated by the same angle. The displacement angle must be a multiple of 120° since the three phases of a three-phase system are separated by 120°. This is shown in the following three cases using currents for illustration.

Case 1. I_B is 120° behind I_A and I_C is 120° behind I_B.
Case 2. I_B is 240° behind I_A and I_C is 240° behind I_B.
Case 3. I_B is 360° behind I_A and I_C is 360° behind I_B.

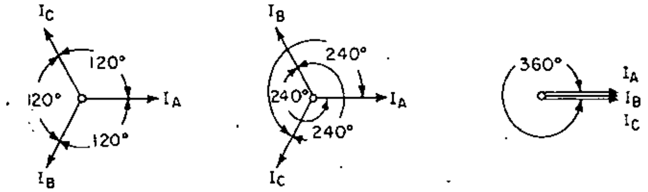
The vector relationships represented by these three cases of symmetrical displacement are shown in Fig. 2.3. Henceforth reference will be made to case 1 as the positive-sequence component denoted by a subscript 1 characterized by three equal vectors 120° apart in the normal sequence ABC; to case 2 as the negative-sequence component denoted by a subscript 2 characterized by three equal vectors 120° apart but with a sequence ACB opposite normal; and to case 3 as the zero-sequence component denoted by a subscript 0 characterized by three equal vectors with zero angular separation (in phase with each other).

Even at the risk of unnecessary repetition, the two important properties of these three symmetrical components are repeated.

The circulation of any one of the three symmetrical three-phase current patterns in a symmetrical three-phase circuit, even though the phase windings are mutually coupled, yields a balanced three-phase impedance voltage drop whose sequence pattern is identical with that of the current pattern. Likewise, the application of any one of the three symmetrical three-phase voltage patterns on the circuit will give rise to a balanced three-phase current whose sequence pattern is identical with that of the voltage.

1. Current flow of one sequence pattern produces voltage drops of the same sequence pattern only.
2. Applied voltage of one sequence pattern produces currents of the same sequence pattern only.
3. For each sequence pattern, the impedance can be regarded as a definite fixed quantity identical in all three phases.

This then is the significance and identity of the symmetrical components (of which there are three types in three-phase systems) and may be applied to voltages as well as currents.



CASE 1 (POSITIVE SEQUENCE) CASE 2 (NEGATIVE SEQUENCE) CASE 3 (ZERO SEQUENCE)

FIG. 2.3 Symmetrical patterns of current.

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THE OPERATOR *a*

In the application of symmetrical-component analysis there will be repeated need to shift a particular vector by multiples of 120°. Particularly in analytical studies it will be advisable merely to indicate the desired operation, leaving the actual resolution until the final solution is approached. Invariably it will be found that combinations of operations appear modifying a particular vector which can be directly reduced to much simpler form, or often simply vanish.

The small letter *a* is used to indicate an angular advance of 120° in the vector to which it is appended. Its use parallels the use of *j* as a 90° advance operator, i.e., aI_b would mean a vector of the same magnitude as I_b but advanced 120°; while a^2I_b would mean a vector of the same magnitude as I_b but advanced 240°.

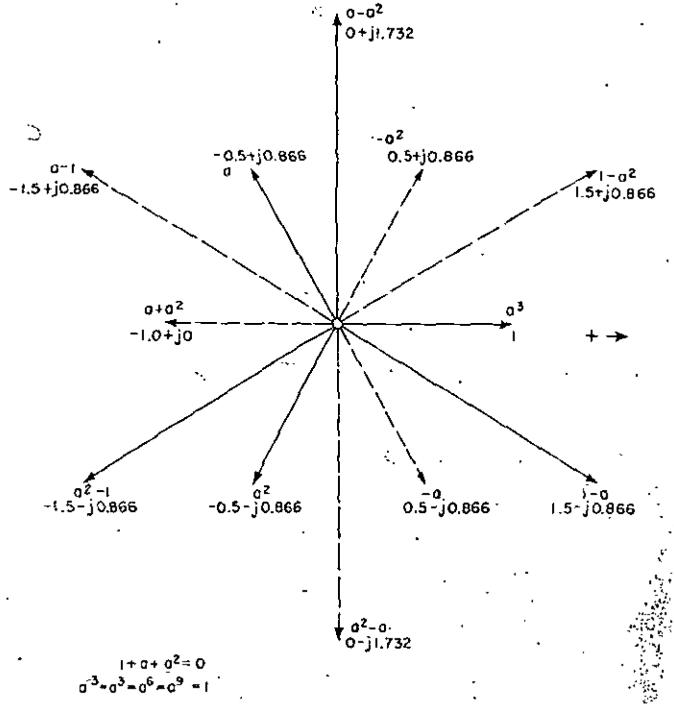

FIG. 2.4 Functions of the 120° operator *a*.

The significance of commonly encountered combinations of *a* operators is indicated in Fig. 2.4. For instance $(a^2\text{-}a)I_b$ would indicate a vector $\sqrt{3}$ times as large as I_b and advanced 270° in angle.

Comparing the operators *j* and *a* in more detail to explain Fig. 2.4, a vector 1 to the right on the horizontal, Fig. 2.4, when multiplied by *j* would be $0 + j1$. That same vector multiplied by *a* becomes (in terms of *j*) $-\ 0.5 + j0.866$; multiplied by a^2 it becomes $-\ 0.5 - j0.866$. 1-*a* then becomes $1 - (-\ 0.5 + j0.866) = 1.5 - j0.866$ or an advance of 270° and $\sqrt{3}$ times as large.

RESOLUTION OF SEQUENCE COMPONENTS

It develops that any possible pattern of three-phase currents or three-phase voltages can be resolved exactly into combinations of the three types of symmetrical components. Some properties of the three symmetrical-sequence components will be of interest in showing the nature of their independence and the manner in which they may be separated.

Referring to Fig. 2.5 it will be seen that, if the vector sum of the three vectors of each component is made, the answer will be zero for the positive-sequence and negative-sequence systems and 3 for the zero-sequence system. If first the *B*-phase quantity is advanced 120° and the *C* phase advanced 240° and the vector sum then evaluated, the answers will be 3 for the positive-sequence system and zero for the negative- and zero-sequence systems. But if first the *B*-phase quantity is advanced 240° and the *C*-phase quantity advanced 120°, the vector sum will then be zero for

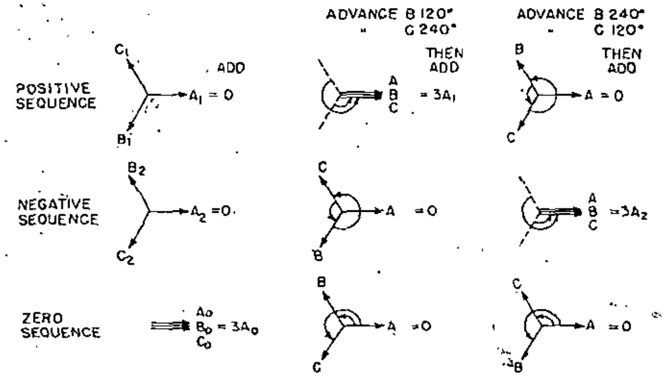

FIG. 2.5 Properties of symmetrical-component quantities.

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the positive-sequence system, three for the negative-sequence system, and zero for the zero-sequence system.

This suggests that the three sequence components have independent degrees of freedom.

Suppose that the three actual line currents I_A, I_B, and I_C are to be resolved into three balanced-sequence components of types positive, negative, and zero. If I_A, I_B, and I_C are added vectorially, it may be expected that whatever positive-sequence and negative-sequence component were contained therein would add up to zero, and the answer should be three times the value of the zero-sequence component.

$$I_A + I_B + I_C = 3I_{a0}$$

$$I_{a0} = \frac{I_A + I_B + I_C}{3}$$

If the B-phase current is first advanced 120° and the C-phase current 240° and then added, it can be expected that whatever negative-sequence and zero-sequence component were contained therein would add up to zero, and the sum should thus be three times the positive-sequence component.

$$I_A + aI_B + a^2I_C = 3I_{a1}$$

$$I_{a1} = \frac{I_A + aI_B + a^2I_C}{3}$$

In similar fashion by first advancing the B-phase current 240° and the C-phase current 120° the sum should then be three times the negative-sequence component in the A phase.

$$I_A + a^2I_B + aI_C = 3I_{a2}$$

$$I_{a2} = \frac{I_A + a^2I_B + aI_C}{3}$$

Since each of the sequence systems is symmetrical, one can immediately identify the corresponding components in the other phases. Refer to Fig. 2.3 to check the angular position of phase components.

Zero sequence:

$$I_{a0} = I_{b0} = I_{c0} = \frac{I_A + I_B + I_C}{3}$$

Positive sequence:

$$I_{a1} = \frac{I_A + aI_B + a^2I_C}{3}$$

$$I_{b1} = a^2I_{a1} = \frac{a^2I_A + I_B + aI_C}{3}$$

$$I_{c1} = aI_{a1} = \frac{aI_A + a^2I_B + I_C}{3}$$

Negative sequence:

$$I_{a2} = \frac{I_A + a^2I_B + aI_C}{3}$$

$$I_{b2} = \frac{aI_A + I_B + a^2I_C}{3}$$

$$I_{c2} = \frac{a^2I_A + aI_B + I_C}{3}$$

All three currents which comprise each of the three component systems now have been defined. The sum of all three component currents of each phase should equal the original actual phase current.

Phase A:

$$\begin{aligned} I_A &= I_{a1} + I_{a2} + I_{a0} \\ &= \frac{I_A + aI_B + a^2I_C}{3} + \frac{I_A + a^2I_B + aI_C}{3} + \frac{I_A + I_B + I_C}{3} \\ &= \tfrac{1}{3}I_A(1 + 1 + 1) + I_B(a + a^2 + 1) + I_C(a^2 + a + 1) \\ &= \frac{3I_A}{3} + 0 + 0 = I_A \end{aligned}$$

Phase B:

$$\begin{aligned} I_B &= I_{b1} + I_{b2} + I_{b0} \\ &= \frac{a^2I_A + I_B + aI_C}{3} + \frac{aI_A + I_B + a^2I_C}{3} + \frac{I_A + I_B + I_C}{3} \\ &= \tfrac{1}{3}I_A(a^2 + a + 1) + I_B(1 + 1 + 1) + I_C(a + a^2 + 1) \\ &= \tfrac{1}{3}(0 + 3I_B + 0) = I_B \end{aligned}$$

Phase C:

$$\begin{aligned} I_C &= I_{c1} + I_{c2} + I_{c0} \\ &= \frac{aI_A + a^2I_B + I_C}{3} + \frac{a^2I_A + aI_B + I_C}{3} + \frac{I_A + I_B + I_C}{3} \\ &= \tfrac{1}{3}I_A(a + a^2 + 1) + I_B(a^2 + a + 1) + I_C(1 + 1 + 1) \\ &= \tfrac{1}{3}(0 + 0 + 3I_C) = I_C \end{aligned}$$

Thus a means now has been devised of separating the three actual line currents (or voltages) into three systems of symmetrical components, and further it has been shown that the sum of the three component quantities of each phase does exactly equal the original true line current (or voltage).

Several fundamental equations and commonly used relationships are listed in Table 2.1.

INDEPENDENCE OF SEQUENCE SYSTEMS

The fact has been developed that, in symmetrical circuits, currents of one sequence produce voltages of the same sequence only and likewise

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Impressed voltages of one sequence produce currents of like sequence only. In other words, there is no mutual coupling between sequence systems. Thus the voltage drops in impedances can be separately evaluated for each sequence component of current and the resulting voltage drops added to get the total voltage drop. Thus in Fig. 2.1 the total impedance drop across the impedance Z in the direction of current flow is

Phase A:

$$(IZ)_a = I_{a1}Z_1 + I_{a2}Z_2 + I_{a0}Z_0$$

Similar expressions could be written for the other two phases, but a simpler attack is possible from concepts already acquired. The positive-sequence drops will all be of equal magnitude and of positive sequence, the negative-sequence drops will all be of equal magnitude and of negative sequence, and the zero-sequence drops will be of equal magnitude and of zero sequence. Therefore,

Phase B:

$$(IZ)_b = a^2I_{a1}Z_1 + aI_{a2}Z_2 + I_{a0}Z_0$$

Phase C:

$$(IZ)_c = aI_{a1}Z_1 + a^2I_{a2}Z_2 + I_{a0}Z_0$$

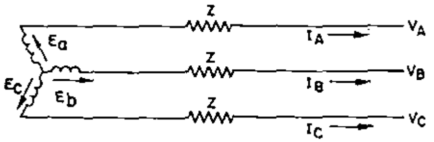
Here for the first time the advantage of the symmetrical-component approach can be appraised. For each symmetrical-component system, impedances can be regarded as having a definite fixed value identical in all three phases. The impedance values in the three component systems may be widely different, however. That is, Z_1 may be altogether different from Z_2 or Z_0. Until the actual currents were resolved into symmetrical components, there seemed no alternate to the use of self and mutual impedances in each phase.

At this point note that under balanced-load conditions the current is entirely of positive sequence. Thus the usual solution of balanced operation is really a special case involving only the positive-sequence system, i.e., positive-sequence voltages, positive-sequence currents, and positive-sequence impedances.

The application of these principles to the solution of unbalanced-load problems now may be studied. It seems appropriate at this point to review some physical concepts of the three component systems.

All source machines generate only positive-sequence voltage. The winding pattern in the A phase will be repeated in the B phase 120 electrical degrees later and in the C phase 240 electrical degrees later. Thus identical voltages will be generated in each phase winding except that the B phase will be 120° behind the A phase and the C phase will be 120° behind the B phase.

TABLE 2.1 Fundamental Equations



With line currents I_A, I_B, I_C known, sequence currents are

$$I_{a0} = \frac{I_A + I_B + I_C}{3} = I_{b0} = I_{c0}$$

$$I_{a1} = \frac{I_A + aI_B + a^2I_C}{3}; \qquad I_{b1} = a^2I_{a1}; \qquad I_{c1} = aI_{a1}$$

$$I_{a2} = \frac{I_A + a^2I_B + aI_C}{3}; \qquad I_{b2} = aI_{a2}; \qquad I_{c2} = a^2I_{a2}$$

With line-to-neutral voltages V_A, V_B, V_C known,

$$V_{a0} = \frac{V_A + V_B + V_C}{3} = V_{b0} = V_{c0}$$

$$V_{a1} = \frac{V_A + aV_B + a^2V_C}{3}; \qquad V_{b1} = a^2V_{a1}; \qquad V_{c1} = aV_{a1}$$

$$V_{a2} = \frac{V_A + a^2V_B + aV_C}{3}; \qquad V_{b2} = aV_{a2}; \qquad V_{c2} = a^2V_{a2}$$

NOTE: Voltages E_a, E_b, and E_c generated within balanced-winding rotating machines are entirely positive sequence.

Commonly Used Relationships:

$$\begin{aligned}
I_A &= I_{a1} + I_{a2} + I_{a0} \\
I_B &= I_{b1} + I_{b2} + I_{b0} = a^2I_{a1} + aI_{a2} + I_{a0} \\
I_C &= I_{c1} + I_{c2} + I_{c0} = aI_{a1} + a^2I_{a2} + I_{a0} \\
V_A &= V_{a1} + V_{a2} + V_{a0} \\
V_B &= V_{b1} + V_{b2} + V_{b0} = a^2V_{a1} + aV_{a2} + V_{a0} \\
V_C &= V_{c1} + V_{c2} + V_{c0} = aV_{a1} + a^2V_{a2} + V_{a0} \\
E_a &= I_{a1}Z_1 + V_{a1}; \qquad V_{a1} = E_a - I_{a1}Z_1 \\
0 &= I_{a2}Z_2 + V_{a2}; \qquad V_{a2} = -I_{a2}Z_2 \\
0 &= I_{a0}Z_0 + V_{a0}; \qquad V_{a0} = -I_{a0}Z_0 \\
V_A &= V_{a1} + V_{a2} + V_{a0} \\
&= E_a - I_{a1}Z_1 - I_{a2}Z_2 - I_{a0}Z_0 \\
V_B &= a^2V_{a1} + aV_{a2} + V_{a0} \\
&= a^2E_a - a^2I_{a1}Z_1 - aI_{a2}Z_2 - I_{a0}Z_0 \\
V_C &= aV_{a1} + a^2V_{a2} + V_{a0} \\
&= aE_a - aI_{a1}Z_1 - a^2I_{a2}Z_2 - I_{a0}Z_0
\end{aligned}$$

Negative- and zero-sequence voltages result from the impedance drop produced by the flow of negative- and zero-sequence components of current. Generally, positive-sequence voltages will be greatest at the source machines and diminish as one moves toward the short circuit. On the other hand, negative- and zero-sequence voltages will be greatest at the

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short-circuit point and diminish as one approaches the source machines.

Positive-sequence voltages and currents produce (and are associated with) magnetic fields within rotating machines which rotate in the same direction as normal rotational direction.

Negative-sequence voltages and currents produce (and are associated with) magnetic fields in rotating machines which rotate in a direction opposite to normal rotation. The latter thus produce machine torques tending to slow down a motor rotor, and the positive-sequence electrical quantities must produce a torque equal to the load torque plus that resulting from the negative-sequence current if normal running speed is to be maintained.

Zero-sequence currents are in phase in all three conductors. For such currents to flow at all it is evident that the electrical neutral must be connected to a fourth conductor or ground. Being in phase, the currents add up numerically at the neutral connection and become $3I_{a0}$ in the neutral circuit. Zero-sequence currents produce a stationary pulsating magnetic field in the rotating machine stator winding which is predominantly of stator-leakage character, very little of which crosses the air gap to enter the rotor. Zero-sequence current will rarely be found in motors since the motor neutral is almost never grounded.

PER-UNIT SYSTEM*

While symmetrical-component analysis is valid regardless of the system of units used, it will be found desirable to adopt the per-unit system.

In the per-unit system, potentials are expressed as a fraction of an arbitrarily assigned line-to-neutral voltage (usually the normal operating voltage). Currents are expressed as a fraction of an arbitrarily assigned circuit current. This base current is usually selected to correspond with a convenient round-number kva such as 1000, 10,000, etc.

Only two quantities can be arbitrarily assigned, i.e., base voltage and base kva or base voltage and base current. Unit values of all other quantities become fixed as soon as the first two are assigned.

Unit base voltage and current are arbitrarily assigned at some one part of the system. The values of unit voltage and current at other parts of the system become those which would result from the turn ratio of interconnecting transformers.

The per-unit impedances define the fraction of base voltage which will be produced by the flow of unit base current.

The value of the per-unit system is at once apparent. The impedances of generators, motors, and transformers when expressed in per-unit on their own rating as a reference base assume almost a constant numerical value throughout a wide range of physical size and voltage rating. For example, the impedance of a transformer will be about 0.05 per-unit (5 per cent) on its own rating as a base quite independent of size or voltage rating. If expressed in ohms, the numerical value of Z would vary widely with no sign of any common denominator. Also, in the per-unit system a particular per-unit value of current flowing into one side of a transformer comes out the other side as the same per-unit value.

Refer to Chap. 1, page 54, for a complete list of equations relating per-unit values.

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* See Chap. 1, p. 52.

SYSTEM APPLICATION

The approach to circuit problems consists of writing the relations existing between generated voltages and impedance drops in the usual conventional manner except that three sequence systems may be involved.

In the simple circuit arrangement shown in Fig. 2.6 it can be seen that one can directly evaluate (in terms of the A phase)

Positive sequence:

$$E_a = I_{a1}(Z_{G1} + Z_{L1} + Z_{T1}) + V_{a1}$$
$$V_{a1} = E_a - I_{a1}(Z_{G1} + Z_{L1} + Z_{T1})$$

Negative sequence:

$$0 = I_{a2}(Z_{G2} + Z_{L2} + Z_{T2}) + V_{a2}$$
$$V_{a2} = -I_{a2}(Z_{G2} + Z_{L2} + Z_{T2})$$

Zero sequence:

$$0 = I_{a0}(Z_{G0} + Z_{L0} + Z_{T0}) + V_{a0}$$
$$V_{a0} = -I_{a0}(Z_{G0} + Z_{L0} + Z_{T0})$$

Combined:

$$\begin{aligned} V_A &= V_{a1} + V_{a2} + V_{a0} \\ &= E_a - I_{a1}(Z_{G1} + Z_{L1} + Z_{T1}) - I_{a2}(Z_{G2} + Z_{L2} + Z_{T2}) \\ &\qquad - I_{a0}(Z_{G0} + Z_{L0} + Z_{T0}) \end{aligned}$$

It will be useful to draw the individual sequence circuits such as indicated on Fig. 2.7. Note that the circuit for the positive sequence is

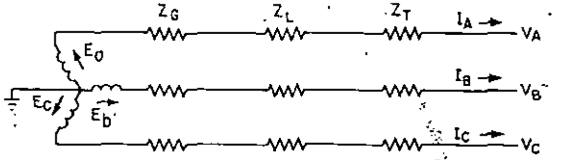

FIG. 2.6 Typical symmetrical three-phase circuit.

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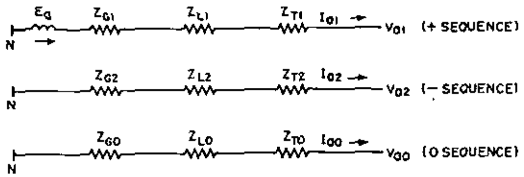

$$E_a = I_{a1}(Z_{G1}+Z_{L1}+Z_{T1})+V_{a1}$$
$$0 = I_{a2}(Z_{G2}+Z_{L2}+Z_{T2})+V_{a2}$$
$$0 = I_{a0}(Z_{G0}+Z_{L0}+Z_{T0})+V_{a0}$$
$$\begin{aligned}V_A &= V_{a1}+V_{a2}+V_{a0}\\ &= E_a - I_{a1}(Z_{G1}+Z_{L1}+Z_{T1}) - I_{a2}(Z_{G2}+Z_{L2}+Z_{T2})\\ &\qquad - I_{a0}(Z_{G0}+Z_{L0}+Z_{T0})\end{aligned}$$

FIG. 2.7 Equivalent sequence circuits of Fig. 2.6 (in terms of the *A* phase).

identically that which would be used alone for balanced-load problems. In the treatment of unbalanced loads, two additional circuits are involved (negative and zero sequence) which appear about the same except that there are no generated voltages therein and the respective sequence impedances are used.

TYPE OF APPROACH

Through experience in the application of symmetrical-component analysis, particular types of approach, appropriate selection of reference phase, and useful equivalent circuits have been discovered which lead to a solution in the simplest manner.

Generalized solutions of problems presented in short-circuit studies of three-phase systems (circuit-breaker selection or relay application) include the following forms of short circuits:

1. Three-phase
2. Line-to-line
3. Line-to-ground
4. Double line-to-ground

THREE-PHASE SHORT CIRCUITS

The three-phase short-circuit condition represents a balanced three-phase short circuit on the system. Only positive-sequence quantities are involved; hence only the positive-sequence impedance system will be needed. The solution thus simplifies to an analysis of a single-circuit network involving only positive-sequence impedances and is done in the familiar conventional manner as follows, using Figs. 2.8 and 2.9:

Balanced operation [(1) (2) (3) tied together]
For balanced load Z_L per phase, make $Z_x = Z_L$
For three-phase short circuit, make $Z_x = 0$
Reference phase: *A*

$$I_A = I_{a1} = \frac{E_a}{Z_1 + Z_x}$$

$$I_B = a^2 I_A$$
$$I_C = aI_A$$

The solution becomes simply

$$I_A = I_{a1} = \frac{E_a}{\text{total } Z_1}$$

$$I_B = a^2 I_A$$
$$I_C = aI_A$$

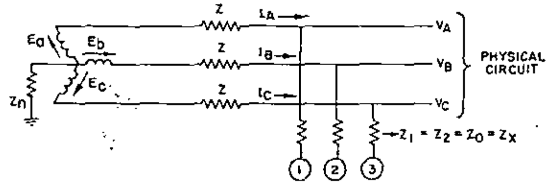

FIG. 2.8 Actual three-phase circuit pattern.

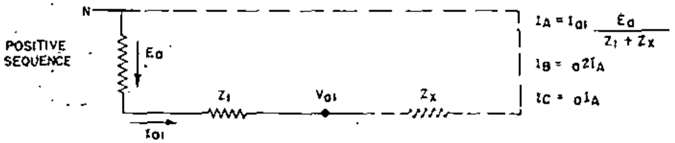

FIG. 2.9 Equivalent circuit for three-phase short-circuit analysis.

LINE-TO-LINE SHORT CIRCUITS

The generalized solution works out in the simplest manner by considering the short circuit to exist between the *B* and *C* phases, using phase *A* as the reference, as illustrated in Fig. 2.10.

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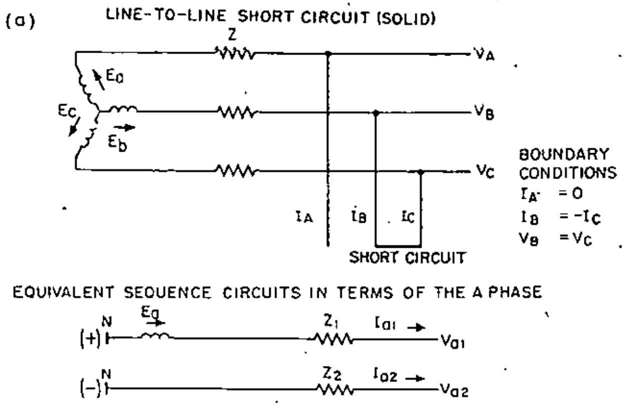
The boundary conditions at the short-circuit point are

$$I_A = 0$$
$$I_B = -I_C$$
$$V_B = V_C$$



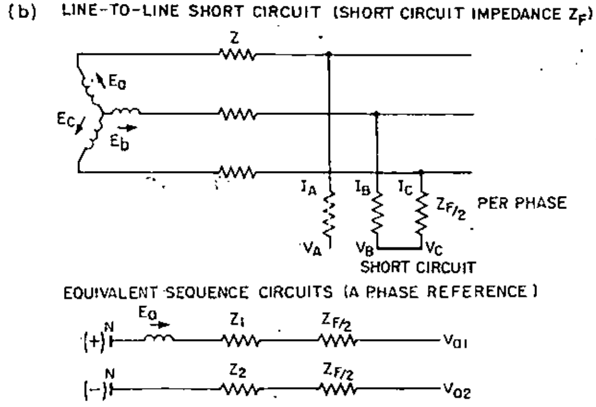


FIG. 2.10 Circuits involved in line-to-line short-circuit analysis.

No zero-sequence current is involved since

$$I_{a0} = \frac{I_A + I_B + I_C}{3} = \frac{0 + I_B - I_B}{3} = 0$$

The positive- and negative-sequence currents in the A phase will be diametrically opposite since

$$I_{a1} = \frac{I_A + aI_B + a^2I_C}{3} = \frac{0 + aI_B - a^2I_B}{3} = \frac{(a\text{-}a^2)I_B}{3}$$
$$I_{a2} = \frac{I_A + a^2I_B + aI_C}{3} = \frac{0 + a^2I_B - aI_B}{3} = \frac{(a^2\text{-}a)I_B}{3} = -\frac{(a\text{-}a^2)I_B}{3}$$
$$I_{a1} = -I_{a2}$$

The solution now hinges on the equality of voltage on the B- and C-phase conductors at the short circuit.

$$V_B = a^2E_a - a^2I_{a1}Z_1 - aI_{a2}Z_2$$
$$V_C = aE_a - aI_{a1}Z_1 - a^2I_{a2}Z_2$$

To make $V_B = V_C$

$$a^2E_a - a^2I_{a1}Z_1 - aI_{a2}Z_2 = aE_a - aI_{a1}Z_1 - a^2I_{a2}Z_2$$

Substituting $-I_{a1}$ for I_{a2} and collecting terms

$$(a^2\text{-}a)E_a = (a^2\text{-}a)I_{a1}Z_1 - (a^2\text{-}a)(-I_{a1})Z_2$$
$$E_a = I_{a1}Z_1 + I_{a1}Z_2$$
$$= I_{a1}(Z_1 + Z_2)$$
$$I_{a1} = \frac{E_a}{Z_1 + Z_2} = -I_{a2}$$
$$I_{b1} = a^2I_{a1} = \frac{a^2E_a}{Z_1 + Z_2}$$
$$I_{b2} = aI_{a2} = -aI_{a1} = -\frac{aE_a}{Z_1 + Z_2}$$
$$I_B = I_{b1} + I_{b2} = (a^2\text{-}a)\frac{E_a}{Z_1 + Z_2} = \sqrt{3}\,\underline{|90^\circ}\,\frac{E_a}{Z_1 + Z_2} = -I_C$$

The portion of the solution which contains the circuit parameters $E_a/(Z_1 + Z_2)$ suggests an equivalent circuit in which the positive-sequence system Z (containing the driving voltage E_a and impedance Z_1) is in series with the negative-sequence impedance system Z_2. Also it is noted that in the reference phase A the negative-sequence current is the negative of the positive-sequence current. This leads to an equivalent circuit connection shown in Fig. 2.11.

The magnitude of total current in the B- or C-phase conductor is $\sqrt{3}$ times as much as either of the components. In most applications, only

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nagnitude is of interest, in which case no attention need be given the ive phase angle between this current and the reference voltage.

e same generalized solution can be applied to a case in which the t circuit contains impedance. Suppose the line-to-line impedance to $_F$. This can be simulated by considering the system to be extended ugh an additional symmetrical branch containing an impedance per phase. A solid line-to-line fault at the end of this branch pros the effect of an impedance Z_F connected line-to-line on the basic m.

e solution is as follows, using Figs. 2.8 and 2.11:

-to-line connection (line B to line C)
onnected to (3); (1) open
a line-to-line impedance Z_F, make $Z_X = Z_F/2$
a line-to-line short circuit, make $Z_X = 0$
rence phase: A
ndary conditions: $I_A = 0$, $I_B = -I_C$, $V_{(2)} = V_{(3)}$]

$$
\begin{aligned}
I_{a1} = -I_{a2} &= \frac{E_a}{Z_1 + Z_2 + Z_F} \\
I_B &= I_{b1} + I_{b2} \\
&= (a^2\text{-}a) I_{a1} \\
&= -j\sqrt{3}\,\frac{E_a}{Z_1 + Z_2 + Z_F}
\end{aligned}
$$

esolving further, the solution becomes simply

$$
\begin{aligned}
I_B &= \sqrt{3}\,\lceil 90^\circ\,\frac{E_a}{Z_1 + (Z_F/2) + Z_2 + (Z_F/2)} = -I_C \\
&= \sqrt{3}\,\lceil 90^\circ\,\frac{E_a}{Z_1 + Z_2 + Z_F}
\end{aligned}
$$

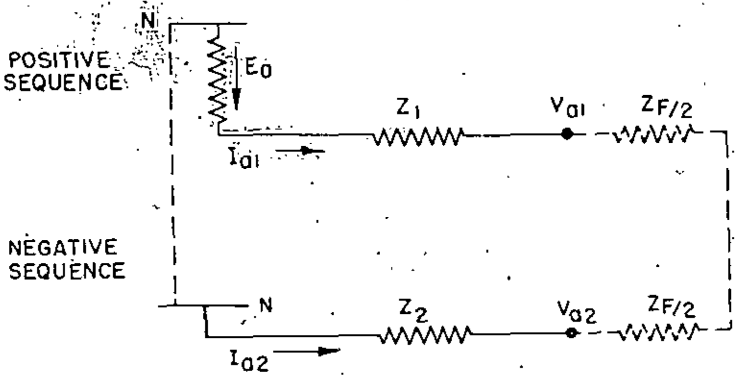

FIG. 2.11 Equivalent circuit for line-to-line short-circuit analysis.

LINE-TO-GROUND SHORT CIRCUITS

Refer to Fig. 2.12 for circuit conditions.

NOTE: Circuit is symmetrical except for short-circuit connections. The simplest solution is arrived at by selecting as the reference phase that phase on which the short circuit exists.

IMPORTANT NOTE: Zero-sequence current flows through the neutral impedance Z_n, but in Z_n the magnitude is $3I_{a0}$. Thus the voltage drop will be three times as much as would be produced by Z_n inserted in each phase. Since Z_0 is defined as the impedance per phase, the correct value of Z_0 to represent the neutral impedance Z_n will be $3Z_n$. This will be true of all circuit impedances appearing in the neutral conductor. Their equivalent Z_0 will be three times the value of Z_n.

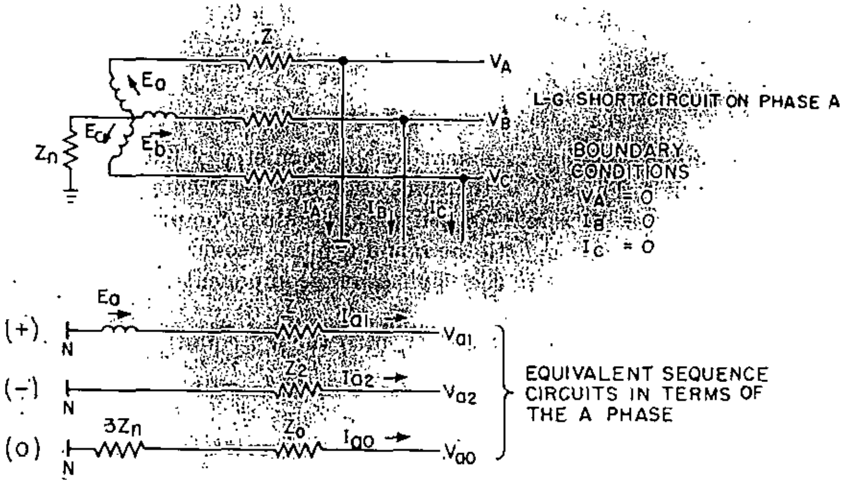

FIG. 2.12 Circuits involved in line-to-ground short-circuit analysis.

Solution. The three sequence circuits are defined in Fig. 2.12. The boundary conditions which must be satisfied at the short circuit are

$$
\begin{aligned}
V_A &= 0 \\
I_B &= 0 \\
I_C &= 0
\end{aligned}
$$

The relationships which prevail in the symmetrical part of the system are

$$
\begin{aligned}
E_a &= I_{a1}Z_1 + V_{a1} \\
0 &= I_{a2}Z_2 + V_{a2} \\
0 &= I_{a0}Z_0 + V_{a0}
\end{aligned}
$$

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ating these to satisfy boundary conditions,

$$V_A = V_{a1} + V_{a2} + V_{a0} = E_a - I_{a1}Z_1 - I_{a2}Z_2 - I_{a0}Z_0 = 0$$
$$I_B = I_{b1} + I_{b2} + I_{b0} = a^2I_{a1} + aI_{a2} + I_{a0} = 0$$
$$I_C = I_{c1} + I_{c2} + I_{c0} = aI_{a1} + a^2I_{a2} + I_{a0} = 0$$

tracting I_C from I_B gives

$$I_B - I_C = (a^2\text{-}a)I_{a1} + (a\text{-}a^2)I_{a2} + 0 = 0$$
$$(a^2\text{-}a)I_{a1} = (a^2\text{-}a)I_{a2}$$
$$I_{a1} = I_{a2}$$

stituting this result into I_B gives

$$I_B = a^2I_{a1} + aI_{a1} + I_{a0} = 0$$
$$= a^2I_{a1} + aI_{a1} + I_{a1} - I_{a1} + I_{a0} = 0$$
$$(a^2 + a + 1)I_{a1} - I_{a1} + I_{a0} = 0$$
$$I_{a1} = I_{a0}$$

is:

$$I_{a1} = I_{a2} = I_{a0}$$

fact might have been evident by the geometry of line currents at ort circuit. The sum of the three component currents in the B and C phase must be zero. Only if the individual component currents al and 120° apart in both the B and C phases could this be possible. is would mean that in the A phase the component currents would al and in phase.

stituting $I_{a2} = I_{a1}$ and $I_{a0} = I_{a1}$ into the V_A equation gives

$$V_A = E_a - I_{a1}Z_1 - I_{a1}Z_2 - I_{a1}Z_0 = 0$$
$$E_a = I_{a1}(Z_1 + Z_2 + Z_0)$$
$$I_{a1} = \frac{E_a}{Z_1 + Z_2 + Z_0}$$

s suggests that the solution can be made in terms of an equivalent in which the generated voltage E_a is impressed on the three impedetworks Z_1, Z_2, and Z_0 in series. It is more accurate to think of be in the form

$$E_a = I_{a1}Z_1 + I_{a2}Z_2 + I_{a0}Z_0$$

s still suggests the series connection of the three networks but izes that the current in Z_1 is I_{a1}, in Z_2 is I_{a2}, and in Z_0 is I_{a0}. Since $I_{a2} = I_{a0}$ there is no conflict with Kirchhoff's law at the junction en the individual sequence networks.

important result is the equivalent-circuit concept by which the ce networks can be interconnected to yield an answer for the value $= I_{a2} = I_{a0}$. The equivalent-circuit concept is helpful even when the solution is to be obtained by numerical computation, but it is of particular importance if use is to be made of a d-c or an a-c network analyzer (calculating board).

Knowing the value of I_{a1}, the value of current in the fault (I_A) is

$$I_G = I_A = I_{a1} + I_{a2} + I_{a0} = 3I_{a1}$$

which is three times the current found directly from the equivalent circuit.

Where there is impedance in the short circuit or in the neutral path, the procedure outlined above is modified as shown in Fig. 2.13.

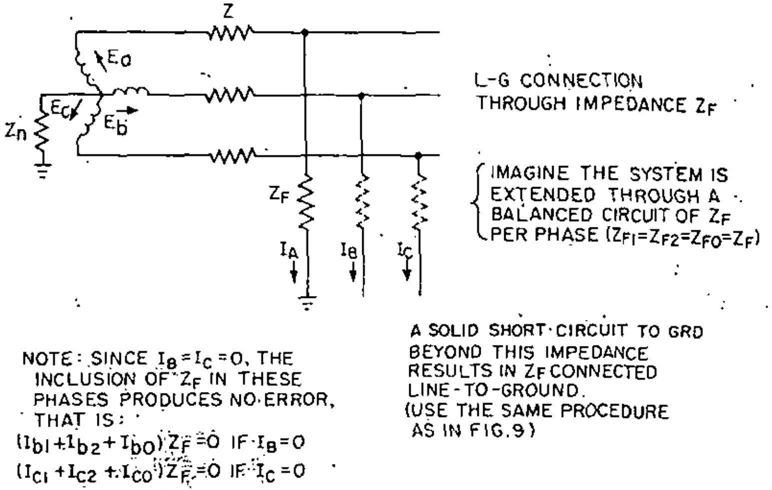

FIG. 2.13 External impedance in the line-to-ground connection.

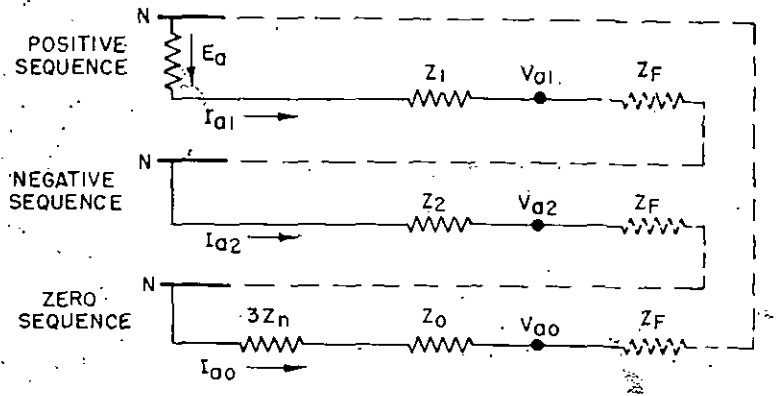

FIG. 2.14 Equivalent circuit for line-to-ground short-circuit analysis.

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narizing, the solution becomes (see Figs. 2.14 and 2.8)

-neutral connection (line A to ground)
nected to ground; (2) open; (3) open
ine-to-ground impedance Z_F, make $Z_X = Z_F$
ine-to-ground short-circuit, make $Z_X = 0$
ice phase: A
ary conditions: $I_B = 0$, $I_C = 0$, $V(_1) = 0$]

$$I_{a1} = I_{a2} = I_{a0} = \frac{E_a}{Z_1 + Z_2 + Z_0 + 3Z_n + 3Z_F}$$

$$I_A = I_{a1} + I_{a2} + I_{a0} = \frac{3E_a}{Z_1 + Z_2 + Z_0 + 3Z_n + 3Z_F}$$

r Cases. The equivalent circuits by which other common cir-nditions can be evaluated are worked out in a similar manner as, mple, a double line-to-ground fault would be solved as follows Figs. 2.8 and 2.15:

line-to-ground solid fault (line B to C to ground)
l (3) connected to ground; (1) open; $Z_X = 0$
ace phase: A
lary conditions: $I_A = 0$, $V(_2) = V(_3) = 0$]

$$V_{a1} = V_{a2} = V_{a0} = E_a - I_{a1}Z_1 = I_{a1}\frac{Z_2Z_0}{Z_2 + Z_0}$$

$$I_{a1} = \frac{E_a}{Z_1 + \dfrac{Z_0Z_2}{Z_0 + Z_2}}$$

$$I_{a2} = I_{a1}\frac{Z_0}{Z_0 + Z_2}$$

$$I_{a0} = -I_{a1}\frac{Z_2}{Z_0 + Z_2}$$

ting-machine Characteristics. Positive-sequence currents are ited with mmf patterns which rotate at synchronous speed in the l rotational direction. The effective positive-sequence reactance sequently influenced by time. For the first cycle of short-circuit t, the subtransient reactance of synchronous machines and the till reactance of induction machines apply. Within a few cycles btransient effects have decreased to negligible proportions and the ent reactance of synchronous machines is in control while the effec-npedance of induction machines has increased to a value close to the l running impedance (in the order of 100 per cent on its own base). ing the next second or two, two actions are taking place in the ronous machine. Induced field currents are decaying, and the

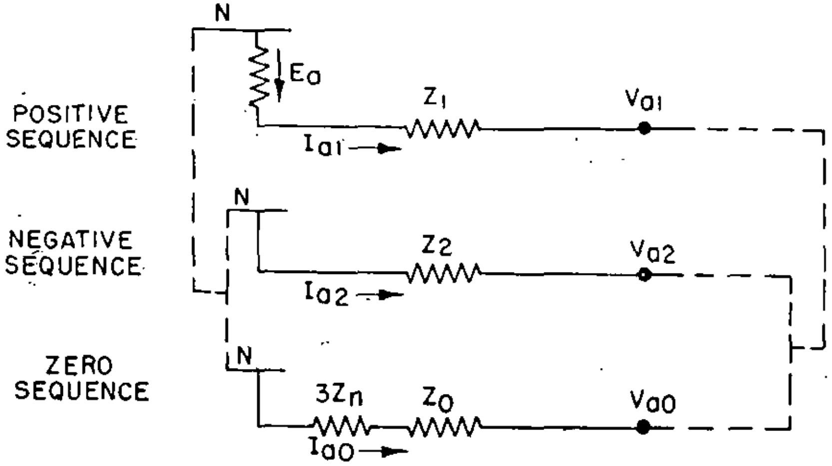

FIG. 2.15 Equivalent circuit for double line-to-ground short-circuit analysis.

effective machine reactance is approaching the synchronous reactance. The effective voltage ahead of synchronous reactance is approaching the value established by the steady-state field current and may be influenced by the operation of an automatic voltage regulator.

Rarely will it be necessary to evaluate short-circuit-current magnitudes for prolonged time intervals, but it will be well to recognize that special treatment will be needed to obtain correct results in such cases.

Negative- and zero-sequence impedances of rotating machines can be considered as remaining constant regardless of the duration of short-circuit-current flow.

TRANSFORMER CHARACTERISTICS

The zero-sequence circuit produced by various transformer connections is often a source of trouble; so a considerable number of typical combinations are defined in Fig. 2.16.

The positive- and negative-sequence impedances are equal as are those of all stationary winding circuits.

There is one tricky aspect associated with Y-delta or delta-Y transformers. There is an inevitable phase displacement between the high- and low-tension line circuits. Standard convention has agreed that the terminals designated H_1 and X_1 shall be those which are only 30° apart. Present standards also state that when operated with electrical sequence ABC on terminals H_1, H_2, H_3 the high-tension system will lead the low-tension system by 30°.

This displacement is the result of winding geometry and is not of the

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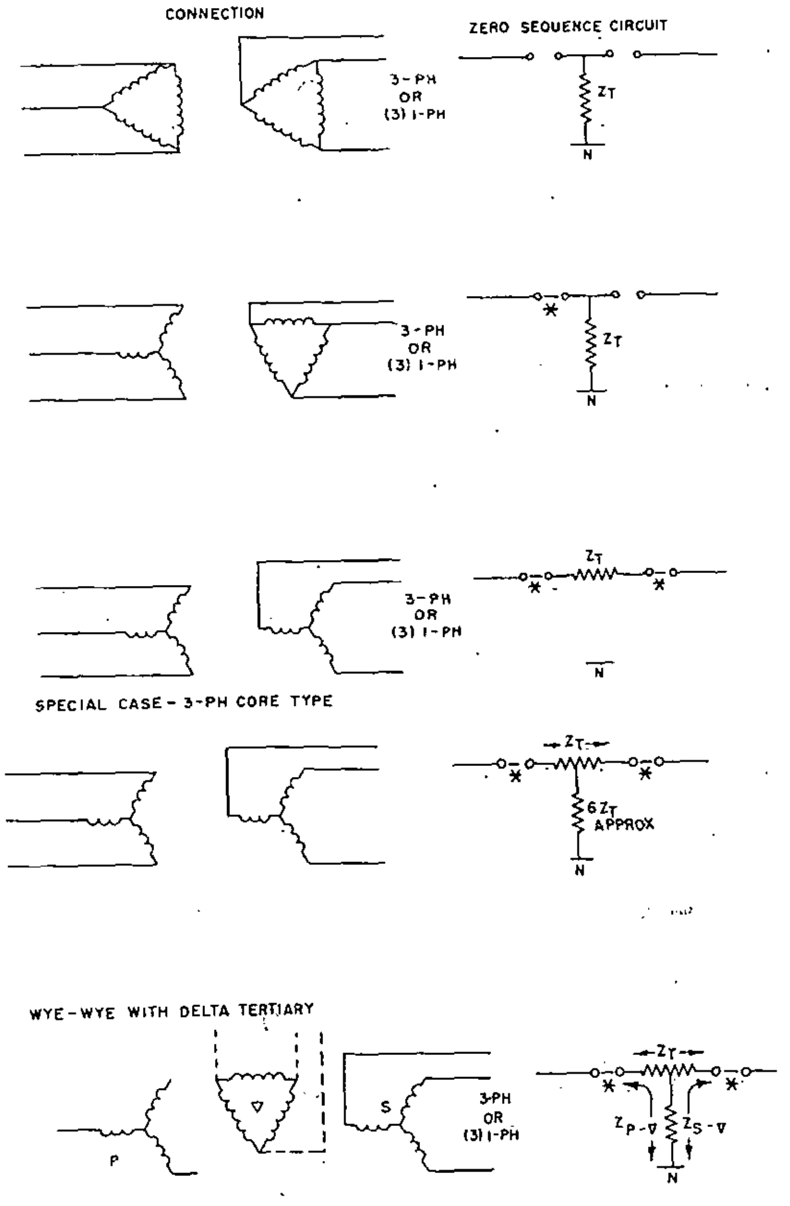

* CLOSED IF THE CORRESPONDING TRANSFORMER NEUTRAL IS GROUNDED. Z_T IS THE NORMAL TRANSFORMER Z (SAME AS POSITIVE SEQUENCE Z)

2.16 Zero-sequence circuits associated with common three-phase transformer ctions.

nature of an impedance voltage displacement angle. Thus if the standard transformer is operated with reversed sequence, i.e., electrical sequence ABC associated with terminals H_3, H_2, H_1, the high-tension system will lag the low-tension system by 30°.

By reason of these facts, in a Y-delta or delta-Y transformer with standard connections operating with normal sequence, the positive-sequence current and voltage in the high-tension circuit will be advanced 30° with respect to that in the low-tension circuit, while the negative-sequence current in the high-tension circuit will be retarded 30°, as is defined in Table 2.2.

Transformer Zero-sequence Circuits. The zero-sequence circuit produced by various transformer connections is often a source of trouble; so a considerable number of typical combinations are defined in Fig. 2.16.

By first examining the zero-sequence properties of simple winding patterns, it will then be possible to identify understandably the zero-sequence circuits of more complicated practical transformer connections.

Delta Winding Connection. Zero-sequence current cannot flow in the circuit to a delta-connected winding (see Fig. 2.17) since there is no electrical connection to ground by which it could return, even though zero-sequence current can flow within the closed delta circuit. Thus the zero-sequence circuit is always interrupted at a junction with a delta-connected winding.

Y Winding Connections. Zero-sequence current cannot flow in a circuit connected to a Y-connected winding if the neutral is not grounded (see Fig. 2.18). Thus the zero-sequence circuit will be interrupted at the junction with a Y-connected winding if the neutral is ungrounded.

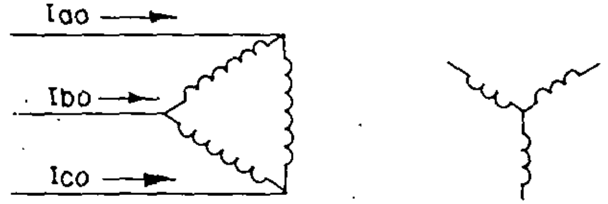

FIG. 2.17 A circuit connecting with a delta-connected transformer winding.

FIG. 2.18 A circuit connecting with an ungrounded Y-connected transformer winding.

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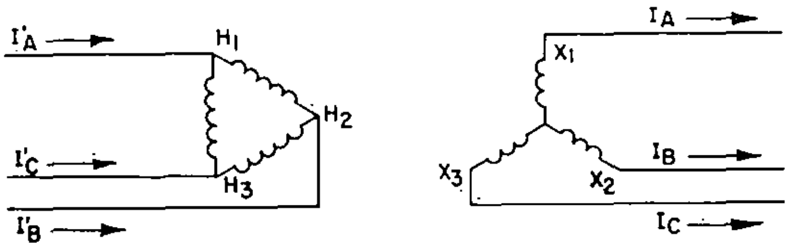
TABLE 2.2 Transformer Phase Shift

ith *standard* delta-Y or Y-delta transformers, H_1 (high voltage) will be 30° ahead $_1$ (low voltage) for normal phase sequence. H_1 will be 30° behind X_1 with oppo- phase sequence.

PHASE SHIFT IN Δ-Y OR Y-Δ TRANSFORMER



ndard, H_1 30° ahead of X_1

$$I'_{a1} = \frac{(1\text{-}a^2)}{\sqrt{3}} I_{a1} \qquad I'_{a2} = \frac{(1\text{-}a)}{\sqrt{3}} I_{a2}$$
$$I'_{b1} = \frac{(1\text{-}a^2)}{\sqrt{3}} I_{b1} \qquad I'_{b2} = \frac{(1\text{-}a)}{\sqrt{3}} I_{b2}$$
$$I'_{c1} = \frac{(1\text{-}a^2)}{\sqrt{3}} I_{c1} \qquad I'_{c2} = \frac{(1\text{-}a)}{\sqrt{3}} I_{c2}$$

30° behind X_1

$$I'_{a1} = \frac{(1\text{-}a)}{\sqrt{3}} I_{a1} \qquad I'_{a2} = \frac{(1\text{-}a^2)}{\sqrt{3}} I_a{}^2$$
$$I'_{b1} = \frac{(1\text{-}a)}{\sqrt{3}} I_{b1} \qquad I'_{b2} = \frac{(1\text{-}a^2)}{\sqrt{3}} I_b{}^2$$
$$I'_{c1} = \frac{(1\text{-}a)}{\sqrt{3}} I_{c1} \qquad I'_{c2} = \frac{(1\text{-}a^2)}{\sqrt{3}} I_{c2}$$

Many investigators prefer to express the relationship between high- and low-ten- line currents in a slightly different manner so as to simplify the associated phase t operation, for example,

ndard, H_1 30° ahead of X_1

$$\begin{aligned} I'_{a1} &= -jI_{c1} & I'_{a2} &= +jI_{c2} \\ I'_{b1} &= -jI_{a1} & I'_{b2} &= +jI_{a2} \\ I'_{c1} &= -jI_{b1} & I'_{c2} &= +jI_{b2} \end{aligned}$$

30° behind X_1

$$\begin{aligned} I'_{a1} &= +jI_{b1} & I'_{a2} &= -jI_{b2} \\ I'_{b1} &= +jI_{c1} & I'_{b2} &= -jI_{c2} \\ I'_{c1} &= +jI_{a1} & I'_{c2} &= -jI_{a2} \end{aligned}$$

NOTE: If currents are not in per-unit, the transformation ratio must also be fac- ed in.

Zero-sequence current in a circuit connected to a grounded-neutral Y-connected winding can flow if zero-sequence current in the secondary windings can be caused to flow in the direction indicated by the secondary arrows, (see Fig. 2.19).

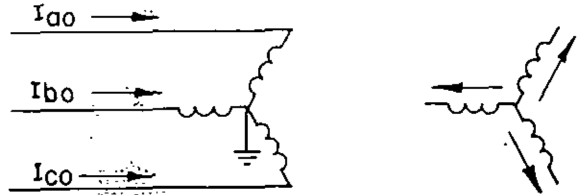


FIG. 2.19 A circuit connecting with a grounded Y-connected transformer winding.

If the secondary currents in Fig. 2.19 cannot flow, the primary zero-sequence current is limited to the magnetizing current of the core (in the order of 5 per cent of rated current for 100 per cent impressed voltage). This represents a Z_0 of about 2000 per cent on the transformer rating, which for practical purposes may be regarded as infinite.

An exception to this rule is presented by the three-phase core-type design whose construction is as indicated in Fig. 2.20. The flow of zero-sequence current in the primary winding produces magnetic flux which is in phase in the same direction in all three core legs. Since there are no external core legs between upper and lower core yokes (as would exist in a shell type of three-phase design), the zero-sequence flux must return largely through the air. The steel tank walls provide a fairly low reluctance path for part of the return circuit, but the crossover to the core yoke at both the top and bottom is directly through air. The magnetizing reactance represented by this flux path will usually be in the order of 30 to 50 per cent on the transformer rating, which is low enough to have practical significance.

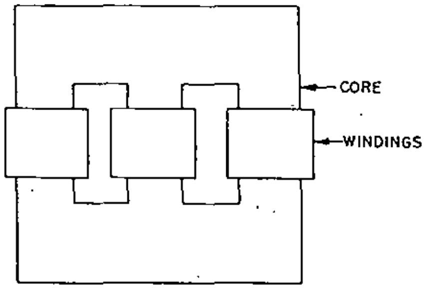


FIG. 2.20 . The three-phase core-type transformer.

Zero-sequence current in a circuit connected to a grounded-neutral Y-connected winding can flow if another set of transformer windings is connected in delta as in Fig. 2.21. The closed delta provides a circuit for the flow of zero-sequence current. The impedance presented to the flow of current is the interwinding impedance Z_T (the same as the normal positive sequence Z_T). Note, however, that the zero-sequence currents are not repeated in the outgoing line circuit but are short-circuited within the delta winding.

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a Y-Y-connected transformer with both neutrals grounded, as in 2.22, zero-sequence current can flow if the reflected zero-sequence ent in the other winding finds a closed circuit at some point along the ected circuit. In this case, the transformer transfers zero-sequence ent from primary circuit to a secondary circuit in the same manner it transfers positive- or negative-sequence current. The transformer ly introduces a series impedance in the zero-sequence circuit which in nitude is identical with the normal positive-sequence impedance Z_T. ith this understanding of elemental behavior, the equivalent zero- ence circuits for the usual transformer connections can be directly lved. Some of the more common ones are identified in Fig. 2.16.

hen drawing zero-sequence circuits for extensive systems, it is a good to designate transformers in the manner shown in Fig. 2.16, showing nterruption of the zero-sequence circuit by an open gap. By this hod one can be constantly aware that a break in the circuit was inten- al and not the result of an oversight.

ircuit Resolution Example. In Fig. 2.23 is illustrated a particular cal system. The resulting composition of the positive-, negative-, zero-sequence circuits is also portrayed. Suppose that the immediate lem concerns the evaluation of various performance qualities on the kv system radiating from bus L_4.

he first step involves a resolution of equivalent impedances by which entire bulk system to the left of bus L_4 is expressed as a single equiva- impedance. This would be accomplished by successively paralleling, until finally a single equivalent impedance value connecting with L_4 is obtained which would then look like Fig. 2.24. In many cases

2.21 A circuit connecting with a grounded Y-connected transformer winding with a winding on the same core structure.

2.22 A circuit connecting with a grounded Y-connected transformer winding with her grounded Y winding on the same core structure.

it will be at once apparent that the impedance of transformer T_5 will be the major controlling impedance in the circuit from M_2. In this case it may be entirely reasonable to consider that rated voltage is sustained on the high-tension side; or consider the short-circuit capacity at the high-tension terminals to be about equal to the interrupting rating of the

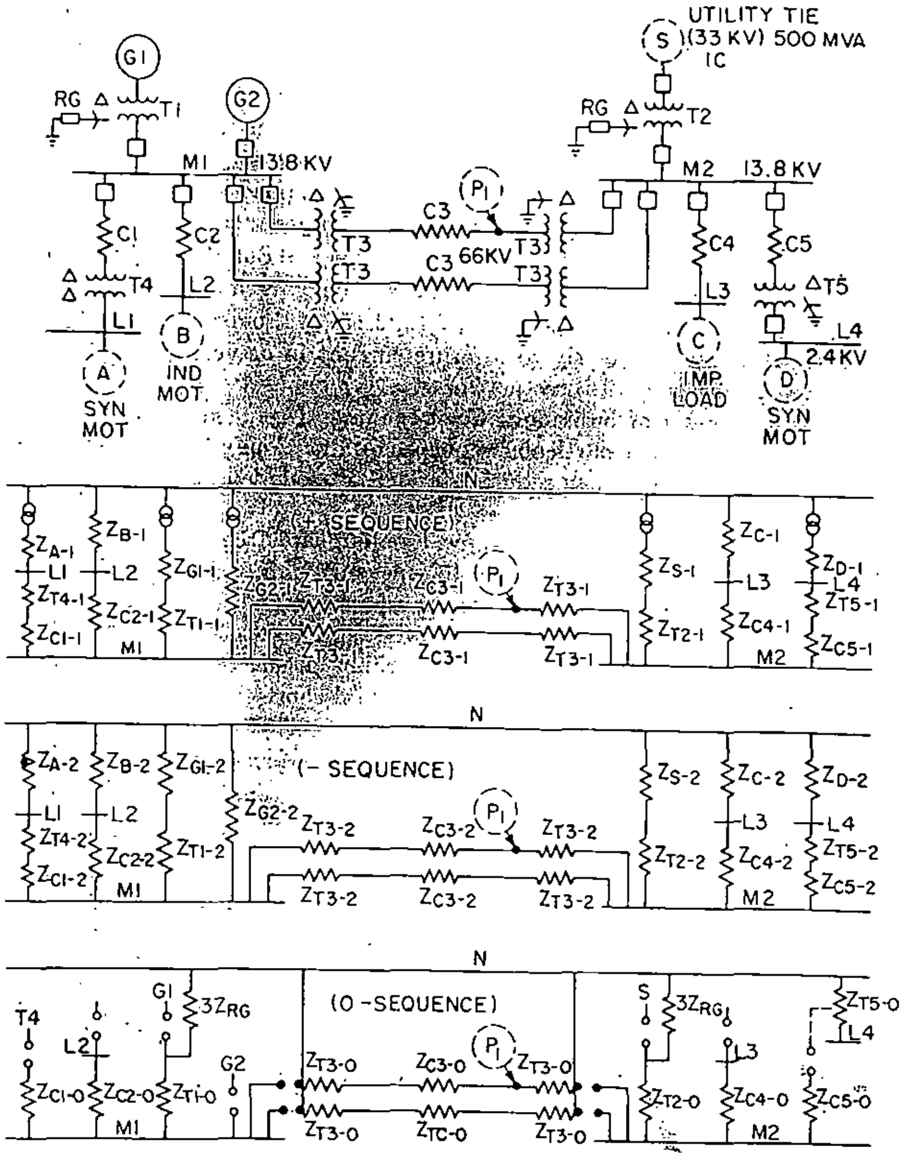

FIG. 2.23 Typical system example.

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:ching equipment on the bus M_2. Obviously, some such approxi- ion will be required in practically every problem since the actual line rconnections will otherwise extend over the entire electrical distribu- . system of several states.

; will be of interest to note that the zero-sequence system is quite :ontinuous, which is typical of practical systems. In the present strative problem the zero-sequence system associated with bus L_4 is ependent of that on bus M_2.

'or comprehensive studies of extensive system networks, the equiva- . sequence circuits shown in Fig. 2.23 might be set up on the d-c or a-c vork analyzer. To examine an operating characteristic at the point each individual sequence circuit would be tapped at the point P_1.

'or each sequence system the correct impedance network is that ained from the tap lead P_1 and its own neutral bus N. The intercon- tions between sequence networks will be governed by the type of alance (see Figs. 2.8, 2.9, 2.11, 2.14, 2.15). Provision is made in the work analyzer directly to measure current in or voltage across indi- ual branches of all three networks.

Aeasurement of Individual Components. Useful measurement con- tions by which a particular sequence quantity may be independently lved, or a particular sequence quantity excluded, are identified on . 2.25.

:he circuits for obtaining I_0 or E_0 alone are frequently used. (In lying potential transformers for measuring E_0 on an ungrounded tral system, line-to-line rated transformers and secondary loading stors should be used to avoid overvoltage hazards.)

:he delta-connected current transformer circuit (which excludes I_0 :he output) is useful in providing internal-short-circuit protection for unding transformers.

The circuits for individually segregating the sequence quantities I_2 and are only rarely used. Possible applications would be (1) making a gle-coil voltage regulator responsive to positive-sequence voltage of

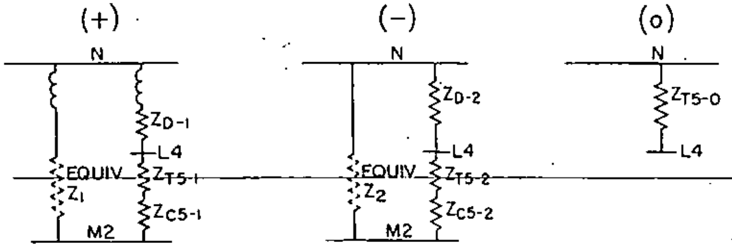
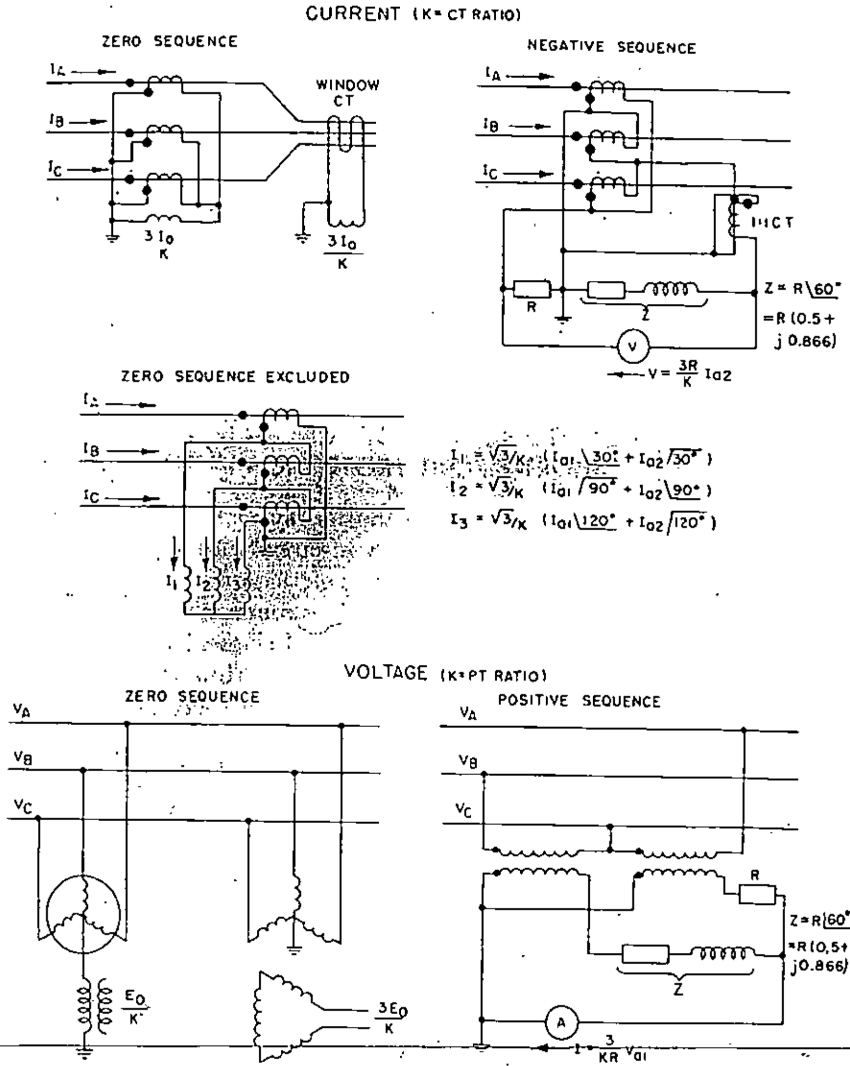


FIG. 2.24 Simplification of Fig. 2.23 for study of performance on bus L4.

the three-phase system, (2) providing a protective relay which will trip if the sustained negative-sequence voltage exceeds a preassigned value.

It is of interest to note that the usual open-delta line-to-line connected potential transformer application excludes E_0 in the secondary.



NOTE:- BY INTERCHANGING LINES B & C METER WILL READ $\frac{3}{KR} V_{a2}$

FIG. 2.25 Measuring circuits for segregating specific components.

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to assure safety to personnel. If disconnecting switches are used (as with some outdoor installations), they should be elevated or metal-enclosed and interlocked in such a manner as to prevent their operation except when the transformer primary and secondary switches or generator line and field breakers are open.

As shown in Fig. 6.21, it is necessary to provide only two neutral breakers, and only one of these is closed, although *all* generators may be in operation. This will eliminate any circulating harmonic zero-sequence currents. When the generator whose neutral is grounded is to be shut down, the second generator is grounded by means of its neutral breaker before the line and neutral breakers of the first one are opened. This procedure will assure that the system is grounded at all times.

In the case of multiple transformers, *all* neutral breakers may be normally closed because the presence of delta-connected windings (which are nearly always present on at least one side of each transformer) minimizes circulation of harmonic currents between transformers.

Selection of Arrangement. When total ground-fault currents with several individual resistors would exceed about 4000 amp, it is suggested *that neutral switchgear and a single resistor be considered for resistance-*grounded systems.

When only one source is involved but others may be added to the station, it is suggested that space be allowed for neutral switchgear to be added if this will be necessary later.

For similar generators with reasonably equal load division, circulating *currents are negligible, and it is often found practical to operate with* neutral breakers of two or more generators closed. This simplifies operating procedure and increases assurance that the system will be grounded at all times.

CALCULATION OF GROUND-FAULT CURRENT

The magnitude of current which will flow in the event of a ground fault on a solidly grounded system is usually determined by the impedance of the grounded apparatus, plus the impedance of the lines or cables leading to the fault and the impedance of the ground return path. For interconnected systems, calculation of the current may be rather complicated. For simpler cases, an approximation of the available fault current may be obtained from Table 6.4. This table applies only for faults near the transformer terminals when power is supplied by a single transformer bank with its neutral directly connected to earth and with the primary connected to a system of relatively large short-circuit capacity.

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1 OF 4

RESISTANCE GROUNDING

When a single line-to-ground fault occurs on a resistance-grounded system, a voltage appears across the resistor (or resistors), nearly equal to the normal line-to-neutral voltage of the system.

The resistor current is equal to the current in the fault. Thus the current is practically equal to line-to-neutral voltage divided by the number of ohms of resistance used. For example, consider a 13,800-volt three-phase system grounded by a 4-ohm resistor. Normal line-to-neutral voltage for this system is $13{,}800/\sqrt{3}$, or 8000 volts. The ground current is, therefore, very nearly equal to 8000/4, or 2000 amp. If two such resistors were used on the system, the ground current would be approximately 4000 amp.

Resistors have a voltage rating equal to line-to-neutral voltage and an ampere rating equal to the current which flows when this voltage is applied to the resistor. Thus, for example, a maximum ground-fault current of approximately 2000 amp will be obtained on a system when using a 2000-amp resistor.

This very simple method of calculating the ground-fault current is not suitable except when the ground-fault current is small compared with the three-phase fault current for a fault at the same location. However, it is usually suitable for systems grounded by resistance of ohmic values normally used.

The method just outlined applies to faults on lines or buses, or at the terminals of machines or transformers. If the fault is internal to a rotating machine or transformer, the ground-fault current will be less. The reduction in current is primarily due to the internal voltage of the apparatus. In the case of Y-connected equipment, this internal voltage is at full value at the terminals and is zero at the neutral. If the fault occurs at the neutral of any apparatus, no voltage will appear across the system grounding resistor; so the fault current will be zero. At intermediate points in the winding between the neutral and a terminal, the fault current will be intermediate between zero and the current to a terminal fault, as shown in Fig. 6.22. For example, at a point 10 per cent of the winding length from neutral, the ground-fault current will be approximately 10 per cent of the value for a terminal fault. For a fault anywhere between this point and a terminal, the current will be more than 10 per cent of the amount for a terminal fault.

In the case of delta-connected machines the internal voltage to neutral may be considered to be 100 per cent at the terminals and 50 per cent at the mid-point of the windings, as shown in Fig. 6.22(c). The mid-points have the lowest potential with respect to the electric neutral of any other

S
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$$I_G = \frac{3E}{X_1 + X_2 + X_0 + 3X_N} \qquad (6.1)$$

(resistance may usually be neglected)

where X_1 = system positive-sequence reactance, ohms per phase
X_2 = system negative-sequence reactance, ohms per phase
X_0 = system zero-sequence reactance, ohms per phase
X_N = reactance of neutral grounding reactor, ohms
E = line-to-neutral voltage, volts
I_G = ground-fault current, amp

An illustration of the method of calculating the ground-fault current in a reactor-grounded system is given under Selection of Reactor Rating (see page 381 of this chapter).

SOLID GROUNDING

In a solidly grounded system with a single line-to-ground fault, the ground-fault current may be computed from the formula

$$I_G = \frac{3E}{X_1 + X_2 + X_0} \qquad (6.2)$$

RATING OF GROUNDING EQUIPMENT

Grounding resistors, reactors, and transformers are normally rated to carry current for a limited time only. The standard time-interval rating usually most applicable for industrial systems, with relays arranged to protect the grounding equipment, is 10 sec.

The voltage rating of a grounding resistor should be the line-to-neutral voltage rating of the system.

The insulation class of a reactor is determined by the circuit line-to-neutral voltage. The voltage rating may be less than line-to-neutral voltage, it being calculated by multiplying the rated current by the impedance of the reactor.

The voltage rating of a grounding transformer should be system line-to-line voltage.

Grounding resistors are rated in terms of the initial current which will flow through the resistor with rated resistor voltage applied. Conventional cast-grid or corrosion-resistant steel resistors will average approximately 7 per cent increase in resistance for each 100 C rise in temperature.

The rated current of a grounding reactor is the thermal current rating. It is the rms neutral current in amperes which the reactor will carry for its rated time without exceeding standard temperature limitations. The rating establishes an rms current which is assumed to be constant during

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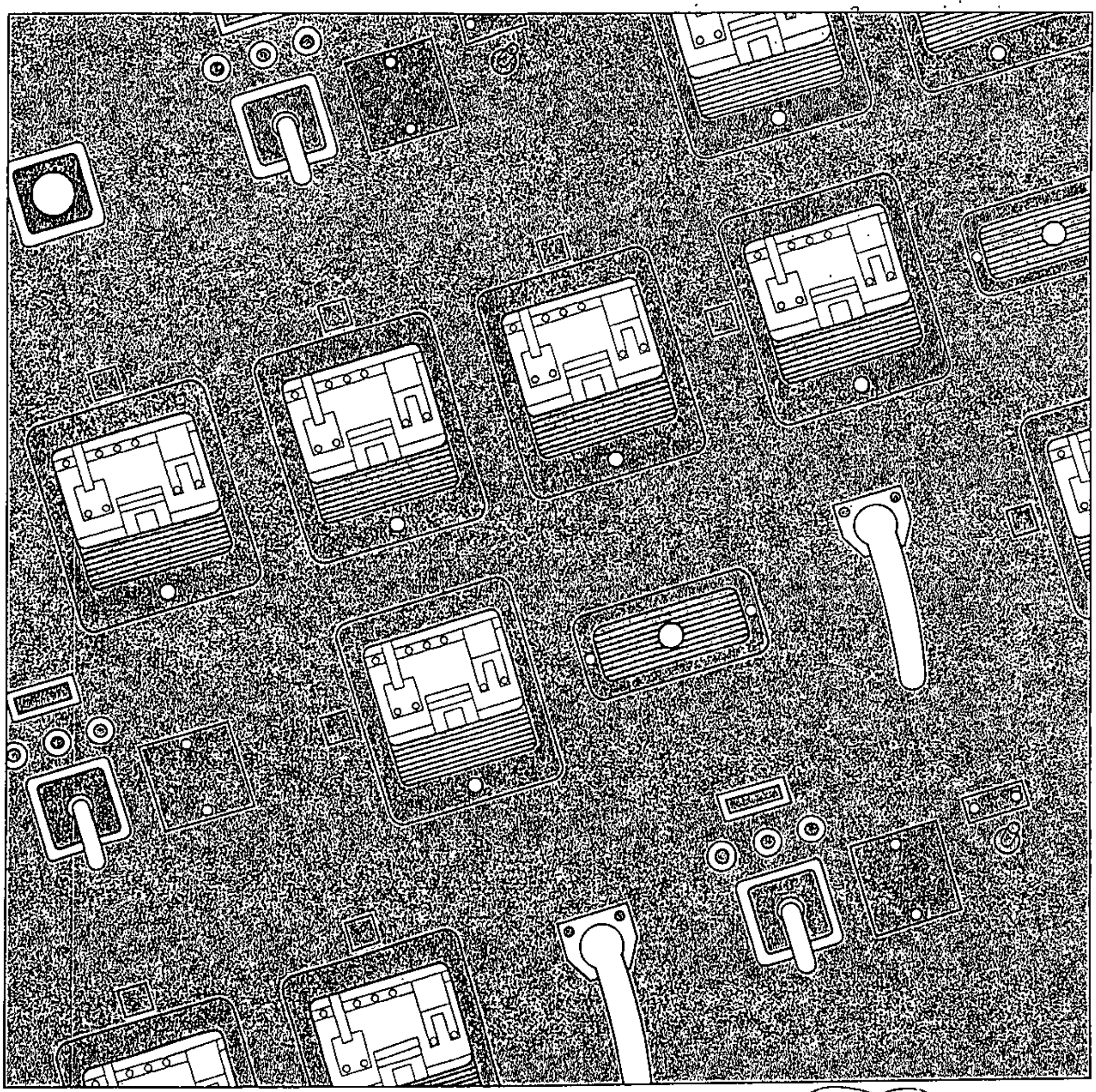
POWER PLANT ELECTRICAL REFERENCE SERIES

VOLUME 8

STATION PROTECTION



ELECTRIC POWER RESEARCH INSTITUTE

EXHIBIT T
1 OF 5

ABSTRACT

Application of protective relaying is a complex field that requires a broad knowledge of power system equipment and its behavior during both normal and abnormal conditions. The purpose of protective relaying is to promptly remove equipment from the system during abnormal conditions while ensuring its availability during normal operation.

This volume is an electrical engineer's guide to the power equipment being protected, the protective devices needed, and the considerations involved in providing a coordinated protection scheme. Illustrated with examples and diagrams, it covers the requirements of equipment, data, the selection of protective devices, and the settings established to calibrate and maintain these devices for the life of the plant.

Because familiarity with the available protective devices is so important, the volume first discusses various types of direct-trip devices (fuses, circuit breakers, and combination starters) and describes the operating principles of protective relays. It then addresses the available protection for each type of electrical equipment: large unit-connected generator-transformers, unit auxiliary and station service transformers, motors, medium- and low-voltage switchgear, motor control centers and other ac and dc distribution centers. The volume presents a balanced approach to the current practice of protective relaying; where there exists a difference in the protection philosophy followed by different utilities, the background for each philosophy is discussed.

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ACKNOWLEDGMENTS

This work is dedicated to the many engineers—too numerous to mention here—who have enhanced the state of the art in station protection; to the unique association with the protection engineers on IEEE's Power System Relaying Committee; and to the personnel in a variety of other organizations who helped during the past 15 years by sharing their knowledge and experience through discussions, critiques, and publications. The author wishes especially to recognize J. L. Koepfinger, A. M. DiCiccio, and T. A. Mayers of Duquesne Light Company; A. H. Ayoub, Georgia Power Company; L. E. Landoll, Ohio Edison; W. A. Elmore, Westinghouse Electric Corporation; S. Zocholl, BBC; P. W. Van Smith, Florida Power & Light Company; R. C. Stein, W. R. McGlamery, and J. N. Green of Arizona Public Service Company; F. B. Hunt, New England Power Service Company; and the late W. H. Butt.

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EXECUTIVE SUMMARY

The application of protective relaying for a power plant is better understood once the basic logic is defined. It is necessary to know complex equations and rotating vectors in order to master the field of study. The numerous practical examples and diagrams in this volume will serve as a guide in the application of protective relays to power plant equipment.

Background

The classic texts in the relaying field are *The Art and Science of Protective Relaying* by C. Russell Mason and *Applied Protective Relaying* published by Westinghouse Electric Corporation. These texts explain the fundamental principles of protective relaying. An expansion of these basic principles into applications for power plant equipment will provide a reliable station protection program for maintaining the operating availability of the plant.

Objectives

This volume is meant to guide the selection of a protection scheme, to illustrate the considerations involved in deciding how to protect equipment, and to provide a sufficient number of detailed examples to cover most relay application problems.

Approach

The volume is based on the experience of the author and others in the protection of different generating stations. The EPRI Review Committee, with members of 11 utilities in various areas of the United States, and other industry experts reviewed the material for technical adequacy and completeness.

Results

The information in this volume will provide guidance in performing relay application and relay coordination studies for both the novice and the experienced specialist. It will aid the engineering, operating, and maintenance departments of generating facilities to select satisfactory equipment and understand relaying logic.

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are selected to be at least 125%, but not greater than 140%, of the circuit full-load current rating. The magnetic circuit breaker is set at least 10 times the circuit full-load current or 173% of the total locked-rotor current of the motors. The selection of the heaters also protects the derated cable ampacity.

- *Motor-operated Valves* Each motor-operated valve has a combination starter with a three-phase, directly heated manual reset, which is basically insensitive to normal ambient temperature changes. A thermal-overload heater provides complete thermal protection for all three phases. The time-current characteristics of these heaters resemble as closely as possible the temperature rise curve of the motor. During an accident, this protection at the emergency motor control center is bypassed by a safeguard actuation signal. This is true for all the motor-operated valves that are required for a safe shutdown of the plant. The completion of motor-operated valve travel deenergizes this circuit by a torque switch contact. For an overload, the output from this protection annunciates and indicates on the sequence-of-events recorder.

  The thermal-overload heaters are selected to be at least 125%, but not greater than 200%, of motor full-load current, if possible. The relays trip in 5 to 10 s at nameplate locked-rotor current.

  Ambient-compensated overload heaters so selected are set at the maximum value of the setting range. For certain low-level loads, non-ambient-compensated overload heaters may have to be used. Settings for these overload heaters are at the minimum value of the setting range.

BUS TRANSFERS AND VOLTAGE MONITORING SCHEMES

Normal 4.16-kV Bus Transfer Whenever a supply to a 4.16-kV bus is lost due to a fault on the system or unit auxiliaries transformer, on a 138-kV switchyard bus, or on 22-kV generator leads, a transfer is made to the alternative source, provided that source has rated voltage and the 4.16-kV bus is not faulted. Either system or unit sources may be selected as the alternative source. Two transfer schemes provided for this unit (Figure 8-117) are briefly discussed below:

- *Fast Transfer* A fast transfer is initiated for a fault in either of the 4160-V sources; the transfer takes place within 0.15 s.
- *Delayed Transfer* Delayed transfers of the 4.16-kV bus are initiated by a sustained undervoltage detected at the 4160-V source. This transfer is effected when the condition results in a voltage reduction for 0.33 s (to allow the high-voltage faults to be cleared by the backup relaying) and the bus voltage is less than 30% of the normal after the preferred source is tripped. Also, the alternative source must have an adequate voltage.

SELECTION OF VOLTAGE RELAYS AND THEIR SETTING BASES

Apart from the overcurrent devices described earlier, undervoltage relays play an equally important role in the overall protection and availability of the auxiliary power system. A three-phase negative-sequence (phase-balance) relay provides blown-fuse protection for the voltage transformers used for these relays. A blown fuse creates enough negative-sequence voltage to be sensed by these relays. The presence of negative-sequence voltage is also possible due to certain external faults; therefore, output from these relays is used in logic. Each 480-V ungrounded system is monitored for grounds by an overvoltage relay connected across wye-open delta voltage transformers. Undervoltage relays used for monitoring 4.16-kV and 480-V systems are also three-phase relays that have the same dropout for a phase-to-phase fault as for a three-phase fault. Voltage profile and relay locations and set points are shown in Figure 8-118. The functions of these relays and their setting procedures are outlined below:

Unit Auxiliaries Transformer Bank Feeding 4.16-kV System Each of these transformer banks feeding 4.16-kV systems has two instantaneous-undervoltage relays (83). One relay is used to initiate a transfer, whereas the second relay is used for voltage checking.

The transfer-initiating relays are set to drop out below the maximum voltage dip expected when starting a large motor. They operate a time-delay relay. The time-delay relay is set to be shorter than the motor-trip timer (to transfer loads prior to motor trip) and still allow sufficient time for clearing close-in high-voltage line faults.

The transformer voltage-checking relays provide permissive interlock for the transfer scheme; so

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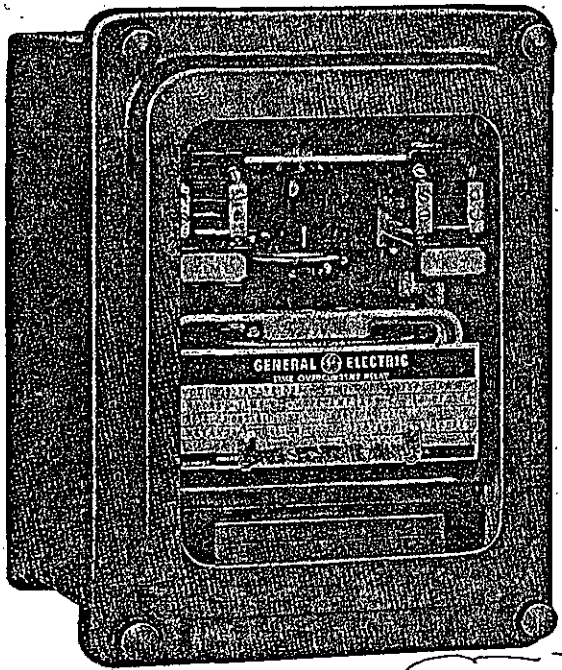
TYPE IAC
TIME OVERCURRENT

SWITCHGEAR
PROTECTIVE RELAYS



The Type IAC relay is an a-c overcurrent relay with time delay for the protection of industrial and utility power systems against either phase or ground overcurrent.

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GENERAL ELECTRIC

GENERAL DESCRIPTION

Switchgear protective relays, Type IAC, are single-phase, current-sensitive, a-c devices used in the protection of industrial and utility power systems against either phase or ground overcurrent. The basic operating mechanism (Fig. 1) consists of a magnetic-core operating coil, an induction disk, and a *damping magnet, all of which combine to* produce a time vs current operating characteristic.

In addition to the basic induction-disk unit, the Type IAC relay may include one or more hinged armature, instantaneous overcurrent units. All models include targets to show whether operation was time or instantaneous. Models are also available which permit direct tripping by the relay operating current or by a charged capacitor, instead of the normal d-c source.

Current transformers are normally used to match these relays to the current levels available in the electrical system. The *time-overcurrent unit operating coil is in* series with the instantaneous-overcurrent unit operating coil, if both are used, and each is set to cover its own portion of the tripping range.

Time-overcurrent units are available in several ranges to meet current settings from 0.1 to 16.0 amperes. Sensitivity is determined by discrete tap-plug settings, and a time dial gives stepless time-delay adjustment over the entire range.

Instantaneous-overcurrent units are available in several ranges to meet current settings between 1.0 and 160 amperes. They are set by adjusting the position of their cores. The adjustment is stepless *over the range.*

The relays are housed in drawout cases of uniform appearance with other General Electric protective relays and designed for either surface or semi-flush mounting. Provisions are included for test connections and for easy replacement or maintenance inspection.

SELECTION DATA

Model	Disk Unit Tap Ranges (amperes)	Instantaneous Unit *Adjustment Ranges* (amperes)		Number of Contacts	Case Size	*Internal* Connection Diagram (Fig. No.)	Instruction Book Number	Comments
		Standard	Hi-Dropout					
INVERSE TIME CHARACTERISTIC (FIG. NO. 13)								
IAC51A	4.0–16.0 1.5–6.0 0.5–2.0	.....	.....	1 NO	S-1	A-1	GEH-1753	
IAC51B	4.0–16.0 1.5–6.0 0.5–2.0	40–160 20–80 10–40 4–16 2–8	.....	1 NO	S-1	A-2	GEH-1753	
IAC51C	4.0–16.0	.....	.....	1 NC	S-1	A-3	GEH-1753	A-c trip unit
IAC51R	4.0–16.0	20–80 10–40 4–16	.....	1 NC	S-1	A-4	GEH-1753	A-c trip unit
IAC51V	4.0–16.0 1.5–6.0	.....	10–30 4–12	1 NO	S-1	A-5	GEI-50254	High-dropout instantaneous unit
IAC52A	4.0–16.0 1.5–6.0 0.5–2.0	.....	.....	2 NO	S-1	A-6	GEH-1753	
IAC52B	4.0–16.0 1.5–6.0 0.5–2.0	20–80 10–40 4–16 2–8	.....	2 NO	S-1	A-7	GEH-1753	
IAC60A	4.0–16.0 1.5–6.0	.....	.....	1 NO	S-1	A-11	GEI-19957	*Torque controlled by external contact*
IAC60B	4.0–16.0 1.5–6.0 0.5–2.0	20–80 10–40 4–16	.....	1 NO	S-1	A-12	GEI-19957	Torque controlled by external contact
IAC60E	4.0–16.0 1.5–6.0	.....	.....	1 NO	M-1	A-13	GEI-83956	*Consists of two basic overcurrent units torque controlled by included auxiliary relay energized by external signal*
IAC60H	4.0–16.0	4–16	.....	1 NO	L-2	A-14	GEI-83952	Same as IAC60E with two included plunger-type instantaneous units

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Model	Disk Unit Tap Ranges (amperes)	Instantaneous Unit Adjustment Ranges (amperes)		Number of Contacts	Case Size	Internal Connection Diagram (Fig. No.)	Instruction Book Number	Comments
		Standard	Hi-Dropout					
VERY INVERSE TIME CHARACTERISTIC (FIG. NO. 14)								
IAC53A	4.0–16.0 1.5–6.0 0.5–2.0	.....	.....	1 NO	S-1	A-1	GEH-1788	
IAC53B	4.0–16.0 1.5–6.0 0.5–2.0 0.1–0.4	40–160 20–80 10–40 4–16 2–8 1–4 0.5–2.0	.....	1 NO	S-1	A-2	GEH-1788	
IAC53C	4.0–16.0	.....	.....	1 NC	S-1	A-3	GEH-1788	A-c trip unit
IAC53M	4.0–16.0 1.5–6.0 0.5–2.0	.....	10–30 4–12 2–6 1–3	1 NO	S-1	A-5	GEI-50254	High-dropout instantaneous unit
IAC53R	4.0–16.0	20–80 10–40 4–16	.....	1 NC	S-1	A-4	GEH-1788	A-c trip unit
IAC54A	4.0–16.0 1.5–6.0 0.5–2.0 0.1–0.4	.....	.....	2 NO	S-1	A-6	GEH-1788	
IAC54B	4.0–16.0 1.5–6.0 0.5–2.0	40–160 20–80 10–40 4–16 2–8	.....	2 NO	S-1	A-7	GEH-1788	
IAC54M	4.0–16.0 1.5–6.0	......	10–30 4–12	2 NO	S-1	A-8	GEI-50254	High-dropout instantaneous unit
IAC80A	4.0–16.0 1.5–6.0 0.5–2.0	.....	.....	1 NO	S-1	A-22	GEI-39019	Torque controlled by external contact
IAC80B	4.0–16.0 1.5–6.0 0.5–2.0	20–80 10–40 4–16	.....	1 NO	S-1	A-23	GEI-39019	Torque controlled by external contact
IAC80E	4.0–16.0	.....	.....	1 NO	M-1	A-24	GEI-83956	Similar to IAC60E
IAC80H	4.0–16.0	10–40 4–16	.....	1 NO	L-2	A-25	GEI-83952	Similar to IAC60H
EXTREMELY INVERSE TIME CHARACTERISTIC (FIG. NO. 17)								
IAC77A	4.0–16.0 1.5–6.0 0.5–2.0 0.1–0.4	.....	.....	1 NO	S-1	A-16	GEH-1787	
IAC77B	4.0–16.0 1.5–6.0 0.5–2.0 0.1–0.4	40–160 20–80 10–40 4–16 2–8 1–4	.....	1 NO	S-1	A-17	GEH-1787	
IAC77C	4.0–16.0	.....	.....	1 NC	S-1	A-18	GEI-31033	A-c trip unit
IAC77R	4.0–16.0	20–80 10–40 4–16	.....	1 NC	S-1	A-19	GEI-38889	A-c trip unit

SEE TABLE NOTES ON PAGE 4

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Model	Disk Unit Tap Ranges (amperes)	Instantaneous Unit Adjustment Ranges (amperes)		Number of Contacts	Case Size	Internal Connection Diagram (Fig. No.)	Instruction Book Number	Comments
		Standard	Hi-Dropout					
IAC78A	4.0–16.0 1.5–6.0 0.5–2.0	.....	.....	2 NO	S-1	A-20	GEH-1787	
IAC78B	4.0–16.0 1.5–6.0 0.5–2.0	20–80 10–40 4–16	.....	2 NO	S-1	A-21	GEH-1787	
IAC90E	4.0–16.0	.....	.....	1 NO	M-1	A-26	GEI-83956	Similar to IAC60E
IAC90H	4.0–16.0	4.0–16.0	.....	1 NO	L-2	A-27	GEI-83952	Similar to IAC60H

INVERSE, SHORT-TIME CHARACTERISTIC (FIG. NO. 15)

Model	Disk Unit Tap Ranges (amperes)	Standard	Hi-Dropout	Number of Contacts	Case Size	Internal Connection Diagram (Fig. No.)	Instruction Book Number	Comments
IAC55A	4.0–16.0 1.5–6.0 0.5–2.0	.....	.....	1 NO	S-1	A-1	GEI-31010	
IAC55B	4.0–16.0 1.5–6.0 0.5–2.0	40–160 20–80 10–40 4–16 3–12 2–8	.....	1 NO	S-1	A-2	GEI-31010	

INVERSE, LONG-TIME CHARACTERISTIC (FIG. NO. 16)

Model	Disk Unit Tap Ranges (amperes)	Standard	Hi-Dropout	Number of Contacts	Case Size	Internal Connection Diagram (Fig. No.)	Instruction Book Number	Comments
IAC66A	4.0–8.0 2.5–5.0 1.5–3.0 1.0–2.0 0.6–1.2	.....	.....	1 NO	S-1	A-1	GEI-28818	
IAC66B	4.0–8.0 2.5–5.0 1.5–3.0 0.6–1.2	40–160 20–80 10–40 4–16	.....	1 NO	S-1	A-2	GEI-28818	
IAC66K	4.0–8.0 2.5–5.0 1.5–3.0 0.6–1.2	40–160 20–80 10–40 4–16	20–60 10–30 4–12 .2–6	1 NO	S-1	A-15	GEI-44233	High-dropout instantaneous unit

INVERSE TIME, OVER- AND UNDERCURRENT RELAYS (FIG. NO. 18)

Model	Disk Unit Tap Ranges (amperes)	Standard	Hi-Dropout	Number of Contacts	Case Size	Internal Connection Diagram (Fig. No.)	Instruction Book Number	Comments
IAC59A	4.0–16.0 1.5–6.0 0.5–2.0	.....	.....	1 NO, 1 NC	S-1	A-9	GEI-21903	Under operating conditions, electrically separate contacts close when current rises or falls to a point outside limits. Contacts seal closed.
IAC59C	4.0–16.0 1.5–6.0 0.5–2.0	.....	.....	1 NO, 1 NC	S-1	A-10	GEI-21903	Same as IAC59A, but contacts do not seal in.

NOTES:

(1) Ranges only are given for overcurrent units, both time and instantaneous. [illegible] should be regarded. Specific models are listed on the back of this bulletin.

(2) Relays are designed to operate repeatedly [illegible] per cent [illegible]

(3) Standard instantaneous overcurrent units drop out at 40 per cent or more [illegible] minimum setting and 50 per cent at maximum setting. High-dropout units drop out at 80 per cent or more [illegible] minimum setting and 20 per cent at maximum setting.

(4) Except for IAC59C all listed models have large [illegible] the [illegible] disk units. Standard instantaneous units have integral targets. High-dropout instantaneous units are constructed without targets. External targets can be provided.

(5) Relays with 2 NO contacts have one side common.

(6) For a-c trip operation see text.

(7) The telephone type auxiliary relay associated with IAC60, 80, and [illegible] relays [illegible] is rated for either 125 or 250 volt [illegible]

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ONSTRUCTION

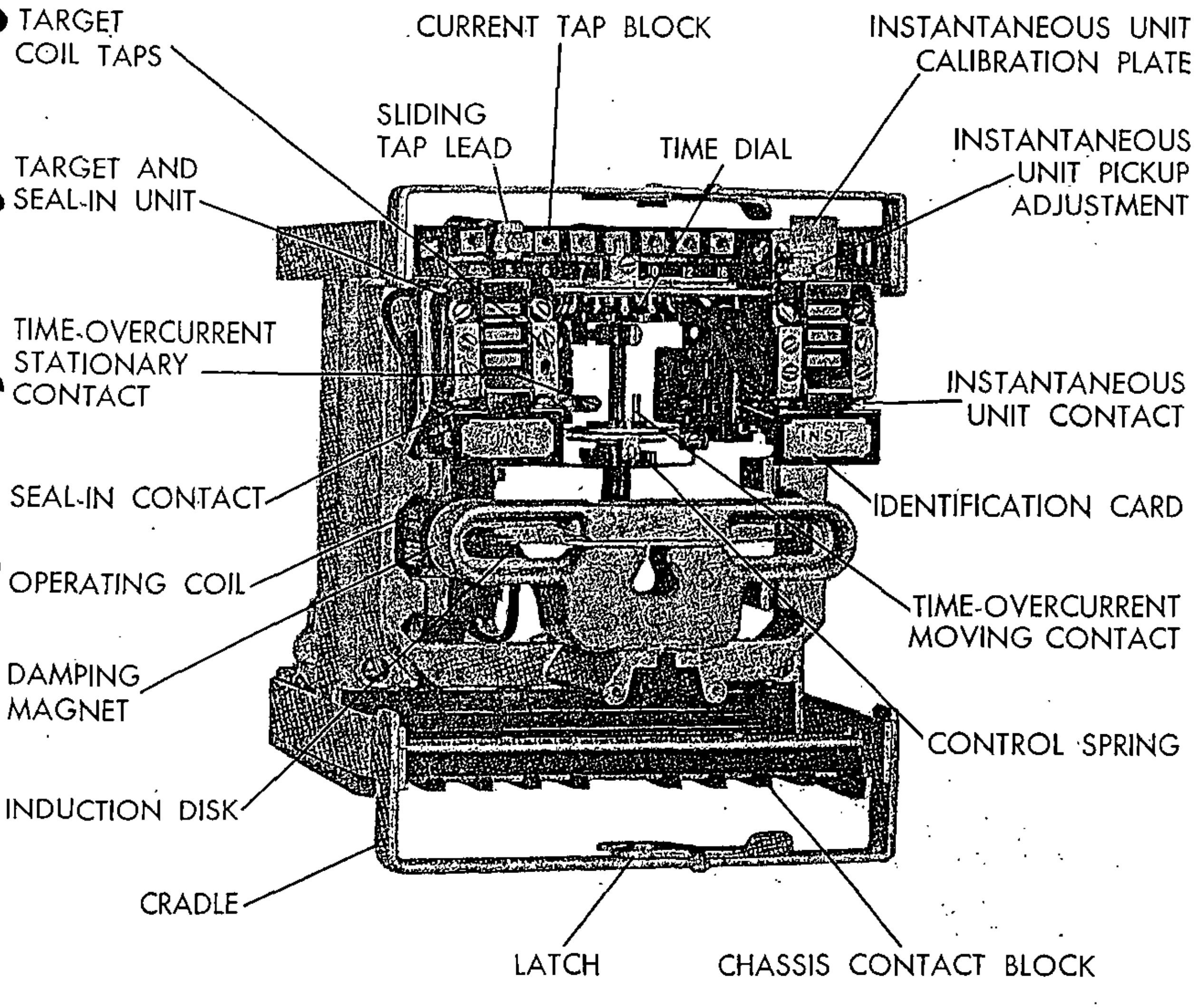

Fig. 1. Typical IAC relay mechanism in cradle with standard hinged armature instantaneous unit (Model 12IAC51B)

For further information, order publications from your General Electric district sales office.

Prices—Apparatus Handbook Sect. 7213
Ordering Instructions—Apparatus Handbook Sect. 7210
Purchasing Information—Apparatus Handbook Sect. 7215
Renewal Parts—GEF-3883

Characteristic Curves (on standard log-log paper):
Inverse, Standard Time—GES-7001
Very Inverse, Standard Time—GES-7002
Inverse, Short Time—GES-7003
Inverse, Long Time—GES-7004
Extremely Inverse, Standard Time—GES-7005

APPLICATION

Overcurrent relaying is used extensively for protection of utility and industrial electrical distribution systems and frequently for overload backup protection at other locations. General practice is to use a set of two or three overcurrent relays (Fig. 2) for interphase faults and a separate overcurrent relay, residually connected, for single phase-to-ground faults. Separate ground relays are advantageous because they can be adjusted to provide more sensitive protection for ground faults.

The overcurrent relay is normally set to operate for currents above maximum load conditions and to provide time coordination between line sections under maximum short-circuit conditions (Fig. 3). The minimum time difference (S) between successive relay settings is equal to the rated interrupting time of the circuit breaker plus relay overtravel time and a safety factor. A value of 0.25 to 0.4 seconds is generally sufficient. Lower values may be used if accurate data are available.

Five time vs current operating characteristics are available in the Type IAC family of relays (Fig. 4). The operating characteristic of the relay determines its ability to coordinate with circuit breakers, fuses, and other protective devices in the system, and the relay is thus selected mainly on the basis of its characteristic curve.

INVERSE AND VERY INVERSE RELAYS

On systems where the magnitude of short-circuit current flowing through any given relay is dependent mainly upon the relative location of the fault to the relay, and only slightly or not at all upon the system generating setup, faster clearing can usually be obtained with very inverse time relays. Where the short-circuit cur-

LEGEND

Device Function Numbers and Letters Used in all Figures

21	Impedance relay
IOC-A	Instantaneous element, standard
IOC-B	Instantaneous element, high-drop-out
51	Time-overcurrent relay
52	Power circuit breaker
N	Neutral
X OX	Auxiliary relay
a	Auxiliary switch which is open when the main device is deenergized or open
SI	Seal-in unit, with or without target
TC	Trip coil

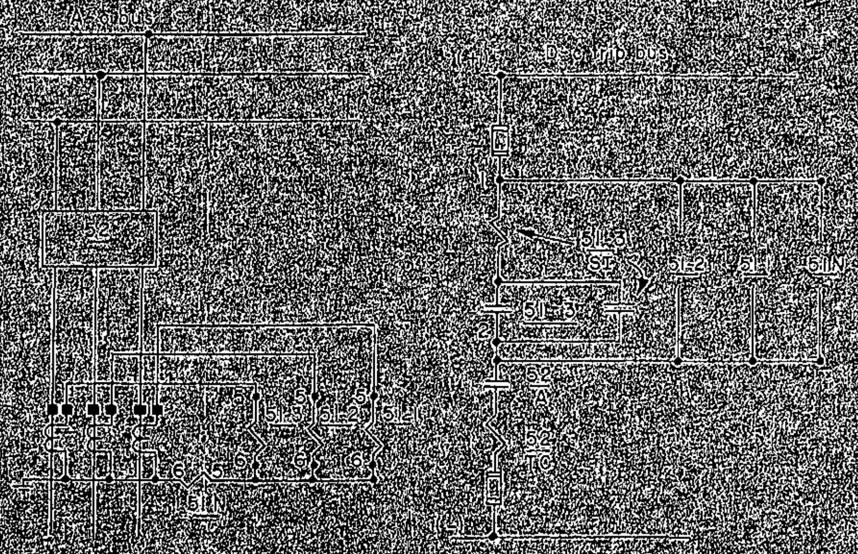

Fig. 2. Typical elementary wiring diagram showing Type IAC relays protecting a 3-phase circuit against phase and ground faults

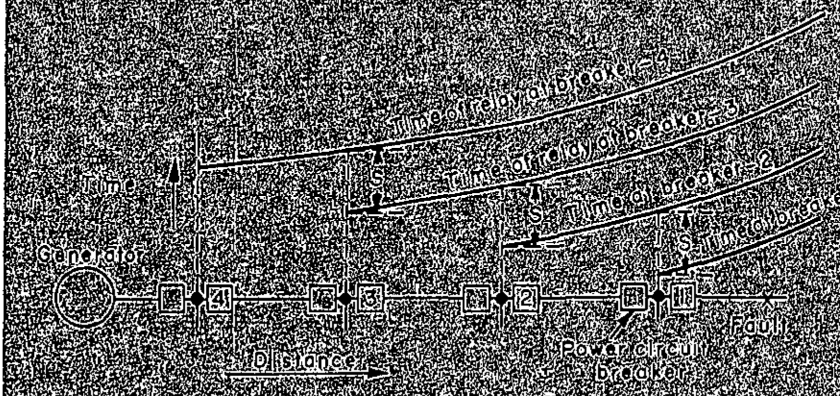

Fig. 3. Schematic one-line diagram illustrating operating time of overcurrent relays with inverse characteristics

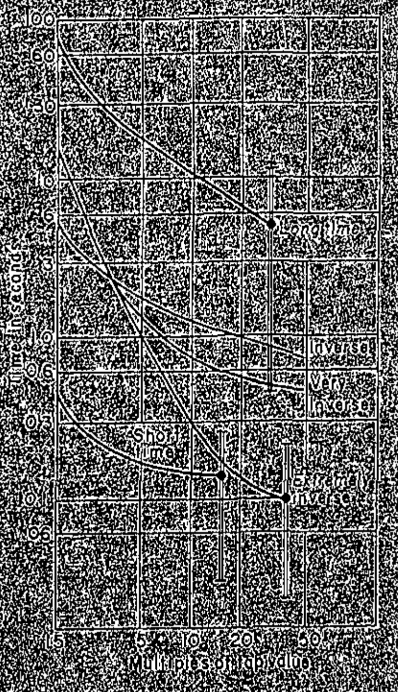

Fig. 4. Typical operating characteristics of Type IAC relays; the No. 5 time-dial setting is shown for each curve, and the range of time adjustment from 0.5 to 10 time-dial settings is shown for the extremely inverse, the short time and the long time relays.

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rent magnitude is dependent largely upon system generating capacity at the time of the fault, better results will be obtained with relays having inverse time characteristics.

EXTREMELY INVERSE TIME OVERCURRENT RELAYS

The extremely inverse time characteristics of Type IAC77 and -78 relays makes them particularly well suited to the protection of primary distribution feeder circuits, because they coordinate best with fuses (See Fig. 5 and 6) and reclosers, and can be set to permit the flow of high inrush currents which occur when feeder service is restored after a prolonged outage.

Feeders generally supply power to a number of automatic, intermittently operated devices, such as oil burners, refrigerators, pumps, and water heaters. In normal operation, there is considerable diversity among the various loads, and the total current flow is significantly less then the sum of the individual load requirements. However, after a prolonged feeder outage, all the various devices start to operate simultaneously, causing extremely high current flow. Protective relays must, therefore, tolerate such a condition for a time until the loads return to normal. The extremely inverse characteristic is best suited for this application.

INVERSE, SHORT-TIME RELAYS

The Type IAC55 relay can be applied for overcurrent protection of equipment where only a short time can be tolerated before the fault is cleared. Power rectifier equipment is a good example of this type of load.

INVERSE, LONG TIME RELAYS

Type IAC66 relays are designed for applications requiring long time delay. The major area of usefulness is in the protection of motors against overloads under conditions where the customary thermal devices are not applicable. Model IAC66A has an induction-disk unit only, Model IAC66B also includes a standard instantaneous unit, and Model IAC66K includes both a standard and a high-dropout instantaneous unit.

The Model IAC66K relays are used for locked-rotor and fault-current protection of squirrel-cage induction motors (Fig. 7). They are recommended for use with motors of 1500 horsepower or over at 2200 volts or higher, and for motors 3000 horsepower and above at any voltage.

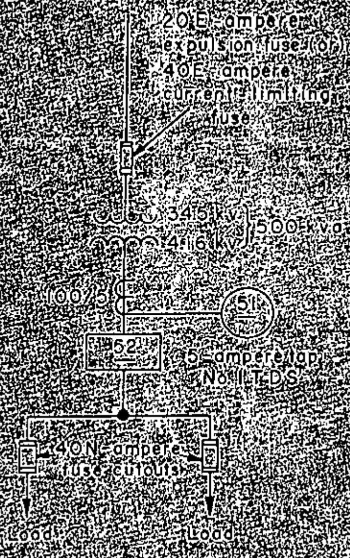

Fig. 5 One-line diagram of typical distribution circuit protected by Type IAC77 time-overcurrent relays

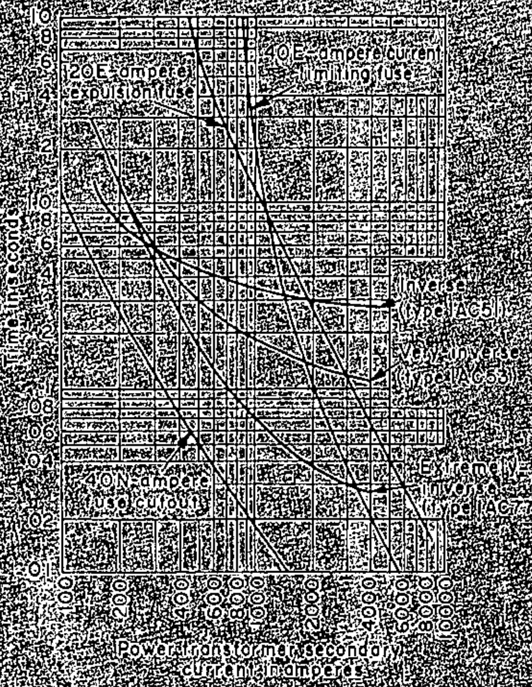

Fig. 6 Comparison of IAC overcurrent relay characteristics showing coordination with typical primary and secondary fuses

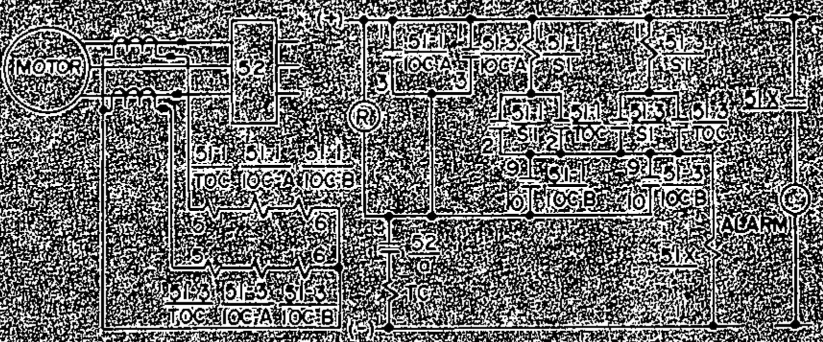

Fig. 7 Typical external connections for motor protection using Type IAC66K relays

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Resistance temperature detectors are generally installed in these larger motors, and they should be used, where possible, for thermal overload protection. For locked-rotor protection, the induction-disk unit and the high-dropout unit work together. The induction-disk unit is set to close its contacts before the allowable stall time limit is reached, and the high-dropout instantaneous unit is set to close contacts above the maximum load current but below the symmetrical locked-rotor current. The contacts of these two units are connected in series, and if both operate, the motor is tripped off the line. Starting current will cause the high-dropout unit to pick up and the induction unit to start to time out. On a normal start, the current level will fall off quickly, and tripping will not occur.

For a motor without resistance temperature detectors, the induction unit can be set to provide both overload protection through an overload alarm (Fig. 7) and locked-rotor protection by tripping. Such an arrangement is used frequently for essential service motors, such as power-plant auxiliaries.

In either case, the standard instantaneous unit is set to provide fault protection.

TORQUE-CONTROLLED OVERCURRENT RELAYS

Types IAC60, -80, and -90 time-overcurrent relays operate only when permitted to do so by the closing of an external circuit. The shading coil on the induction unit is wire-wound, not solid as in standard IAC relays, and its leads are brought out to external terminals. When the shading-coil circuit is closed through contacts of another device, torque can be developed on the induction disk; otherwise it can not.

External control of these relays permits their use as second-zone timing relays with zone-packaged distance relays, and these relays with suffixes -E and -H are specifically designed for this purpose. Suffix -E relays have two induction-disk units, torque controlled through a telephone-type auxiliary relay. The telephone relay is operated by external contacts. Suffix -H relays are similar except that they have additional instantaneous-overcurrent units of the plunger type.

Figure 8 is a simplified, functional diagram of a torque-controlled IAC relay used with Type CEY15 and CEY16 relays. The CEY15 is a first-zone directional mho relay that trips without time delay, either directly or through the instantaneous-fault-detector units of the IAC relay. The CEY16 is a second-zone

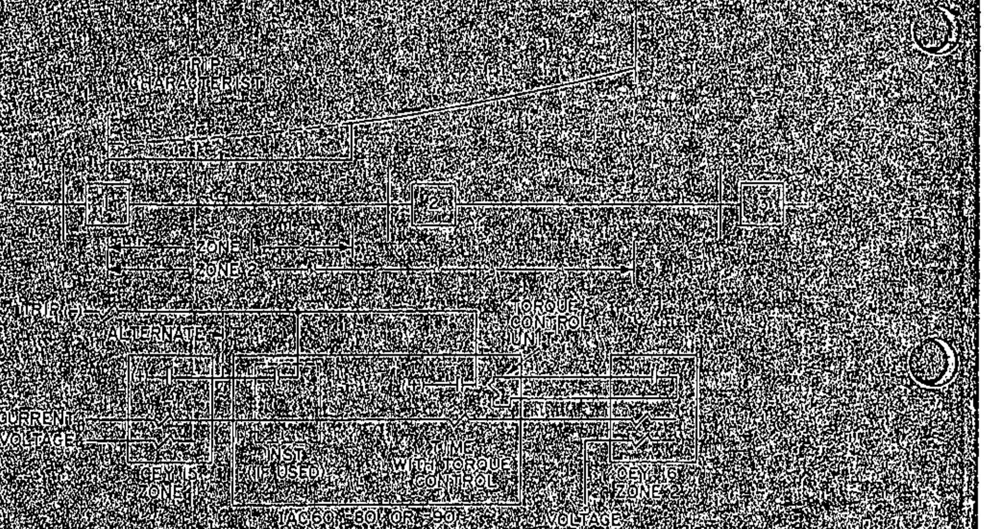

Fig. 8 Simplified functional schematic diagram showing Type IAC60, -80, or -90 relay used as second-zone timing relay

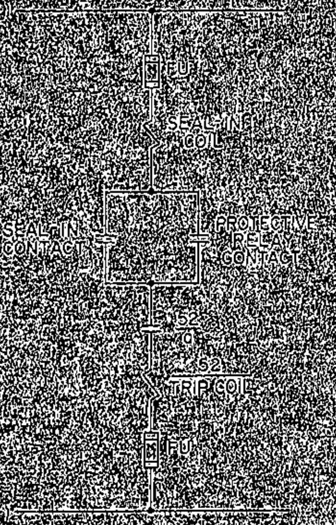

Fig. 9 Typical d-c tripping circuit

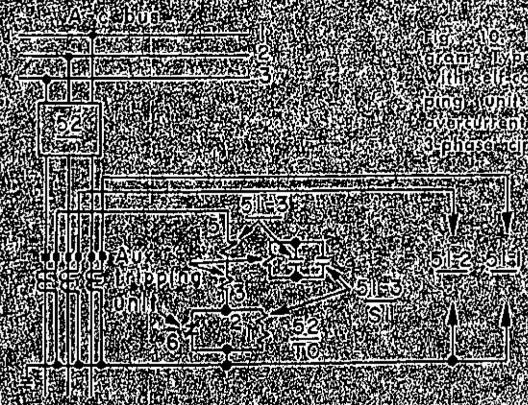

Fig. 10 Elementary diagram of Type IAC51C relays with self-contained d-c tripping units connected for overcurrent protection of a 3-phase circuit

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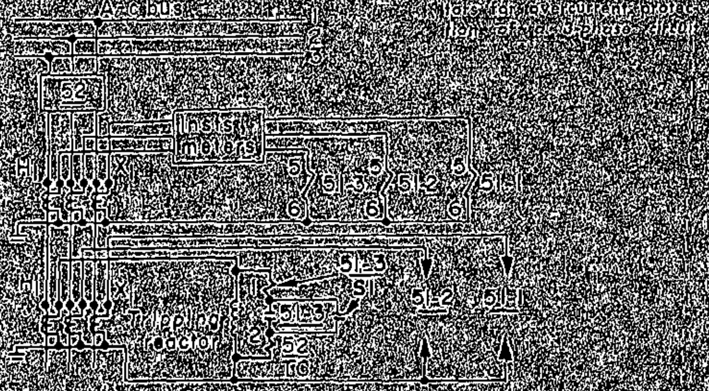

Fig. 11. Elementary diagram, Type IAC relays used with external tripping reactors for overcurrent protection of a 3-phase circuit

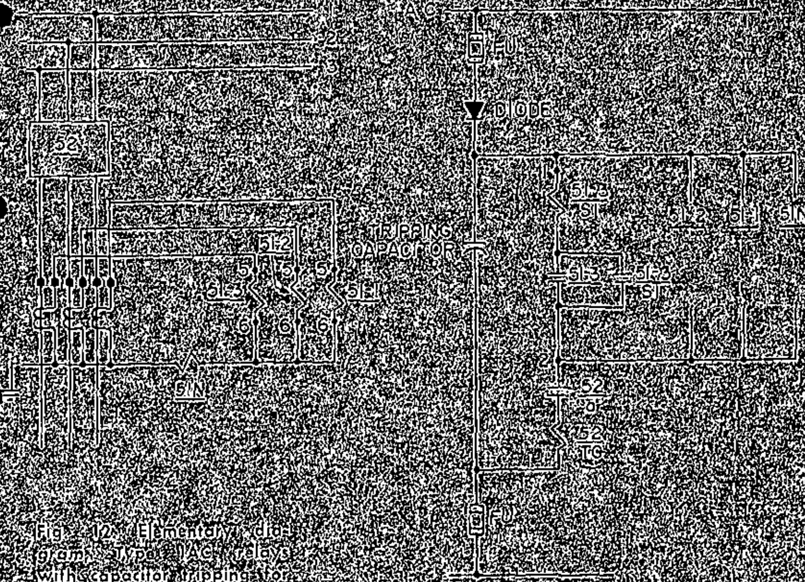

Fig. 12. Elementary diagram, Type IAC relays with capacitor tripping for overcurrent protection of a 3-phase circuit

TABLE I

Coil and Contact Data IAC 60H, 80H and 90H Plunger-type Instantaneous Unit

Coil Ratings	Burdens (at minimum pickup unless otherwise noted)
Continuous—12 amperes	Effective resistance—0.055 ohm
One second—275 amperes	Reactance—0.11 ohm
	Impedance—0.13 ohm
	Impedance
Contact Ratings	at 3 times pickup—[illegible]
Tripping—30 amperes at 250 v d-c or less	at 10 times pickup—0.06 ohm
	at 20 times pickup—0.05 ohm

directional mho relay that operates the d-c auxiliary telephone unit to permit torque development in the time-overcurrent unit and give a time-delay trip.

Table I gives coil and contact data for plunger-type instantaneous units.

CALCULATIONS

Time and current settings of Type IAC relays are made by selecting the proper current tap and adjusting the time dial to the number which corresponds to the characteristic required. The following example *illustrates* the procedure.

Assume a Type IAC inverse time relay in a circuit where the circuit breaker *should trip on a sustained current of* approximately 450 amperes, and that the breaker should trip in 1.9 seconds on a short-circuit current of 3750 amperes. Assume further that current transformers of a 60:1 ratio are used.

Find the current tap setting by dividing the minimum primary tripping current by *the current transformer ratio:*

$$\frac{450}{60}=7.5$$

Since there is no 7.5-ampere tap, use the 8-ampere tap.

To find the time setting which will give 1.9-second time delay at 3750 *amperes,* divide 3750 by the transformer ratio. This gives 62.5-amperes secondary current, which is 7.8 times the 8-ampere tap setting. The time-current characteristic of the inverse time relays (Fig. 13) shows that 7.8 times the minimum closing current gives 1.9-second time delay when *the relay is set at approximately the 6.5* time-dial setting.

TRIPPING CIRCUITS

Figure 9 shows a typical d-c tripping circuit. Except as noted in the Selection Data table, the induction-disk units of all IAC relays covered by this book include universal target and seal-in units, and these are significant in the tripping circuit. Table II gives application data. Note that the 0.2-ampere tap can safely carry tripping currents as high as 5 *amperes; however, in practice, the upper* limit is determined by the permissible voltage drop, which should not exceed 10 per cent of the normal battery voltage. If the 0.2-ampere tap is used with a trip coil that takes more than 2 amperes at 125 volts, there is a possibility that the 7-ohm resistance of the coil will reduce the tripping current to such a *low value that* the circuit breaker will not be tripped.

For proper operation, the seal-in unit *coil requires at least minimum operating* current at minimum control voltage. Therefore, when two or three relays can

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operate simultaneously and divide the tripping current, the minimum current should be calculated on the basis of one half or one third of the total minimum.

Note that the continuous rating of the seal-in unit is well below its tripping rating. The tripping circuit must therefore be opened by an auxiliary switch on the circuit breaker or by other external, automatic means.

The induction-disk unit contacts will reset when the current level decreases to less than 90 per cent of the minimum closing value.

Where a reliable d-c tripping source is not available, a model with an integral a-c tripping circuit should be chosen—for example, IAC51C. Such a relay will trip a circuit breaker using current from the secondary of the current transformer. Table III gives application data.

The a-c trip unit has the effect of transferring the circuit-breaker trip coil into the secondary circuit of the current transformer when the overcurrent unit functions, and removing it when the breaker trips, without opening the secondary circuit.

The application of these relays is illustrated by the circuit of Fig. 10. Current from the secondary of the current transformer circulates through the IAC current coil and the main (lower) coil of the auxiliary tripping unit, returning through the auxiliary unit contact. Normally, most of the flux generated by the main auxiliary unit coil passes through the upper limb of its magnetic structure and holds the armature firmly against this limb. When the contacts of the IAC unit close, the shorting (upper) coil of the auxiliary unit is short circuited, and current flows in this coil by transformer action which causes a redistribution of flux; this actuates the armature and the auxiliary-unit contacts. The opening of the auxiliary-unit contacts causes the secondary current to flow through the trip coil, which trips the breaker.

While Type IAC relays with self-contained auxiliary tripping units are recommended wherever applicable, tripping reactors are also available. Whenever practical, it is preferable to have the relay coil and tripping reactor on separate transformers, as in Fig. 11, because the time-current characteristics of the relay may be affected by the high burden and non-linear characteristics of the tripping reactor when both are connected in the secondary of the same transformer.

In capacitor tripping schemes, any Type IAC relay of a suitable d-c voltage rating can be used. A typical circuit arrangement is shown in Fig. 12.

TABLE II
Universal Target and Seal-in Unit Coil Data

Trip coil current	Seal-in unit tap	D-c resistance (ohms)	Impedance (ohms)	Ratings (amps)	
				Tripping	Continuous
0.2 to 2.0 amps at min. control voltage	0.2	7.0	52	3	0.3
2.0 to 30 amps at min. control voltage (up to 250 vdc)	2.0	0.13	0.53	30	4.0
Above 30 amps	Use auxiliary relay in trip coil circuit				

TABLE III
Application Data, A-c Trip Units

Circuit Breaker Trip Coil Rating (amperes)	A-c Trip Minimum Pickup (amperes)	Coil Rating (amperes)	Contact Transfer Rating (amperes)
3.0	3.5	150	100

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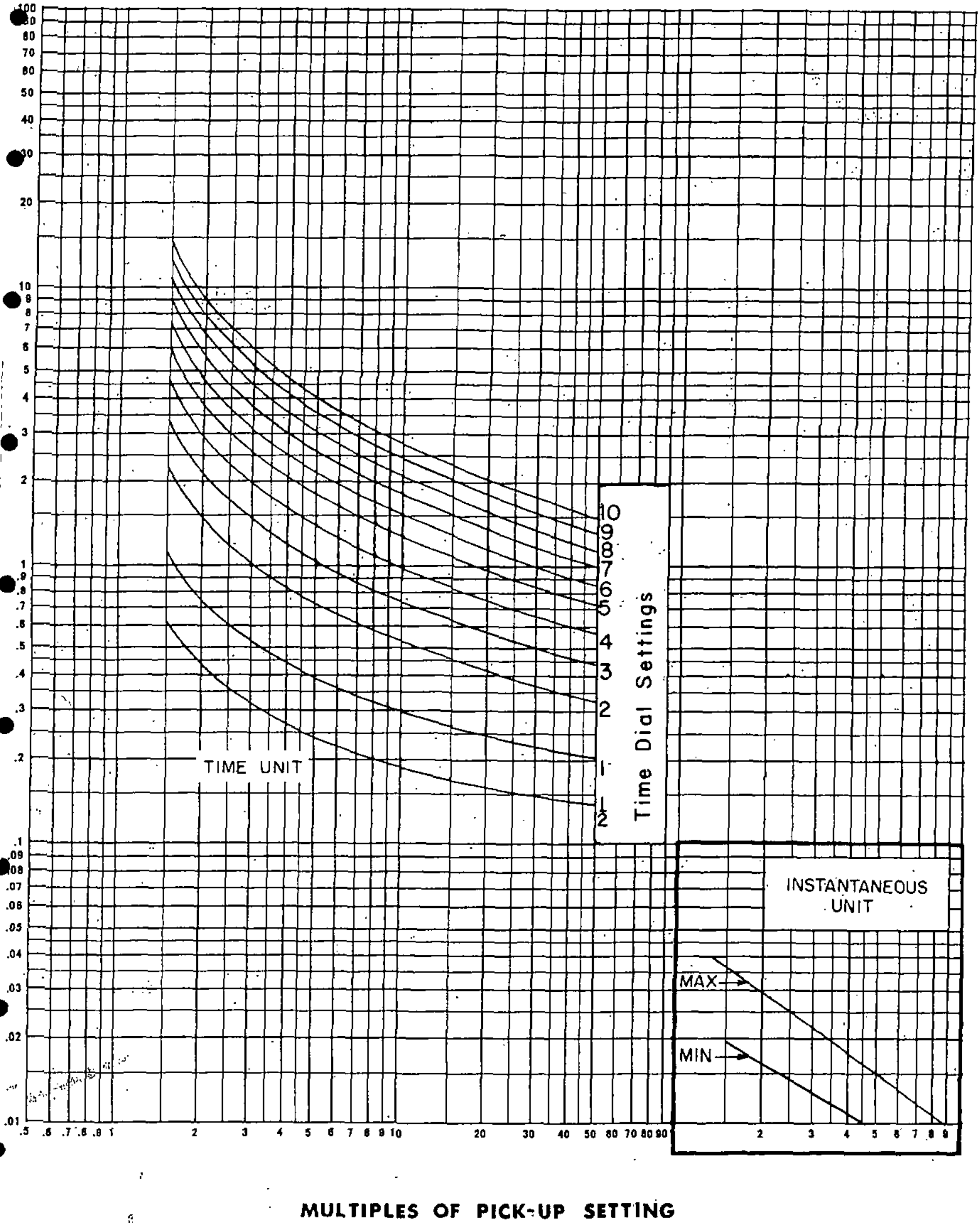

Fig. 13. Type IAC relays, Inverse Time-characteristic Curve (GES-7001)

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Product Comparison Charts

Distribution Protection

	SEL-451	SEL-351	SEL-351A	SEL-351S	SEL-751	SEL-751A	SEL-632	SEL-501/501-2	SEL-551/551C	SEL-547	SEL-2431	SEL-734B	SEL-351RS Kestrel	SEL-351R Falcon	SEL-351R	SEL-651R
APPLICATIONS																
Distribution Feeder Protection	•	•	•	•	•	•		•	•				•	•	•	•
Breaker Failure Protection	•	/	/	/	•	•		*	/				/	/	/	/
Generator Intertie Protection	•	•	•	•	*	*				•				•	•	•
Recloser Control													•	•	•	•
Synchronism Check	•	•	•	•	*	*				•				*	*	•
Underfrequency Load Shedding	/	•	•	•	•	•				•		/	•	•	•	•
Undervoltage Load Shedding	/	•	•	•	•	*				•		/	•	•	•	•
32-Step Single-Phase Voltage Regulator											•					
Capacitor Bank Control												•				
PROTECTION																
27/59 Under-/Overvoltage	•	•	•	•	•	*				•		/	•	•	•	•
32 Directional Power Elements	/	*		*	•	*	•			•		/	•			•
49 Thermal Overload	/															
50 Overcurrent Element (50P, N, G, Q)	•	•	•	•	•	•		•	•				•	•	•	•
51 Time-Overcurrent Element (51P, N, G, Q)	•	•	•	•	•	•		•	•				•	•	•	•
67 Directional Overcurrent (67P, N, Q)	•	•	•	•	*									•	•	•
81 Over-/Underfrequency	•	•	•	•	•	•				•		/	•	•	•	•
Separate Neutral Overcurrent	•	•	•	•	•	•			•					•	•	•
Load-Encroachment Supervision	•	•	•	•	*									•	•	•
Mirrored Bits® Communications	•	*		*	•	•						•	•	•	*	•
Sensitive Earth Fault Protection		*	*	*		*								•	•	•
Directional Sensitive Earth Fault Protection		*	*	*										•	•	•
Pilot Protection Logic	•	•		•										•	•	/
Rate of Change of Frequency df/dt	/				•	*										
Arc Sense™ Technology (AST) High-Impedance Fault Detection	*				*											
Arc-Flash Detection					*	*										
Phantom Phase Voltage		*	*	*									•	•	•	•
Current/Voltage Channels		4/4	4/4	4/4		4/4	3/6	6/0	4/0	1/4	1/2	3/3	1/1	4/4	4/4	4/6
Complete Two-Breaker Control	•							•								
INSTRUMENTATION AND CONTROL																
79 Automatic Reclosing	•	•	•	•	*	*	•		•				•	•	•	•
Fault Locating	•	•	•	•	•								•	•	•	•
SELogic® Control Equations With Remote Control Switches	•	•	•	•	•	•			•	•	•	•	•	•	•	•
SELogic Counters	•				•	•					•	•	•	•	*	•
Voltage Check on Closing	•	•	•	•	*	*	•			•			•	•	•	•
Operator Control Pushbuttons	•			•	•	•					•	•	•	•	•	•
SELogic Nonvolatile Latch	•	•	•	•	•	•			*		•	•	•	•	•	•
Nonvolatile Local Control Switches	•	•	*	•	•	•			•		•		•	•	•	•
Display Points	•	•	*	•	•	•			•		•	•	•	•	•	•
Multiple Settings Groups	•	•	•	•	•	•				•	•		•	•	•	•
Substation Battery Monitor	•	•	•	•	*	*										
Breaker/Recloser Wear Monitor	•	•	•	•	•	•							•	•	•	•
Trip Coil Monitor	/	/	/	/	/	/			/				/	/	/	/
Voltage Sag/Swell/Interrupt Recorder		*		*								•	•			•
Load Profile Recorder		*		*	•	•					•	•	•	•	*	
Load Sense® Technology (LST) Load Characterization											•					
Sequential Events Recorder	•	•	•	•	•	•			•	•	•	•	•	•	•	•
Demand Meter	•	•	•	•	•	*		•	•		•	•	•	•	•	•
DNP3 Level 2 Outstation	*	•	•	•	*	*					•	*	•	•	*	*
Modbus® Slave		•	•	•	•	•		*	*	•		•	•			•
Synchrophasors IEEE C37.118	•	•	•	•	•	•					•	•	•			•
Bay Control	•															
Ethernet	*	•	•	•	*	*						*	•			•
IEC 61850	*	*	*	*	*	*							*			*
Simple Time Network Protocol (SNTP)			•	•	•	•	•						•			•
Independent Trip/Close Pushbuttons	*	*	*	*								/				
Harmonic Metering		•	•	•							•	•				•
RMS Metering	•				•	•	•					•				•
MISCELLANEOUS FEATURES																
Accepts Delta Voltage Transformers		•	•	•	•	•					•	•				
Connectorized® (Quick Disconnect) Available	*								*		•				•	
Configurable Labels	•			*	*	*					•	*	*	*	*	*
Vac/Vdc Power Supply	•	•	•	•	•	•		•	•			•	•	•		

• *Standard Feature*   * *Model Option*   / *This function may be created using settings*

EXHIBIT
V

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SEL-351 RELAY GUIDEFORM SPECIFICATION SHEET

Protection, control, and monitoring for substations and transmission lines will be provided as an integrated microprocessor-based relay package. This package must contain four separate current inputs and four separate voltage inputs for ac current and voltage measurements. This package must also provide a minimum of six configurable opto-isolated control inputs and seven configurable programmable output contacts as well as one self-test alarm contact. Options must be available to increase the contact I/O count. The output contacts must be rated for tripping duty per IEEE C37.90 standards and provide ordering options for high current interrupting capability. The programmable outputs must be flexible and support AND, OR, and INVERT Boolean operations of internal relay elements and logic outputs.

Standard Protective Functions Include:

- Phase TOC (51P, 51A, 51B, 51C), ground TOC (51G), and neutral TOC (51N) elements with IEEE and IEC curve selections to provide 2 levels of phase and ground/neutral TOC protection.
- Six levels of Instantaneous phase (50P), ground (50G), and neutral (50N) elements.
- Ordering options for Sensitive neutral ground TOC element (*or* sensitive earth fault - SEF) (51N) with a 0.005-1.500 A setting range.
- Negative-sequence TOC element (51Q).
- Six levels of negative-sequence instantaneous elements (50Q).
- Phase directional element with positive sequence polarizing memory for three-phase faults (32P) that can be used to polarize the phase TOC or instantaneous overcurrent elements.
- Ground directional element that automatically selects between negative sequence voltage, zero-sequence voltage, or traditional neutral current polarization (32G).
- Two levels of single phase overvoltage and single phase undervoltage elements (59/27).
- One level of Sequence overvoltage elements
- Load encroachment logic for phase TOC and instantaneous element supervision.
- Six voltage controlled underfrequency or overfrequency elements (81).
- Six independent setting groups.
- Cold load pickup logic.
- Sequence coordination.

Standard Metering Functions Include:

- Single- and three-phase real and reactive power (MW and MVAR).
- Single- and three-phase real and reactive directional energy (MWh, MVARh).
- Single- and three-phase power factor (PF).

Metering Accuracy:

- V_A, V_B, V_C, V_S: ±0.1% (33.5 - 150 V; wye-connected)
- Voltage magnitudes and angles: V_A, V_B, V_C, and V_S.
- Current magnitudes and angles: I_A, I_B, I_C, I_G, and I_N.
- System frequency and station battery voltage monitoring.
- Demand Ammetering (current): phase, negative-sequence, residual, and ground.

Standard Monitoring and Control Functions Include:

- Programmable four shot internal reclosing function with shot and reclose state indication.
- Sync. element that can be combined with bus and line voltage elements for reclose qualifications.
- Maximum and minimum log for I_A, I_B, I_C, I_G, I_N, V_A, V_B, V_C, V_S, 3ϕ MW and MVAR.
- Interrupting contact wear monitor that can be referenced to manufacturer's data or published standards.
- No fewer than 15 of the latest event reports containing voltage and current measurements, contact inputs and output status, fault location, and relay element conditions. Record formats displaying 4 and 16 samples per cycle shall be available. Nonvolatile memory storage.
- A sequence of events recorder (SER) consisting of the 512 latest time-tagged events. Nonvolatile memory storage.
- Three EIA-232 serial ports, one located on the front panel, two on the back panel that support ASCII text communication to allow relay setting entry via PC based terminal emulation package.
- One 4 wire isolated EIA-485 serial port located on the back panel.
- Optional DNP 3.0 Level 2 protocol with bit-mapping.
- IRIG-B time synchronization input with battery backed clock to retain the time during deenergization.
- Front-panel 2 line by 16 character LCD display for local numeric setting and interrogation.
- Trip and close circuit monitoring.

EXHIBIT W
1 OF 3

SEL-351-5, -6, -7 Relay Guideform Specification

The microprocessor-based relay shall provide a combination of functions including protection, monitoring, control, fault locating, and automation. Relay self-checking functions shall be included. Specific operational and functional requirements are as follows.

Phase Fault Overcurrent Protection. The relay shall incorporate phase and negative-sequence overcurrent elements for detection of phase faults. For added security, the relay shall provide directional elements, load encroachment logic, and torque-control capability (internal and external).

Adaptive Phase Overcurrent Elements. The relay shall incorporate adaptive phase overcurrent elements that perform reliably in the presence of current transformer saturation, dc offset, and off-frequency harmonics.

Ground Fault Overcurrent Protection. The relay shall incorporate residual ground and neutral ground overcurrent elements for detection of ground faults. For added security, the relay shall provide directional elements and torque-control capability (internal and external).

Directional Ground Protection. The relay shall incorporate directional ground elements for ungrounded, Petersen Coil-grounded, and impedance-grounded systems, using a neutral current channel that can withstand 500 A for one second (thermal rating).

Under-. and Overvoltage Elements. The relay shall incorporate undervoltage and overvoltage elements for creating protection and control schemes, including but not limited to the following: voltage checks (e.g., hot bus/dead line) for reclosing; blown transformer high-side fuse detection logic; control schemes for capacitor banks.

Sequence Voltage Elements. The relay shall incorporate positive-, negative-, and zero-sequence voltage elements that can be logically configured for either under- or overvoltage applications.

Under- and Overfrequency Protection. The relay shall incorporate six levels of under-/overfrequency elements for detection of power system frequency disturbances. Each setting level shall use an independently set timer for load shedding or generator tripping schemes.

Autoreclosing Control. The relay shall incorporate a four-shot recloser. It shall include four independently set open time intervals, an independently set reset time from reclose cycle, and an independently set reset time from lockout.

Synchronism Check or Broken-Delta Voltage Input. The relay shall include two synchronism check elements with separate maximum angle settings (e.g., one for autoreclosing and one for manual closing). The synchronism check function shall compensate for breaker close time and constant phase angle differences between the two voltage sources used for synchronism check (phase angle differences settable in 30-degree increments). Alternatively, the relay shall accept a broken-delta (zero-sequence) voltage input (in place of a synchronism check voltage) to use as a polarizing source for the zero-sequence voltage-polarized ground directional elements.

Selectable Wye or Delta Voltage Inputs. The relay shall operate with either wye-connected (four wire) or open-delta-connected (three wire) potential transformers.

Event Reporting and Sequential Events Recorder (SER). The relay shall be capable of automatically recording disturbance events of 15 or 30 cycles with settable prefault duration and user-defined triggering. Events shall be stored in nonvolatile memory. The relay shall include an SER that stores the latest 512 entries.

Fast SER Protocol. The relay shall be capable of communicating unsolicited binary SER messages.

Status and Trip Target LEDs. The relay shall include 16 status and trip target LEDs.

Overload and Unbalance Alarms. The relay shall include user-settable demand current thresholds for phase, negative-sequence, neutral, and residual demand measurements.

Circuit Breaker Monitor. The relay shall include a breaker wear monitor with user-definable wear curves, operation counter, and accumulated interrupted currents by phase.

Substation Battery Monitor. The relay shall measure and report the substation battery voltage presented to the relay power supply terminals. Two user-selectable threshold parameters shall be provided for alarm and control purposes.

Fault Locator. The relay shall include a fault locating algorithm to provide an accurate estimate of fault location without communications channels, special instrument transformers, or prefault information.

Digital Relay-to-Relay Communications. The relay shall have eight send and eight receive logic elements in each of two communications ports for dedicated relay-to-relay communications.

W
2 of 3

PGS351-02

Automation. The relay shall include 16 local control elements, 16 remote control logic points, 16 latching logic points, and 16 display messages in conjunction with a local display panel included in the relay. The relay shall have the capability to display custom messages.

Power Elements. The relay shall include four independent directional power elements that can respond to either real or reactive power.

Voltage Sag/Swell/Interruption Report. The relay shall include automatic monitoring of system disturbances, triggered by settable voltage thresholds as a percentage of the predisturbance voltage. The report shall be stored in nonvolatile memory.

Relay Logic. The relay shall include programmable logic functions for a wide range of user- configurable protection, monitoring, and control schemes.

Communication. The relay shall include three independent EIA-232 serial ports and one isolated EIA-485 serial port for external communications.

Distributed Network Protocol (DNP). The relay shall incorporate compliant DNP3 Level 2 Slave protocol communications capability.

IRIG-B. The relay shall include an interface port for a demodulated IRIG-B time synchronization input signal.

PC Interface. The relay shall be capable of being set by Windows®-based graphical and ASCII terminal interfaces.

Synchrophasors. The relay shall include operation as a phasor measurement and control unit (PMCU).

Warranty. The relay shall have a minimum 10-year warranty.

W
3 of 3

EXHIBIT X

EXHIBIT Y
1 OF 2

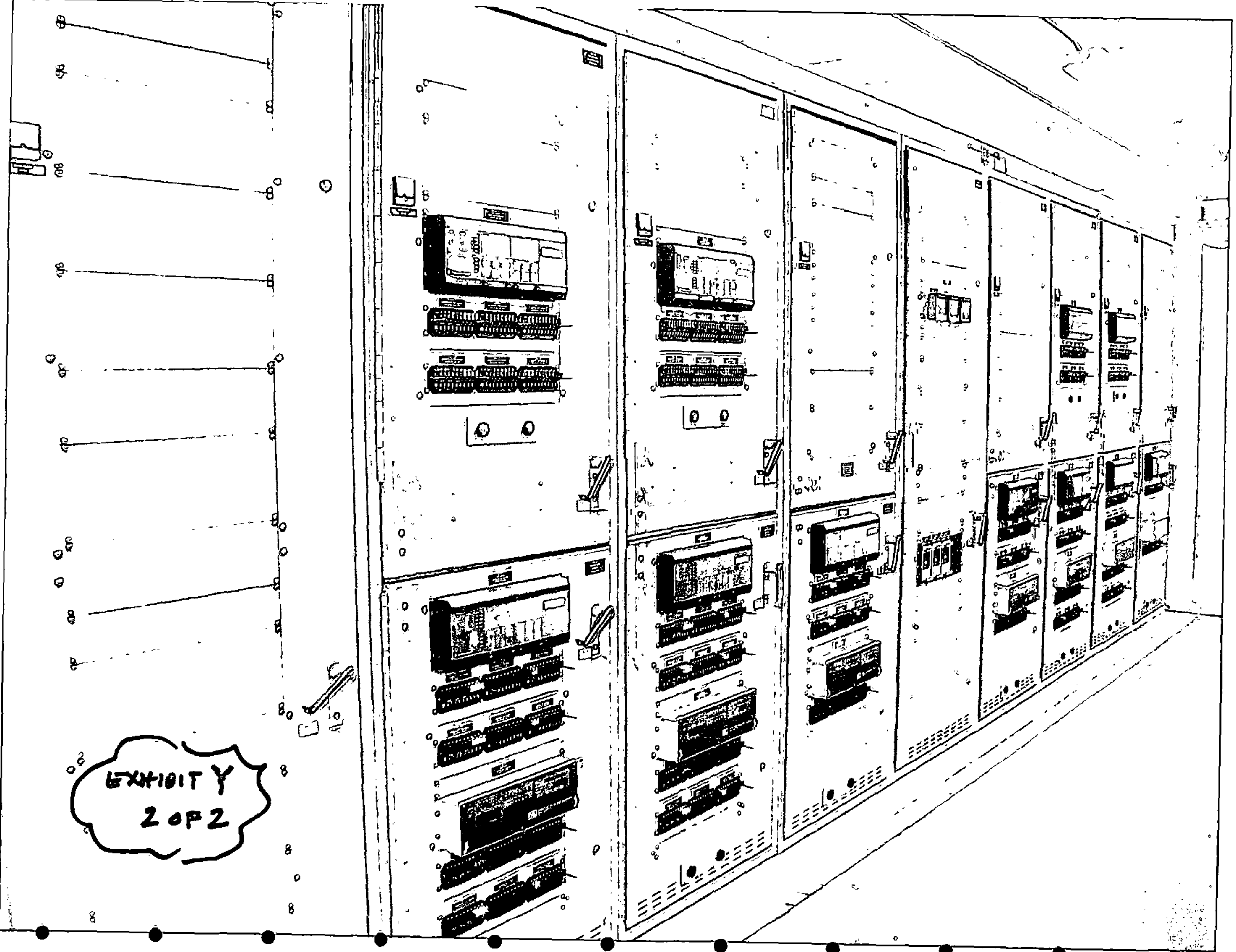
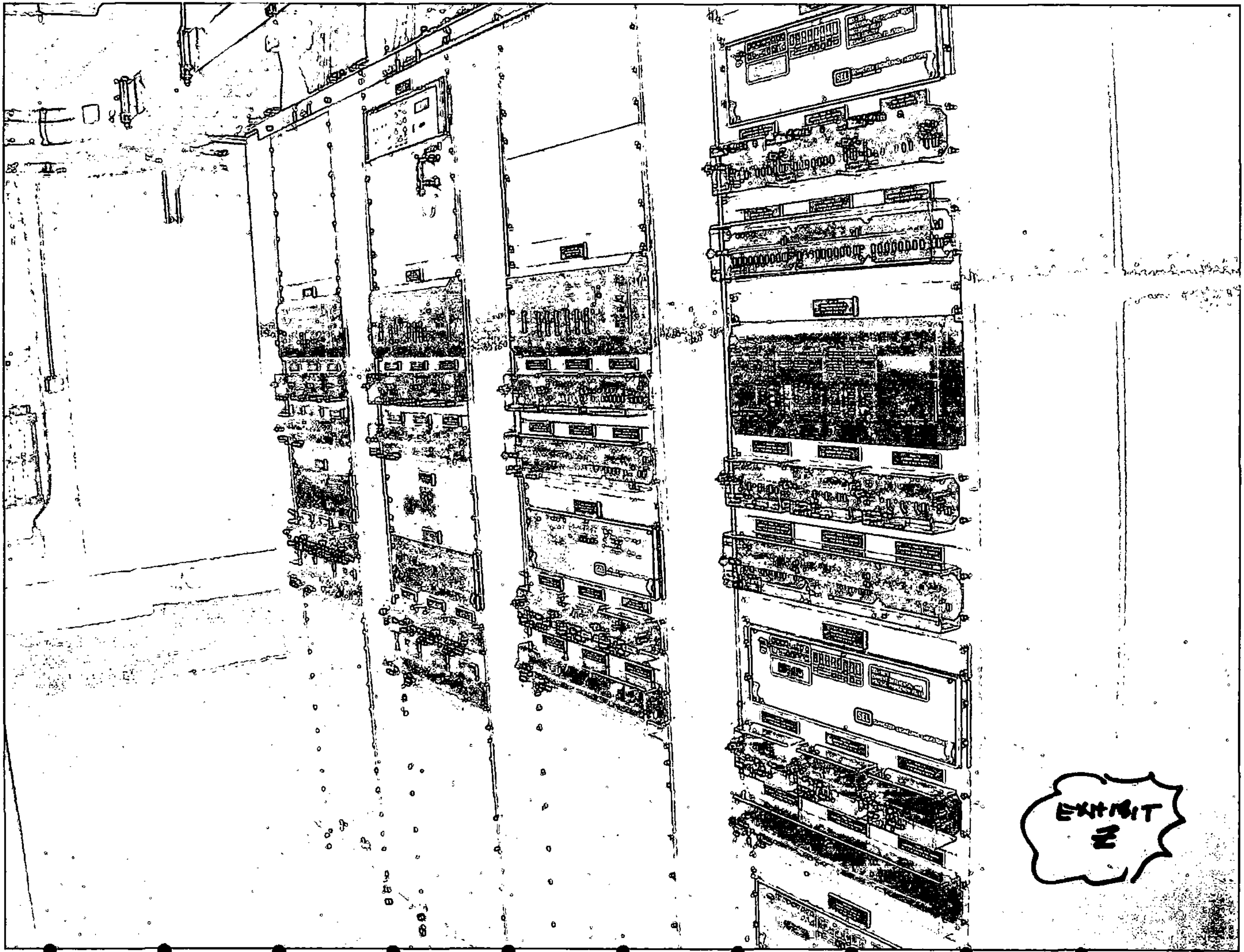


EXHIBIT Y
2 OF 2



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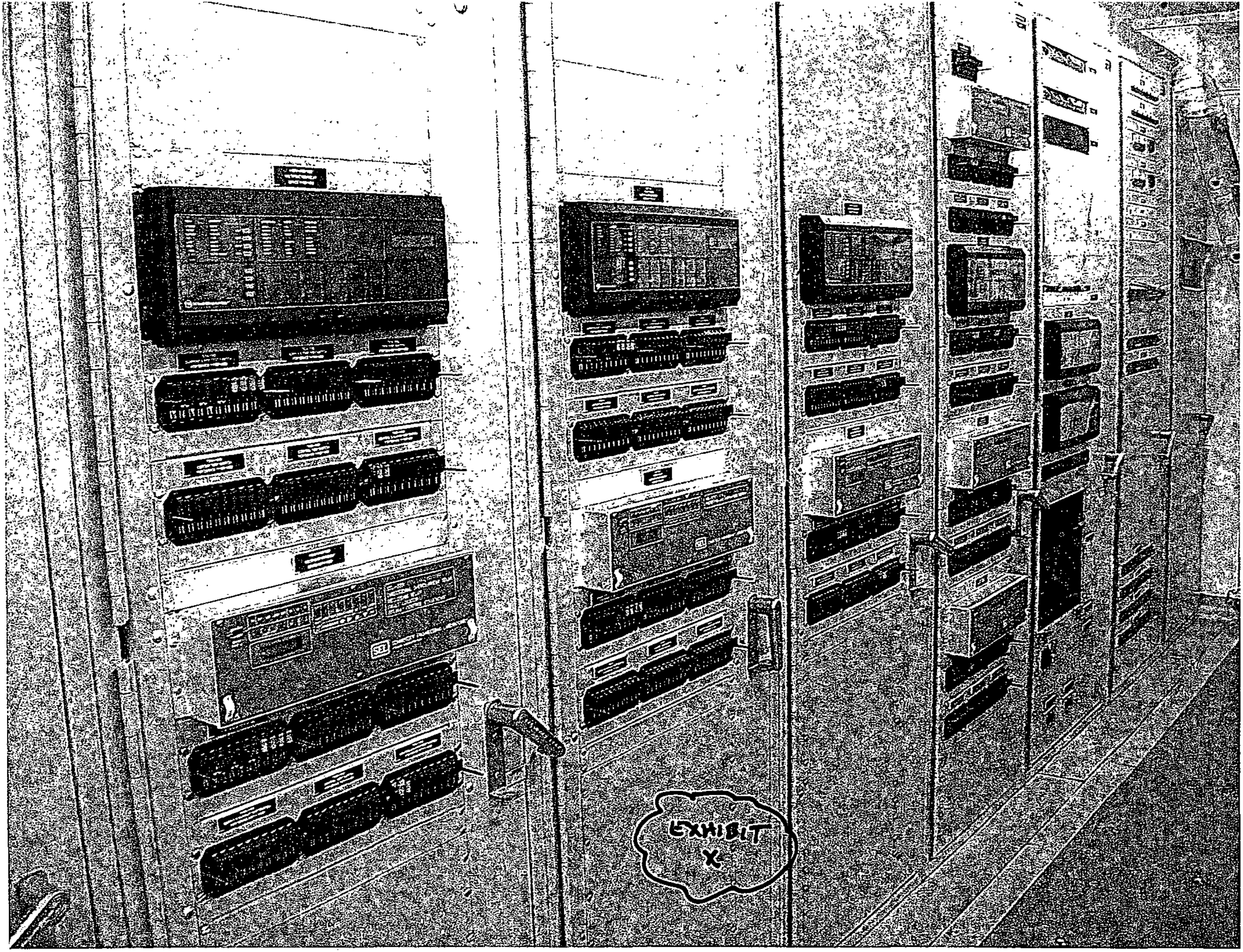

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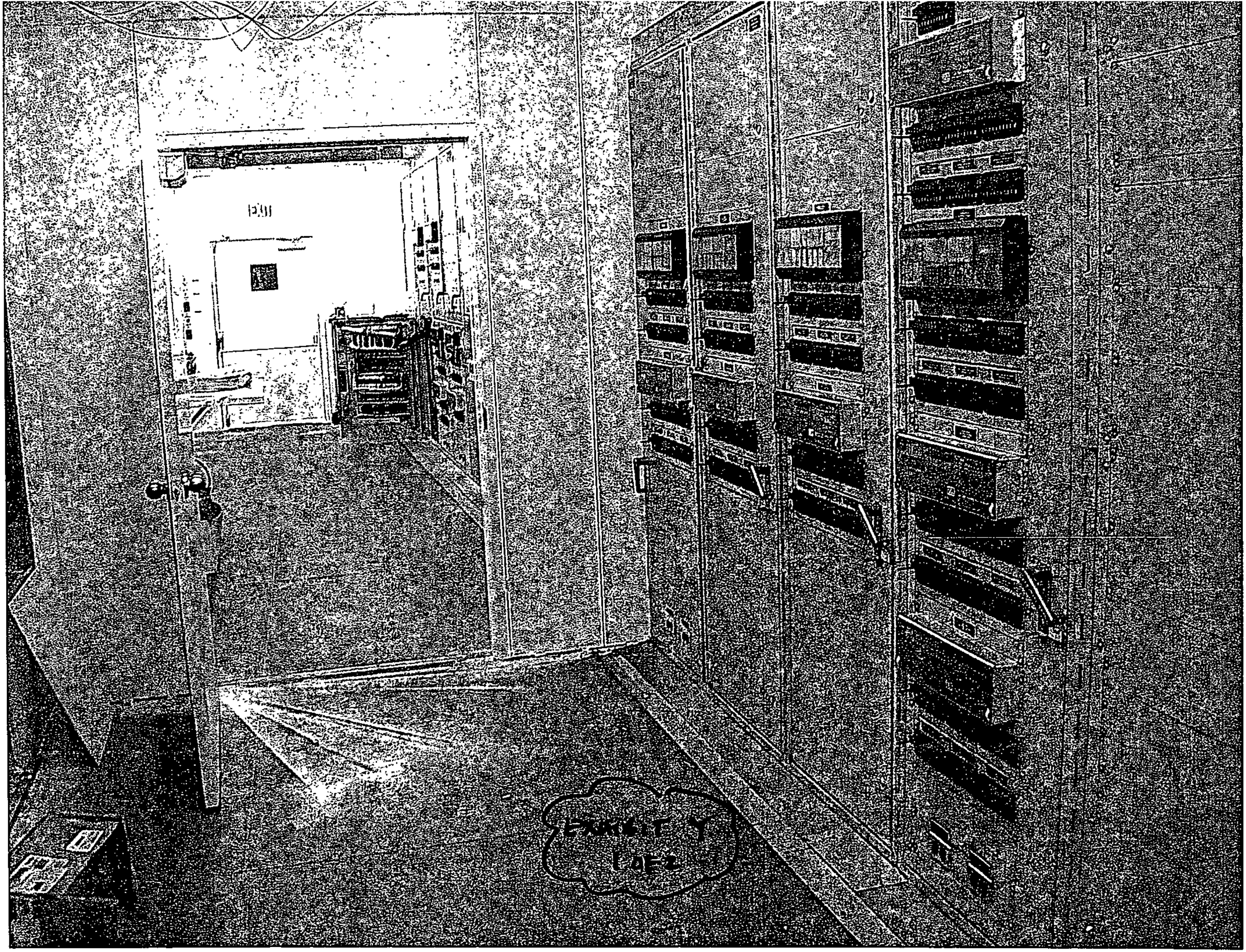


EXHIBIT Y
LAF2

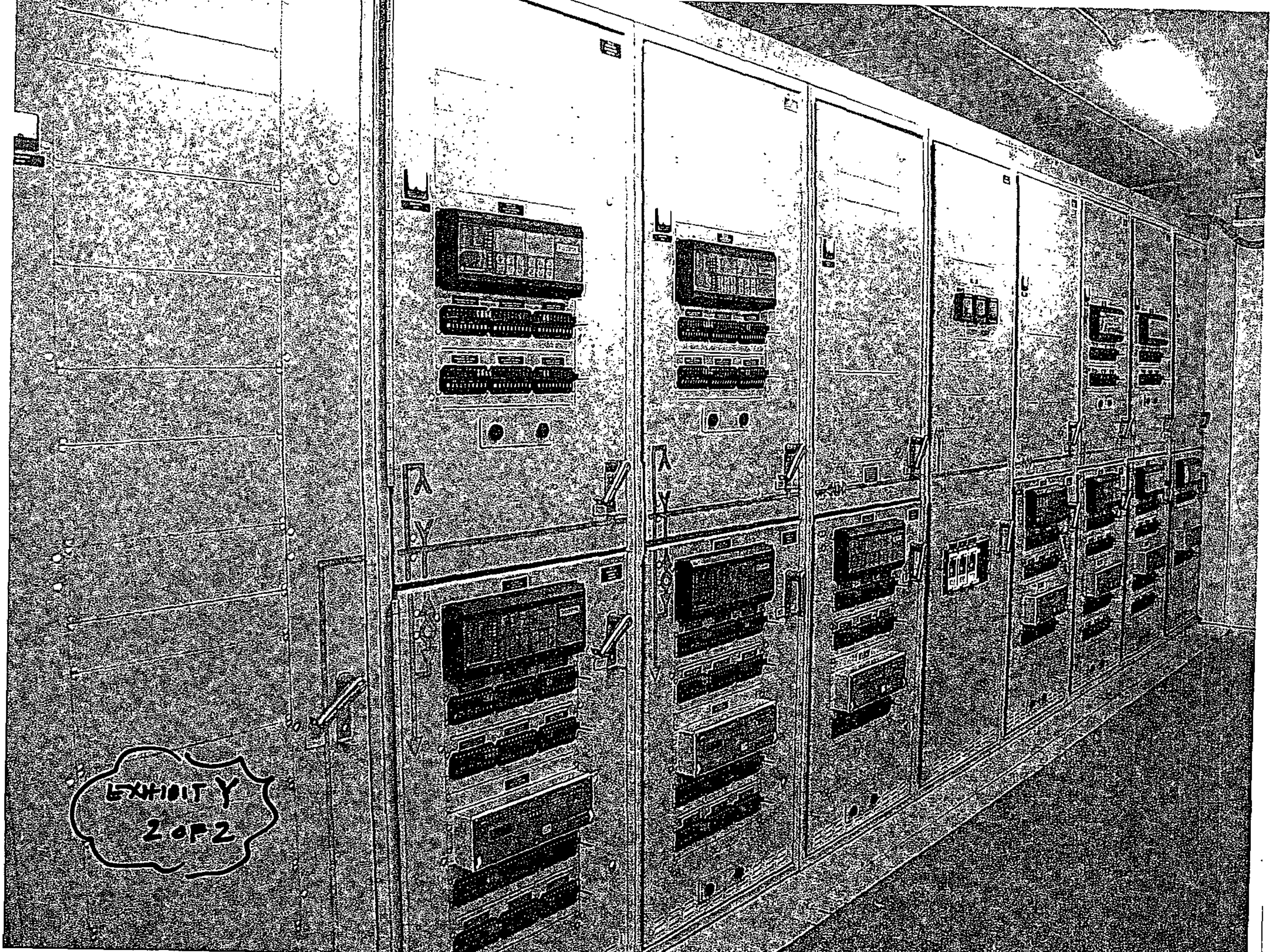
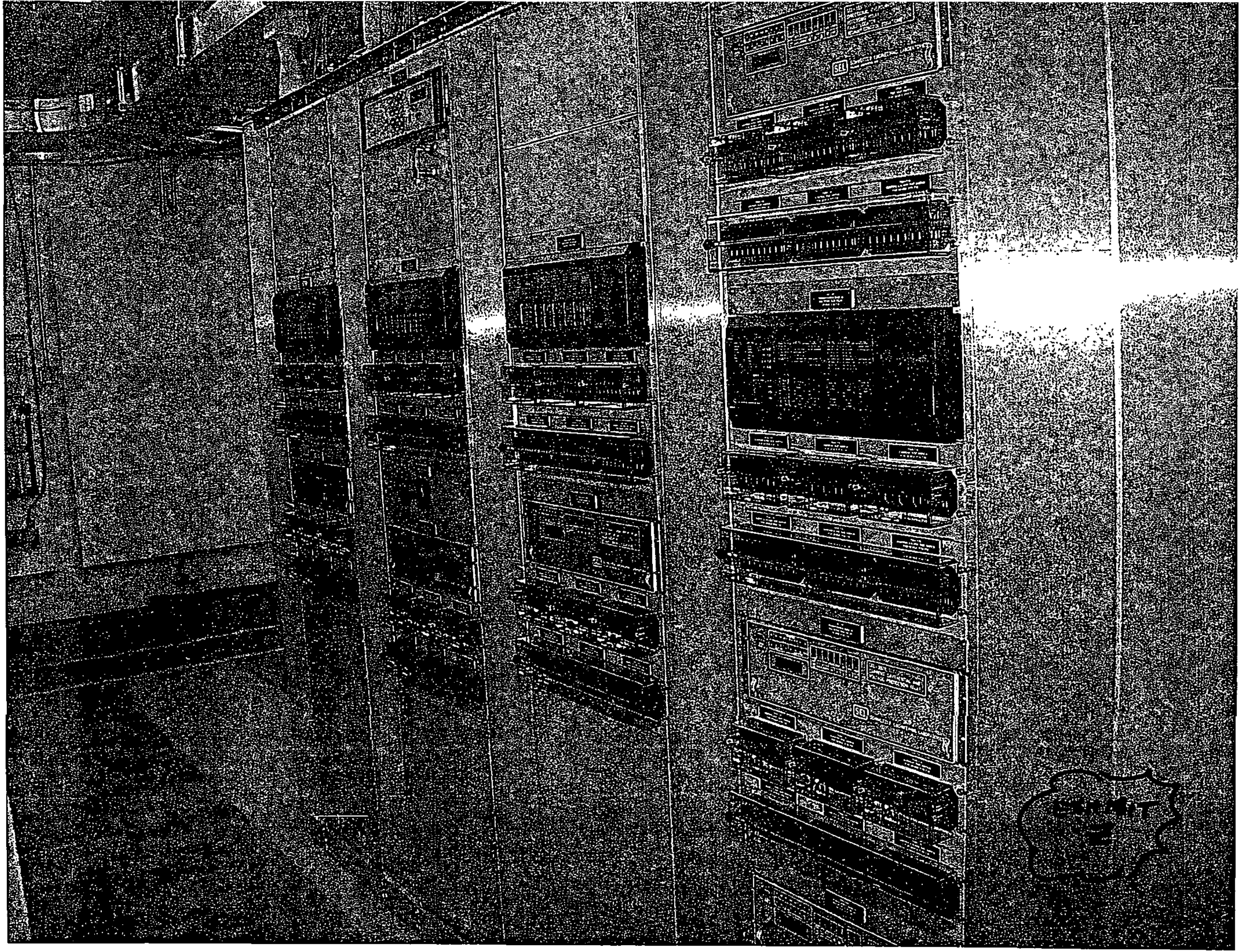


EXHIBIT Y
2 OF 2



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