USE OF THE NATIONAL ELECTRICAL SAFETY CODE IN THE PETRO-CHEMICAL INDUSTRY

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Abstract

A review of the National Electrical Safety Code (NESC) is presented with emphasis placed on high-voltage transmission, distribution and utilization of electrical power. Electric power system requirements are discussed for the installation of electric supply station and distribution systems which are in compliance with the code.

Common violations of the safety code are presented, with an explanation on each violation. The explanation will be followed by a brief discussion on the possible remedies for the violation.

Finally, aspects of the code will be presented with recommendations given for the design, operation and maintenance of safe electrical systems in compliance with the current edition of the NESC. Failure in any one of these areas may result in an unsafe system which could result in a serious injury or death to an employee or the general public.

Introduction

The decade of the seventies brought many changes to the petro-chemical industry. Oil prices skyrocketed from an artificially low value of three dollars a barrel to well into the thirty-dollar range. Strict environmental laws and policies were implemented, and the Occupational Safety and Health Act was passed by Congress.

The rise in fuel prices, the increased environmental concern, and additional safety requirements placed a heavier burden on the electrical utility industry than it did on the petro-chemical industry. The electrical industry was faced with harsh political reactions each time it requested a rate increase. In order to minimize the need for rate increases, many utility companies began increasing rates to industrial customers. One such subtle rate increase was to make secondary service much more expensive than primary electrical service. By charging the higher rates for secondary service, the utility was able to offset costs associated with increased capital, labor and maintenance expenditures. Many industrial customers succumb to the higher costs of electrical service and continued purchasing electricity at a secondary service rate.

However, other industrial users reviewed the rate differential between primary and secondary service. Of these users, the vast majority found the primary service rate to be quite attractive, with very short pay-back periods for the additional capital expenditure. The petro-chemical industry is probably the leader among electrical users to convert to the primary service.

An unfortunate but reconcilable oversight by the engineers and managers who decided on primary service was that of operating, inspecting and maintaining the system in accordance with the National Electrical Safety Code (NESC). Very few of the electrical users had or do have personnel trained in the operation, inspection and maintenance of high-voltage electrical equipment. The consequence is that many systems were either built or have degraded into unsafe, poorly operated, unmaintained and unreliable systems. Proper use of the NESC will allow the electrical user to review his system in either the design or maintenance stages and then take appropriate action.

A Review of the NESC

The National Electrical Safety Code is published by the Institute of Electrical and Electronic Engineers. The code is part of the American National Standard Institute's approved standards and is presently designated ANSI C2-1984. The NESC is normally reviewed and revised on a three-year interval. The present code supercedes the 1981 edition, which followed the 1978 code, and so forth.

The code is written as a means of providing rules for safeguarding employees and the general public during the installation, operation and maintenance of electrical supply systems and communication lines. The code is not intended nor should be construed to be a design specification.

The NESC covers:

1) Grounding methods for electrical supply and communication facilities (Section 9);
2) Electric supply stations (Part 1);
3) Overhead lines (Part 2);
4) Underground lines (Part 3); and
5) Work rules (Part 4);

The first four items primarily cover the installation, while the last item, work rules, covers the procedures for operating and maintaining the system in a safe manner.

The system design engineer is responsible for building the electrical system so that it is in compliance with the installation requirements of the code. The operator of the system is required to maintain the system in a condition consistent to the original installation, along with operating and maintaining the system in a safe manner consistent with the NESC.

The industrial electrical user is required to have the installation in compliance with the code that is in effect at the time of installation. Modifications to installations which were in compliance with prior editions of the code are not normally required to be modified except as deemed necessary for safety reasons by the local administering agency.

Electrical Clearances

The NESC states that an insulated conductor is one that is "...separated from other conducting surfaces by a dielectric (including air space) offering a high resistance to the passage of current." There are many dielectrics used for the protection of conductors, including paper lead, EPR and XLP to name a few. However, probably the most common and widely used dielectric is that of air.

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Air has good insulating qualities and requires a potential of approximately 10kV per cm (30kV per inch) to cause a flashover. Minimum air clearances have been established for the common voltage levels and take into consideration switching surges and lightning impulses. These clearances for standard conditions (with sea level atmospheric conditions) are shown in Table I.

TABLE I

NOMINAL VOLTAGE BETWEEN PHASES	REQUIRED AIR SPACE FOR INSULATION *, cm (INCHES)	
151 - 600 Volts	5.1	(2)
2.4 kV	7.6	(3)
7.2 kV	10.2	(4)
13.8 kV	15.2	(6)
23.0 kV	22.9	(9)
34.5 kV	30.5	(12)
46.0 kV	41.0	(16)
69.0 kV	58.0	(23)
115.0 kV	94.0	(37)
138.0 kV	109.0	(43)
161.0 kV	132.0	(52)
230.0 kV	193.0	(76)

*Standard Conditions

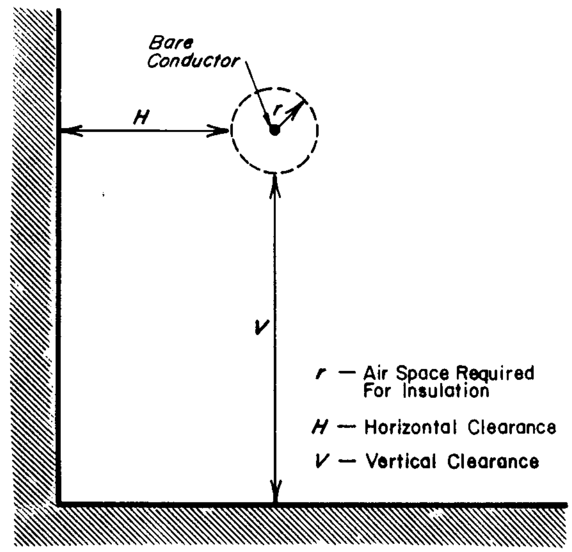

FIGURE I: HORIZONTAL AND VERTICAL CLEARANCES FOR A BARE CONDUCTOR

The air space required to provide the insulation shown in Table I will increase as the relative air density decreases. Although many tests have been conducted to establish the characteristics of the insulating qualities of air under various temperatures and barometric conditions, it is sufficient to increase the required air space at a rate of one percent for every 100m of elevation above sea level. For example, an installation at 2000 meters above sea level will require 20 percent more air space than a similar installation at sea level.

The decrease of the insulating qualities of air with increasing altitude can be compensated with additional air space or with the proper application of surge arresters. The surge arresters limit switching surges and impulses to levels which can be adequately protected by the reduced insulation. The NESC has recently begun recognizing that air insulating requirements can be reduced under standard conditions, provided that the surges on the system are limited. However, this reduction is only allowed at voltages 345kV and above.

Figure 1 represents a conductor in air and illustrates the air space required for insulation. In order to protect persons from coming into contact with the conductor, isolation of the air insulated conductor is required both horizontally and vertically. Section 124 of the NESC discusses the requirements for electric supply stations and numerous sections are devoted to the clearances of overhead lines.

The horizontal clearance H and the vertical clearance V depend on the accessibility of electrical employees and the general public to the conductor. As can be intuitively understood, conductors that are either inaccessible or accessible only to the qualified personnel can have lower horizontal and vertical isolation clearances. It should also be noted that the values for H and V are not factors involving the insulation of the conductor, but only isolation.

Within an electrical supply station which is accessible to only qualified personnel, the values for V and H are approximately 2.6 meters (8.5 feet) and .93 meters (3 feet), respectively. In contrast, a bare conductor accessible to the general public must have a total vertical clearance in excess of 4.6 meters (15 feet), including the space required for the air insulation. Reference to Table 232-1 of the NESC will provide the minimum vertical clearances of conductors above the ground. As can be noted in that table, conductor clearances are grouped into ranges such as 750V to 22kV and 22kV to 50kV. The air insulation used for these classes must obviously be based on the maximum voltages such as 22kV in the 750V to 22kV range. Therefore, the clearances become much more conservative at the lower end of the voltage range such as 750V.

Industrial users of electricity in the petro-chemical industry typically utilize and distribute electricity in both the 750V to 22kV and 22kV to 50kV ranges and sometimes above. As a result, the petro-chemical companies with these systems typically have electric supply stations which are only accessible to qualified employees, and electric distribution systems which are accessible to non-qualified employees and many times the general public. As such, the company must be aware of the proper use of the code for each application. Too large of a clearance, for example, in a supply station could drastically increase the construction and maintenance costs, while inadequate clearances on a bare conductor which is accessible to a non-qualified employee (or the general public) could result in an electrical accident causing serious injury and/or death.

Grounding

Section 9 of the NESC covers the grounding practices recommended and required by the code. In particular, the purpose of that section of the code is "...to provide practical methods of grounding, as one of the means of safeguarding employees and the public from injury that may be caused by electrical potential."

The section on grounding should be of special interest to the industrial user of electricity who has an electric supply station and distribution system. This is especially true for those systems which have high line to ground fault currents caused by a strong interconnection with an electric utility. Fault currents in excess of 20,000 amperes are becoming quite common and can cause serious safety hazards from ground grid potential rises. For example, a 4000-ampere ground fault into a ground grid with a low resistance of .5 ohms will create a 2000-volt potential rise. (Equation 1)

Equation 1 $$V_{rise} = I_{fault} \times R_{grid}$$

Where, V_{rise} is the ground grid potential rise (Volts)
I_{fault} is the line to ground fault current (Amperes)
R_{grid} is the ground grid resistance (Ohms)

A ground grid potential of several thousand volts can be quite common and can result in a safety hazard for people both inside and outside of an electric supply station. Although the NESC discusses limiting values for the step and tough potentials (Equation 2 and 3), reference to IEEE Standard 80 is quite essential to the understanding of the safety hazards and to designing an effective ground grid.

Equation 2 $$E_{step} = (1000 + 6\rho_s) \times \frac{0.116}{\sqrt{t}}$$

Equation 3 $$E_{touch} = (1000 + 1.5\rho_s) \times \frac{0.115}{\sqrt{t}}$$

Where, E_{step} is the maximum tolerable voltage difference between any two points on the ground surface which can be touched simultaneously by a man with his two feet separated (Volts)

E_{touch} is the maximum tolerable voltage difference between a point where a man can touch with his hand and a point where he can touch with his feet. (Volts)

ρ_s is the surface soil resistivity (Ohm-cm)

t is the maximum fault clearing time for the line to ground fault. (Seconds)

To safely design a grounding system, the surface and soil resistivities should be known, along with the maximum available line to ground fault current and fault clearing time. Although there have been numerous papers written on designing grounding systems, along with the fact that IEEE has developed Standard 80, numerous grounding systems are in existence and are continuing to be installed without regard to the NESC safety requirements.

For example, a ground grid may be installed with a low ground grid resistance as a design factor. However, if the step or touch potentials are still high, a serious injury or fatality can result, while conversely, a ground grid with a relatively high grid resistance with low step and touch potentials could be safe and reliable.

Some considerations in designing an industrial grounding system can be found by reviewing Equations 2 and 3:

1) A reduction in the fault clearing time by proper relaying would allow higher tolerable step and touch potentials.

2) An increase in the surface resistivity would also allow a higher tolerable step and touch potential. This can be accomplished by placing a layer of clean, washed gravel on the surface.

3) A reduction of ground fault current would reduce the step and touch potentials. This can be accomplished through the proper use of resistance and reactance grounding which would limit the ground fault current.

Finally, equipment and fences which may inadvertently become energized should be properly grounded. Fences that surround electric supply stations must be carefully reviewed to assure that a person standing outside of the fence is not injured by a fault within the fence. A design consideration for the ground grid should include an extension of the grid to outside the fence. (See Figure II and III.)

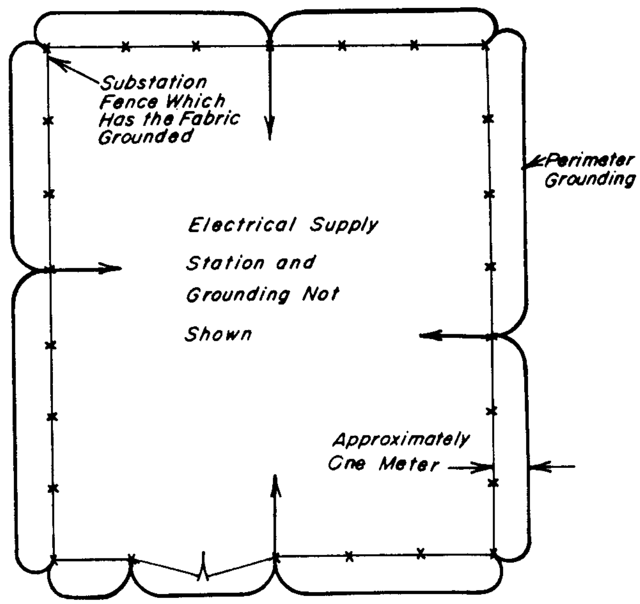

FIGURE II: SUBSTATION PERIMETER GROUNDING

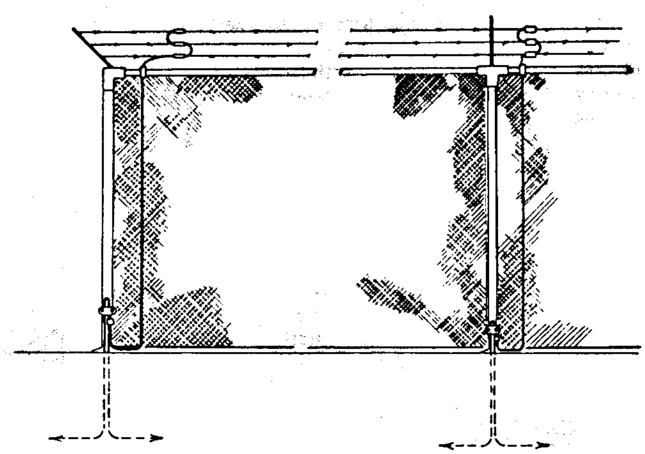

FIGURE III: FENCE GROUNDING

Electric Supply Stations

The NESC has made provisions for the installation, operation and maintenance of electrical facilities which are accessible to only qualified (electrically trained) individuals. By allowing such facilities, the NESC has provided the electrical user a more economical, more accessible and oftentimes a more easily maintainable system in allowing a reduction in the electrical clearances. Some examples of such areas are electric substations, switchgear rooms and generator rooms. Each of these examples are systems which are becoming much more prevalent in the petro-chemical industry.

Some basic requirements are listed in the code for these electric supply stations:

1) The area shall be made to minimize the possibility of unauthorized people entering the area. The use of fences, walls, partitions and so forth should be used, and entrances should be kept locked or guarded.

2) Warning signs shall be placed on all entrances.

3) The construction shall be as non-combustible as practical.

4) Fences shall provide at least a seven-foot barrier, should be properly grounded and preferably have a barbed wire extension to minimize unauthorized entry to the supply station.

Other requirements are listed in the code which are dependent on the type and location of the electric supply station.

Some additional considerations for the electric supply station and, in particular, an electrical substation are:

1) The provision of adequate space and clearances for any type of moving equipment or vehicles which may be required or allowed in the substation.

2) Provisions and space for allowing the removal and replacement of electrical equipment within the substation.

3) Adequate clearance for maintaining the electrical equipment.

4) Provision for proper ventilation to maintain a suitable operating temperature.

5) Equipment should be kept dry.

6) Provisions for two or more means of unobstructed means of egress should be made available.

The code requires that the electric supply station be periodically inspected and shall be maintained so as to safeguard the personnel as far as practical. Furthermore, new equipment that is installed shall be inspected and tested prior to being placed into service. Some examples of such tests include:

1) Meggar and high potential testing;
2) Relay acceptance, calibration and functional testing;
3) Current transformer ratio, polarity and meggar testing;
4) Insulation power factor tests;
5) Load tests after being placed in service; and
6) Mechanical torque requirements for all connectors.

Electric Power Distribution Systems

The petro-chemical industry has been involved with electrical distribution systems for many years. Although the industry has considerable experience with the distribution of electrical power, there still appears to be a lack of compliance with the NESC. This is primarily a result of ignorance of the code and its application to the power distribution system.

The NESC has two sections of the code devoted to power distribution: One section is for overhead lines, and the other is for underground lines. The power distribution engineer is responsible for reviewing the code requirements, as well as any other safety constraints in desigining the line. However, once the distribution system is built, it must be operated, inspected and maintained per the NESC.

Some general requirements are listed in the NESC for both overhead and underground electric supply and communication lines:

1) Equipment which must be examined or adjusted during operation shall be arranged so that accessibility to authorized personnel is provided by adequate climbing spaces, working spaces and clearances between conductors.

2) The operator shall inspect, test, record and repair defects on lines and equipment at intervals such that a safe installation is maintained. This applies to lines that are in service and lines that are out of service for any particular reason.

3) Proper grounding of circuits, support structures and equipment must be provided.

4) Switches must be arranged in a fashion that will maximize accessibility. Switch position shall be clearly indicated, and switches shall have the means to be locked out. All switches exposed to the public shall be locked in the position of normal operation.

Other considerations for overhead electric supply and communication lines that can be found in the NESC include requirements for different grades of construction, clearances of conductors (for numerous applications), and line insulation, just to mention a few.

Some additional requirements for underground electric supply and communication lines that can be found in the NESC include considerations for underground conduit systems, direct burial cable, risers, and supply cable terminations.

The operation, inspection and maintenance of the electrical distribution system is of utmost importance and must be in accordance with the code. This portion of the electrical system allows the greatest exposure of the system to non-qualified employees and, many times, to the general public. These people have little or no knowledge regarding electricity and must be properly isolated from the electrical conductors and equipment. Proper compliance with the code will help to safeguard these people from the distribution system.

Work Rules

To provide a practical means of safeguarding employers, employees and the public from injury, the NESC has included in it a number of work rules. These work rules are to be followed during the installation, operation and maintenance of electric supply and communication systems. Many times, injuries that occur while employees are working on an electrical supply system can be directly related to the fact that commonsense work rules and procedures were not followed. It is the employer's responsibility to see that proper work rules and procedures for operating and maintaining an electrical supply system are available. It is also the responsibility of the employers to enforce these procedures, making sure the proper channels are being used by employees. The NESC should be referenced to clear up any questions an employer might have concerning the responsibility he has to protect his employees from an electrical mishap.

Some basic work rules to be followed by employers include:

1) The employer shall inform the employee of work rules and procedures that will help secure the employee's safety.

2) The employer shall designate a person to be responsible for the operation of equipment and the overall safety of the job.

3) The employer shall provide protective equipment, in-

cluding but not limited to, insulated gloves, mats, covers, headgear and body belts. The employer shall also enforce the use of such equipment where deemed necessary.

The employee also has a responsibility to his employer. Once given proper work rules, it is up to the employee to carefully read, study, and understand any procedures that are stated. If the employee has any questions regarding a work rule or procedure, he should request the employer to clarify that particular point. Under no circumstances should an employee be required to work on an electrical supply system if he does not understand the work rules or procedures.

Some other work rules to be followed by employees include:

1) The employee should take considerable care in safeguarding not only himself, but others. When working with others, communication is essential to assure the safety of everyone.

2) Inexperienced employees working on or around energized equipment shall work under the direct supervision of a qualified person at the job site.

3) Employees shall use the protective equipment provided by the employer whenever applicable. Before using any equipment, it should be carefully inspected by the employee to assure that it is in working order.

4) The employee should be aware of emergency and general first aid procedures.

Operating procedures are nothing more than a guideline to be followed to assure the safety of all parties. The following includes a simple maintenance procedure which requires the system to be de-energized.

1) Authorization must be granted by the employer or immediate supervisor for work to be done.

2) The electrical system is to be de-energized by disconnecting switches, breakers, etc. It is best to have a visible disconnect, but where that is not practical, there should be a means to lock out that particular device. The employee doing the actual work should perform this step.

3) A tag including a description of the work being performed shall be placed to plainly identify the equipment being serviced.

4) Protective grounds shall be secured on the equipment being serviced, making sure the first connection is one end of the grounding device to an effective ground. Again, this should be performed by the employee doing the actual work.

5) Employee is then to proceed with the work in orderly fashion.

6) After the work is completed and all employees have cleared, all protective grounds and tags are to be removed.

7) The system can then be re-energized.

As a result of many years of in-plant low-voltage experience, too often employees are not qualified to work on high-voltage or medium-voltage electrical supply systems. It is a common tendency for employees to feel uncomfortable with a system that is not familiar to them. To compound the problem, many employers do not have work rules and maintenance procedures available to them. Thus, preventive maintenance on the electrical supply system suffers. The electrical supply system is one of the most important links in the chain of petro-chemical production, but it is the link that receives the least attention.

Therefore, management should make an honest effort to educate employees and express the importance of the NESC. Formal training should be given to employees with the most exposure to the electrical supply system. Management should work together with employees, using the NESC, to form work rules along with operating and maintenance procedures to better equip the employees in the field. Management should also encourage positive feedback to better tailor their work rules and procedures to their electrical supply system. When used, the NESC can be a very useful tool in the petro-chemical industry.

Common Violations of the Code

Unfortunately, many code violations are left unnoticed until someone is injured or killed. In the majority of cases where someone is hurt and a code violation is involved, some type of legal action is taken against the owner of the system for negligently operating the system. Settlements in the millions of dollars are not a bit uncommon in such actions.

A few of the more common code violations are:

1) Inadequate clearances;
2) Inadequate ground grid;
3) Improperly grounded fences;
4) Inadequate testing;
5) Inadequate inspection and maintenance; and
6) Inadequate operationg procedures.

Although a great deal can be said about each violation, a few examples of actual violations found in the petro-chemical industry are warranted.

Inadequate Clearances: An overhead distribution system existed in a well-established oil field when a decision was made to build a new road between well locations. Prior to building the road, the required clearance for the 12.47kV distribution line was 4.62 meters (15 feet) between the conductor and ground. (Space or ways accessible to pedestrians only, Table 232-1, "Minimum Vertical Clearances of Wires, Conductors, and Cables above Ground, Rails and Water.") However, as soon as the road was built, (not much more than a path), the required clearance became 6.15 meters (20 feet).

Inadequate Ground Grid: Numerous industrial ground grids in existence are not in compliance with the code because of a lack of engineering in the design stages. The reason is that most ground grids do not take into consideration the code requirements. In many cases, step and touch potentials could exist under line to ground fault conditions that would be lethal to a person. The improper and inadequate design and/or installation would allow such a condition to exist.

An example of an inadequate ground grid involved an electric supply station that had only a perimeter ground grid consisting of insulated copper conductor to two corner ground rods. The effective grid consisted of basically the two ground rods which were spaced over 31 meters (100 feet) apart and no additional grounding material. Although the system would still not have been in compliance, a much better system would have existed if the copper wire would have been bare.

Improperly Grounded Fences: Most petro-chemical plants have a fence which surrounds the entire plant. A common practice is to connect the plant fence to the substation fence. By so doing, the plant is now metallically connected to the substation fence and can cause dangerous transfer potentials. The plant fence should now be grounded at uniform distances similar to the substation fence in order to reduce the safety hazard of the transfer potential. To avoid the need to ground the entire plant fence, some electrical users have provided insulated connections between the two fences or kept the two isolated, making sure that both fences cannot be touched simultaneously by outstretched arms.

Inadequate Testing: One common problem in the industry is that electrical equipment arrives from the manufacturer and an electrical contractor installs it. The equipment is then placed into service without proper testing. An example of such a situation involved a substation that was placed into service without proper testing. The overcurrent relays were improperly wired and went unnoticed until a fault occurred. Since the relays were improperly wired and not properly tested, the breaker which was supposed to trip did not operate and the fault continued until a major failure and fire occurred. Fortunately, at that time, the remote relays operated, removing the faulted switchgear from service. Proper ratio and polarity testing of the current transformers along with load testing of the relays would have located the error and prevented a considerable amount of damage by allowing the wiring error to be corrected.

Inadequate Inspection and Maintenance: Once an electrical system has been installed, inspected and tested, it is ready for operation. Unfortunately, too many electrical users in the petro-chemical industry tend to ignore the electrical system at this point. This is especially true with a well-built and tested system because of the relatively high reliability of electrical systems. At the time that the system is placed in service, it is at the peak of performance and reliability, from which point the system starts to deteriorate.

An example of inadequate inspection and maintenance occurred in a substation one cold and wintry night. A large power transformer was supplying a lineup of metal-clad switchgear via a 3000-ampere bus duct. The bus duct failed, causing the transformer differential relays to trip the transformer primary and secondary breakers. The gas plant was immediately placed in the dark, causing a loss of revenue in excess of $40,000 per hour. Fortunately, load was picked up by a second transformer, but not before there was a loss in excess of one million dollars.

An inspection of the bus duct was made to determine the cause of the failure. The cause was from loose connectors in the bus duct splice. This failure could have been avoided by proper inspection and maintenance. After the bus duct was repaired, the bus duct between the second transformer and the switchgear was inspected. The bus duct connections were also found to be loose, and a probable failure was avoided.

System Operations, Inspection and Maintenance

The electrical system should be monitored like any other process within the petro-chemical industry. The main problem with this is the fact that most operators are not electrically qualified to operate the electric system, much less inspect and maintain it. Therefore, an electrical staff with qualified persons to perform high-voltage work is essential. This staff should be responsible for the safe operation of the electrical system.

The responsible persons are required by the NESC to be familiar with the code and to follow it. The system is to be periodically inspected, defects noted and repaired, and the system is to be properly maintained. Proper safety practices outlined in the code and proper safety equipment shall be used. Operating records should be maintained, along with records of all maintenance and inspections.

Inadequate Operating Procedures: As previously mentioned, the training of employees is of utmost importance in maintaining efficient petro-chemical production. If an employee does not thoroughly understand the electrical supply system or is not confident in his actions, terrible consequences may result.

An example of inadequate operating procedures occurred in a substation one weekend when the normal company electrician was on vacation. A fault occurred on a 13.8kV bus, knocking out the power transformer. Unsure of operating procedures, but eager to get the production back on-line, an apprentice electrician closed a tie breaker directly feeding the fault. This knocked out the second transformer, did extensive damage to the faulted 13.8kV bus, and "blacked out" the entire electrical supply system. If the problem had been investigated by conducting a simple visual inspection, the faulted bus would have been discovered, thus avoiding the "black-out" conditions, lost production and extensive bus damage.

Conclusion

The development and expansion of electric power distribution systems in the petro-chemical industry bring new and additional responsibilities to the industry. The National Electrical Safety Code has been written to provide requirements and guidelines for the safe operation of the power system. The code provides rules for properly safeguarding employees and the general public from the hazards of electrical power.

Generally, the administrative authority responsible for electrical installations adopts the NESC. As such, compliance with the code becomes a legal responsibility of the owner/operator of the electrical system. In the event that a person becomes injured on a system that is not installed, operated and maintained in accordance with the code, legal action may be taken against the company and its management. Furthermore, if the legal authority responsible for electrical installations finds that a company is not in compliance with the code, legal action can be brought against the company in order to bring the system into compliance with the code. Such action can even result in shutting down the system until it is brought into compliance with the National Electrical Safety Code.