On-line monitoring of electric power equipment

A new on-line monitoring system for power transformers´ high voltage bushings was designed and constructed. The system provides information on the magnitude and phase of the capacitive currents circulating through the three bushings, as well as the high frequency electric noise levels for each phase. It also measures partial discharge activity at high frequency. The system carries out continuous measurement to detect apparatus malfunctions in the incipient stage to prevent catastrophic failures. The deterioration of the bushings generates changes in the current that flows to ground through the capacitive tap. The equipment developed detects these small current changes and generates an alarm when the magnitude surpasses the pre-established levels. The system will be used to monitor CFE´s power transformers after concluding the field testing. The capacitive current monitor is planned to be incorporated into the already developed on-line monitoring systems for power transformers (Sistemas de Monitoreo en Línea para Transformadores de Potencia, SMLTP), also developed at IIE.
Basic substation electric equipment

115 kV substations overhaul

Continuous supply of electrical power is a crucial task for proper operation of Pemex petrochemical plants, mainly oil refineries and gas processing centers (complejo procesador de gas, CPG). Although these centers generate their own energy, they also have a 115 kV feeder provided by CFE. Several failures occurred in the link substation during 1999 causing many economical and technical problems. In order to improve the reliability of the installed equipment in the link substation, Pemex asked IIE for technical assistance to refurbish the 115 kV substations. IIE performed the assessment of the electric equipment installed at the interconnecting 115 kV Substation of the Lázaro Cárdenas Refinery, in southern Veracruz. The evaluated equipment included the circuit breaker, the power transformer, the disconnecting switches and the instrument transformers. Additional inspections were carried out on the 13.8 kV metal clad substation and its power cables.

Additionally, an evaluation of the underground power cables of one of the main circuits (CF-17) of the Pilot Substation 9 was also performed. A similar study was carried out at the Ing. Antonio M. Amor Refinery in Salamanca, Guanajuato. Also, a complete analysis focused on the elimination of the spurious disconnection of a high voltage motor in the Cryogenic Plant at the Matapionche Gas Processing Center in Veracruz. Several power transformers were evaluated in the 115 kV interconnecting Substation 1 of the Nuevo Pemex Gas Processing Center in Tabasco. The evaluations identified the degradation processes of the underground power cables, mainly due to treeing phenomena, and catastrophic transformer failure originated by partial discharges. With these experiences, several options were found to improve the equipment connection topology and their protection schemes. Due to the similar arrangement in all the interconnecting CFE substations with Pemex Gas Processing Centers and Refineries, the implemented techniques can be applied to improve the reliability of all Pemex’s production centers.

Power transformers and gas-insulated substations reliability improvements

A project was initiated in 1996 to improve the reliability of power transformers. At the initial stage, ultrasonic techniques to detect and locate partial discharges in power transformers were implemented. Afterwards, important improvements in the instrumentation and development of mathematical models were performed. Also, several diagnostic techniques such as the impedance measurement on the frequency domain Z(f), the low voltage impulse (LVI) response of the windings, and the dissolved gas analysis (DGA) were applied, in order to obtain reliable power transformer diagnoses. In 1999, 49 substation power equipment elements were assessed, including step-up transformers, auto-transformers, static voltage compensators, capacitive dividers and gas-insulated substations. The equipment was diagnosed with on-line and off-line measurements to detect incipient degradation. The equipment belonged mainly to CFE’s Northeast and Northwest Transmission and Transformation Areas. The detected problems that are worth mentioning include the phase A of Bank AT-2 of Villa de García Substation, phases A and B of Bank AT-1 of the Lauro Villar Substation, and phases A, B and C of Bank AT-1 of Guamuchil II Substation. Also some problems were found on the voltage transformer of the transmission line VDG-A2450-FRO’s, serial number 142DB4. As a consequence of this evaluation, internal inspections were performed to correct the problem and verify the diagnosis. Also, there were several meetings with manufacturers to analyze and solve problems of...
the power substation equipment. The application of non-invasive on-line and off-line diagnostic techniques allowed the engineers to detect incipient degradation inside power equipment, thus permitting prompt action to eliminate potential defects. This reduces catastrophic failure risks and helps in the understanding of failure mechanisms.

Rotating electric machines

Generator diagnostic testing

IIE began providing generator diagnostic services in 1993. In 1999, 17 generators were assessed for CFE, LyFC, Pemex and private industries such as Hylsa, Alstom and the Tamazula Sugar Mill in Jalisco. The most important problems found in the power plants were the following: two generators, one installed in the Miguel Hidalgo Refinery, and the other in Temex company, presented high vibration levels. Using diagnostic techniques, shorted-turns in the rotor windings were found. It was necessary to implement and supervise the respective repair procedures. In the gas processing complex in Ciudad Pemex the cause of high temperature readings in the TG-3 generator was determined. During the last few years, IIE has made several efforts to improve the generator diagnostic techniques. The on-line diagnostic technique was implemented by installing a set of temporary sensors; this technique is economical since it permits the assessment of the generator while in service. In a single analysis, the state of all generators in a power plant may be obtained and an off-line
Transformer bushings capacitive current measurement system.

study may be programmed in order to determine the origin of the detected defects and perform the necessary maintenance. In the period of 1998 to 1999, the integral diagnosis of the high voltage equipment of two gas processing complexes (La Venta and Coatza coalcos) was carried out using on-line and off-line diagnostics. Generators, cables, transformers, motors and metal-clad type substations were assessed. Additionally, the Diagnostic Mobile Lab, developed by IIE, was used for the first time in field diagnosis of electric equipment. Permanent sensors were installed in three generators for measuring the voltage on the neutral of the generators, the induced voltage on the rotor shaft, and partial discharge levels. In La Venta several deterioration mechanisms were detected in motor windings; IIE is performing several off-line studies in order to determine the origin of these mechanisms and the repair procedures will be implemented in the year 2000. Also, specifications were established for motor repair and a technique for on-line monitoring of partial discharges was implemented.

Motor diagnostic testing

The electric motor is the most used equipment in the productive sectors. For example, CFE, Pemex and the cement, paper and sugar industries all use a large quantity of motors for their processes. IIE focused its effort on the specification, installation, maintenance, operation and rehabilitation of this equipment. In this field, the institute has diagnosed the main electric motors for PEP at the Dos Bocas Maritime Terminal in Tabasco. Thirty motors of 4160 and 13800 volts were evaluated on-line, analyzing their current phase signature; all the electric equipment installed in the plant was inspected by infrared thermography.

Additional activities

Residual field and demagnetization measurement in generators, turbines and speed reducers

The residual field and demagnetization measurement of generators, turbines and speed reducers was performed in the Catalytic II Plant at the Ingeniero Antonio Dovali Jaime Oil Refinery, in Oaxaca. Also, similar analyses were conducted at the El Carmen S.A. de C.V. Sugar Mill and the Tereftalatos Mexicanos Plant in Veracruz. Also, the Motor Testing and Control Laboratory and the Household Refrigerator Testing Laboratory were installed and commissioned at IIE.

Pemex electric substation.
Electric energy use

Demand side management

Standards for energy efficiency in buildings

During the last ten years, IIE has supported the National Commission for Energy Conservation (Comisión Nacional de Ahorro de Energía, Conae) in the elaboration of energy efficiency standards. This year, the ante-project for energy efficiency standards for commercial buildings was completed. It was necessary to obtain a consensus of different engineering and architectural organizations. For this purpose, 15 seminars were organized around the country; in this activity, a total of 500 engineers and architects participated. It is expected that the mandatory standard will be published officially during the year 2000. The implementation of this standard is expected to save energy in the use of air-conditioning systems in new buildings, as well as provide a more comfortable environment for their occupants.

Daylight savings time

Since the implementation of Daylight Savings Time in 1996 in Mexico, IIE has evaluated the benefits of its application each year. Using the data obtained from Cenace-CFE for the 1999 evaluation, it was concluded that electrical energy savings in both consumption and demand were similar to those obtained during the years 1996, 1997 and 1998; that is, on the order of 1% of the annual national consumption.

Industrial electric systems

Coordination of protections at the “Dos Bocas” maritime terminal

With the objective of increasing the reliability in the operation of the electrical distribution system, the maritime terminal of the Southwest
Marine Region of PEP in Dos Bocas, Tabasco required a study of the short circuit and protection coordination of its electrical distribution system. The results of the study provided the adequate capacities for the protection devices, such as switches and fuses, as well as the setpoints for an adequate coordination of the operation of these devices. As a result, the reliability of the system was improved, reducing the number of trips of the electric system and providing an improved quality in the distribution of electric power.

**Power flow and reactive compensation studies of the electrical distribution system at the “Dos Bocas” maritime terminal**

The maritime terminal for crude oil distribution in Dos Bocas required studies about the operating conditions of its electrical system, with the objective of applying measures for energy savings and improving reliability. The studies provided the form of utilization of the equipment, the power factor under different operation alternatives and was the basis for evaluating of the different options of operation with reactive compensation. In this way reducing penalization payments due to the excessive reactive power consumption, saving energy and improving the efficient use of the electrical energy and of motor start-up.

**Hazardous areas classification for electrical installations in Pemex**

Within installations where flammable products are processed, transported, stored and dispatched, there is a risk of fire or explosions due to the presence of flammable gases, vapors and liquids. Therefore, the specification, selection and installation of electric equipment are a function of the level of hazard that the explosive atmospheres represent in the different areas of the installation. The hazardous area classification is the first step to determine the type of protection that the electric equipment must have in order to operate safely in the classified areas. To obtain the correct classification there are national and international technical codes, standards and recommended practices governing the many aspects of electrical safety in petroleum facilities, in particular standards like the API and NFPA are related to oil installations. With the objective of complying with the safety requirements of the corresponding standard, PEP requested IIE to perform a revision of the actual conditions of the installed equipment in the different areas of the plant, update the diagrams of the areas and classify the risk areas. This work was performed for the Atasta Process and Transport Gas Center and the Marine Gas and Condensed Distribution Center of Ciudad Pemex. In this manner, the areas with electric installations in flammable atmospheres were classified and maps were produced.
System for Planning Electric Energy Distribution Networks (Sipladis)

Since 1979 IIE has developed tools for planning distribution systems. One of the products is integrated in the System for Planning Electric Energy Distribution Networks (Sistema para la Planeación de Redes de Distribución de Energía Eléctrica, Sipladis). Sipladis consists of a set of methods and mathematical programming models oriented towards aiding the distribution engineer in planning. The system contains interactive graphics and is easy to use for managing, storing and controlling relevant data. In 1998, the Toluca-Cuernavaca Division of the LyFC electric company solicited a study for long term planning of the distribution substations in the Toluca zone, with the help of Sipladis. The results present various alternatives for enlarging existing substations or building new ones in order to satisfy the demand increase in the Toluca zone in a time frame of ten years. The
Expansion Plan for Distribution Substations in the long term provided LyFC with the following benefits: evaluate the present conditions of the distribution network; identify the location and size of new substations; program the growth stages of the new substations in order to plan the investment required; anticipate land purchases for the future substations; identify the weak points of the distribution network, and identify the feeders with voltage regulation problems.

**Distribution engineering at LyFC**

IIE integrated for LyFC the CYMDIST and CYMTCC tools for the distribution engineering and the interface product SAD-CYME. With the development of this project, all the Divisions at LyFC will have tools which will permit the distribution, planning or maintenance engineer to back up his decisions under different conditions and serve as the interface for network planning in the short term. The interface between the CYME and SAD databases looks to insure the integration between systems, in order to avoid repetition of information.

**Continuity of the electric energy supply**

Presently, the electric network at the General Lázaro Cardenas Refinery is being modernized. In the modernization, the following is considered: an increase in the local generation, reconfiguration of the feeders and rehabilitation of the electric equipment. As a result of the modernization process, the nominal current and short circuit levels will change. For this reason it is necessary to verify that the existing, as well as future equipment, comply with the new operating conditions. It is necessary to review the protection and control schemes to take advantage of the capacity of the recently acquired equipment. In this manner, the Institute proposed and verified scenarios for the operation of the refinery´s electric network, in which the system operating under normal circumstances as well as abnormal must be considered. The benefit obtained from this work is greater reliability in the operation of the refinery´s electric network. This is a result of reliable operation of the protection equipment within its design range, improved utilization of the protection and control equipment capacities, increase in the precision from the transducer´s currents obtained due to their re-dimensioning. In addition, strategies will be provided for reducing the amount of energy demanded from the supplier.

**Insulator bank testing**

In the particular case of the Gulf of Mexico, the northern winds drastically influence the contamination level of the insulators installed in the overhead distribution networks. These northern winds can lead to very severe contamination levels. In 1995, the Institute designed the System of Current Leakage (Sistema de Picos de Corriente, Sipico) for the diagnosis of the operative state of the insulators installed in the transmission lines. During the years that the system has been in operation, the Sipico has demonstrated its effectiveness for the on-line diagnosis of insulators; for this reason, the evaluation of its use in distribution networks was proposed.

In 1999 the relation between the evaluation methods of contamination levels in external insulators was documented in order to choose the most adequate insulation. Although no flashovers were reported in 1999, the contamination levels are predicted to be higher in 2000, especially during winter. Also, the contamination level generated by the northern winds was determined in five insulators. The accumulation of north winds will lead to failure conditions in the insulators, and for this reason it is considered that some of the insulators will flash due to contamination next year. As far as monitoring of the contamination, the density equivalent of deposited salt (DESD) and leakage currents proved to be the most representative
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of the behavior of the diverse insulators. The leakage current levels in the monitored insulators in extreme conditions can be more than one ampere. Given this, it is possible to assert that the leakage current in distribution lines may be a good diagnostic method for programming maintenance of the electric network operating under contamination.

Additionally, three other Sipico systems were installed in the Veracruz area network in order to learn about the evolution of the leakage current of the four monitored insulator profiles at three points in that city.

Transmission lines and substations

Evaluation of compound electrodes for grounding networks in transmission lines

CFE needs to combat the outages due to lightning in their transmission lines in an efficient and economic manner. One possibility is to reduce the values of resistance at the ground connection by installing chemical composite electrodes. IIE conducted field measurements of the ground resistance in various types of chemical electrodes installed in two experimental centers in Temecatlita, Morelos, and Salazar, Estado de México. In parallel, ground resistance measurements of three chemical composite electrodes installed in the lines ZAP-MAZL 93240 and 93250 of CFE were registered. Also impulse tests simulating lightning currents were performed on three prefabricated electrodes in the Laboratory of Materials and Equipment Testing (Laboratorio de Pruebas de Equipos y Materiales, Lapem) to determine their transient response. The use of chemical electrodes could be one of the solutions to the problems encountered in grounding networks, in which the present designs do not comply with low resistance requirements or in cases where traditional systems do not directly apply.

Series gag arrester applied to 230 kV transmission lines

55 Line Arresters (supresores de sobretensiones por descargas atmosféricas, SSDA) were installed in the most critical zones of the three lines: 18 in the Peñitas line 93920-km 20; 17 in the Hermosillo III line 93210-Nacozarí, and 20 in the Mazatlán II line 93820-Durango II. The results obtained until now show that in the protected zones failures due to lightning have not occurred and that the SSDAs are intact. However, there have been outages in unprotected zones thus making it necessary to install more line arresters.

FACTS and new technologies in the National Electric System

IIE has been developing the capacity to study the so-called Flexible Alternative Current Transmission Systems (FACTS), which is understood as the application of power controls that influence the electric system parameters, that in turn, affect the transfer of electric energy. Preliminary studies were done to analyze the feasibility of installing series compensation controlled by tiristors in 400kV lines in southeastern Mexico for maximum demand scenarios corresponding to the period 2002 to 2007. The preliminary studies consisted in steady state, transient stability and voltage stability analyses. From this work, the fixed as well as variable degrees of series compensation in the transmission lines were determined. The FACTS technology is an option for transmitting more energy through the existing transmission lines and deferring the construction of new lines.

Map of frequency of atmospheric electric discharges in Mexico

In Mexico, one of the main causes of transmission line outages is lightning. For this reason, it is necessary to identify the zones with greater discharge frequency in order to improve
or implement preventive measures. IIE acquired a NASA database of discharges detected by sensors installed in satellites. From this information a map of electric storm frequencies in Mexico was developed.

During 1999 the information about discharges detected by sensors installed in different satellites was reviewed. Given that the satellite travels all around the world, the information analyzed is partial with respect to the time of observation (the time Mexico is monitored is small compared to the entire database).

The review of the behavior of the atmospheric discharge (cloud-ground and cloud-cloud) in the years when there is the most relevant information (1995 to 1998) detected a higher frequency in the western cordillera and in the south-southeast of Mexico. According to the statistics, there is a relationship between the seasonal maps, especially summer, and the statistics of transmission line outages.

The detection of the zones with high storm indices by atmospheric discharge levels is very useful since the information can be employed for improving transmission lines, and positioning lightning rods, as well as for detecting storm zones that significantly affect the functioning of the insulation systems.

**Polymeric Insulation**

The use of polymeric insulators has increased notably in the world during the last decade, and Mexico is considering them as a solution to the contamination problem; in fact, various transmission and distribution lines are insulated with these materials. However, one of its limitations as an exterior electric insulator is its resistance to the effects of electric discharges on its surface, especially to the high temperatures generated. For this reason the Institute performed tests of accelerated aging on polymeric insulators using a laboratory system for measuring leakage current. The purpose of this evaluation was to learn about the behavior and degradation that an insulator contaminated with hygroscopic material presents. It was shown that the smaller leakage currents are those that cause greater deterioration in the insulator.

Thus, evaluation parameters are being looked for in order to incorporate them in the Mexican specifications for polymeric insulators for transmission lines, and with this, the consequent benefit for CFE.

**Installation of synthetic insulation in the transmission line 93430 Villita-Fertimex**

The 230 kV transmission line 93430 Villita-Fertimex comprises seventy structures and supplies power to a Fertimex Plant. The last twenty-two structures on the Fertimex side are the most exposed to marine and industrial contamination effects, as well as the humidity provoked by the marine breeze. These problematic structures were chosen for installing synthetic insulators instead of porcelain ones, which required maintenance (washing) in order to avoid outages. During 1999 critical levels of saline and industrial contamination were found in the line 93430 Villita-Fertimex that degraded the insulation of three structures. Analysis of the information of the monitoring systems detected activity that
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alerted about the state of the insulators. This situation was corrected in time and insulation with a robust design was installed in the most critical structures. This allowed the compilation of information in one of the zones with the highest level of contamination. At this time washing is done once a year only in the three critical structures and the others have not needed maintenance since the insulation was installed.

Diagnosis of transmission line insulation

Contamination is the second cause of failures in transmission lines. IIE has decided to approach this problem by installing diverse types of insulation, measuring the leakage current on the surface due to the accumulation of contaminants and moisture. There are insulators with coverings based on silicone rubber or grease, insulators with glass semiconductors and polymeric insulators. Among the benefits that these insulators provide, is the reduction in outages due to contamination, as well as the reduction in preventive maintenance to the lines.