LIMITS AND OBJECTIVES OF THE PROJECT

The objectives of this project, aimed at replacing the traditional cycles of maintenance with condition based maintenance, can be summarized as follows:

- Lowering of maintenance costs for prevention and correction
- Greater control over the plants in terms of reliability and safety
- Greater availability of the plants for both planned and unplanned outages
- Improvement or stability of continuous service indicators

A great effort was made to ensure that the benefits obtained from these new maintenance methods could be quantitatively assessed from the beginning.

To ensure that this was carried out successfully a series of “condition based maintenance manuals” on HV circuit breakers were initially prepared, starting from those models which were more often present in the plants. Such activity consists in analysing in detail both the design and building characteristics of the system and its actual operational performance. The ultimate goal of this investigation was to identify the most important control parameter for the functionality-reliability status of each single component. The next phase consisted in establishing the timing at which such parameters had to be determined, while taking into account both the rate of degradation of the components and the improvement or stability of continuous service indicators.

Preservation of those operational advantages provided by the effective planning of maintenance services

METHODOLOGY OF DEVELOPMENT

The project was developed by AEM Elettricità with the outside support of professionals for both planning and construction of the basic components of the plant, such as HV circuit breakers and transformers, and the development and management of IT systems for the maintenance services.

To determine the initial requirements for the plants and components of the project a simplified method of Reliability Centered Maintenance was applied at different levels. This was adopted both for the “bays” – essential plant components which are critical for the operation of the system, in case of accidental failure of certain parts of the plant (HV lines bay or transformers bay) - and for critical maintenance, which considers factors such as safety (of the plants, the people and the environment) and the time required to carry out repairs.

From these observations it was decided that the new maintenance policy had to be based on “items” which played a crucial role in the system. For this reason priority was given to the HV circuit breakers and HV/MV transformers. These were to be central in the development of a surveillance system, monitoring the status of the plants, and in the definition of maintenance interventions which would involve all equipment or components of the respective bays.

To understand better the scale of the planned intervention, one must consider that the 10 substations consist of n. 32 transformer bays, n. 20 of HV overhead power line bays (220 kV and 130 kV), n. 12 A-type cables and n. 3 bus coupler bays for the double bar cabinets. Three of such plants consist of HV sections of the steel-reinforced type (GIS -insulated with sulphur hexafluoride).

A project has been set up to renew and update the maintenance methods, in order to improve their efficiency and effectiveness. This has affected, in particular, the Primary Plants of the distribution network which consists of 10 HV/MV substations and the 20 MV/MV substations used for transformation and sorting.

The extent of the project has been determined by the fact that most of the work of maintenance aimed at prevention was carried out on Primary Plants rather than on the secondary distribution network, where the maintenance was usually targeted on corrective measures. Moreover, with regard to Primary Plants, the major effort on maintenance and prevention was on the HV air insulated plants (AIS), which were regularly and systematically subject to an annual maintenance cycle by AEM Elettricità.

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INTRODUCTION

AEM Elettricità is the company of AEM group spa which supplies electricity to Milan and the nearby town of Rozzano. In 2002, AEM Elettricità acquired the remaining supply network and business branch of Enel Distribuzione in Milan, thus becoming the sole supplier of electricity in the area of the above mentioned cities. This was made possible by the “Bersani Law Decree” which liberalized the market in the electricity sector.

The scope of the company’s business is summarized in the following figures [1]:

- Number of customers: 850.000
- Maximum Output: 1420 MW
- Electrical power distributed annually: 7000 GWh
- Size of MT network (23 kV, 9 kV, and the rest at 6,4 kV): 3700 km
- Size of LV network: 5500 km
- Number of MV/LV substations: 5440
- Number of HV/MV substations: 10
- Number of MV/MV satellite substations: 20

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methods used to measure such values. This initial phase was deemed complete with the classification of the maintenance operations, required for individual components, and their organization into three different levels of intervention, based on their ability to exceed the threshold control parameters which had already been identified. This classification was essential to guarantee that the maintenance operations were programmed properly and that outages of the plants were organized logically.

To rationalize further maintenance operations, it was decided to extend to other bay equipment (HV overhead lines and cables and transformers) both the activities of surveillance and control (to be carried out simultaneously with those already planned for the circuit breakers) and the maintenance operations, which would also be done together with those programmed for the circuit breakers.

In practice these are performed:
- monthly, where simple and quick maintenance inspections and controls on the circuit breakers would be done;
- quarterly, where detailed recordings and controls would be done on all bay equipment.

With regard to full maintenance servicing, that of “first level” includes roughly those operations which were traditionally carried out during the cyclic annual interventions on the HV bay, and which included the cleaning of the porcelain insulators. Such interventions are generally performed every three years rather than annually, but, in contrast to the cyclic maintenance method, here the monitoring activity, which is carried out periodically, allows the continuous control of the status of the equipment itself.

The other levels of intervention (second and third) are similar to those of corrective and standard exceptional maintenance, respectively. The former is performed following breakdowns while the latter occurs every 5-10 years and may require the direct intervention of the builder of the equipment if spare parts or particular specializations are needed. It is expected that with condition based maintenance it will not be necessary any longer to carry out the exceptional maintenance interventions (those occurring every 5-10 years) which are contemplated by equipment manuals, but which do not take into account the operational use of the components and therefore the real need for such interventions.

Currently, the maintenance manuals for the transformers are being prepared, inclusive of the values of control parameters and the resulting maintenance operations required.

To determine the control parameters it has been found necessary to invest in new equipment, mostly regarding the local control panels. Such intervention involved the installation of appropriate sensors, terminal boards and connectors which allow the required control parameters to be determined, through a manual or a “semi-on-line” method. In practice, this is carried out every quarter by connecting the sensors to a standard mobile Data-Logger which records the parameters desired. The advantage of this system is that the plants do not have to be stopped to perform this operation.

An essential component for the implementation of the entire process has been the development of the software for handling the collected data. With the use of simple and effective interfaces the software allows the data collected either manually or through the memory-card of the Data Logger, to be downloaded on the maintenance computer system SAP R/3. The program allows any stored data to be extracted in formats which can be easily used for further analysis and to provide an overall picture of the status of the equipment. In addition to this, the software contains functions which can raise the alarm, classified according to urgency, when one or more parameters reach a critical level, thus allowing the appropriate maintenance intervention to be carried out. Currently, the software for collecting, storing and analysing data is being implemented throughout all the bays, both the AIS and GIS type ones.

It is expected that by 2005 the system will be fully operational in all HV plants.

It is also anticipated that the next system development will consist in the implementation of the decision support functions as well as the operational programming functions (types of interventions and resources required).

Currently the advantages of moving from the “semi-on-line” recordings to the more realistic determinations “on-line”, with data readings taken remotely, are being considered. Such decisions will have to take into account the investments needed and any benefits obtained in terms of the resources required during the scheduled controls. However, any decision would also have to consider the limited number of AEL plants and their geographic distribution which, to date, has not made the implementation economically viable.

The fundamental characteristics of the system and the implementation strategy which have been selected according to the operational conditions of AEM Elettricità can be summarized in the following points:
- the initial decision to carry out the recordings “semi-on line”, using the minimum number of sensors required, in order to save on the investments necessary to modify the plants and establish immediately effective control of the system (naturally, the alarms already used for managing the plants are on-line)
- the decision to create a maintenance System separate from conduction systems, which will not be changed even if on-line recordings are implemented; this is to avoid burdening the latter and to keep some degree of autonomy in deciding maintenance objectives which are at the moment still distinct from those of conduction.
- The continuous and direct involvement of the maintenance operational staff, from the initial phases, has been a winning factor for the success of the project. This is also demonstrated on a daily basis by active participation at both plant modifications, which are designed and implemented by the maintenance staff itself, and by the improved knowledge of the operators on the plants themselves obtained through the continuous monitoring of the parameters.

A further future expansion of the system will concern the
MV distribution power panels of the substations and, in particular, the circuit breakers of the distribution feeder. These have been identified, through simplified RAMS (Reliability, Availability, Maintainability, Safety) analysis and direct experience, as crucial components, whose efficiency may have a major impact on the continuity indicators. With regard to this, the recordings of the manoeuvring times of the accumulated interrupted currents and of the number of operations for MV circuit breakers, used for electrical protections of the digital type, are already being carried out.

MONITORING PARAMETERS

In conclusion, we can summarize the main monitoring parameters of the most important plant components for the condition based maintenance system as follows (the electrical parameters and the alarms are excluded because they are already part of the operating system).

Monthly Recording of HV Circuit Breaker (eg through a compressed air command):
Number of operations, hours of activity of compressor, efficiency of condensation discharge.

Quarterly Controls of HV Circuit Breaker:
Accumulation of Interrupted current, time for recharging and starting up of compressor, compressed air pressure, current of compressor engine, consumption of oil in compressor (efficiency and resistance of compressed air system), efficiency of anti-condensation circuits, pressure of SF6 in interruption chamber, environmental temperature, control of overall status and electrical accessories.

Quarterly Controls of other bay equipment:
General thermography of clamps and connectors, condensers, CT, VT, Disconnectors; cleaning status of porcelain insulators, oil levels of CT and VT, number of interventions of surge arresters, determination of ultrasound emissions (a visible-UV light camera for controls will soon be acquired).

Transformers:
On-line monitoring of gas (mainly hydrogen) and water content in the oil, continuous recordings of electrical parameters and temperature.
Condition based maintenance: Analysis of oil by gas chromatography, dielectric strength of oil, control of efficiency of cooling systems.

Other monitoring activities for condition based maintenance:
Electrical measurements of Transformers and related HV bushings, CT, VT, Condensers, Superficial Insulation of porcelain insulators, conduction currents of surge arresters.

Within this framework of activities, aimed at carrying out condition based maintenance interventions, it is also important to mention that together with the above project other specific monitoring systems for the plants have been developed:
- Use of local centralized data-loggers to collect in continuous mode the temperature of the HV/MV transformers and of the associated loads aimed at rebuilding the remaining activity of the machines themselves.
- For the GIS plants, use of local centralized data-loggers for the on-line collection of both SF6 gas pressure in all compartments (the aim is to avoid carrying out visual inspections and to readily identify any problems which may arise in the SF6) and monitoring parameters of circuit breakers and in the disconnectors (manoeuvring times, currents absorbed by the motors); viewing of all the processes would be done remotely by the maintenance operator through the company’s communication network.
- Use of PLC for the control and monitoring of the centralized oil-water cooling systems of some HV/MV transformers (logics of function for pumps and aerotherms, currents absorbed by motors, temperatures of liquids during entry and exit, etc); viewing of the operational status of the system would be done remotely by the maintenance operator through the company’s communication network.

CONCLUSIONS

As already mentioned in the description of the project, the positive results achieved during the first years of development vis-à-vis the initial expectations, ensures that the condition based maintenance policies will be extended to other distribution plant components. The “maintenance engineering” activities, and in particular, the location and monitoring of truly significant parameters for the reliability of critical equipment, will progressively become more important for the maintenance operators, who need to ensure the reliability and availability of the plants against the ever present challenge of cutting costs.

REFERENCES