Structuring the Monitoring and Supervision Systems of Hydroelectric Plants as Intelligent Systems

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Abstract - **This research evaluates existing technology in monitoring and supervision area, the hydroelectric plants. The aim is to select the best methods that minimize the failures in these plants through a rigorous evaluation and efficient diagnosis indicating its root cause and location in real time. Define the criteria and necessary conditions that will allow transforming the monitoring and supervision networks of hydroelectric plants in intelligent monitoring systems. These innovations will enable the prediction of incipient faults accurately and quickly through mathematical signs and processes model, ensuring greater reliability and availability of plants and a safe and economical operation.**

Keywords - **Automatic control; Availability; Intelligent systems; Monitoring; Predictive Maintenance.**

I. INTRODUCTION

The monitoring and supervision processes, aimed at providing, undesirable states of equipment, allowing take corrective action to avoid technical and economic losses. Deviations from the normal process behavior are produced by failures and/or errors. These faults can be short or long in duration and, as such, the necessary corrective must be taken to reduce their impact on electrical systems. The main function of monitoring and supervision systems is to avoid such failures in the systems by collecting information in real time the behavior of a device or system [15].

Preserve the stages of the life cycle of most of the hydroelectric equipment, requires large investments, therefore it becomes necessary to seek return appropriate time, a condition that requires the optimization of maintenance processes and operation, thereby reducing the costs of these investments, while ensuring high reliability and availability of the equipments [5]. Such performance can be achieved by reducing the number of failures and management of their severity, providing also the added benefit, increasing the safety of these plants. To achieve these objectives, account with two techniques for establishing an optimized maintenance management, known as predictive and proactive, but complemented by corrective and preventive techniques. This set of methods offers its best results through the implementation of effective monitoring and supervision systems in real time, making the plants, highly reliable and secure supplier of energy [1].

The results of this research will contribute mainly in the areas of monitoring and supervision by signaling changes that should be effected in these two systems to structure them and deploy them as a set only through the smart grid technique. The proposed methodology will integrate the various areas of a plant in a single set, making the generation, economically efficient and improving its performance, quality, production reliability, operational flexibility, etc. In addition to this innovation, it is also proposed to integrate all generation plants a set only through intelligent systems technique, enabling greater oversight of the performance of generating plants, its optimal management through efficient operational policies, and consequently providing the rational use of energy resources and the generation of electrical systems.

The improvements in monitoring and supervision systems, with the incorporation of these innovations, optimize maintenance processes of all equipment of power plants, in particular those generators (higher-cost physical assets), allowing to minimize the risk of failure them (decreased failure rate) and the conservation of its useful life period, postponing investments and increasing the quality of energy supplied to users [9].

Technological developments in the monitoring and control systems, will allow the structuring and optimized evolution of automated diagnostic systems, which is the next step to the simple monitoring. Monitoring takes place through sensors that send information to a processing center, the state of parameters under observation. Then an expert system, manages a "knowledge bank", called knowledge base, where the information sent by the sensors, will be processed and, based on the evaluation of their behavior, looking up a real-time action to mitigate their variations. This will be possible since the monitoring system will have the ability to seek the root cause that is causing these changes, because the system has become intelligent and therefore autonomous [10].

II. Proposed Methodology for the Transformation of Monitoring Systems in Intelligent Systems

The purpose of the monitoring systems is to provide information on the physical quantities measured in the various equipment of operating conditions without interfering with its operation. They can be classified according to the type of installation of the sensors (permanent or mobile), or even by information acquisition strategy that they are submitted ("continuous/on-line" or "periodic/off-line"). Its importance lies in conditions offered for the implementation of predictive maintenance strategies [5], [7], [15].

The monitoring systems will often work an integrated basis with the supervisory and control systems, or "Supervisory Systems" of the plants, taking individually requirements for data acquisition, totally distinct from one another. The main objective to be achieved through the transformation in intelligent monitoring and control systems is getting "continuous" operation data and the slowly varying quantities, usually available in the "Supervisory Systems" (temperature, level, position values, static pressures, etc.) [7], [8].

This research has the main objective, the transformation of monitoring and supervision systems the hydroelectric plants in intelligent monitoring systems, supported a broad network of sensors, located in the most conflicting areas in the performance of these plants. This innovative technique will increase the reliability and availability of generation, ensuring quality care and the rational use of energy resources and the generation of electrical systems. Monitoring operating as an intelligent system also allows optimize maintenance processes and increase the useful life period of generation units, and consequently the postponement of investments.

The proposed methodology is based on the collection of a set of data and their respective assessment, which will indicate the behavior of a given parameter, considered of interest in the development of the operation of generation of a hydroelectric plant. The innovative technique is structured in the following hierarchical sequence of procedures, cataloged into eight modules:

1. Collection of information in real-time the behavior of a given parameter;
2. Transmission, these data to an operations center;
3. Construction of a database;
4. Evaluation of the data in the information processing center;
5. Diagnosis of the state of the monitored parameters;
6. Search and determination of the root cause of the changes produced in the observed parameters;
7. Decision making of the actions to be taken;
8. Execution of actions;

The application of these procedures will allow the intelligent monitoring system; select the action that will be applied to improve the performance of committed variables and can be online or offline, depending on its magnitude and the affected areas.

III. Methodology Proposed Configuration

The development and application of the proposed methodology for the transformation of monitoring and supervision systems in intelligent systems, require an addition to their implementation. This add-on will, the technique may be consolidated as an assessment tool, diagnostic and decision-making in real time, either online mode or offline, depending on the type of action to be applied. The technique is supported by the following configuration for each of the modules that comprise:

Module 1 - Information gathering. The data collected and stored in a database, are obtained on site, where it is going, any change in the physical, mechanical and electrical of an element through a robust sensor system. These sensors are installed in the most vulnerable areas or at high risk of failure within a particular element or system of a hydroelectric plant [11].

Module 2 - It is integrated by a wide communications system. The selection of patterns and communication technologies is a key challenge in designing a Smart Grid, since it is necessary to consider the convergence of various applications. The question becomes even more emblematic in the Distribution Automation (DA) applications, since these require more stringent specifications such as f. ex. higher network availability and faster response time in decision-critical events, such as in situations of interruption of electricity supply [12].

The protocols and standards significant to DA are those that implement the SCADA systems (Supervisory Control And Data Acquisition), which have traditionally been applied to Electric Power Systems. Among the most important are cited DNP3, IEC 60870-5-101/104, Modbus, IEC 61850, ICCP (IEC 60870-6/TASE.2) and IEC 62351 Parts 1-8 (safety standard in operations control) [2].

Module 3 **-** Is made up of a database, or a large data storage system and very special characteristics, for their management and utilization. This database will be saved, data representing the behavior history of a certain parameter of an equipment or system. Thus, it is possible, make available information on continuously for analysis and monitoring of the behavior of predefined variables of interest.

Module 4 **-** Evaluation of the information sent by the monitoring system. This stage is carried out to detect variations or changes in normal behavior of one parameter. To this is accomplished by a process of comparison with a predetermined reference value. This review takes place in real time and its result compared to past behavior, this will set if is presenting itself an abnormality, or simply it is an isolated event [8].

The historical behavior is analyzed, and it creates a state of the image of the selected parameters. This image is compared with the behavior of these same parameters in real time. This evaluation uses only part of the stored digital data that reach a threshold value. Alternatively makes up an assessment of the registered oscillograms, relating to the behavior of a given parameter, interpreting all registered graphics.

To perform the evaluation process, it is had statistical and probabilistic tools that allow its accomplishment in optimized and efficiently. The application of each depends on what type of signal is being monitored [15]:

- *Statistical techniques and probabilistic:* (least squares). Mainly applies to linear process;
- *Kalman filter:* applies to mainly non-stationary periodic signals;
- *Fourier transform:* mainly applies to periodic signals;
- *Wavelet Transform*: applies to mainly non-stationary signals Periodicals;
- *ARMA model (Auto-Regressive Moving Average models):* Applies to adjust functions based on their past values and the average of the series.

Module 5 **-** Diagnostics status of the monitored parameters. At this stage determines the type of change, type of failure that is causing, intensity and impact on the performance of an element or component and, in particular, identifies the root cause of this disturbance [7].

To achieve these goals the fault diagnosis, it has based techniques:

- *Analytical symptoms observed;*
- *Symptoms heuristic;*
- *Heuristic knowledge of the processes.*

Module 6 **-** Search and determining the root cause of changes in the parameters. Within the various existing alternative solutions to the elimination of these changes in the behavior of a given parameter, seeks the best from a technical and economic point of view and, most importantly, that can be applied in real time [5], [7]. This optimized solution is found by applying intelligent optimization techniques such as Expert Systems and Neural Networks.

The use of these techniques allows to manage a "Knowledge Bank" (storage area information of an expert system, that is, the facts and rules) where the information obtained from various physical parameters are crossed and integrated to produce a closer result, that really desired: an effective aid to decision-making.

Module 7 **-** Decision making of the actions to be performed. The action or actions to be taken, are the optimized solution, it is through the application of intelligent optimization techniques such as Expert Systems and Neural Networks [4], [15].

Manages become a "Knowledge Bank", to find the closest result that you want really. The intervention must be in real time (online or offline) and should show the type of procedure to be performed, the point where the intervention will be made, the components to be achieved and its intervention time. This solution can be predictive/proactive maintenance or replacement of equipments.

Module 8 **-** Implementation of these actions. This step should be carried out in real time (online or offline), the best solution indicated. There must be a prior evaluation, to program, the operational actions to be taken during this process, especially when the procedure must be performed offline. In this situation, the computer system (software), describes the operational measures to be adopted. As for an online procedure, the computer system performs all operational measures autonomous way [14].

IV. Statistical Evaluation of the Results of the Incidence of Failures in Hydrogenerators

Describes the evaluation results performed on existing statistics on the incidence of failures in hydrogenerators, their impact and their disposal, primarily concentrated in the failure of local, type of failure and root cause. It is intended to emphasize, what are the areas of a generation plant, most affected by failures, and what higher incidence of failures. These statistics allow deciding the places that need monitoring and permanent supervision. This procedure will carry out an effective treatment in real time this information accurately diagnosing the causes of hidden and early disorders that a future can be transformed at high risk of failure for the plant and the system in general.

A. *Fault Inspection*

It is intended to emphasize, what are the areas of a generation plant, hardest hit by faults and which higher incidence of failures.

It was established four categories of failures or malfunctions: insulation, temperature (thermal), mechanicals and bearings. It was observed that evaluation, that the damage to the insulation, represent the highest percentage of failures considered, followed by the failure of the mechanical type, logo appear failures by temperature and finally the bearing failures. It follows that it is necessary to concentrate efforts to reduce the failures in the insulation used in the construction of these devices [5], [7].

B. *Root-Cause of Failures*

When a chain of causes and effects precedes a known final state, one is returning to the origin or starting point finding themselves therefore the root cause of an event. Try to find the root cause of an event is to solve a problem that has happened or prevent an incipient problem that can become very serious. It can be concluded that: the solution of a problem by looking for its root cause is more effective than simply treating the symptoms or direct causes.

It is very clear that the rotor vibrations and oscillations, deteriorate the insulation of the generators, so the vibration monitoring (stator, rotor, termination of the coils and bearings) have a major influence in damping the root cause of failures in isolation. The monitoring of partial discharges is another well-known method, and increasingly used in power generation plants, since it indicates the increasing deterioration of the insulation machine [5], [6].

To identify the root cause of a failure is needed relates it to the results of malfunction or damage: root cause of failures in isolation, by temperature, mechanical and bearings. According to statistics, it was observed that three root causes have significant behavior in the isolation of faults: aging (32.8%), winding contamination (24.3%) and internal partial discharges (24.3%). Since the mechanical faults, major root causes are, the material fatigue (15.7%) and loosening of the rotor parts (12.8%) [7].

C. *Nature of Failures*

According to statistics, the nature of the failures may indicate areas or neuralgic locations of these machines. Therefore are adopted, the necessary measures to reduce or eliminate these causes. It can indicate the nature of the proposed fault, setting up a reference in order to assess these behaviors.

The quality of the material used in the construction of the equipment represents 50% of failure events followed by the weakness in the design or drawing with 27.9% of the occurring events. The intervention of users, appears only 8% of cases, since the manufacturers are responsible for 92% of the remaining cases. Therefore, manufacturers are directly responsible for the vast majority of failures occurred in hydroelectric plants, specifically in generators [5], [7].

D. *Methods for Reducing the Risk*

The root cause of failures can be eliminated by methods of reducing the risk of failure [7].

The root cause of failures in isolation is sensitive to some of the risk reduction methods, such as:

- Remodeling the large scale;
- Improved maintenance techniques - new techniques - optimization.

The root cause of the mechanical failure is sensitive to the following methods to reduce the risk of failure:

- Improvement of quality control during the planning, production and installation;
- Increased project requirements or design;
- Large-scale remodeling.

Maintenance techniques retard this process, but only a complete remodeling recover initial performances, or even more advanced.

E. *Integrated Monitoring for Fault Detection*

Monitoring systems and supervision allow it to be detected the root cause of many incipient faults evolving process, eliminating them and reducing the risk of failure systems [3]. Usually this is done through predictive maintenance techniques [5], [7].

When analyzing the occurrence of failures in power generation plants, it appears that among other things:

- The symptoms generated by the occurrence of a particular fault, never manifest themselves by changing a single physical parameter monitored (Ex. excessive vibration in a bearing and its corresponding variation in oil temperature, shoes or segments, etc.);
- A certain monitored parameter never suffers the influence a single failure mode, the range (Ex. amplitudes of vibration characteristic frequencies, measures on between the shaft and the bearing of a rotating machine, may be related to efforts imbalance, misalignment, bearing housing of roundness, etc.) [13].

In addition to these conditions, one can also mention cases where the occurrence of a particular failure mode is responsible for the creation of another or the failure symptoms generated by abnormal operating conditions, due to problems that occurred in the equipment control systems (synchronism errors, hysteresis control, etc.). Such situations suggest that in order to deal with such failure modes, it is necessary to have a larger amount of information on the physical and operational parameters of the equipments [5].

V. Selection of Greatnesses to be Monitored

The determination of greatnesses to be monitored, should be carried out, taking into account technical and economic criteria. Initially they should be minimally monitor, the physical quantities that indicate the relevant problems that occur in the equipment. This relevance is based on the severity of the failure criteria, important for the production process, the cost of repair of the equipment or pure and simple security. Usually a combination of one or more of these factors is used. It is important to include in the selection of these parameters to be monitored, some equipment parameters that make up the auxiliary systems [1].

VI. Incipient Fault Identification

It should save prudently for detecting incipient failures, especially in determining the values to be used as reference, as well as defining the detection limits (maximum and minimum), which requires specific values for the various operating conditions equipment. Should be differentiate the quantities that have normal values dependent on the equipment in operating condition (greatnesses limits for) those whose variation has a direct relation to the operating point thereof (absolute limits of quantities). The selection of these limits during the customization/parameterization of the systems should be made compatible with the fixed limits of the SCADA system. Disagreements or contradictions in determining these values may generate absurd situations such as excess events or false alarms (excessively conservative system) or events not detected (overly permissive system). In conclusion it can be said that it is necessary to keep consistency and avoid exaggerations in establishing the limits in order to ensure high efficiency and accuracy in monitoring and supervision [8].

VII. Methodology Proposed Application

It was carried out a simulation with a hypothetical case, considering a hydrogenerator operating in continuous manner.

In this generator, various digital sensors were installed to monitor the temperature in the generator itself and the bearings, the bearings vibration, high temperature in the stator windings and rotor vibration of the rotor. It should also monitor partial discharges between the stator core and coils and between the rotor core and the field winding, sudden variation of the field current, voltage regulator saturation and partial discharges between the stator and rotor.

Through the communication system (SCADA system), the information of the monitored greatnesses are sent to an operating center, to be processed and evaluated. In addition, account with oscillograms that register in graphic form the real time behavior of all monitored parameters.

The monitoring system records an event - temperature change - automatically this information is received from the location where the problem is happening and the magnitude of these variations. The system recognizes the sensor is sending this data and also the location where it is installed.

Is carried out, an evaluation by the computer system and it is concluded that this temperature range is appearing in the bearings that support the rotor shaft. This first conclusion is complemented with the help of oscillograms that capture this situation graphically displayed, vibration bearings.

According to information stored in computer system database, is indicated, the failure mode present at this location since the monitored characteristics match those stored. The diagnosis made by the computer: failure of bearings, friction between its constituent parts.

In the next step, the computer system performs an exhaustive search of the root cause of this failure mode. It is used to this, an expert system and through its "knowledge bank" and the inference engine determines that the root cause of this failure mode is wear of moving parts of bearings for lack of a proper lubrication and the presence environmental contamination.

In the next step, the computer system performs an exhaustive search of the most favorable alternative from the technical point of view as economic. Decision making for the optimal solution alternative, signals in the first instance, the addition of a viscous lubricant and high density, an action that will be performed automatically (online mode). It also indicates that after a while, after a direct observation of the moving parts of bearings and according to their status, should be made the exchange of bearings (offline mode).

TABLE I - Typical software developed Output

ACTION	DESCRIPTION
Sensor	45
Transmitted signal	Variation of the field current.
Evaluation	Failure mode: sudden and continuous change of the field current. Machine rotor vibration. Failure mode: saturation voltage regulator. Machine capacity reduction. Reduction if the magnetic field in some windings.
Fault type	Mechanical and electrical.
Root-Cause	Increased resistance of the field windings of the machine. Loosening of the connection between field coils of the magnetic poles.
Actions to take	Unavailable for the machine operation. Change system linking field coils of the magnetic poles.

VIII. Original Research Contributions

a) Transformation of the monitoring and supervision of hydroelectric plants in intelligent systems;
b) Detection root cause of failures in generating units in real time;
c) Evaluation and diagnosis of changes in the behavior of the variables of interest generation plants in real time;
d) Online execution of maintenance equipment;
e) Centralization of the operation of generation plants by intelligent systems methodology;
f) Increased efficiency, reliability and availability of the generation of electric power systems;
g) Optimization of maintenance;
h) Reduced risk of failure;
i) Autonomy of monitoring and supervision systems, to operate a system intelligently.

IX. Conclusions

Intelligent monitoring and control systems allow minimize the risks of failure of generation systems and consequently increase its reliability (reduced failure rate/year) and the availability, improving the quality of energy supply by reducing the periods and interruption frequency of power supply, by improving indicators DEC, FEC, DIC, FIC and DMIC, and reliable management charge and distributed generation.

Centralization of information processing by intelligent monitoring systems will improve the efficiency of operation of electrical systems, optimize maintenance processes within the generation plants and consequently increase or maintain the estimated useful life of the generators, economically benefiting utilities power.

The transformation of the current systems for monitoring and supervision of hydroelectric plants in intelligent systems, effectively represents a technological advancement over conventional monitoring systems. What defines the quality of the response of these systems, in relation to the supervision and diagnosis, it is the experience of those responsible for analysis of failure modes.

The data management infrastructure, established by the power utilities, will be responsible for more or less extracted benefit of the system as well as for maintaining the efficient operation of the same. The choice of the best strategy for the Data and Information Management, will depend on the policies adopted by companies to their treatment. The benefits of smart grid technology, in monitoring systems will come when there is a data management policy functional within the utilities.

Should be avoided as much as possible "excess of monitored parameters". Prioritization criteria of failures "detectable" or "observable" must be considered. For each observable failure mode, there will always be a form of detection, which keeps a relationship "sensitivity/installation cost" more, and that in principle, should be chosen.

An action of great interest, which should be considered in the monitoring and supervision system is the integration of auxiliary systems, to conduct their analysis and diagnosis, together with those from the main systems, causing minimal impact on its cost of installation. The influence of failures in auxiliary systems (ancillary services) with the probability of generating, forced stops of the equipment and system is high and in some situations similar to those of the main systems.

Importantly, there is not a single application and solution of systems or smart grids. Many of these functions will not become viable if coexist with others and should be implemented according to the needs of utilities. Thus, individual functions such as monitoring and fault detection in generators or feeder circuits, may not have their benefits evaluated separately.

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