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INTELLIGENT MONITORING IN ELECTRICAL POWER SYSTEMS

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Abstract: The paper presents some recent measurement procedures which can be used to improve the management of electrical power systems. Presently, new intelligent instrumentation permits to recognize and at the same time classify the state of a monitored system. On the other hand, different techniques enable to improve measurements accuracy even using the signal noise. The appropriate use of these means leads to an easy management of power systems with better efficiency, reliability and safety.

In the paper some applications in transmission and distribution systems are also illustrated.

Keywords: Intelligent measurements, Power systems, Monitoring and Management

1 INTRODUCTION

The latest measurement improvements, in both instrumentation and methods, has greatly contributed to a better automatic management in electrical power systems. As a matter of fact, intelligent measurements enable:

- to obtain more or less accurate classification of the states of the monitored system (training);
- to foresee the behavior of the monitored system in its environment taking a limited number of parameters in a limited time interval;
- to quickly decide programmable actions from information acquired throughout the monitored system's history.

During classification, the intelligent measurement system (subject) slowly gets a structure to quickly acquire data from the monitored system (object) and store such data in special memories, to associate them to "forms" known in advance. This procedure enables the subject to quick recognize the state of the object by means of partial and short acquisitions. If previous measurements are carried out, tests for the object state characterization can be scheduled in advance (knowledge-based), or gradually identified by statistical methods using either fuzzy logic or neural techniques. Depending on the coherence of the signal source and the mechanism of emission, a model (Gaussian, Markovian etc.) may be applied. In order to verify the correctness of the statistical model, a follow-up check can be made. Scientific and final-test stages are carried out simultaneously. Often final-test systems are intermediate between knowledge-based and statistical-neural characterization.

Sometimes for complex several-class systems the use of training and classification techniques similar to voice recognition methods may be very useful [1], [2]. In this case from the signal spectrum segments of 20ms are acquired for long periods. Spectra are then obtained as vectors of 19-20 elements. If we have N vectors, at random $n<<N$ vectors k_i (for $i=0, 1, \dots, n$) are taken. Then, other N-belonging vectors (which are closer to the n-vectors) are grouped near the n vectors. In this way n-aggregates are build; for each the mean value is computed using the mean of vector k_i^j (for $j=1, 2, \dots, max$); the operation is then repeated. The process is asymptotic and usually quickly reaches convergence. Each k_i^{max} vector represents a state of the object.

2 NEW METHODOLOGIES IN MEASUREMENT PROCESS

Different states of an object can be recognized by means of intelligent measurements; the state of an object can be known by means of tests at short notice. To perform intelligent measurements on a complex system different methods can be used. In the following the main procedures are reported.

2.1 Fuzzy and neural techniques

Fuzzy technique is an interpolation technique to get parameters from recorded data, using different, graphically expressed segment-by-segment algorithms. They are used for obtaining parametrical coefficients necessary to define the system [11].

As an example let us consider a quantity *y* depending on other acquired quantities X_1, X_2, …, X_k. When *y* is evaluated, its values are known for discrete value sets (X_1^1, X_2^1, …, X_k^1) … (X_1^p, X_2^p, …, X_k^p) of the acquired quantities. Interpolation techniques enable to obtain each *y* value as a function of X_1^g, X_2^g, …, X_k^g. Once the continuity hypothesis is verified, the interpolation can be carried out using in advance either linear or second order polynomial interpolation. The method is based on fuzzy logic procedures using interpolation techniques which vary point by point. In this way the interpolation procedure is customized.

Neural techniques enable to build intelligent instruments, which can quickly classify the object states and monitor configurations [9], [10].

2.2 Dedicated software techniques

The states of a system can be classified stressing the object artificially by means of sophisticated software programs. The technique is particularly useful in Knowledge-based diagnostics.

Dedicated software also can be used for simulating capabilities of digital instruments based on over-sampling techniques obtained by means of decimators and digital filters.

An example to this regard is the Sigma-delta converter [12]. In this case, using both high frequency and low resolution power (0 or 1), the system's behavior can be accurately foreseen firstly acquiring object information and secondly processing data by means of statistical methods.

2.3 Non ortonormal transform techniques

Up to few decades ago, in practice only the spectrum Fourier transform made an alternative to the time domain representation possible.

In order to analyze transients, such as the open-close operation of a breaker, the frequency spectrum with zeros and poles cannot represent the phenomenon correctly. The vibrations associated to the breaker closing can be represented as sequences of damped oscillations each having its own ω_i pulsatance, α_i damper coefficient and $\Delta t_{i,i+1}$ delay, usually caused by springs and evaluated against the next oscillation. In order to establish the correct behavior of a breaker, its vibrations during an open-close operation can be compared with those of a well-functioning breaker. Varying ω_i, α_i and $\Delta t_{i,i+1}$, "maximum" values are obtain; if these values are coincident, the tested breaker works correctly. This technique, introduced by Gabor, is completely explained by the wavelet theory. The procedure is particularly effective for transient representation and can be implemented using instruments based on fast signal processing (DSP) [13].

2.4 The role of noise in measurements

In classical approaches, if there are non linear blocks in measurement apparatuses, the increase of noise amplitude versus the signal may be greater than a linear increase. In this case, if the signal-noise ratio $R=S/(N_e+N(S))$ decreases, negative consequences on measurements are produced. In the formula, S is the signal amplitude, N_e the external noise and N(S) the noise. The reciprocal influence between N(S) and S greatly influences the R optimization.

Deterministic and quantum chaos (i.e. transition from ordinate to chaotic states) affects the role of noise on measurement process. The signal itself can cause noise.

Contrary to old convictions, in recent years, the development of sophisticated acquisition apparatuses has greatly contribute to take advantage by the use of noise in diagnostic field to foresee object behavior. As a matter of fact, experience has shown that noise is not always noxious. In accordance to the stochastic resonance theory, noise sometimes improves measurements. For instance, when "barriers" are present between sensor and object and in the processing system, measure process can be improved by noise. Barriers can be treated by classical or quantum models [3], [4], [5], [6], [7].

3 VALIDATION OF THE CLASSIFICATION PROCESS

The object representation greatly depends on the classification process. In the following a method is presented to check the correctness of a classification procedure.

Let us define the |OI| operator which transforms the N vectors (functions) of the ensemble (I) on a sub-ensemble of n<<N vectors each one characterizing a system state. The |OI| is defined "ensemble

operator”; sometimes it can be represented as the product of k elementary operators with $k \to \infty$: $|OI| = \lim_{k \to \infty} |OI_0|^k$.

Let us define the |U| operator as the “element operator” which biunivocally transforms each element of an x> ensemble (g dimension vector) on an ensemble element y> having |U| x> = y>.
|U| changes the state representation, i.e. the vector (or data string) which represents the state itself. For definition, the $|U|^{-1}$ can be expressed as.

$$|U|^{-1}\, y> = x>$$

If the following relations are verified:

$$|OI|\,(x') \to (x'')$$
$$|OI|\,(y') = |OI|\,(|U|x') \to (y'')$$
$$|U|^{-1}\, y'' = x''$$

the operators commute.

Referring to the system classification process, if the operators commute, the two representations of the acquired data (which enable to record either x> vectors or y> vectors) are equivalent.

4 INTELLIGENT INSTRUMENTATION IN MONITORING PROCEDURES

Intelligent instrumentation is able both to classify the system states through measurements and then to quickly detect the present state of the system in order to foresee its evolution from the initial conditions, taking into account the influence of the external environment.

In the measure process, particularly important are sensors, which supply signals to both instruments and acquisition systems. The signal must be proportional to the taken quantities without distortions or frequency range limitations. The main transducers are:

- Opto-electric transducers for voltage and current acquisition, which can be used instead of voltage and current transformers; they are very useful to implement fast diagnostic procedures in electric distribution systems, e.g. to quickly distinguish a short circuit from an overload current.
- Piezoelectric sensors, which can be used for monitoring even the slightest vibrations in mechanical structures.
- Interferometer laser techniques, which can be used for geometric measures; laser can be used for temperature measurements, referring to times linked to the re-emitted radiation.

To process signals, extremely quick chips can be used which process acquired data in real time executing previously defined programs (D.S.P.). In order to obtain correct programs for measurements, knowledge based or statistical methods (partially knowledge-based) can be used. Also neural networks and WRAP (Weight Approximate Rule Processor) for fuzzy techniques can be classified as D.S.P. By means of fuzzy processes interpolations are customized for each segment. The kind of interpolation depends on the behavior of all quantities concerning the acquisition and refers to different segments [9].

To store data, recent memory registers can be used, which are characterized by high storage capacity and very quick access. FIFO (First Input, First Output) boards store million of 16 bit figures in less than 50 nsec and AD converters are very fast (up to 100 megasamples/sec).

5 POWER SYSTEM MONITORING AND MANAGEMENT

Transmission and primary distribution systems have become very complex and always are controlled via a supervision center. In these cases, with an intelligent monitoring the maximum system efficiency must be reached and at the same time the following quality parameters in power supply need to be known and guaranteed:

- The voltage stability.
- The frequency stability.
- The continuity supply level, locating the transient source (short circuit, high load insertion, etc.) and distinguishing between different kinds of sources to avoid untimely protection operations.
- The location of distorting non-linear loads, responsible for current and voltage distortions in order to eventually perform actions to compensate or eliminate harmonics and distortions.

For a correct operation, measurement apparatus must be the fastest possible taking into account the classification power resolution.
In this case, an important question regards the time and the minimal number of samples necessary for a good acquisition, in order to diagnose the cause of transients both in *ac* and *dc* networks in real time. The minimum time depends on:

1) Circuit characteristics of the network, such as linear or non linear behavior, line constants values (i.e. resistance, inductance, capacity, mutual-links), the number of supply nodes, presence of saturable and non linear components responsible for sub-harmonics.
2) The network state (e.g. steady state or transient conditions) before the fault.
3) The desired precision in locating both the cause and the characteristics of the transient (e.g. for a short circuit the resistance and inductance).
4) The stability of parameters defining the transient.

Voltage and current samples are acquired at 3-5 kHz because high sample frequency enables a correct network simulation to both identify the cause of the transient (kind of short circuit, high load insertion) and adopt correct actions. Processing time depends on network complexity. Times increase also due to the presence of capacitance in the system.

Also in distribution and utilization systems the diagnosis must be very fast to enact protections in real time. The longer the time available, the more accurate are both the diagnosis and the system state classification. In distribution (or in rail-way) systems, by recording currents and voltages sampled with a frequency of thousands of Hz and usually for times shorter than 10 ms, it is necessary to establish whether a transient is due to short circuit or overload current.

Signal processing can be obtained following two different approaches:

1. Knowledge-based. The electrical network is simulated by means of equivalent circuits. The current and voltages associated to a short circuit are computed referring to both the point and characteristics of the short circuit. Projecting currents and voltages on wavelet, frequencies and damping coefficients of the transient are identified referring to dominions on the ω, α space of the different sources of transient (short circuits, one or two kinds of loads connected by the user).
2. Statistical methods. Once the equivalent line circuit is defined, with targeted software the line behavior is simulated referring to both short circuits and load insertions. Then, by means of a specific statistic procedure, transient sources are recognized and classified. The technique used is similar to that used for voice recognition.

6 CONCLUSIONS

Electrical power system management has greatly improved thanks to the evolution in measurements. New procedures such as stochastic resonance, wavelet theory, neural techniques and fuzzy approaches joined to the use of intelligent instrumentation enable to monitor and control power systems with fastness, efficiency and safety.

Applications, with reference either to normal or fault conditions, demonstrate the powerful of the different procedures in monitoring and supervising transmission and distribution electrical systems.

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