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Usage of Information Obtained from PMU-Type Synchronized Measurement Devices to Estimate Parameters of Complete Mathematical Model of Power System

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1 INTRODUCTION

The widespread usage of synchronized measurements devices (PMU - Phasor Measurement Unit) for diagnostics of electric power system models has been started recently. We assume that power system diagnostics is the estimation of unknown parameters of the system with its topology, parts of the system parameters and its reaction on various impacts known.

Complete model of power system should take into account electromagnetic and electromechanical transients. Changes of synchronous machines' rotation speeds and torques of turbines as well as actions of automatic control systems should be considered. This model can be formulated as a differential-algebraic equation system. Solution of this system describes both forced and autonomous oscillations of system's state variables.

A number of simplified power system models which correctly describe various stages of transient process can be derived from complete model. *On the first stage* of transient process it is important to take into consideration electromagnetic transients in electric transmission system and stator windings of synchronous machines. Electromechanical transients can be neglected on this stage and rotor speeds can be assumed constant. *On the second stage* of the transient only electromechanical transients may be considered and electromagnetics may be disregarded. In this case differential equations describing transmission system and stator windings are reduced to algebraic equations. Transients in excitation windings and rotor speed oscillations are described using differential equations. *On the third stage* of the transient aggregate dynamics of power system generators are examined. Oscillations of mutual angles of generators fade out and new synchronous rotor rotation is formed. A new post-fault operation frequency is formed. The new frequency gradually changes and, in case the stability of the power system is retained, becomes equal to the new steady-state frequency.

Mathematical models of the first stage of transient are used for calculation of overvoltages to choose commutation and protective equipment and for development of relay protection devices. Mathematical models of the second and third stages are used during examination of power system transient stability and development of power system emergency control automatics. In all cases the quality of the engineering decisions made is significantly affected by a correctness of employed mathematical models. That is the reason why lots of attention is devoted to power system model verification.

2 PMU USAGE IN MONITORING SYSTEMS

PMU measurement devices are used for diagnostics of power system models, which represent the steady states and to some extent the second and third stages of the transition process.

The algorithm of PMU usage is shown on the Figure 1.

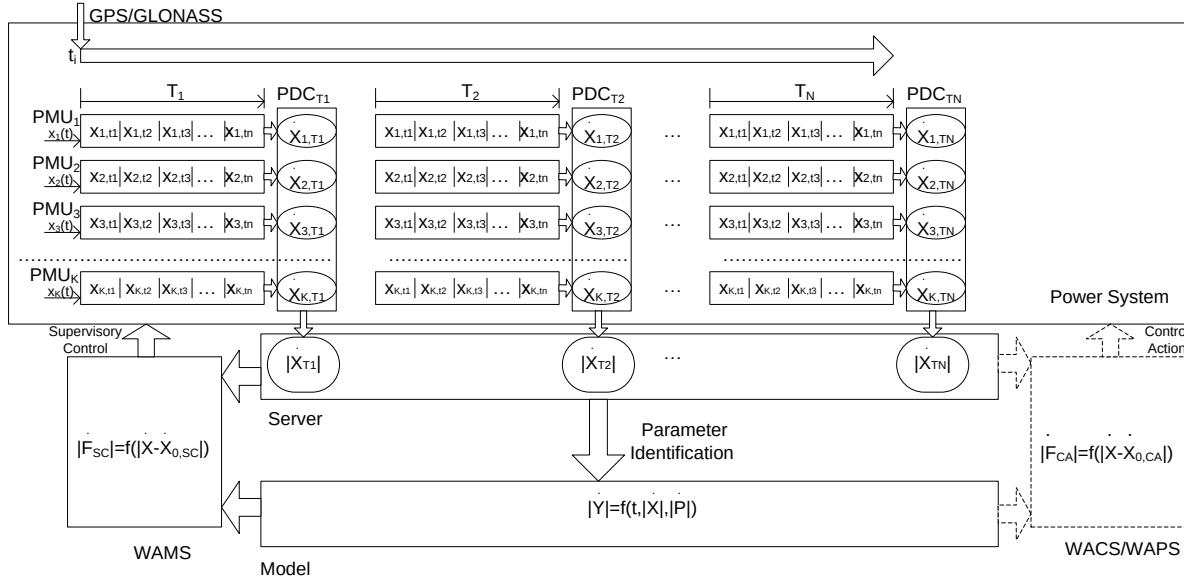


Fig. 1: The usage of PMU in a power system.

Figure 1 represents the following elements: $x(t)^1$ are the input variables for PMU₁, PMU₂, PMU₃, ..., PMU_K. $x(t)$ are sampled with set frequency (usually with a sampling frequency divisible by 2^n over a period of industrial frequency, such as $f_s=6400$ Hz, ie 128 points of reference or $f_s=12800$ Hz, ie 256 points of reference within the period of 0.02 second to apply the fast Fourier transform).

Each PMU_i device processes the information obtained during the period of time² T_j in a local point of power system to the complex (vector in polar coordinates) quantities $\dot{X}_{i,j}$, which respectively characterize this local point. Aggregation to $|\dot{X}_{T_j}|$ quantity is produced by PDC (Phasor Data Concentrator) device. The set of values $|\dot{X}_{T_1}|, |\dot{X}_{T_2}|, \dots, |\dot{X}_{T_N}|$ characterizes the model of the whole power grid. These values are used in the monitoring system WAMS (Wide Area Measurement System). So far as the data obtained in the power system is in a complex (vector) form, so the diagnostics are performed for a model of power system, which is based on complex values.

The monitoring system, based on synchronized vector measurements, is used for supervisory control. Currently, the task of using measurements by devices such as PMU to control and protect the power systems is set. The simple transfer to WACS (Wide Area Control System) and WAPS (Wide Area Protection System) is impossible for PMU devices applicable to WAMS. Technical requirements for such devices (which are named PMU-P, where P is the reduction from the word protection) differ. And the main requirement is the adequacy of work in the transitional modes, when, strictly speaking, the control, and the protection of the power system are used.

If the data is recorded on each period (0,02 second), the cutoff frequency of processes available for monitoring will be equal to 25 Hz. It is more than enough to control the electromechanical process.

However, both the forced components provided by synchronous generators and the autonomous components provided by capacitive and inductive elements of power system are presented in any electrical network with the transients. With unknown frequency of forced component it is impossible

1 In the three-phase network $x(t)$ variables are voltages u_A, u_B, u_C, u_N and currents i_A, i_B, i_C, i_0 .

2 $T_1=T_2=\dots=T_N$, or adaptively change in accordance with the current line frequency.

to separate the forced component from the autonomous components during the transition process in a given point of the electrical network.

Note that there are $x(t)$ variables on the inputs of the $PMU_1, PMU_2, PMU_3, \dots, PMU_K$ devices. These variables may represent the transients after sampling to the 3.2 kHz cutoff frequency (in case of digital substations - up to 6.4 kHz). These transients represent almost all electromagnetic (switching) and electromechanical processes described by the complete mathematical model of the power system, which consists of a set of differential and algebraic equations.

3 USAGE OF PMU FOR DIAGNOSTICS OF POWER SYSTEM'S COMPLETE MATHEMATICAL MODEL

Let's show on Figure 2 another way of usage of information about power system coming to PMU.

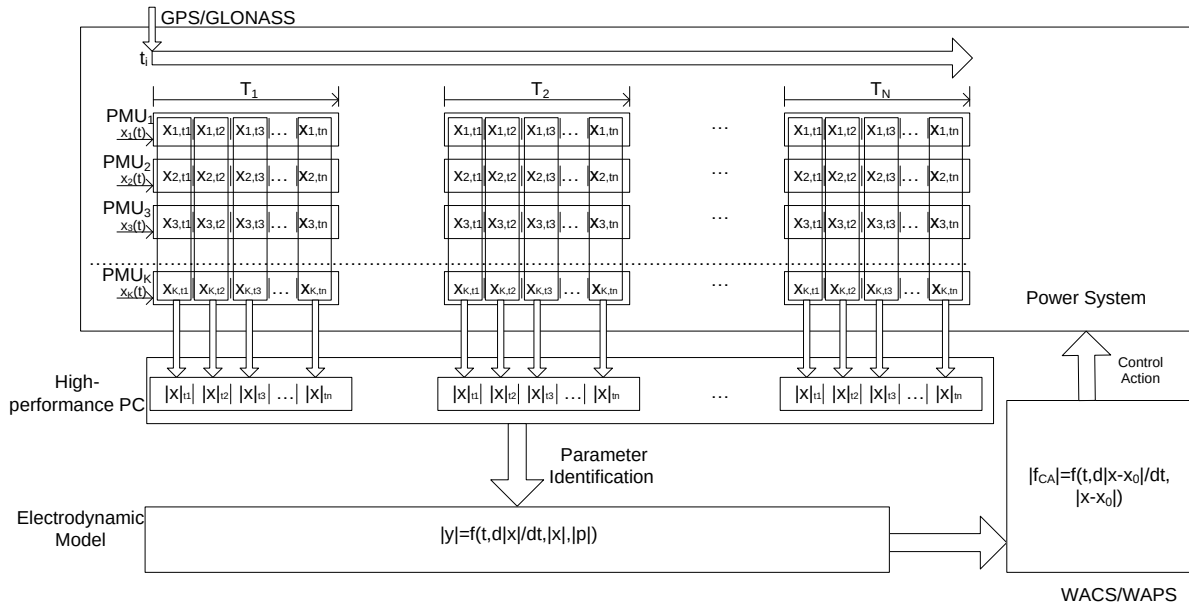


Fig. 2: Alternative way of PMU usage in a power system

Discrete quantities of sample values x_{i,t_r} from each PMU_i are assembled in high performance computer (HP PC). Quantity $|x|_{t_r}$ is a slice of sample values for power system electrodynamic model represented in a form of $|y| = f(t, \frac{d|x|}{dt}, |x|, |p|)$, where $|p|$ is the vector of parameters. The set of quantities $|x|_{t_1}, |x|_{t_2}, |x|_{t_3}, \dots, |x|_{t_n}$ will be obtained at every time interval T_j , which can be used for the identification of the considered power system model represented in differential-algebraic form.

Let's estimate the amount of transmitting and gathering information while using PMU in such a way. Every transmitting frame consists of 700 bits:

Measurement data: 4 currents, 4 voltages	GPS/GLONASS Signal	Overhead information	Overhead TCP information	Overhead IP information
128 bits	64 bits	256 bits	192 bits	60 bits

Considering rated frequency is 50Hz, each PMU device will transmit $700 \times 128(256) \times 50 = 4375(8750)$ kbit/s³. Thus, there are up to 23(11) PMU devices may be connected to the receiving computer working in the 100 Mbit/s Ethernet network. Thereafter, about 8 megabytes of information (without overhead TCP and IP information) will be accumulated in the receiving computer every second. Using ring buffer scheme for saving incoming data, computer using 1 Gb RAM can store information about power system state for 125 seconds. Such duration of registration is enough for

3 It is possible to generate a frame with several measurements data to reduce the amount of transmitted bits per second.

practically all transients in power system. If necessary RAM may be increased or HDD memory may be used.

Considered approach of using PMU shown on Figure 2 may be simultaneously used with a traditional PMU usage shown on Figure 1. Acquisition of synchrophasor quantities may be delegated to HP PC, while only sampling and data transferring to high level devices tasks are left for low level devices. All information processing including synchrophasor quantities acquisition is executed on one HP PC.⁴ Advantage of such way of data processing is the ability to separate forced components of the process in the power system from autonomous components. Lesser influence of lost values on the calculation results is an advantage too. The disadvantage is the requirement for communication networks bandwidth raise.

Fundamental change in the case under study is an opportunity to operate with a complete power system model, which opens new capabilities to build WACS/WAPS systems.

It is possible to apply system design with greater quantity of information gathering and processing levels for large power systems. Considered second level consisting of HP PC may be regarded as a system of distributed computing of higher third level operating at large power systems level.

4 COMPLETE POWER SYSTEM MODEL DIAGNOSTICS

Any mathematical differential-algebraic model of power system can be represented in a difference form as a system of algebraic equations with high dimension sparse matrix. Diagnostics problems with sparse matrices are solved by the decomposition methods [1]. In [2], [3] large schemes analysis based on subschemes decomposition is examined. Large matrix is partitioned on smaller size block-diagonal matrices with further solving it on multiprocessor computers with parallel programming methods usage. The developed analysis methods can also be efficiently applied for solving of power system's diagnostics problems.

At present methods of power system parameters diagnostics based on arrays of sample quantities of currents and voltages are developed intensively [4].

5 CONCLUSION

- The usage of PMU devices in WACS systems is well adjusted. Power system model's diagnostics based on phasor parameters is also developed with acceptable level of specification.
- Alongside with traditional architectures of data gathering and processing systems describing power systems regimes, alternative architectures are possible. Such alternative architectures may be applied instead of or together with traditional ones.
- System of synchronized sample information gathering may be used for diagnostics of complete power system mathematical model based on system of algebraic and differential equations. Appliance of such power system model clears the way to the development of new WACS/WAPS systems.

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4 PMU devices acquiring synchrophasor quantities in such way may be referred as distributed PMU.