MODERN SCADA PHILOSOPHY IN POWER SYSTEM OPERATION – A SURVEY

Nicoleta ARGHIRA[1], Daniela HOSSU[2], Ioana FĂGĂRĂŞAN[3], Sergiu Stelian ILIESCU[4], Daniel Răzvan COSTIANU[5]

Lucrarea prezintă aspecte legate de sistemele SCADA utilizate pentru sisteme electroenergetice, sisteme ce reprezintă o infrastructură critică în toate sectoarele de activitate. Operatorii de sistem din întreaga lume sunt puşi în faţa unor cerinţe deosebite pentru reţeaua electrică legate de calitatea şi eficienţa energiei, circulaţia puterilor sau stabilitatea sistemului. Noile strategii de control şi monitorizare a sistemelor electroenergetice prevăd sisteme SCADA cu performanţe îmbunătăţite şi introducerea unor noi sisteme de măsurare care să includă sincrofazori. Principiile SCADA prezentate în lucrare au fost aplicate în cadrul dispecerului energetic naţional, dar şi la nivel de centrală electrică.

This paper presents SCADA concepts used mainly in power systems, as a critical infrastructure in all life sectors. New power system demands regarding energy quality and efficiency, power system load or stability has risen for system operators all around the world. The new control and monitoring strategies include better SCADA systems and new measurement systems (wide area measurement systems with synchrophasors). The SCADA concepts discussed in the paper were implemented at the national power system dispatcher and also, at the power plant level.

Keywords: power system, SCADA concepts, real time monitoring, wide area measurement systems

1. Introduction

The current necessity for more and more energy in all the industrial sectors brings a variety of challenges for engineers involved in power system control. The

[1] Assist., Dept.of Automatic Control and Industrial Informatics, University POLITECHNICA of Bucharest, Romania, e-mail: arghira.nicoleta@gmail.com

[2] Conf., Dept.of Automatic Control and Industrial Informatics, University POLITECHNICA of Bucharest, Romania, e-mail: andone_dana@yahoo.com

[3] Conf., Dept.of Automatic Control and Industrial Informatics, University POLITECHNICA of Bucharest, Romania, e-mail: ioana@shiva.pub.ro

[4] Prof., Dept.of Automatic Control and Industrial Informatics, University POLITECHNICA of Bucharest, Romania

[5] PhD Student, Faculty of Automatic Control and Computers, University POLITECHNICA of Bucharest, Romania

requirements of a proper power system operation, as shown in [1], cannot be accomplished without a supervisory control and data acquisition system (SCADA).

The main objective in power systems is maintaining the balance between power generation and production, assuring the reliability of the system. This purpose is becoming harder to achieve hence to the new renewable power sources that bring new uncertainties and parameters' variations into the power grid. Considering these aspects, is shown, one more time, the importance of monitoring systems.

SCADA system supervises, controls, optimizes and manages generation and transmission systems. The main component of these systems are RTUs (Remote Terminal Units) that collect data automatically and are connected directly to sensors, meters, loggers or process equipment. They are located near the monitored process and they transfer data to the controller unit when requested. They often include integral software, data logging capabilities, a real-time clock (RTC) and a battery backup. Most of the RTUs are time redundant. These devices are complete remote terminal units that contain all of the transceivers, encoders, and processors needed for proper functioning in the event that a primary RTU stops working. Meter readings and equipment status reports can also be performed by PLCs (Programmable Logic Controllers).

The purpose of the paper is to show modern SCADA concepts and their links with new measurement systems that include phasor measurement units in order to fit the complex requirements of the power system in the current context of environmental and economical challenges.

2. Challenges in modern power systems

The critical infrastructures, such as electric power systems, telecommunication networks and water distribution networks are systems that influence society's life. Designing, monitoring and controlling such systems is becoming increasingly more challenging as a consequence of the steady growth of their size, complexity, level of uncertainty, unpredictable behavior, and interactions, [2]. In center of the well functioning of society lies the electric power system.

The secure and reliable operation of modern power systems in Europe represents a competitive task due to the penetration of variable renewable energy sources. Starting with the European recommendation that 20% of Europe's energy should be obtained from renewable sources by the year 2020, new issues occurred in power systems.

The new requirements for the electric networks are related to the different involved parameters, as shown in Fig. 1. Further, these aspects will be discussed in detail.

A. Power system load is the main aspect to be considered for a good operation of the grid (maintaining the power balance of the system: active power production should meet consumers' needs).

In order to maintain the load balance in the power system, generation planning and forecasting is an essential task. Generation planning usually involves centralized generation facilities with a reasonable size and with an operation that is controlled by a dispatching center. All small generation units such as micro-hydro power plants, small cogeneration units and isolated wind power plants are not included in the planning in a detailed manner. This has to be analyzed on the basis of the characteristics of the system under review.

Regarding load balance, the challenge is to forecast or to plan the distributed generation in a way that does not affect the stability of the system.

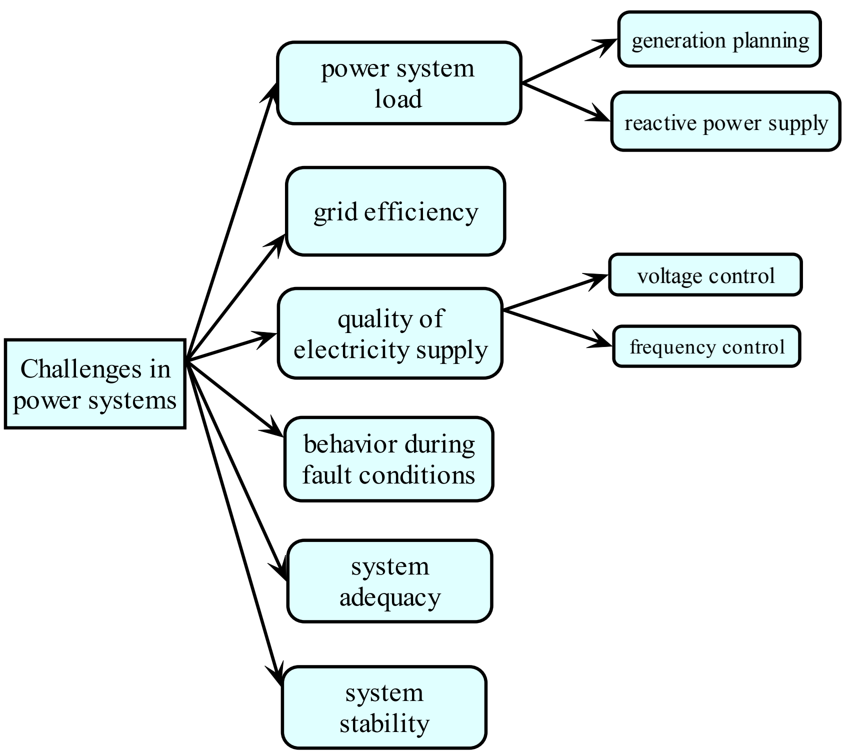

Fig. 1. New challenges in power systems

B. The problems related to the **quality of the electricity supply** concerns network operators and network users (energy consumers or producers) also. Still, this issue will be handled by the system operator who is in charge of setting up the facilities that will enable the control of energy quality.

Mainly, from consumer's point of view, power quality reduces to the continuity in power supply and the voltage characteristics.

The power supply continuity is also related to the load balance. But voltage quality is set according to its characteristics: frequency, amplitude, waveform and symmetry. These parameters should be kept into the limits accepted by the ENTSOE regulations.

C. Grid efficiency refers to a load balances in an economical and environmental manner. The main purpose is to reduce the power consumption during the peak load demand and to increase it when the load demand is low.

D. The behavior during fault conditions should be monitored and data should be stored in a historian server in order to improve system stability.

E. System adequacy represents the power system capability of matching the evolution of the power flux. The system adequacy can be considered from two points of view:

- The capacity of the production units in the power system to cover the demand (load).
- The ability of the transmission system to transport the power flows between the generator units and the consumers.

F. System stability is influenced by both voltage and frequency control.

All the previous mentioned aspects are subjective to the presence of the distributed generation units, which are referred as decentralized plants. Most of these plants bring uncertainties into the system as they are influenced by factors other than just the electricity demand – heat requirement in the case of cogeneration units and climatic conditions when it involves wind power plants. The additional demands for the system operator are, [3]:

- to adopt a probabilistic approach for managing the network;
- to foresee greater power flux flexibility between centralized and decentralized plants;
- to transfer most of the ancillary services to the centralized units;
- to review reactive energy compensation plans for voltage regulation;
- to ensure a clean network infrastructure to guarantee stability.

In order to increase the security of the power grid, interconnections were made between different networks around the world. Some of these networks are being used close to their stability and security limits due to economic constraints. Under these conditions, unavoidable disturbances such as short circuits, temporary outages or line losses can throw them outside their stability zone at any time. These big networks with their increased power flows are becoming very complex

to manage and coordinating their command and control systems is becoming problematic.
In this context, power companies in different parts of the world are therefore feeling the need for a real-time wide area monitoring system (WAMS). Network control using phasor measurements synchronized through satellites and spread over the entire network could become essential mainly to dampen the power swings between interconnected zones.

3. SCADA concepts

A SCADA control center performs centralized monitoring and control for field sites over long-distance communications networks, including monitoring alarms and processing status data. Based on information received from remote stations, automated or operator-driven supervisory commands can be pushed to remote station control devices, which are often referred to as field devices. Field devices control local operations such as opening and closing valves and breakers, collecting data from sensor systems, and monitoring the local environment for alarm conditions, [4].
Although SCADA is a widely used application in most industries, requirements within the electric utility industry for remote control of substations and generation facilities has probably been the driving force for modern SCADA systems.
Fig. 2 shows the components and general configuration of a SCADA system. The control center contains the SCADA Server (MTU) and the communications routers. Other control center components include the human machine interface (HMI), engineering workstations, and the data historian, which are all connected by a LAN. The control center collects and logs information gathered by the field sites, displays information to the HMI, and may generate actions based upon detected events. The control center is also responsible for centralized alarming, trend analyses, and reporting. The field site performs local control of actuators and monitors sensors. Field sites are often equipped with a remote access capability to allow field operators to perform remote diagnostics and repairs usually over a separate dial up modem or WAN connection. Standard and proprietary communication protocols running over serial communications are used to transport information between the control center and field sites using telemetry techniques such as telephone line, cable, fiber, and radio frequency such as broadcast, microwave and satellite.
The communication architectures are different depending on the implementation. Fig. 3 shows four types of architecture used: point-to-point, series, series-star, and multi-drop. Point-to-point is functionally the simplest type; however, it is expensive because of the individual channels needed for each connection. Series configuration reduces the number of channels used; however, channel sharing has

an impact on the efficiency and complexity of SCADA operations. The series-star and multi-drop configurations use one channel per device which results in decreased efficiency and increased system complexity.

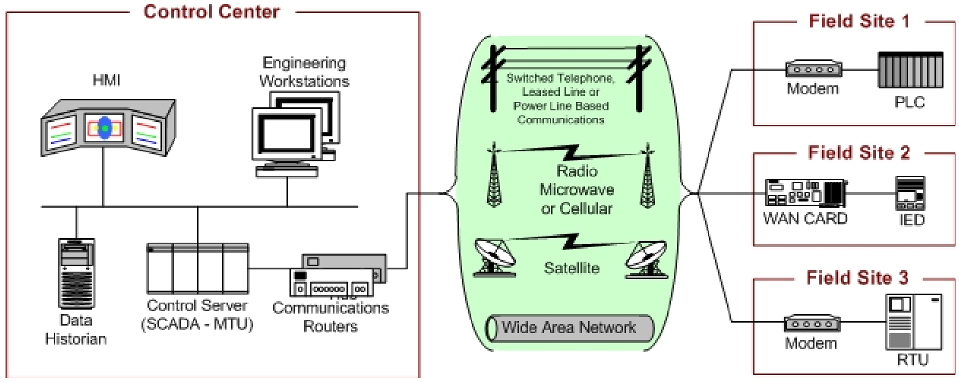

Fig. 2. SCADA architecture

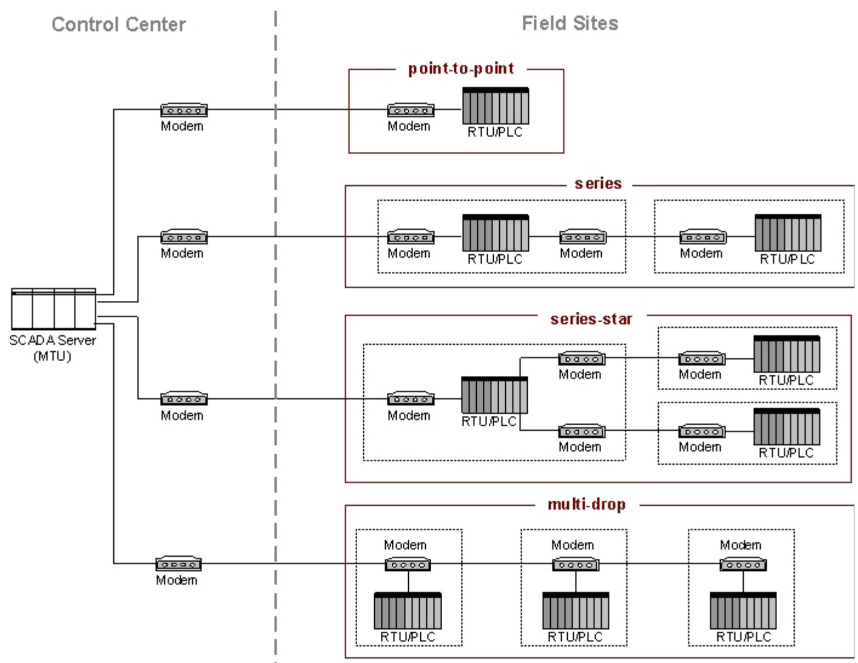

Fig. 3. SCADA Communication Topologies

For SCADA systems used in power grids there are specific demands (shown in chapter 2) that have to be accomplished (Fig. 4),[5]. Different SCADA implementations for power systems were described in literature, [6-9].

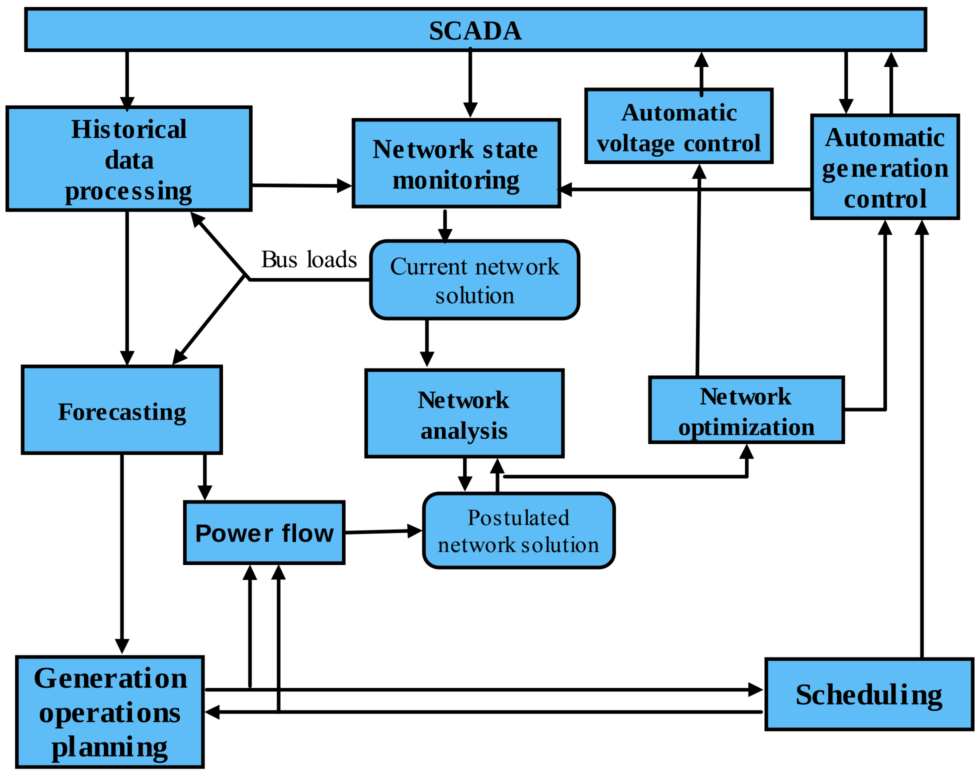

Fig. 4. SCADA functions in a power system

A detailed view of this functions is given below:

- *Supervisory control and data acquisition* - Supervises the status or the changes of breakers, connectors, and protective relays; induces of charged/uncharged status of lines and buses; supervises active/reactive power against operational/emergency limit; judges network faults;
- *State estimation and scheduling* - Estimates most likely numerical data set to represent current network;
- *Load forecasting* - Anticipates hourly total loads (24 points) for a few days ahead based on the weather forecast, type of day, etc. utilizing historical data about weather and load;

- *Power flow control* - Supports operators to provide effective power flow control by evaluating network reliability, considering anticipated total load, network configuration, load flow, and contingencies;
- *Data maintenance* - Enables operator to modify the database of power device status and network topology by defining parameters;
- *Voltage/reliability monitoring* - Monitors present voltage reliability and transient stability and predicts future status some hours ahead;

4. Wide area measurement systems

Wide area measurement systems consist of advanced measurement technology, information tools, and operational infrastructure that facilitate the understanding and management of the increasingly complex behavior exhibited by large power systems. A WAMS may be used as a stand-alone infrastructure that complements the grid's conventional supervisory control and data acquisition system. As a complementary system, a WAMS is expressly designed to enhance the operator's real-time information about the parameters status,as shown in [10-15]. This is necessary for a safe and reliable grid operation, [16].

Important parts in WAMS high-quality operation are the phasor measurement units (PMUs). These are devices which use synchronization signals from the global positioning system (GPS) satellites and provide the phasors of voltage and currents measured at a given plant, as shown in Fig. 5.

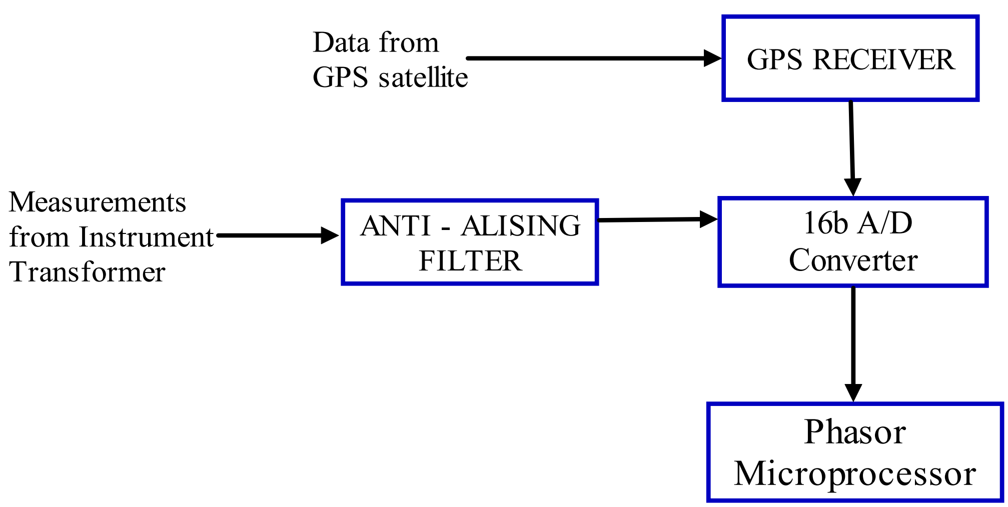

Fig. 5. Basic architecture of a PMU

A phasor is a mathematical representation of a sinusoidal waveform (Fig. 6), [17]. The magnitude A is either a peak or RMS value of the sinusoid. The phase angle θ is determined by the sinusoidal frequency and a time reference. This reference is arbitrary and is generally chosen to be convenient for the particular situation. *Synchrophasors* are phasor values that represent power system sinusoidal waveforms referenced to the nominal power system frequency and coordinated universal time (UTC), the international time standard. The phase angle of a synchrophasor is uniquely determined by the waveform, the system frequency, and the time of measurement. Thus, with a universal precise time reference, power system phase angles can be accurately measured throughout a power system, which brings a new perspective to the electrical power system monitoring.

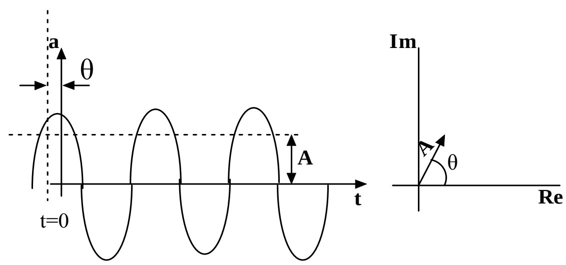

Fig. 6. Phasor representation of sinusoidal waveform

Most phasor measurement-based WAMS operate at 6–60 measurements/s, which is ideal for system dynamics measurement. A large quantity of information can be obtained at these rates using PMUs, so it should be employed for system monitoring. Fig. 7 shows a wide area measurement system using PMUs and phasor data concentrators (PDCs).

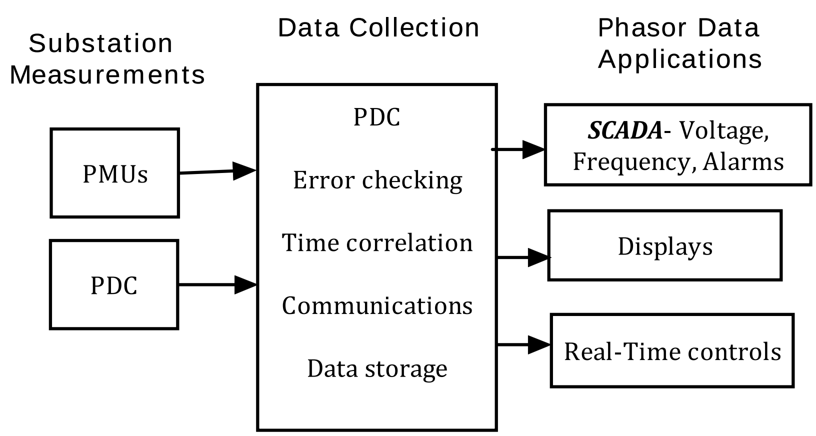

Fig. 7. Wide area measurement system using PMUs

PMUs are considered an important technology employed by WAMS. That is the reason why they are installed and tested in different countries around the world, as seen in [18-21] and used in applications such as real time system monitoring and post disturbance analysis.

In a general manner, the PMU applications (Fig. 8) can be divided into four main domains: state estimation, protection, supervision and network control. These sections are neither mutually exclusive nor exhaustive. In fact, a measurement given by a device for the state estimator can also be used for a machine control loop or FACTS.

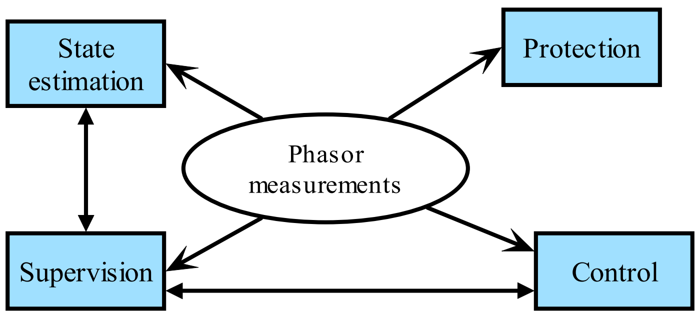

Fig. 8. PMU application domains

State estimation has become a critical application function for power and energy control centers. WAMS with phasor measurement avoids the problems of convergence and topology errors encountered with traditional estimation. The most commonly used phasor estimation is the discrete Fourier transform (DFT). This technique uses the standard Fourier estimate applied over one or more cycles at the nominal system frequency. With a sufficient sample rate and accurate synchronization with UTC, it produces an accurate and functional phasor value for most system conditions. There are problems with this approach, however, such as off nominal system frequency, limited data rates, and interfering signals and studies such as [22] discuss the possibility of overcoming these issues.

The main advantage of using synchronized measurements is improving the already installed *protection systems* in the networks. In opposition to the currently installed systems that operate in the time scale of seconds, it takes just a few milliseconds using synchronized measurements.

System control meets progress with the usage of synchronized phasor measurements, especially in an interconnected power system.

The introduction of phasor measuring units (PMUs) in power systems significantly improves the possibilities for *supervising power system dynamics*. A number of synchronized phasor measurement terminals, installed in different locations of a power system provides important information about different AC quantities e.g.voltages, currents,active and reactive power, all of them based on the same GPS time reference.

5. SCADA and WAMS for a reliable power system operation

For a reliable power system operation, the two monitoring systems (SCADA and WAMS) have to collaborate perfectly. Data from all the components of the grid are gathered using SCADA. A state estimator can be build in order to have a view of the real time performance, as shown in [23]. It influences all the functions involved in system's operation, as depicted in Fig. 9.

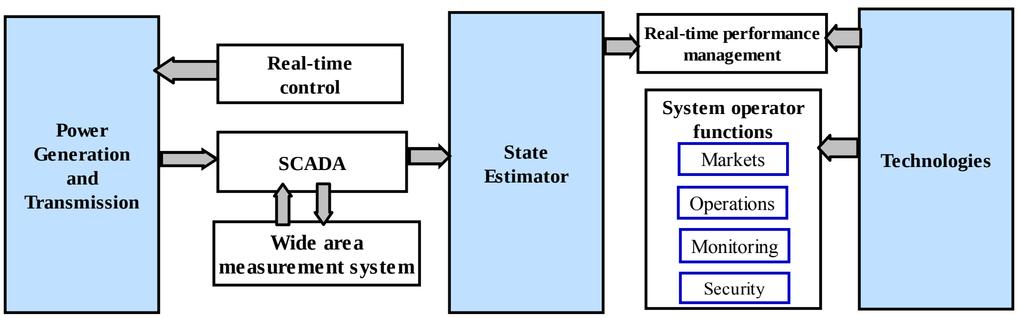

Fig. 9. Power system operation

State estimation, as a major function in any monitoring system, has shown an improved action with PMUs. Data across the interconnected electrical system is received synchronous in the state estimation center. Fig. 10 presents a hybrid SCADA/PMU system to show the interactions between these two systems,[24].

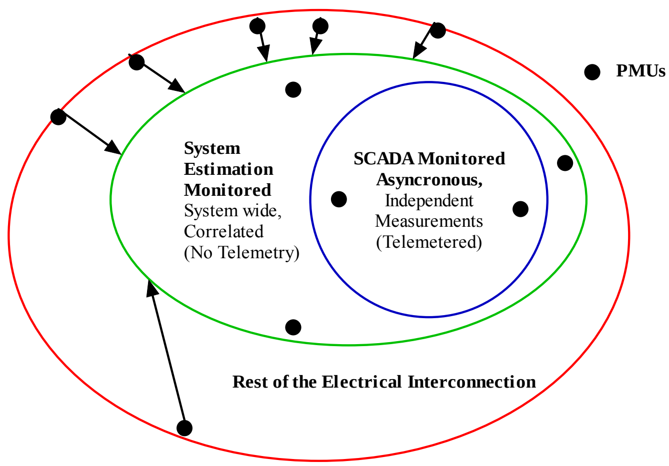

Fig. 10. Power grid monitoring

6. Conclusions

The given economic, social and quality-of-life aspects and the interdependencies among infrastructures call for a modern power grid with an upgraded SCADA system.

A continuous improvement of SCADA functions, mainly on the automatic voltage and generation control is imposed. Implementations of load frequency control, as a key component of the SCADA system in the Romanian Power System are shown in [26-31].

The energy management system/SCADA control center is the heart of the power system grid. Its main objective is to inform the system operator about the current state of the electrical grid and to recognize possible threats to the grid integrity. In order to avoid these risks, the state estimation function of SCADA needs to improve. One solution, presented in the paper, is the deployment of real-time phasor measurements. They can be exploited to provide greater power system reliability.

The usage of synchronized SCADA/PMU data is one of the most powerful tools for wide-area monitoring and control since it uses current system conditions to predict potential problems ahead of time.

R E F E R E N C E S

[1] *I. Fagarasan, S. St. Iliescu, N. Arghira*, Advances in Power System Control, Proceedings of the 1st Workshop on Energy, Transport and Environmental Control Applications, pp 62-71 ISBN 978-973-618-218-1, Targoviste, 2009

[2] *S. Chakrabarti, E. Kyriakides, T. Bi, D. Cai, V. Terzija*, Measurements get together, IEEE PEM, **Vol. 7**, no 1, 2009

[3] *M. Crappe*, Electric Power Systems 2nd Edition, John Wiley & Sons, Great Britain, 2009

[4] *K. Stouffer, J. Falco, K. Scarfone,* Guide to Industrial Control Systems (ICS) Security (Final Public Draft), USA, 2008

[5] *N. Vidal*, AGC Operator Training – Transelectrica project, Bucharest, 2005

[6] *D. Andone, D. Merezeanu,* Modern Power Plant Control Philosopies, Proceedings on the 12th International Conference on Control Systems and Computer Science, **vol. I,** pp 171- 177, Bucharest, 1999

[7] *D. Robescu, S.St. Iliescu, I. Catana, I. Fagarasan, s.a.*, Controlul automat al proceselor de epurare a apelor uzate, Ed. Tehnica, ISBN 978-973-31-2335-4, 388 pag,, Bucuresti, 2008

[8] Contract de cercetare AMCSIT 174/20.06.2006, CEEX - MODUL 1, Cercetări teoretice şi experimentale asupra sistemelor expert de exploatare optimă a proceselor tehnologice de epurare a apelor uzate din stațiile de epurare orăşeneşti şi industriale, 2006-2007

[9] *B.D. Guzun,* Hydro power storage complex, SCADA integrated, Maintenance of Numerical Protection and Control Systems Conference, Brasov, 2005

[10] *S. Skok, I. Ivankovic, R. Matica, I. Sturlic,* Multipurpose architecture model of phasor data concentrator, CIGRE 2010

[11] *M. Chenine, L. Nordstrom,* Performance Considerations in Wide Area Monitoring and Control Systems, CIGRE 2010

[12] *V. Terzija, D. Cai, A. Vaccaro, J. Fitch,* Architecture of wide area monitoring systems and their communication requirements, CIGRE 2010

[13] *B. Ayuev, P. Erokhine, Y. Kulikov,* Communications needs for different applications of IPS/UPS wide area measurements (WAMS), CIGRE 2010

[14] *F. Mahmoodianfard, M. Mohammadi, G.B. Gharehpetian, H. Askarian Abyaneh,* Optimal PMU Placement for Voltage Security Assessment using Decision Tree, Proceedings on 2009 IEEE PowerTech, ISBN: 978-1-4244-2234-0, Bucharest, 2009

[15] *A.M. Glazunova, I.N. Kolosok, E.S. Korkina,* PMU placement on the basis of SCADA measurements for fast load flow calculation in electric power systems, Proceedings on 2009 IEEE PowerTech, ISBN: 978-1-4244-2234-0, Bucharest, 2009

[16] *M.D. Hadley, J.B. McBride, T.W. Edgar, L.R. O'Neil, J.D. Johnson*, Securing Wide Area Measurement System", Contract DE-AC05-76RL01830, Richland, 2007

[17] *K.E. Martin, J.R. Caroll*, Phasor Measurement Devices and Systems for Wide-Area Monitoring, IEEE PEM, **vol.6**, no 5, 2008

[18] *N. Baranovic, A. Cernicki Mijic, J. Bujak,* Implementation of security management system in period of SCADA/AGC/EMS refurbishment in Croatian TSO, CIGRE 2010

[19] *C. Bruno, C. Candia, C. Franchi, G. Giannuzzi, M. Pozzi, R. Zaottini, M. Zaramella,* Possibility of enhancing classical weighted least squares State Estimation with linear PMU measurements, Proceedings on 2009 IEEE PowerTech, ISBN: 978-1-4244-2234-0, Bucharest, 2009

[20] *M. Chenine, K. Zhu, L. Nordström,* Survey on Priorities and Communication Requirements for PMU-based Applications in the Nordic Region, Proceedings on 2009 IEEE PowerTech, ISBN: 978-1-4244-2234-0, Bucharest, 2009

[21] *N. Chiosa, N. Pantazi, B. Luştrea, I. Borlea, C.Barbulescu, D.M. Paunescu,* Aspecte esenţiale ale introducerii sistemului de măsurare a sincrofazorilor în sistemul energetic naţional (Synchrophasor measurement system implementation in the national power system – essential aspects), Proceedings on the 7th International Power Systems Conference, ISSN 1582 – 7194, pp 158-166, Timisoara, 2007

[22] *N.H. El-Amary, Y.G. Mostafa, M.M. Mansour, S.F. Mekhamer, M. A.L. Badr,* Measurement Units' Allocation in Unified Electrical Power Network of Egypt , Proceedings on 2009 IEEE PowerTech, ISBN: 978-1-4244-2234-0, Bucharest, 2009

[23] *C. Martinez, H. Huang, R. Guttromson,* Archiving and Management of Power Systems Data for Real-Time Performance Monitoring Platform, Consortium of Electric Reliability Technology Study, 2005

[24] *J.S. Thorp, A. Abur, M. Begovic, J. Giri, R. Avila-Rosales*, Gaining a wider perspective, IEEE PEM, **vol.6**, no 5, 2008

[25] *N. Arghira, I. Dumitru, I. Fagarasan, S.St. Iliescu, C. Soare,* Load Frequency Regulation in Power Systems, Proceedings of 2010 Int. Conf. on Automation,Quality and Testing, Robotics, ISBN 978-1-4244-6722-8, pp 94-99, Cluj, Romania, 2010

[26] *N. Arghira, I. Fagarasan, C. Soare, S.St.Iliescu,* Generation Units Models for Load Dispatch Simulator, Proceedings on the IFAC Large Scale Systems: Theory and Application, ISBN: 978-2-915-913-26-2, Lille, 2010

[27] *I. Fagarasan, S.St. Iliescu, C. Soare, D. Ilisiu, F. Biliboaca, N. Arghira,* Power Generation Unit Models for Load Frequency Control Simulator, Proceedings of the 17th Int. Conf. Control Systems And Computer Science, **vol. 2** , pp.147-153, Bucureşti, 2009

[28] *I. Fagarasan, S.St. Iliescu, C. Soare, N. Arghira,* Modelling of Generation Units for Power System Control, Annals of DAAAM for 2009 & Proceedings of the 20th International DAAAM Symposium, ISBN 978-3-901509-70-4, ISSN 1726-9679, pp 1383-1384, Vienna, Austria, 2009

[29] *S.St. Iliescu, I. Fagarasan, C. Soare, V. Popescu,* Gas Turbine Modelling for Load-Frequency Control, Scientific Bulletin, University POLITEHNICA Bucharest, Series C: Electrical Engineering, **vol. 70**, nr. 4, ISSN 1454-234X, 2008

[30] *S.St. Iliescu, I. Fagarasan, C. Soare, D. Ilisiu, F. Biliboaca,* Process modelling for Load Frequency Control in power systems, Proceedings on 2009 IEEE PowerTech, ISBN: 978-1-4244-2234-0, Bucharest, 2009.