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Subject: Power System II

Unit: IV

Topic: All topics

Syllabus covered: Overview of Energy Control Centre Functions: SCADA systems. Phasor Measurement Units and Wide-Area Measurement Systems. State-estimation. System Security Assessment. Normal, Alert, Emergency, Extremis states of a Power System. Contingency Analysis. Preventive Control and Emergency Control.

1. Topic: <u>Overview of Energy Control Centre Functions</u>

The energy control center (ECC) has traditionally been the decision-center for the electric transmission and generation interconnected system. The ECC provides the functions necessary for monitoring and coordinating the minute-by-minute physical and economic operation of the power system. The main task of ECC is to control the energy rather than the power. Here monitoring is of main concern i.e. matching of energy at consumer side with the total energy generated on the generation side. In order to have an efficient power system operation and control, various control centers have to be operated in a hierarchical manner. Table-1 shows the level decomposition of control centres in the power system. There are 4 types of control centers. i) Local Control Centre ii) Area Load Dispatch Centre iii) State Load Dispatch Centre iv) Regional Control Centre.

Table-1. Level Decomposition of Control Centers

Level	System	Monitoring & Control
First	Generating stations, Substations	Local Control Centre
Second	Sub transmission & Transmission Network	Area Load Dispatch Centre
Third	Transmission System	State Load Dispatch Centre
Fourth	Interconnected Power Systems	Regional Control Centre

These are run in an off-line or via a remote terminal linked to a large computer center.

1.1 Local Control Centre: A number of control functions are performed locally at the power stations and substations. The typical controls carried in the local control center are:

- Load Monitoring and Control
- Protection, Circuit Breaker to re-close
- Voltage Regulation
- Capacitor Switching
- Feeder Synchronization
- Load Shedding
- Network Restoration and Network Re-configuration etc.

1.2 Area Load Dispatch Centre: In this, groups of generating stations or substations control are carried out. This requires system data a network topology for control. The area control center receives information and processes for appropriate control actions.

1.3 State Load Dispatch Centre: In this center, all the information is received from area load dispatch center and local centers. Then minute-to-minute operation of the power system at the state level is carried out. It may have the following functions,

- System Generation and Load Monitoring and Control for Demand Control.

- System wide State Monitoring and Control
- Circuit Breaker Condition Monitoring and Control
- Load Shedding and Restoration
- Supervisory Control for Transmission Lines and Equipment.
- System Alarm Monitoring and Corrective Actions.
- Planning and Monitoring of Power System Operation

1.4 Regional Control Centre: The Regional Load Dispatch Centre may be regarded as a coordinating and monitoring center for state level load dispatch center with covering main objectives:

- Integrated Operation of State Level Dispatch center
- Operation and Maintenance Schedules for maximum capacity Utilization
- Operation and Maintenance Schedules for Generating Plants
- Monitor and Control of inter-state Power Transactions
- Monitor and Control of inter-regional Power Transactions

Components of Energy Control Centre

The system control function traditionally used in electric utility operation consists of three main integrated subsystems: the energy management system (EMS), the supervisory control and data acquisition (SCADA), and the communications interconnecting the EMS and the SCADA (which is often thought of as part of the SCADA itself). Figure 1 provides a block diagram illustration of modern Energy management system comprising of Initial load forecast and scheduling, SCADA, Security assessment and analysis; and finally, the optimal power flow/constrained economic dispatch.

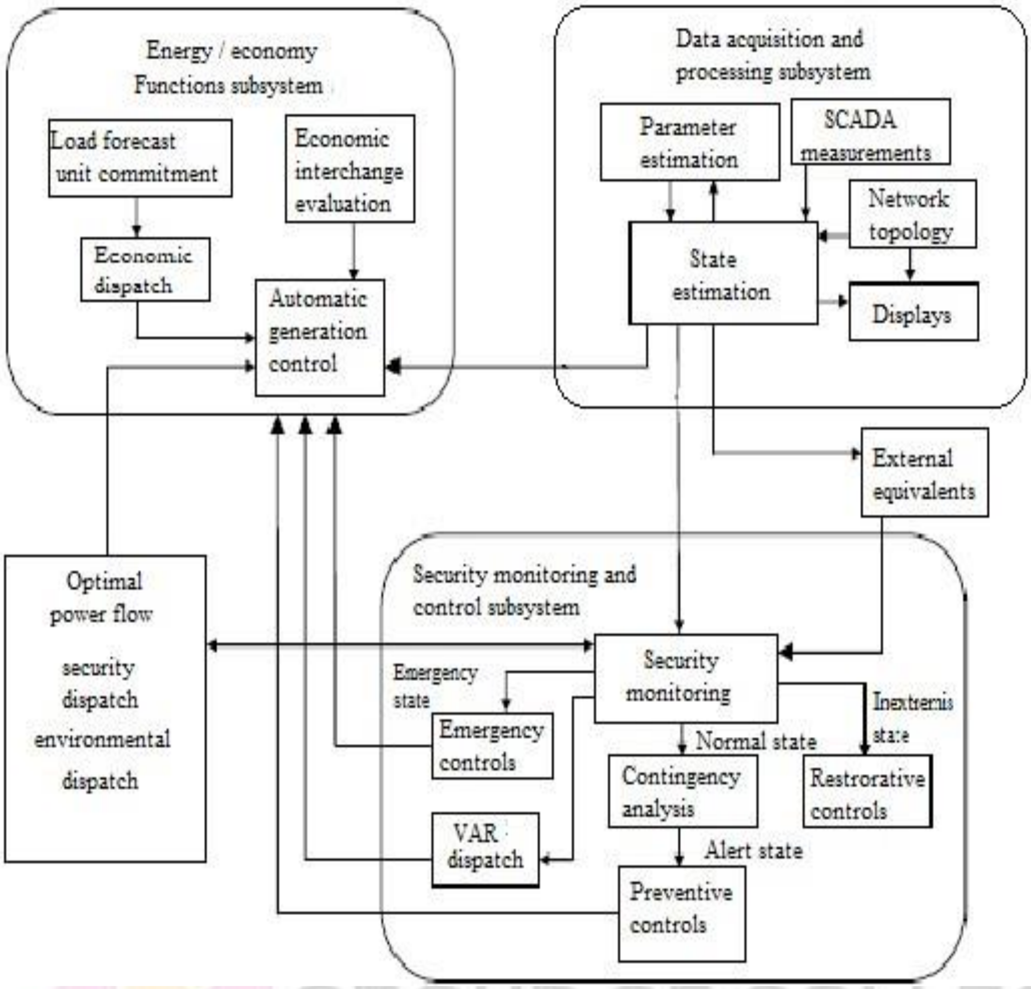
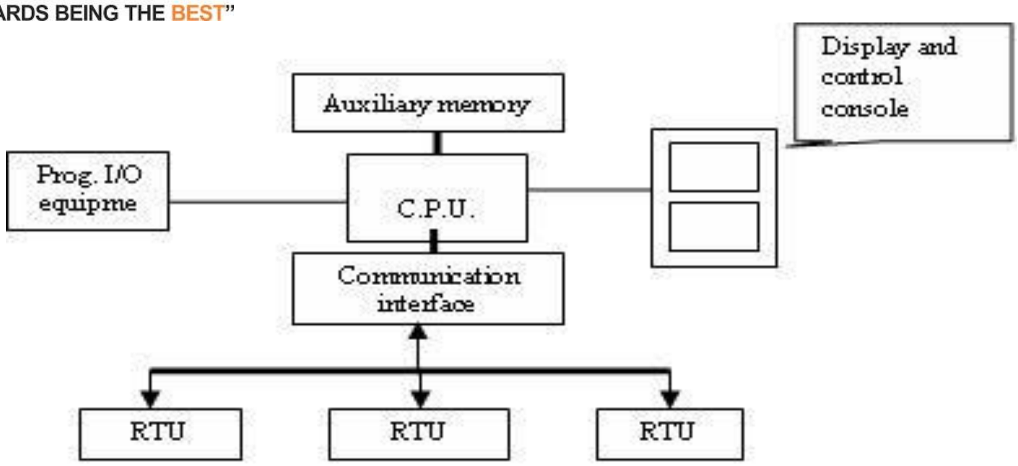


Figure 1: Functional Diagram of a Modern Energy Management System

2. Topic: SCADA systems

Today's Supervisory control systems normally consist of a computer system and a number of remote terminal units (RTUs), located in the power stations and substations. Communications between the RTUs and the computer usually take place via radio links or via power line carrier equipment. The computer serves the personnel in the control centre by presenting information about the current status of the power system and by passing on manually initiated control actions. Automatic control is used for different sub functions, e.g. sequential control and control of the network frequency. Video display units and keyboards are normally used for the man machine communications. In addition, map boards; printer and analog recorders are installed as required. Major supervisory control systems generally consist of several energy control centres, which cooperate in a hierarchical configuration as shown below.



Simple SCADA system with single computer

SCADA (Supervisory Control and Data Acquisition) comprises of two parts namely:

- Supervisory control: This indicates that the operator, residing in the energy control centre (ECC), has the ability to control remote equipment. For example, relays located within the RTU, on command from the ECC, open or close selected control circuits to perform a supervisory action. Such actions may include, for example, opening or closing of a circuit breaker or switch, modifying a transformer tap setting, raising or lowering generator MW output or terminal voltage, switching in or out a shunt capacitor or inductor, and the starting or stopping of a synchronous condenser.

- Data acquisition: This indicates that information is gathered characterizing the state of the remote equipment and sent to the ECC for monitoring purposes. For example: Information gathered by the RTU and communicated to the ECC includes both analog information and status indicators. Analog information includes, for example, frequency, voltages, currents, and real and reactive power flows. Status indicators include alarm signals (over-temperature, low relay battery voltage, illegal entry) and whether switches and circuit breakers are open or closed. Such information is provided to the ECC through a periodic scan of all RTUs. A 2 second scan cycle is typical.

The basic functions in a supervisory control system consist of

- Acquisition from the power system of telemetered data, indications and other variables
- Simple arithmetic and logic operations on these variables. e.g. calculations of the variables e.g. calculation of the apparent power P 2 +Q2 Where P & Q are telemetered values.

- Supervision of acquired and calculated variables with respect to changes and violation of limit values.
- Storage of current variables for sequent use. e.g. in trend curve daily reports
- Presentation of acquired calculation, stored variables on video display units and other media.

These variables may be presented in the form of one line diagram or curves

- Transmission of commands to RTUs.

Systems incorporating primarily these basic functions are traditionally called SCADA (Supervisory Control and Data Acquisition) systems. A characteristic feature of these systems is that they treat individual variables, which corresponds to transducers and actuators in the process. This means that the system doesn't need models of the power system as such. A SCADA system can consequently be built up to a large extent from standard software, which is not dependent on the fact that the process being treated involves a power system. Combining the variables available in a SCADA system with a model of the power system makes it possible to introduce functions that handle the power system and its components instead of individual measuring points.

3. Topic: Phasor Measurement Units and Wide-Area Measurement Systems.

3.1 The Phasor Measurement Unit (PMU): PMU is a microprocessor-based device that uses the ability of digital signal processors in order to measure 50/60Hz AC waveforms (voltages and currents) at a typical rate of 48 samples per cycle (2400/2880 samples per second). PMUs are used in the transmission side of the grid. These are installed at various places on the grid and are time synchronized using Global Positioning System (GPS). Thus, synchronised real time measurements are obtained from multiple measurement points on the grid.

PMUs provide power system automation in the grid: First, the analog AC waveforms are synchronously sampled by an A/D converter for each phase. In order to provide synchronous clock for the entire system, the time from GPS satellites are used as input for a phaselock oscillator and thereby, waveforms of the entire system are sampled with 1 microsecond accuracy. In the next step, PMU uses digital signal processing techniques to calculate the voltage and current phasors. Also, line frequencies can be calculated by PMU at each site. By using this technique, a high degree of resolution and accuracy can be achieved. The measured phasors are tagged by GPS time stamps and are transmitted to a PDC (Phasor Data Concentrator) at the rates 30-60 samples per second. A network of PMUs is called Wide Area Measurement System (WAMS) that can be used for large scale monitoring of the grid.

3.2 **Wide Area Measurement Systems (WAMS):** A general definition of WAMS may be presented as follows: "The WAMS combines the data provided by synchrophasor and conventional measurements with capability of new communication systems in order to monitor, operate, control and protect power systems in wide geographical area". A WAMS process includes three different interconnected sub-processes: data acquisition, data transmitting and data processing. Measurement systems and communication systems together with energy management systems perform these sub-processes, respectively. In general, a WAMS acquires system data from conventional and new data resources, transmits it through communication system to the control centre(s) and processes it. After extracting appropriate information from system data, decisions on operation of power system are made. Occasionally, WAMS may command some actions that are performed by system actuators in remote sites. WAMS in general provides efficient usage of data and data flow to achieve a more secure and a better strategy for the flow of electrical energy.

4. Topic: State-estimation (SE)

The state estimator is a program that receives the SCADA measurement information and then uses statistical procedures to obtain the very best estimate of the actual state of the system. The result of state estimation is a power flow model that can be used for security assessment.

4.1 Importance/need for state estimation: Given the topology of the system, it still remains to determine the operating conditions, i.e., the bus voltages, load levels, and generation levels. At first glance, this appears to be an easy problem – just take the corresponding information from the SCADA. However, one must recognize the reality of data unavailability and of data error.

- Data unavailability comes from two sources. First, there may be some substations that have no SCADA. Second, there may be some substation RTUs or telemetry systems that are unavailable due to maintenance or unexpected trouble.
- Data error comes from the fact that all analog measurement devices contain some measurement error. Typically, this error is small for any single device, but the use of many thousands of devices, each having small error, can result in significant inaccuracy in regards to the overall system analysis.

The measurement set obtained using state estimation is understood to contain an adequate degree and spread of redundancy to allow the statistical correlation and correction of the measurements detect and preferably identify bad data, and yield calculated values for nontelemetered quantities. The measurement set consists of active and reactive line flows, bus injections, and voltage measurements. The SE runs every minute using the last set of measurements which are scanned every second. In addition, SE is started whenever there is a network change.

The purpose of the SE is to obtain the vector of bus injections; check for abnormal metering errors. The vector of bus injections is then used by a Newton-Raphson on-line load flow for security analysis and for determining closed-loop corrective control for certain line outages. Bad data detection is based on the value of the sum of the squared residuals, i.e., the performance index, J. After two consecutive failures of the J-test, procedures are initiated for bad data identification based on the estimation cycle. If this still fails after a few attempts, a logic procedure is initiated for determining network model errors.

Important features of State Estimation:

- SE runs every 15 minutes or on request for major system changes.
- The most important aspect of state estimation is bad data identification. The bad data detection is based on the performance index J. The measurement set consists of real and reactive power flows, real and reactive bus injections and bus voltages. This data

is available to companies whose lines are represented in the SE model. This alone could be a worthwhile justification for including state estimation in a system control centre.

- The purpose of the SE is for security monitoring and for security analysis of the power system.
- The results of the SE are used for security monitoring and the operator is informed of overloads or other critical conditions.
- The SE results are stored in a historical file for a (7-day) particular period.

Briefing: Some important words/phrases Power

System Security:

What is meant by power system security?

Ans: The power system needs to be secured, we need to protect it from the black out or any internal or external damage. The operation of the power system is set to be normal only when the flow of power and the bus voltages are within the limits even though there is a profitable change in the load or at the generation side. From this we can say that the security of the power system is an important aspect with respect to the continuation of its operation.

2. What are the two functions of security?

Ans: Security function are of two type as follows:

Security control: - It determines the exact and proper security constraint scheduling which is required to obtain the maximized security level.
Security assessment: - It gives the security level of the system in the operating state.

5. <u>Topic: System Security Assessment. Normal, Alert, Emergency, Extremis states of a Power System</u>

Power system security assessment is the assessment of the operating network in a manner so as to identify the possible failure/s that may occur in the system, its consequences and its remedial actions.

The power system may be assumed as being operated under two sets of constraints: load constraints and operating constraints. The load constraints impose the requirement that the load demand must be met by the system. The operating constraints impose maximum or minimum operating limits on system variables and are associated with both steady state and stability limitations. Mathematically, the load constraints can be expressed in the form of the familiar load flow equations. The operating constraints can be expressed in the form of inequalities such as an equipment loading, bus voltage, phase angle differences, generator real and reactive powers etc. The operating conditions of the power network can then be categorized into three operating states (refer Fig 1):

- Normal (or Preventive) State
- Emergency State
- Restorative State

5.1 Normal state: A system is in the **normal state** when the load and operating constraints are satisfied. It is reasonable to assume that in the normal state the power system is in a quasisteady-state condition. For any given time, the intersection of the load constraints and the operating constraints defines the space of all feasible normal operating states. The power system may be operated anywhere in this space.

A normal operating point can be classified as being either secure or insecure with reference to an arbitrary set of disturbances or next contingencies. A normal system is said to be secure, i.e. at a secure operating point, if it can undergo any contingency in the next-contingency set without getting in to an emergency condition. On the other hand, if there is at least one contingency in the next-contingency set which would bring about an emergency, the normal system would be called insecure or in an **alert state.**

5.2 Emergency State: A system is in the **emergency state** when the operating constraints are not completely satisfied. Two types of emergency may be noted. One is when only steady state operating constraints are being violated, e.g. an equipment-loading limit is exceeded or the voltage at a bus is below a given level. The other is when a stability operating constraint is violated and as a result of which the system cannot maintain stability. The first type of emergency may be called "Steady State emergency" and the second type, "dynamic emergency".

5.3 Restorative State: A system is in the **restorative state** when the load constraints are not completely satisfied. This means a condition of either a partial or a total system shutdown. when the extreme emergency **(extremis state)** comes into action there is occurrence of extreme disturbance. That is If the emergency control actions also fail, the system may enter extremis state which is characterized by disintegration of the entire system into smaller islands, or a complete system blackout. In this case the power system is in up stable state and may lead to shutting down of the major parts of the power system. Control action should be powerful such that the shedding of the load of the unimportant load are needs to be done. In case of a partial shutdown the reduced system may be in an emergency state. This is the start of a cascading situation and, if uncorrected, would lead to a further deterioration of the system.

6. Topic: Contingency Analysis. Preventive Control and Emergency Control.

For a power system to be secure, it must have continuity in supply without a loss of load. For this security analysis is performed to develop various control strategies to guarantee the avoidance and survival of emergency conditions and to operate the system at lowest cost. Whenever the pre specified operating limits of the power system gets violated the system is said to be in emergency condition. These violations of the limits result from contingencies occurring in the system.

6.1 Contingency: It is the unexpected failure of a transmission line, transformer, or generator. Usually, contingencies result from occurrence of a fault, or short-circuit, to one of these components. When such a fault occurs, the protection systems sense the fault and remove the component, and therefore also the fault, from the system. Of course, with one less component, the overall system is weaker, and undesirable effects may occur. For example, some remaining circuit may overload, or some bus may experience an undervoltage condition. These are called static security problems. Dynamic security problems may also occur, including uncontrollable voltage decline, generator overspeed (loss of synchronism), or undamped oscillatory behaviour.

6.2 Contingency analysis technique is being widely used to predict the effect of outages like failures of equipment, transmission line etc, and to take necessary actions to keep the power system secure and reliable. The contingency analysis is divided into three different stages

- **Contingency definition** – It comprise of set of contingencies that occur in the power system.

- **Selection** – The process of identifying the contingencies that actually leads to the violation of the operational limits is known as contingency selection. Thus, this process removes the unimportant contingencies and hence the contingency list is shortened.

- **Evaluation** – In this process it involves the necessary security action or control to function in order to remove the effect of contingency**.**

6.3 Preventive Control and Emergency Control

The first function of security analysis (SA) is to determine whether the normal system is secure or insecure. The second function is to determine what corrective action strategy should be taken when the system is insecure. The first function commonly classifies under contingency definition and selection since, by definition, the security of a system is determined with reference to a set of next contingencies. The second part of security analysis is "Corrective Action Strategy". whether the system would respond in an acceptable manner and reach an acceptable state following any one of a pre-defined contingency set. That is, if the system is insecure, can it be made secure? If so, how and at what cost? Conditions improve? Suppose the system is now insecure and there is no way of making it secure, how much load would be shed.

6.3.1 Preventive Control: If a system operator infers from the operating data that a system is in an alert state, then he takes preventive control actions to bring the system back to a normal state. If the state is normal, then a system operator may wish to do some minor changes in real and reactive scheduling (from an economic perspective), if such flexibility exists. However, if any such change cannot bring the system out of the secure state, the system is not secure (alert), then the operator has to try to steer it into the secure state by real or reactive power rescheduling (Preventive Control). However, re-scheduling is only done to improve security and may result in higher cost if cheaper generators are asked to "back down" their generated power while costlier ones are ramped up. Therefore, even if preventive control is to be done, it should be done in a way which will minimize any cost increase while simultaneously ensuring security.

6.3.2 Emergency Control: If a system operator infers from the operating data that a system is in an alert state, then he takes preventive contrl actions to bring the system back to a normal state. However, it is possible that the system operator is unable to act in time before a contingency actually occurs or a grid may even operate insecurely (in an alert state) due to high cost of preventive control or due to inadequate reserve margins. In such situations, a system in an alert state may cascade into an emergency and subsequently into a total blackout if no control actions are taken. Emergency control measures can be used to retrieve such situations. Since most equipment can withstand a short-time thermal overload, there is a small window of time in which some manual emergency measures can be executed. For other emergency situations (like instability), time may be too short and predesigned automatic emergency measures are necessary. Some emergency control actions that can be taken are:

- Control of generation (reducing or increasing as per requirement).
- Tripping of generation or load shedding.
- Control of voltage and Re-routing of power flows.

What is meant by corrective rescheduling?

It is basically defined as the measures taken to avoid the faults after it has occurred i.e.to isolate the defective fault from the non-faulty part of the power system and then further rectify the fault. After the rectification of the fault in the power system it is then restored in the power system from where it was isolated.

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Assignment

My dear students, as the topic/s which we have covered in this section require your inquisitive imagination for a clear understanding; you all are required to explain the questions given below using illustrations of an operational power system giving all operational conditions and constraints needed to justify your answers.

Q 1. *Use an example of an operational power network to effectively describe the normal, alert and emergency operating states in a power system clearly defining the condition/s and changes in the output under which the given state are observed to occur.*

Q 2. Using only individual blocks (individual block sub process configuration as shown in Fig 1 is not required) connect the following blocks to give an overview of the software functions used in an energy management system - power system, network topology, state estimation, contingency analysis, EDC (Economic Dispatch Calculations), AGC (Automatic Generation Control) and load forecast and control room.

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