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Power System Security and Optimum Load Flow

Definition — Significance — Case studies — Monitoring — EMS software functions — Alarm conditions — Action by operator — Contingency Analysis — Optimum Load Flow — Summary — Conclusions.

55.1. POWER SYSTEM SECURITY

"The ability of a power system to operate in normal state even with occurrence of specified contingencies" is called power system security. Ref. Sec. 50.9.

Another definition of power system security is *"the ability of the power system to keep operating in stable condition during and after specified failures without cascade tripping and overall blackout"*.

Failures of equipment in power system cannot be eliminated completely. The principle reasons of failures are insulation failure, auxiliary failure, equipment failure, mechanical failure, thermal overload failure etc.

Protection and switchgear are arranged to take the faulty equipment out of service quickly and automatically. However, such an action invariably results in diversion of power flow through remaining healthy paths resulting in their overloading and likely tripping due to overloads. Failures and isolation of a faulty equipments result in overloading of adjacent *healthy equipment.* The overload protective relays of these healthy adjacent equipment are set for overload protection of respective equipment. Hence without security measures, the adjacent healthy parts may also trip. Hence overloads in healthy parts of the system must be quickly eliminated by appropriate operating means at the disposal of control operator. For this the overload must be quickly diverted to other paths which are underloaded.

The control room operators decisions affect the further course of events as seen from the following case studies.

Case 1 : Tripping of a Generating Unit (single outage).

When the generator unit is taken out of service, the remaining generators in parallel must take up the overloads due to the loss of generation. However, if there is insufficient remaining generation, the frequency drop can be of so severe that recovery is impossible. Operators must therefore be sure to commit enough generation so that the loss of any generating units will still leave enough generating capacity to restore the frequency safely.

Case 2 : Tripping of a Transmission Line (single outage)

When a transmission line trips, the current flowing through it will redistribute on the remaining adjacent circuits. If the new load flows on the remaining circuits cause one or more of them to be over-loaded, their relay protection will operate, resulting in further more redistributions of currents. This process, if it continues, is called *a cascading failure* and can result in a blackout on large parts or all of the system.

A large scale blackout occurred in USA and Canada during Nov. 1964 due to a similar cause.

55.2. PURPOSE OF SECURITY ANALYSIS

Primary purpose of 'Power System Security' is to keep the power system operation continuing such that failures do not lead to cascade trippings and overall blackout. Time available to ensure, appropriate actions is limited. Control room operator must take advance actions such that the system security is not lost during a single failure. Contingency analysis indicates which actions are to be taken by the operator in advance.

To achieve high power system security the control room should-have data collection system and computerised power system security analysis program software. Such system are called Energy Management Systems (EMS).

55.3. EMS CONFIGURATION AND SECURITY ANALYSIS

An EMS generally has a *Centralised* Digital Computer System connected to Remote Terminal Units (RTUs) *via* communication channels. The computer software includes a variety of programs (Fig. 50.6).

Various types of Data is collected periodically from various parts of the system. Data includes status *on/off*, Analog Measurements (AM) ; MW flow, MVA flow, Bus kV etc from various power stations and substations. Such data are *monitored* with the help of computer system. When the quantity tends to go beyond safe limits, alarm is sounded in the control room indicating the position of likely trouble. The control room operator sends commands to respective substation or generating station to take appropriate action *e.g.* open/close certain circuit-breakers ; increase/decrease MW ; change Tap-position ; Switch-in/off shunt capacitors etc. Such commands are sent *via* communication channel *e.g.* Power Line Carrier , Microwave, Telephone Wire, Fibre-optic cables etc.

The Control Room Operator takes various types of actions to maintain adequate power system security.

Table 55.1
Actions by Control Room Operator for Maintaining System Security

Action by Operator	*Variables to be adjusted*
Generation commitment	Generator on/off status
Generation dispatch	Generator megawatt output schedule
Generator bus voltage	Unit exciter setting
Network configuration	Substation circuit breaker open/close
Load shedding	Distribution feeder circuit breaker
On-Load tap changing transformer	Tap position
Phase-shift transformer	Tap position
Tie-line system interchange	Interchange schedule

55.4. POWER SYSTEM MONITORING AS ESSENTIAL PART OF SECURITY IMPROVEMENT

Power system monitoring is an essential part of maintaining system security. Monitoring System has several software programs. Ref. Fig. 50.6 and Table 55.2.

Courtesy : Modern Power Systems.

Table 55.2
Power System Monitoring Functions in EMS Software (Fig. 50.6)

Function	*Function performed*
Data acquisition	To process message from RTUs To check analogue measurements against limits To check status values against normal value To send alarm conditions to alarm processor
Alarm processor	To send alarm messages To transmit messages according to priority
Status processor	To determine status of each substation for proper connection To determine status of network for equipment out of service, islanding, To send alarm messages to alarm processor
Reserve monitor	To check generator megawatt output on all units against unit limits To send alarm if insufficient reserves
State estimator	To determine system state variables using measured values and network model To detect presence of bad measured values To identify location of bad measurements To initialize network model for other application programs

Sec. 46.3 describes the Data Acquisition System and Table 46.3, 4 give the data to be monitored from control room.

The first job of control room operator responsible for system security is monitoring the system. (Ref. Sec. 25.6.2.) The values of substation and power station variables are scanned periodically and are transmitted to the EM system through the RTUs and note is taken of any out-of-limit or other unusual conditions. However, with thousands of status and analog values, this is a humanly impossible task and is therefore usually handled by *the computer system.* Each value is checked as it comes into the system. Changes in status and out-of-limits analog values are brought to the operator's immediate notice through *alarm messages* on the console displays.

The abnormal or unusual values are known to the control room operator through EM system.

The functions incorporated in the monitoring system of EM software are listed in Table 55.3.

Table 55.3. Important Programs in the EMS Software for Improving Power System Security (Ref. Fig. 50.6).

Software	*Description*
Alarm Processing	Part of monitoring system. Alarms are given in advance so that operator can take advance action to improve security.
Topology Processor (Status Processor)	Identifies of prevailing network configuration (topology) as to which units and lines are connected.
State Estimator	Calculates on the basis of mathematical model of prevailing network. Results can be compared with actual data to identify bad measurements
Contingency Analysis	Calculates effect of hypothetical outage on the system security
Performance Monitor	Monitors performance and suggests improvements

55.5. SOFTWARES IN ENERGY MANAGEMENT SYSTEM

For achieving maximum security, several programs are available in the EM software for the control room operator.

Table 55.3 gives a list.

Fig. 50.6 gives the block diagram. Some blocks are described below.

55.5.1. Alarm Processing

When some of the variables in power stations or substations are out-of-limit, the operator gets corresponding *alarm message.*

The operator receives the alarm signals. By virtue of past experience and human reasoning, the control room operator determines the cause of trouble and takes appropriate follow-up action to ensure system security.

The knowledge of single alarms by themselves is often insufficient, and the operator must be able to draw conclusions from knowing the *status* and values of many other *variables.* In the case of breaker status values, the operators are provided with *one-line display diagrams* have graphic indications of breakers, busbars, switches, transformers, etc. Further, the breaker positions are shown so that a quick accurate assessment of a switching action can be obtained by looking at the display.

Table 55.4. Alarm Indications in Monitoring System

Monitored Quality	*Alarm indication and Sounding*
Voltages of buses	Bus kV above/below limit
Load flow through lines	Megawatt, MVA, MVAr, I above/below limits.
System frequency	Above/below target limits
Load	MW, MVAr above limit
Load shedding equipment	Load/shed/load restore/Islanding
Generator status	On/off line
Generator unit	MW, MVAr, kV above limit
Network transformers	Temperature above or below limit
Tele-communications channel to RTU	Normal/failure
Protective relay communication channel	Normal/failure
Circuit-breaker status	Open/close
Circuit-breaker (SF_6)	Normal/low pressure

55.5.2. Topology Processor. (Status Processor)

When a switching action affects more than one substation, the computer system can analyze the transmission system network using a topology processing program (Fig. 50.6). This program requires a complete description of the transmission system stored in the computer. When supplied with the telemetered status values, the status processor analyzes the topology of each substation and then the entire network to see which buses are connected together and which lines are in service and whether the system is connected or has been switched into electrical islands. Often the output of the status processor is sent to indicators on large graphic diagrams of the electrical system placed on a wall in the control room.

Reserve Monitor

Another information required by the control room operator for maintaining system security is the generation reserves.

Energy Management System has a program which calculates the generation reserves and compares this amount to established reliability criteria. The reserve monitoring program *provides* the operator with a display of present reserves as well as gives alarm messages when insufficient reserves are reached.

55.5.3. State Estimation Program

The software of Energy Management System includes state Estimation Program. The principle of state estimation has been described in Sec. 50.10.

The actual measurements may be doubtful due to errors in transducers, poor data transmission etc. The operator has to depend within the framework of such doubtful measurements. Sometimes, the telemetry fails and the operator has to depend on estimated values. State Estimation Program provides such values to the control room operator/EM system. The state estimator takes a *mathematical model of the power system* using the output of the *status processor* plus measured *analog values* and calculates a *best estimate* of the state variables for the system. The basic state variables are the voltage magnitudes and phase angle at each bus in the network. If there are more measured values than states, the quality of the estimate improves. Once the voltage magnitude and phase angle are available, the state estimator can calculate the load flows in all transmission lines in the network. In addition, if sufficient redundant measurements are available, the presence of a doubtful measurement can be detected and identified so that repair action can be taken. The state estimator uses the mathematical model of the prevailing system. Hence it also provides base for modelling contingencies.

55.5.4. Contingency Analysis (Security Analysis)

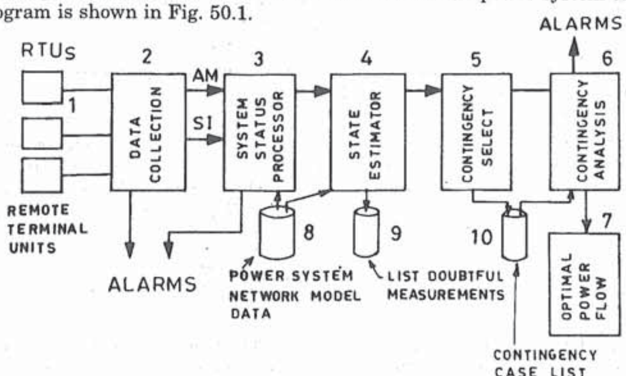
Refer Sec. 50.9.1. During one or two failures, the system security should not be lost. However, in modern networks the time available to control room operator is too short to take corrective actions immediately. Many problems occurring on power system cannot be corrected quickly and system security is difficult to be maintained unless the operator takes advance actions.

Contingency Analysis or Security Analysis refers to the process of studying the prevailing power system for hypothetical failure.

The contingency analysis mathematical model is based on actual configuration of the power system. Outages in generating unit or transmission line or both are assumed.

The model of Network for contingency analysis consist of admittance matrix which is built from the information given by the *status processor*.

The P and Q for each bus comes from the *state estimator*. The P and Q and voltages are computed on an ac load-flow program. The ac load-flow solves two simultaneous quadratic equations (one for the real power and the other for reactive power) for each bus in the network. By keeping the bus loading conditions as determined by the state estimator and then altering the admitttance matrix to reflect the outage, the contingency analysis program can calculate the effects of the outage and alarm the operator. The basic flow of information from the power system to the contingency analysis program is shown in Fig. 50.1.



1. RTUs Remote Terminal Units [Ref. Fig. 50.5 *a*] 2. Data Collection [Ref. Sec. 46.4]
3. System Status processor [Topology Processor] 4. State Estimator [Ref. Sec. 50.9.1]
5. Contingency Select 6. Contingency Analysis 7. Optimal Power Flow.

Fig. 55.1. Block diagram of Sequence in Power System Security Program. (This is a part of EMS – Fig. 50.6)

Contingency Analysis programs calculates the effects of hypothetical outages and gives alarm to the operator.

Fig. 55.1 shows the interrelationship and data flow from the Remote Terminal Units to the Contingency Analysis Program in Energy Management System (Ref. Fig. 50.6).

The power system changes continuously with change in load flows, switching of units, lines etc. Hence contingency analysis should be repeated for present conditions in the power system.

The AC load-flow calculation can take a long time to perform, especially if the network being modeled is large. Typical *contingency analysis models* can encompass several thousand buses. In modern Energy Management Systems, and this may take anywhere in the range of 15 s to several minutes to solve contingency program depending on the capability of the computers in the energy management system. If, for example, the execution time of the ac load flow took 2 min for each outage and several hundred were to be tested, the operators might not know all the results for a few hours — which is much too long. In order to solve the contingency analysis in a reasonable time, three methods are applied (1) Contingency selection (2) Faster load-flow calculation techniques (3) Expert Systems.

After a failure, the operator does not have enough time to think about alternatives. Hence, contingency analysis is carried out periodically in advance and is made available to the operator. Appropriate actions are taken in advance to ensure system security.

Contingency Selection

Out of various substation and generating station failures only a *few failures* result in loss of system security. Therefore it is a practice to *select only such* contingencies for contingency analysis and neglect all other failures. For contingency selection, two methods are used in practice.

1. To use screening technique by calculating partial load-flows for various failures (outages) and identify potential cases which are heading towards trouble. For such cases full load flow results are computed.
2. Use a *single calculation* based on performance index of system loading conditions and obtain an approximate ordering instruction for *each* possible network outage. *e.g.* outage of one unit or outage of one line. Table 55.3 gives the comparison of the two methods for selection of contingency.

Table 55.5. Description of Contingency Selection Methods

Method of contingency selection	*Description method*
Contingency screeing method	Based on calculation of partial AC load flow calculations If partial load flow indicates possible limit surpassing, then remainder of load flow is run and limits checked and alarm are sent. Time to perform screening is equal to twenty pecent of time for AC load-flow for each possible contigency event. Can select contingencies for bus voltage and line/transformer flow-limit surpassing.
Single calculation method	Makes use of performance index of network loading. Calculates ordered list of contingency event (ordered with most severe contingency at top of list) Full AC load flows computation are run on top members of list and limits checked and alarmed Time to calcualte list equal to run time for one to two full AC load flows Present technology does not include ordering based on out-of-limit bus voltages Time is much shorter than contingency Screening method.

55.6. OPTIMAL LOAD FLOW

The term load flow refers to the flow of power from one or more sources, through available paths, to the loads consuming the energy.

In load flow studies, the direction and amount of real power and reactive power flowing through various paths is indicated on the system single-line diagram.

Load Flow Studies is an important branch in power system analysis. For complex AC power systems, the load flow studies are carried out by means of a computer program. By means of load flow program, the P, Q and V at various substation buses and generating station buses can be quickly computed.

Load flow studies and useful in EMS and security planning.

Optimum Load Flow refers to load flow which gives maximum system security by minimising the overloads. The optimal load flow aims at minimum operating costs and minimum losses. Optimal load flow should be based on operational constraints.

Table 55.6 gives the limits and objectives on load flow planning.

Table 55.6. Optimum Load Flow — Objective and Limits

Objectives (only one in use at one time)	*Limits and Constraints*
Minimize system operating cost (Rs/hr) Minimize system megawatt losses (MW) Minimise overloads (ΔI, ΔMVA)	*Generation* Generator unit megawatts within limit Generator unit megawatts within limit *Interconnection* Area interchange within limit Transmission substations Transformer tap position within limit Bus voltage magnitude within limit Transmission line megawatts, MVA, or amperes within limit Flow over groups of circuits within limit AC load-flow conditions met at all buses.

Methods of Optimum Load Flow

Two methods are used to calculate the proper adjustments to a power system to relieve overloads and voltages beyond limits. The first method makes use of linear programming and solves a decoupled model much as in the decoupled load-flow calculation. In the linear-programming routine, the objective is to minimize operating cost for any given supplied load while meeting a variety of constraints such as circuit flows and bus voltages.

The second method solves a completely coupled AC load-flow model and uses megawatt losses or operating cost as the objective function. Generally the same constraints are used as in both the methods.

The load flow studies are carried out with the help of a model of power system. The model is in form of an admittance matrix built for the particular network topology. The quadratic equations for P and Q are solved simultaneously to obtain P, Q, V at each of the bus.

SUMMARY

Power system security deals with continuity of service even with certain outages. The power system security program is incorporated in Energy Management System Software. The power system security programs prove their economic worth many times in preventing costly system blackouts. In addition, the power system security programs also allow operators to operate the system closer to its limits, thus giving better economic operation. Large AC networks are managed optimally by means of EMS. The cost of EMS is justified by the major benefits such as (1) Prevention of major outages (2) Better loading of plants and lines (3) Energy saving.

With the help of contingency analysis program in power system security management, the operator can decide in advance how to react to certain hypothetical failure and what actions can be taken to prevent the cascade trippings in the network. Necessary steps can be taken by control room operators to improve power system security.

Conclusions

Modern Power system are large interconnected systems.

Power system studies are useful and essential for proper operation, planning, design. *Modern*

Power System Operation aims at maximum reliability, availability, and security. These objectives are achieved by means of modern Energy Management Systems.

Microprocessor based combined protection, monitoring and control relays form an essential play a vital role in the Energy Management.

In EMS, the central load control centre is connected to Remote Terminal Units (RTUs) *via* communication channels. Functions such as contingency analysis, optimal load flow, security analysis expert systems, etc. are centrally located. Data from various generating stations and substations is received by the central computer. The software in the EMS analyses the off-circuit and real time data and sends appropriate instructions to various substation control rooms and generating station control rooms. Appropriate actions are taken and maximum reliability, availability and security is ensured.

For special requirements Expert Systems based on Artificial Intelligence are being developed and used. Several new techniques such as FACT, HVDC, SVS have been introduced during 1980's to improve the controllability of large power systems and to minimise the operating costs.

The Computer Aided Engineering (CAE) and computer Aided Automation (CAA) is of vital importance in todays power system operations.