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EARLY DETECTION OF POWER SYSTEM DITURBANCES AS A CONDITION FOR SAFE OPERATION OF THE DUKOVANY NPP IN THE "ISLAND OPERATION MODE"

Ivan Petruželа
EGU Praha a.s.
Czech Republic

Abstract

System failures are statistically documented facts in the operation of large power system. There are many failure modes (e.g. sudden short cuts, inadequate interventions, and malfunction of protective devices), the majority of the root causes, however, originates in a transmission grid itself. The probability of grid disturbances is generally low but the impact of a single event could have resulted in heavy economical losses. (The severe disturbance of the Californian power system in August 96, leading to tripping of a number of thermal and nuclear unit, may serve as a recent example of the event of interest.)

The power plants have to be of satisfactory design level to overcome all events accompanying the disturbances. They also must cope with non-nominal parameter values. This operation is typical after any heavy grid disturbance causing the power system to separate into several less-stable islands.

A change in the frequency values serves as a problem indication. If the frequency difference exceeds the limit value of 0.2 Hz, the system regulation reserve would probably be exceeded and the system should be separated into islands. A load should be decreased by frequency relays in accordance with predefined set of frequency levels. If the intervention of these relays is insufficient, the frequency is dropping further and eventually activates the local frequency relay in generators, which results in cutting off the units from the power system. The "Frequency Plan" worked out for the Czech Power System specifies a set of preventive measures along with the set of the frequency ranges.

This problem was solved in details for the Dukovany nuclear power plant. The design changes under preparation support a reliable as well as safe operation in the island-operation mode until a full restoration of the whole power system. The design modifications are based on the following three main innovations

- *An incorporation of the FREA 16 frequency relay into the protection circuits*
- *Large modifications in turbine control loops*
- *Installation of software routine for the operator to support the island operation mode*

The capability of the island operation has been demanded by relevant regulations both for the operating units and for that under construction. The capability can be tested under the transition to houseloads, as well as through the direct simulation of abnormal grid conditions.

1. Power system disturbance

Nuclear power plants are a part of the Power System (PS). Individual elements (simultaneously operated power plants, transformer stations, transmission lines, electrical loads) influence each other and a failure of any of them affects the other ones. The most serious disturbance is the splitting of a large synchronous system into several less-stable islands.

The causes of these failures vary (heavy short-circuits, inadequate interventions, and malfunction of protective devices), and, mostly originate in the transmission network itself. The failure propagates very quickly and worsens operating conditions of all power system elements, particularly the power plants.

The major disturbance generally arises from multiple unfavorable incidental events. Each disturbance is, therefore, analyzed in detail and corrective actions are taken. Despite of this the power system disturbaces occur relatively very frequently.

In very short period since well-known black-out in New York (1977) there had been several PS disturbances with heavy economic losses. We could mention Italy (November 1978, May 1989), North Germany (April 1979), England (August 1981), Sweden (December 1983), France (January 1987). The splitting of the power system in California in 1996 may serve as a very recent example.

On Saturday, 10th August 1996, at 15:48, a disturbance in the western system (WSCC) created four separate islands. Subsequent interruption of power supply to 7.5 million customers lasted for the period from several minutes up to nearly six hours. The disturbance began with a loss of 500 kV line in the area of Port Island, caused by carelessly performed coordination of power system control and maintenance. Parallel lines were overloaded, and transmission voltage dropped. The conditions resulted in subsequent tripping of other lines and power stations.

Besides the interruption of power supply to plenty of customers the disturbance caused the total trip of fifteen thermal and nuclear units in California. Several of these units could not start the power operation for several days.

2. Early failure detection - the condition of the NPP safe operation during PS disturbance

On occurrence of a failure in the PS, the main task is to clear the failure, protect the process equipment against damage, and restore the normal operation as quickly as possible. The power plant design must meet the following requirements:

- The power plant must not cause system disturbances
- The power plant must not worsen an already arisen disturbance
- The power plant must overcome transient effects accompanying the disturbance

- The power plant must cope with the operation on non-nominal parameters, which is characteristic for steady state following a heavy system disturbance accompanied by system splitting into islands.

Early PS failure detection is the basic presupposition to meet the above requirements. The magnitude of a change in PS frequency serves for detection of occurrence of a heavy PS disturbance. Relevant actions on the side of both power generation and consumption are initiated on reach of certain values. These limit frequencies are defined in so-called "Frequency Plan".

Table 1 Actions on frequency decrease

49.8 Hz	Automatic transition of TG control to speed control with switching off the power governor
49.0 Hz	Level 1 of frequency unloading by 12% of the load
48.7 Hz	Level 2 of frequency unloading by 12% of the load
48.4 Hz	Level 3 of frequency unloading by 12% of the load
48.1 Hz	Level 4 of frequency unloading by 14% of the load
47.9 Hz	Disconnection of Dukovany NPP from the grid and transition to the houseload conditions

Table 2	Actions on frequency increase
50.2 Hz	Transition of TG control to speed control with switching off the power governor
52.5 Hz	Disconnection of Dukovany NPP from the network and transition to the houseload conditions

3. PS disturbance detection and clearing

If frequency deviation exceeds 0.2 Hz, it indicates a splitting of a large synchronous system into several islands. It means the system regulation reserve would probably be exceeded. The power plants shall maintain the frequency within acceptable limits by changing their power outputs. If the to the disturbance propagates and the frequency deviations rise, the power plants must be disconnected from the outside network.

The effects related to the system splitting may be divided into three phases.

<u>1. Disturbance occurrence</u>
The first time phase means fast and big changes in all parameters of alternators. The right behavior of the unit is conditioned by as quick as possible

a) disconnection of power control of turbines (of PI character)
b) switching-over the turbine control to speed control (of P character)

<u>2. Island operation</u>

The development of frequency in the second time phase determines the ratio of resource power to "island" consumption.

a) In more favorable case the resource power is higher than the consumption of the area supplied. The proportional speed control of power plants ensures the balance between the sources and consumption. After attenuation of the transition effect the frequency stabilizes on the level that would be a bit higher than the one prior to the disturbance.

b) Otherwise the source power is less than the consumption. The frequency might not stabilize. Due to the proportional speed control, machines are loaded with maximum values on certain frequency, but the frequency still continues to drop. On further drop a part of the load must be cut off by unloading frequency relays. On their proper function an excess power is ensured and frequency is stabilized. On their incorrect or insufficient function the frequency continues to drop until the local frequency relays in individual plants are activated and cut off the units from the power system.

3. Island liquidation

Final phase involves controlled achievement of nominal frequency of the island. After fulfillment of synchronizing conditions, individual islands are interconnected. To ensure successful synchronization:

a) maximum level of active power peak of individual units must not be exceeded
b) network protection must not act

To ensure prevention against occurrence of power system disturbances and to eliminate their propagation, analyses have been carried out of behavior of decisive plants including analyses of protection function with heavy short-circuits in the vicinity of the plant connected with cutting off the equipment affected.

4. Assurance of safe operation of Dukovany NPP in the island mode

The requirement of Dukovany NPP resistance to heavy power system disturbances means to cope with transition to the island and to ensure reliable operation of Dukovany NPP within the island system for the period necessary to restore synchronous operation of the whole power system. Dukovany NPP design solves only two basic modes:

- basic load operation with normal power system
- houseload operation (or idle operation) on disconnection of the 400 kV output switch.

Island operation represents a new operating mode. Designs and effectiveness of protective automatics were verified on the interconnected PS model (MODES) and the model of NPP Dukovany (DYJE).

EGU Praha performed model verification of dynamic stability of the Dukovany nuclear power plant with large frequency disturbances of power system. They found out insufficient resistance of Dukovany NPP to failure states of the power system (2). Safe operation of the

Dukovany NPP in the island-operation mode **is not possible at present**, because it mainly depends on the characteristics of turbine generator unit control and cooperation with reactor power control. On big changes in frequency the hydraulic speed governor has been applied practically without limitation (static set to 5%). Pre-governor of the turbine output is working against the power system/island requirements, and goes to the manual mode after achievement of its extreme position. On frequency drop TGs increase the power irrespective of reactor capability. With long-time drop in frequency TGs achieve the nominal power with electro-hydraulic transducer opening to approx. 20%. It is unacceptable from the viewpoint of unit protection effectiveness that requires decrease in TG output.

Without special modifications the big PS failures mean higher risk for safe operation of Dukovany NPP. The actions taken can be divided into 3 groups as follows:

I) Incorporation of FREA 16 frequency relay into the protection system

The basis of the modification for island-operation mode of Dukovany NPP is installation of the frequency automatics that is based on the FREA 16 frequency relay. The automatics generates output initiating signals that are introduced into I&C and PIS.

II) I&C modifications

The modifications ensure safe transitions on occurrence of an island and safe operation of the unit in speed control

III) Installation of SW supporting the operator in the "ISLAND OPERATION" mode.

Since the "island operation" is an event with low with low frequency of occurrence the unit control room operators must have sufficient information during PS failure. By means of the SW support they will be given better overlook of the technological process during the unit operation in the island.

The modifications performed are clearly drawn in the process diagram of the Dukovany NPP unit as shown in Fig. 1.

1. Installation of frequency automatics
2. Turbine governor modifications
3. Reactor controller modifications
4. Modifications ensuring limitation of condensate flow on sudden power decrease in the island operation mode.

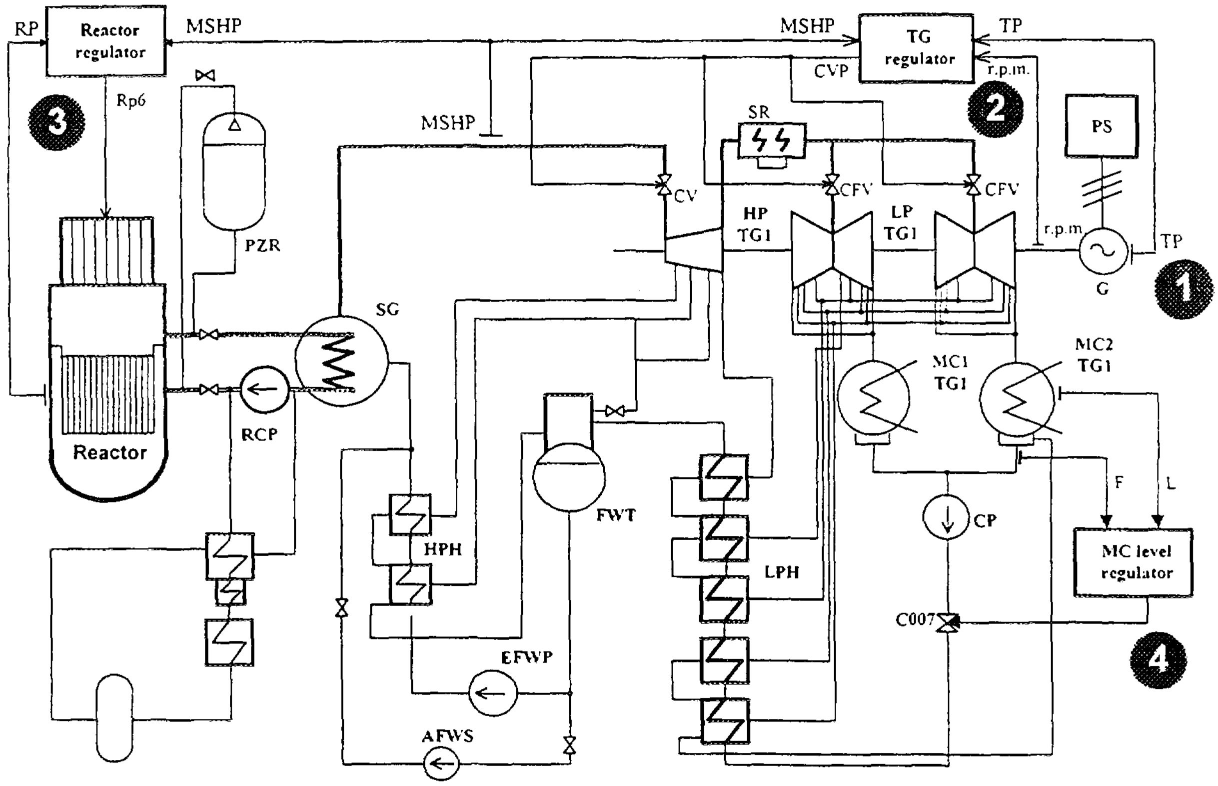


Fig.1 Principal diagram of Dukovany NPP unit with controllers and identification of modifications for island operation mode

5. Verification of safe operation of the nuclear power plant in the island operation mode

At present, when the Czech Power System has been already connected to UCPTE, the requirement of safe operation of the unit in emergency situations in the Power System becomes more important. The operating characteristic of the units is defined in the following UCPTE documents:

- Measures to prevent from occurrence of heavy failures and eliminate their extent - UCPTE document no. 13
- Measures against heavy failures in interconnected network - UCPTE document no. 16
- Thermal power station operation with lower frequency and voltage - UCPTE document no. 20

Verification of capability of the unit in the ISLAND OPERATION mode (including the method of evaluation) is stated in relevant regulations for both the operating units and those under construction. The basis is the breaking test of the unit with blocked signal of switching-off the 400 kV output switch. The test simulates real process of sudden transition of the unit from stable PS to so called minimum island, whose power corresponds to the houseload.

From the moment of its disconnection from the Power System till its re-synchronization to the grid after houseload operation, the power unit undergoes electromagnetic, electro-mechanic, thermodynamic (working medium: water-steam), thermo-mechanic, and mechanic transients.

Satisfactory behavior of the unit mainly depends on the correct function of:

- excitation system and alternator voltage controller
- steam turbine control system (speed control and protections) including by-pass stations
- reactor control system (maintaining the steam parameters within acceptable limits)
- unit electrical system
- unit operators, whose interventions influence significantly upon successful performance of the whole transient

6. Breaking test performance and evaluation

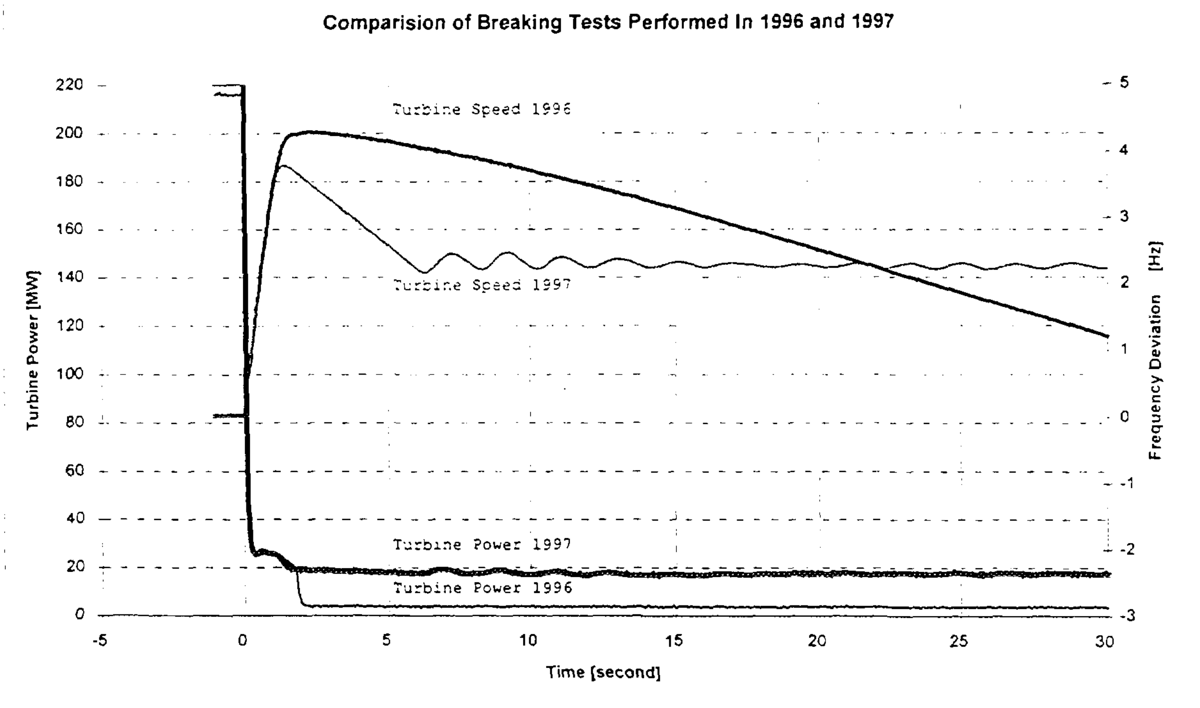
The tests have been designed and implemented in such a way that they would simulate as truly as possible the real conditions with minimal risk of damage of the unit and affected part of the power system. For the safety reason, the breaking tests differ from the real process in several aspects:

- Breaking test is implemented on the unit in good technical state, after inspection and adjustment of all decisive control and safety systems;
- Operators are prepared for and concentrated on the breaking test;
- Other qualified specialists from the power plant and manufacturers take active part in the breaking test;
- Breaking test is prepared organizationally, including collaboration with dispatching centre and relevant switching station;
- Important parameters of selected equipment are measured by special devices
- The moment of cutting-off is stated in momentary optimum operating conditions of the unit and network

The basic criterion of success is a reliable transition to the houseload with 2-hour operation in this state. In detail it means that:

- During the breaking test, the maximum transition speed of the turbo-set must not reach the limit speed, in which the turbine could be cut off by quick-acting valves. The speed characteristic during the transiet to the houseload must be damped, with fast stabilization at required value.
- Dynamic behavior of the other parameters comply with expectations and must be evaluated individually. Their incorrect characteristic should finally reflect in the resulting characteristic of the turbo-set speed.
- On the breaking test, the maximum transition voltage on the turbo-alternator terminals must not reach the limit value, for which the overvoltage protection is set up.
- Other process equipment of the unit must function in such a way that the turbo-set would get enough steam of appropriate parameters. These factors mainly influence upon the subsequent island operation, not initial phase of mechanical transition mode.

Prior to project work order the NPP Dukovany had performed the breaking test of one of the unit turbine generators (in February 1996, Unit 3). The test confirmed the conclusions of analyses, although it had not been successful. After implementation of modifications ensuring the island mode operation, the test result was positive (June 1997, Unit 3). The characteristics of TG speed and power are shown in Fig. 2 for both tests.



7. Conclusions

At present a system has been installed in all power plants in the Czech Republic to ensure safe operation on heavy power system disturbances. The capability of operation in so called island mode is verified according to the UCPTE documents.

Modifications have been implemented gradually for all units of the NPP Dukovany. In June 1997 the modifications were tested successfully for Unit 3 by means of:

- breaking test
- 2-hour houseload operation

The newly installed equipment enables to detect the PS disturbance early. At the same time the unit control room operators get sufficient information to control the transition from full load to the houseload island. The units may be operated in this mode for up to several hours. This decreases the probability of origin and mainly of propagation of disturbances in the power system in the vicinity of NPP Dukovany.