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Power System Blackouts: Analysis and Simulation of August 9, 2004 Blackout in Jordan Power System

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Abstract: Large blackouts are usually caused by a complicated sequence of cascading failures. Initial failures weaken the system and cause further failures, which further weaken the system and so on. This study investigates the blackout that occurred on 9th August in the Jordanian Power System. For modeling the blackout, a base case was established by creating a power flow simulation for the system with both of Egypt And Syria links. The analysis shows that the blackout has occurred as a result of full stoppage of Aqaba TPS (Thermal Power Station) and false switching-off the Egypt power system link, as a result, frequency dropped below 49.0 Hz, which in turns, caused a Frequency Load Shedding (FLS) in Syria power system and consequently, the blackout of Jordan power system. The study shows that the blackout could be avoided if the proposed arrangement of emergency automatics had been in use.

Key words: Power system blackout, emergency automatics, frequency load shedding

INTRODUCTION

Modern society has come to depend on reliable electricity as an essential resource for national security; health and welfare; communications; finance; transportation; food and water supply; heating, cooling and lighting; computers and electronics; commercial enterprise and even entertainment. Providing reliable electricity is an enormously complex technical challenge, even on the most routine of days. It involves real-time assessment; control and coordination of electricity production at thousands of generators, moving electricity across an interconnected network of transmission lines and ultimately delivering the electricity to millions of customers by means of a distribution network (Makarov *et al*., 2005).

Maintaining reliability is a complex enterprise that requires trained and skilled operators, sophisticated computers and communications, careful planning and design. Large outages or blackouts are infrequent because responsible system owners and operators protect the bulk power system through layers of safety-equipments. In searching for the causes of the blackout, the investigation team usually looks back through the progression of sequential events, actions and inactions to identify the cause(s) of each event (Bialek, 2005).

World experience since the American blackout in 1965 has shown that if no well-organized control of modern power pools is taken into account, the opportunity of cascading faulty processes may result in blackout of extensive areas even at the presence of big reserves of power (Bihain *et al*., 2002).

In order to localize the source of failure and to prevent its cascading, a defense organized in consecutive echelons is to be adopted; the first is the automatic security of stability, the second is the automatic fault clearing of the asynchronous state and the third is the frequency load shedding. With these consecutive reactions, even in case of small reserves of generating and transmission capacities, the large failures with a long break of electric supply can be avoided (Avramenko, 2003).

This study describes the application of emergency automatics as a powerful mean for maintaining of power system survivability.

THE POWER SYSTEM MATHEMATICAL MODEL FOR THE CALCULATION OF LONG-TERM TRANNSIENT

During large system failures, such as those, which have taken place recently in power pools of America and Europe, the frequency variations caused by these failures have a significant duration due to the development of emergency processes (Stanton, 1972). Modern computers with ordinary programs allow analyzing these processes in big multi-machine systems for calculation of the transient stability by based on the individual dynamic equations for each unit. However, the so-called infrequent model (IFM) is more adequate in this case, as it reduces the time of calculation (Grenier *et al.*, 2005). The theoretical background of this approach is based on considering the common motion of the rotors of the parallel operating machines as the characteristic of power system as a whole.

Summing the equations of motion of the individual machines, in which rotational moments are equal to power:

$$\sum M_i \cdot \ddot{\delta}_i = \sum P_{mi} - \sum P_{ei}, \quad (1)$$

Where, $M_i = T_{ji} \cdot P_{ri}$ is the constant of inertia of the system (MW.s),

T_{ji}-The constant of inertia of the unit in seconds,
P_{ri}-Rated power,
P_{mi}-Mechanical power of the turbine,
P_{ei}-Electric power of the generator,
δ_i-Generator's rotor angle.

If the average-load angle of system δ_s is taken as the characteristic of system motion as a whole:

$$\delta_s = \frac{\sum M_i \delta_i}{\sum M_i}, \quad (2)$$

Then, Eq. 1 can be transformed into the following form:

$$\ddot{\delta}_s \cdot \sum M_i = \sum P_{mi} - \sum P_{ei} \quad (3)$$

The individual angle can be presented as the sum of its deviation and the angle of system as follows:

$$\delta_i = \delta_s + \Delta\delta_i \quad (4)$$

Substituting (4) into (1):

$$\ddot{\delta}_s \cdot \sum M_i + \sum M_i \Delta\ddot{\delta}_i = \sum P_{mi} - \sum P_{ei} \quad (5)$$

From (5), It is clear that at $\Delta\delta_i \neq 0$ (as case of symmetric radial circuit with load and disturbance in the center) all, δ_i = iden = δ angle δ_s completely determines the system motion.

If insignificant deviations $\Delta\delta_i \neq 0$ are found, they can be neglected. However, it is possible for the calculation of system dynamics to apply Eq. 3 for describing the infrequent model (IFM) of system motion.

Angles δ_i determine the EMF angles of the synchronous generators used for the determination of a quasi-stationary electric state on each step of calculation. In traditional (for calculation of transient stability) model, which takes into account individual motion of rotors, calculation of electric state is carried out at fixed angles δ_i of EMF. However, in case of IFM, the situation is different, fixed EMF results (if the system is not strictly symmetric) in obtaining of various individual unbalances (P_{mi}-P_{ei}) and consequently, various increases in the frequency *f*, which contradicts with the initial assumption of IFM regarding the equality of all frequencies, i.e., f_i = iden = f_s = $\delta_s + f_0$. To overcome this contradiction, it is necessary to execute iterative calculation of quasi-stationary state, in which EMF angles of generators are different; pulling them together into a point of swing, which fades and finally results in a stationary electric state. As condition of stationarity, the equality of accelerations δ_i = idem = δ_s is considered instead of Pm ≠ P_e:

$$\ddot{\delta}_i = (P_{mi} - P_{ei}) / M_i, i = 1 \ldots n \quad (6)$$

Where P_{ei}, which is a function of all angles δ_i of the synchronous machines working in parallel, enters in both of Eq. 3 and 6, (n is the number of generators), their joint iterative decision is necessary and it will result in the equality $\delta_i = \delta_s$.

DESCRIPTION OF JORDAN POWER SYSTEM BLACKOUT ON 9.08.2004

Pre-fault conditions before disturbance at 19:28:51 were characterized by the following parameters: Total load of the system was about 1270 MW, total generation was 1100 MW, imported power from Egypt (on Taba-Aqaba 400 kV cable) was 206 MW and exported power to Syria was 6 MW.

Jordan grid is a double-circuit, 400 kV overhead lines Aqaba-Amman South-Amman North-Deyr Ali (Syria) (with total length of 365 km) and 132 kV network. Aqaba Thermal Power Station (ATPS) has 5 units with total power generation of 650 MW; Hussein Thermal Power Station (HTPS) near Amman has 7 units with total power generation of 362 MW.

The main events of the accident were:

Time:

19:28:51.590: A trip signal is given to fast valve closing at turbines of ATPS as a result of fast decreasing of pressure in gas pipe line.

19:29:00.473: All generators of Aqaba TPS are switched-off from power system.

19:29:01.055: 400 kV cable line Taba-Aqaba is disconnected at Taba. The trip was caused by the action of distance protection, where the line fast overloading was identified as a remote fault on the system.

19:29:04.055: Trips of generators G1, G2, G3 of El Risha power station.

19:29:04.641: Trips of generators G4, G2, G7, G5, G6 of HTPS. Stage 1 load shedding at Jordan and Syria power systems.

19:29:05.017: 400 kV line Amman North-Deyr Ali is disconnected at Amman North by the action of frequency emergency automatic.

Total load shed was about 600 MW and blackout of Jordan power system has taken plcae.

RECONSTRUCTION OF THE EVENTS

For digital simulation, the external connections to Egypt and Syria power systems were represented by their equivalent generation and load. Trips of generators and lines were taken according to real actions of relay protection during the accident. Start of digital simulation begins at 0.1s before appearance of trip signal for unit No. 4 of Aqaba TPS.

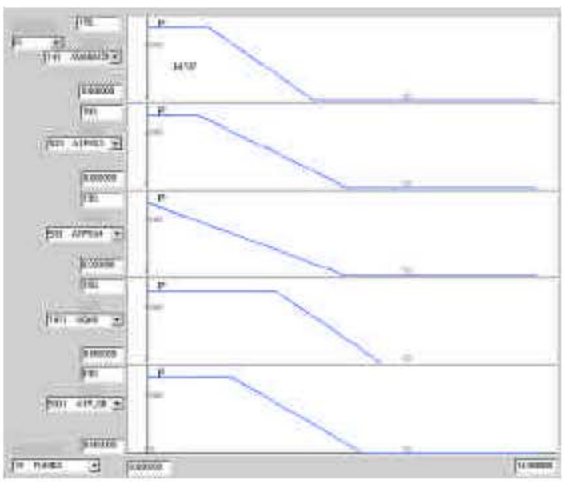

Fig. 1: The decreasing power of turbines at Aqaba TPS

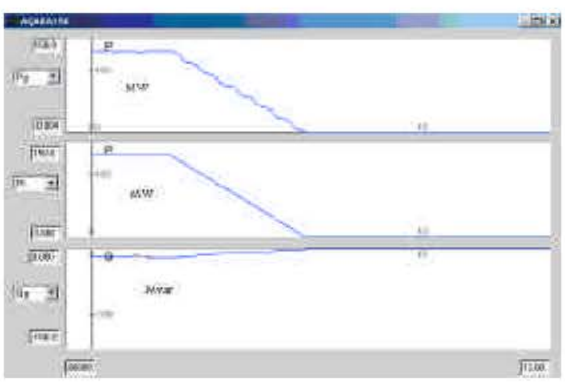

Fig. 2: The mechanical, active and reactive power of unit No. 1 of Aqaba TPS

Table 1: Settings of FLS

f	P_l(%)
49.1	8
48.8	10
48.6	12
48.4	15
48.0	7

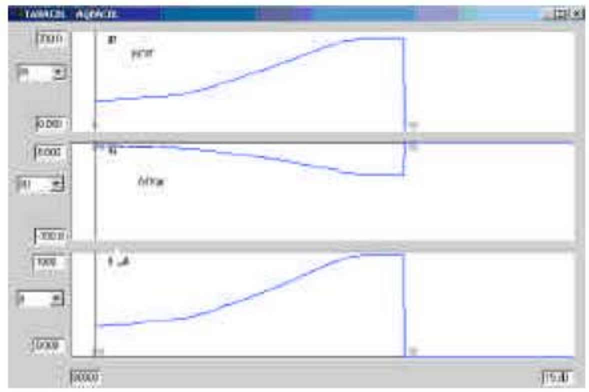

Fig. 3: The Active, Reactive Power Flows and Current of the Marine Cable Taba-Aqaba

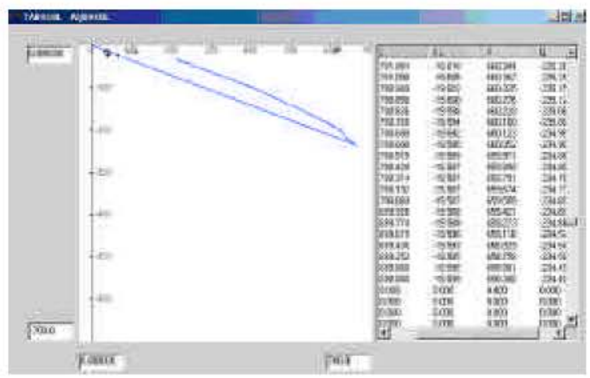

Fig. 4: P, Q Locus for the marine cable Taba-Aqaba

Settings of Frequency Load Shedding (FLS) obtained from Dispatching Center of Jordan Power System (JPS) are given in Table 1:

The difference between calculated value of the load tripped by FLS (768 MW) and the real value (about 600 MW) confirms the effectiveness of this automatic.

Figure 1 and 2 show the mechanical and electrical power decreasing during the accedent.

Figure 3-5 show the power flows, P, Q locus and R, X locus for the cable of Taba-Aqaba, which was tripped by the fast overloading of the line after tripping 5 units of Aqaba TPS with a power of 650 MW.

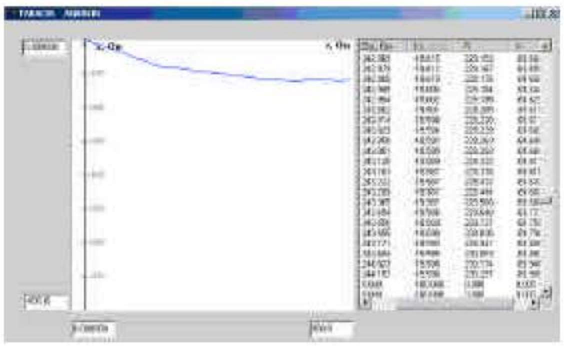

Fig. 5: R, X locus for the cable Taba-Aqaba

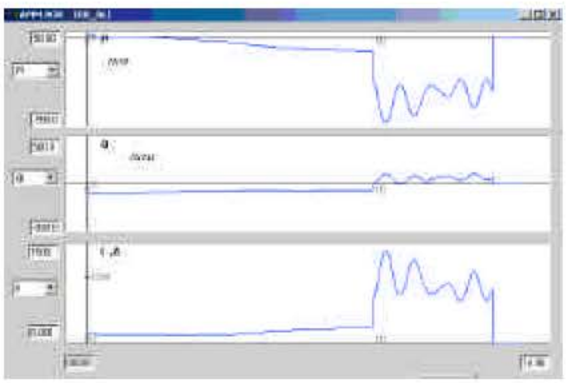

Fig. 6: The active, reactive power flows and current of the line North Amman-Deyr Ali

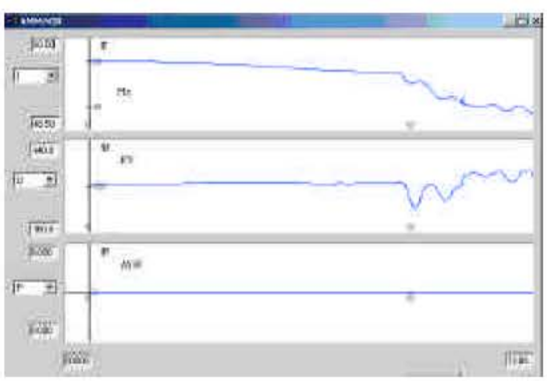

Fig. 7: The frequency and voltage at North Amman substation

Figure 8 shows power flows on the line Amman North-Deyr Ali before it was tripped by the action of frequency emergency automatic.

Figure 6-8 show the frequency curve for North Amman (Jordan) and for the equivalent node of Syria.

The comparison of results of digital simulation with the records of fault parameters during the accident on

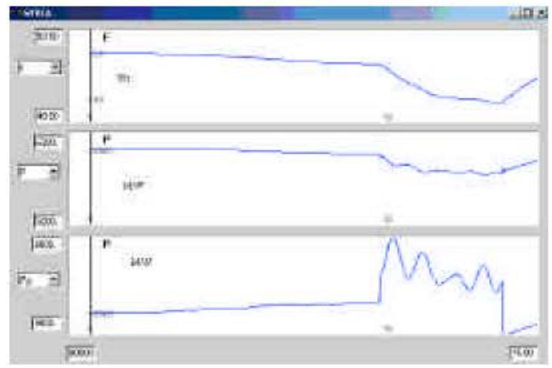

Fig. 8: The frequency, active load and active generation for the equivalent node of Syria

9.08.2004 has confirmed sufficient accuracy of simulation, as a base for investigation of new automatic means to prevent failures with enormous unacceptable damage.

THE PROPOSED EMERGENCY AUTOMATIC TO PREVENT JPS BLACKOUT

The main feature of emergency automatic that is used to prevent failure with huge unacceptable damage is the admissibility of controllable (quantity and duration), decrease of the functioning level for the sake of achievement of the strategic purpose-preservations of electric supply for the most important consumers and the possibilities of fast restoration of electric supply. Practically, decrease of the functioning level of the Electrical Power System is expressed in emergency switching-off a part of consumers in an extreme situation. However, in some cases, similar to failure 9.08.2004 in JPS, emergency disturbance is so great, that ordinary FLS had no time to react properly and blackout of the whole of the system has taken place.

9.08.2004 failure shows that the desire to use cheaper fuel on Aqaba TPS-gas instead of black oil-creates danger of emergency stoppage of all generators. It should be noted that, although all of the 5 units of the station were consistently tripped, but initial independent outage was one-pressure decrease in a gas pipeline, such probability should have been taken into account. This outage then imposed on some other outage-false action of the distance protection that has tripped the link with Egypt, which resulted in development of the failure down to full blackout of Jordan power system.

The structure of external links of JPS which, carry out the function of emergency preservation, is such one, that loss Egypt connection to Aqaba TPS results to a sharp increase of the imported power on the connection with

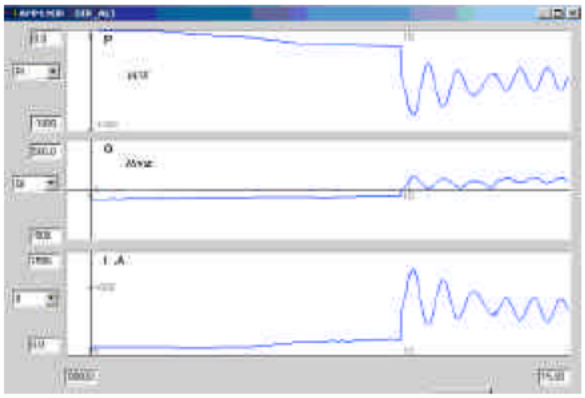

Fig. 9: The active and reactive power flows and current North Amman-Deyr_Ali Connection. (The proposed emergency automatic)

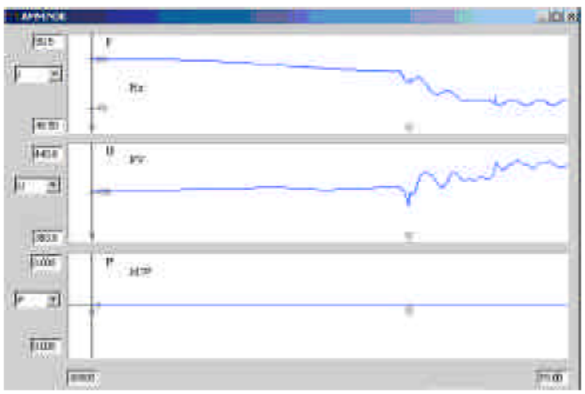

Fig. 10: The frequency and voltage at North Amman Substation. (The proposed emergency automatic)

Syria power system. Therefore, this can be used as a signal for emergency automatics, which at once will trip a part of load to prevent decrease of frequency below the allowable level.

The analysis of the grid of Jordan power system shows that by emergency switching-off 5 132 KV lines-Amman South-Abduon (2 circuits), Bayder-Abduon, Amman South-Ashrafia, HTPS-Abdali it is possible to trip total load of 175 MW. Simulation have shown, that such automatics, together with FLS stage, which has a setting of 49.1 Hz and trips 121 MW, provides fmin = 49.03 Hz (Fig. 10) at a disturbance similar to failure 9.08.2004 (Fig. 9).

CONCLUSIONS

- In Jordan power system, there is a probability of two heavy outages-the full stoppage of Aqaba TPS and the false switching-off of the link with Egypt power system. As result, the frequency in Jordan power system (together with Syria power system) decreases below 49.0 Hz. Under frequency protection will disconnect Syria power system, which in turns result in blackout of Jordan power system.
- At the above-described disturbances, ordinary FLS with an action depending on the decrease of frequency cannot prevent the development of emergency process that results in blackout of Jordan power system.
- Using the emergency automatics, proposed in this work, will trip out part of the load on the basis of fast increasing of the imported power through the link with Syria power system and consequently, preventing the complete blackout of Jordan power system

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