Analysis of the National 8th November 2003 Libyan Blackout

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Abstract--**During last few years many blackouts have been experienced throughout the world. It seems that modern power systems are more exposed to major blackouts. Studying and analyzing real-world blackouts can play a very important role in the avoidance of such events. In this paper, the experience of 8th November Libyan blackout is presented. The blackout is studied and analyzed from a dynamic point of view. A comparison between the Libyan blackout and some international blackout is also introduced. Some suggestions and solutions are given to improve the security of the system during future major disturbances.**

I. INTRODUCTION

During the last few years, many different major blackouts have been experienced around the world. Apparently, the modern power systems are more exposed to major disturbances. The capability of power systems to respond promptly and properly to major disturbances has been decreasing. This might be due to the fact that the modern power systems are suffering from lack of investment or due to the degree of complicity and power system deregulation with its related non-mature rules.

Blackouts are consequences of various complicated phenomena and abnormal events. These complicated phenomena have to be studied carefully in order to gain sufficient knowledge of the blackout evolution. Lack of careful and detailed studies of power system transient events and protection practices during the disturbances can lead to reoccurrences of system collapse.

The main objective of a detailed study of blackouts is to clarify the reason causing the collapse by verifying the behavior and performance of the system components and identifying the phenomena affecting the system during the transient evolution. Another objective is to find some improvements in system performance on the basis of the dynamic response. In order to be able to do this, a well dynamic reconstruction should be performed [1].

In this paper, the 2003 Libyan blackout is fully reconstructed and analyzed. Performance of various power system protective schemes is analyzed. Power system stability, out-of-step protection, real power deficit, frequency relaying, and load shedding are among the aspects which are studied. Some suggestions and solutions are also recommended to decrease the chance of collapse reoccurrences. Improving the current protection scheme and revision of system relay settings are among the solutions considered to improve the system performance during abnormal events.

II. LIBYAN BLACKOUT

A. *Libyan Power System*

The power system in Libya consists of four geographically well-dispersed, totally interconnected major island systems. The transmission system is supplied via 55 generating plants. These are mainly simple-cycle gas-turbine plants and steam units with some diesel generators located in rural areas of the Libyan Desert. The prime fuels are natural gas, residual fuel oil and distillate. The ultra high voltage level is 400 kV with a total circuit length of 442 km, a high voltage transmission level of 220 kV, and a total circuit length of 13,472 km. The sub-transmission voltage level is 66 kV, with a total circuit length of 13,582 km. The distribution network's voltage level is 30 kV with a total circuit length of 6,237 km. Geographically; the Libyan Network is characterized by heavy loads with most of the generation located in the north. Light loads are located far away from the generation in the south [2].

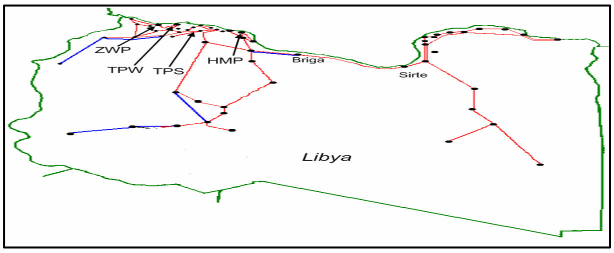

Figure 1 Libyan Power System

B. *Incident*

Four years ago, one of the most severe blackouts was experienced in Libya. The blackout, which affected 74.0% of the served loads, was triggered by a short circuit on the 220/30 KV transformer at the power production plant on the west side of the Libyan Power System (Tripoli West Plant). The Libyan power system was connected to the Egyptian power system with zero power exchange, and the power transfer from the West to the East was 30 MW. Before the occurrence of the fault, the power system was 69.6% loaded. The fault was cleared on the second zone.[3]

III. LIBYAN BLACKOUT VS INTRNATIONAL BLACKOUTS

In this section the Libyan blackout will be compared to some international blackouts, in terms of blackout severity, pre-fault conditions and Causes of the blackout. This comparison is based on ten well known blackouts including the Libyan blackout

A. Severity

To give general idea, Table (1) presents some facts and figures ten well known blackout.[4,5,6,7,8,9,10]

Table 1 Blackout information

Blackout	Customers without service	Lost load	Time duration	Affected populations
Brazil Mar. 11,1999	75.000.000	24.731	Up to 4 hours	%44.65
Iran Mar.31,2003	22.000.000	7.063	8 hours	%32.22
London Aug. 28 2003	410.000	724	0.62 hours	%5.43
Denmark & Sweden	4.000.000	6.550	5 hours	%27.86
Italy Sept. 28,2003	57.000.000	24.000	5 to 9 hours	%100.00
North America August 14,2003	50.000.000	61.800	16 to 192 hours	%15.51
Libya Nov 8 ,2003	4.000.000	1.876	0.5 to 6 hours	%70.0

In order to classify the severity of the Libyan Blackout among other blackouts, a new blackout Severity Index (SVI) was produced to give a sensible indication of system blackout severity.

A good severity index should include the effect of blackout on domestic and industrial demand. The first term (AP) on the severity index equation represents the percentage of the affected population within the domestic demand. The second term (UL/GC) is a ratio of unserved energy during the blackout period to the generation capacity of the whole network. So, the size of the unserved load and the duration of the blackout are included. Assuming the effect of blackout on the industry and the domesticity is equal; the severity index can be presented as following:

$$SVI = \sqrt{(AP)^2 + (UL/GC)^2}$$

Where AP is the percentage of affected population and the UL is amount of the unserved load in MWh and GC is the Base of the power. Based on the SVI, figure (2) presents the ten blackouts in severity order.

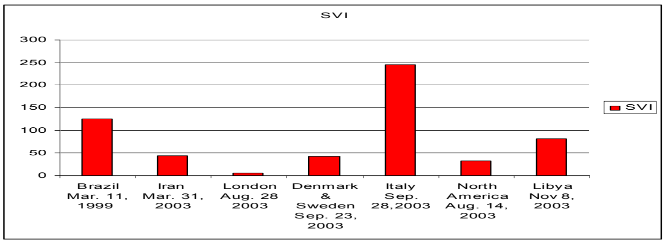

Figure 2 The Severity of Blackouts

B. Pre fault conditions & Causes of Blackouts

Table (2) summarizes the operation condition prior to the incident.

Table 2 blackouts Pre Fault conditions

Blackout	Pre fault conditions
Brazil Mar. 11,1999	Normal loading operation
Iran Mar.31,2003	High load level and some lines and power plant were out of services
London Aug. 28 2003	Two lines were out of services
Denmark & Sweden	Five transmission lines and four generation units were out of service
Italy Sept. 28,2003	High power transfer toward the country
North America August 14,2003	High temperature , High load level and some generation units and five capacitor bank were out of service
Libya Nov 8 ,2003	Normal loading operation

Table 3 Blackouts causes

Blackout	Initial cause	Supporting cause
Brazil Mar. 11,1999	Phase to ground fault as a result of lightning	Unexpected heavy loaded line tripped causing a stability problem
Iran Mar.31,2003	Unknown	Unknown
London Aug. 28 2003	Transformer Fault combined with Human Error of setting power	------
Denmark & Sweden	Internal valve fault in nuclear power plant	Double busbar fault lead to loss of two nuclear power plants
Italy Sept. 28,2003	Tree fault indirectly cause interconnection lines to trip	Heavy import of power
North America August	Significant reactive power deficiency combined with Tree	Software Problem at control centre causes the corrective action not to
Libya Nov 8 ,2003	Transformer fault	inadequate defense plan

Considering the fact presented on table 2 and 3, the incorrect protection elements was not only the initial cause in some blackouts but also a factor that accelerated the system outages in some others. Inadequate vegetation trimming which causes the contact of lines with trees was also one of the main causes that initiate the system outages. Although, the deficiencies in voltage stability and the supplying of reaction power were amongst the causes of one blackout, it played the main role in spreading the system outages in some others. The inadequate defense plan and lack of maintenance was reported in some cases. It is worthy of note that the absence of the sense of urgency before the situation degraded and inadequate training, information technology problem were reported in some cases.

IV. PRE FAULT CONDTIONS OF THE BLACKOUT

It is vital in this stage to produce an accurate steady state operating condition prior to the incident. This will help to produce an accurate dynamic model. The grid structure consists of two main areas, which are the western part of Libya (West) and the Eastern part of Libya (East). These two areas are connected through a long double line connection called the Sirte-Briga connection. The East is connected to the Egyptian network through a long, double circuit connection called the Tobruk-Salume connection. The operation condition prior to the incident can be summarized in the following numbers:

Available Power = 2536 MW
Load at the time of incident =2345Mw
Spinning reserve= 190 Mw
Sirte-Briga connection transient = 30 Mw through the East
Tobruk-Salume connection transient = 0 Mw

The situation prior to the incident presents two weak connections with risk of instability in case of severe contingencies.[3]

V. RECONSTRUCTED DYNAMIC PERFORMANCE

A. Overview

At 18.30 a severe disturbance occurred on 220Kv consisting of a three phase to ground fault on the 220/30 kV transformer at TPW power plant. The differential protection operated and gave a trip command but the circuit breaker on 220kV side did not respond due to control trip circuit failure. Therefore, distance protections at the second end of all the line connected to the busbar of TPW (busbar with the faulted transformer) operated in second zone and isolated the fault in about 380 ms leading to outage of main generation groups and 220Kv lines in Tripoli region.

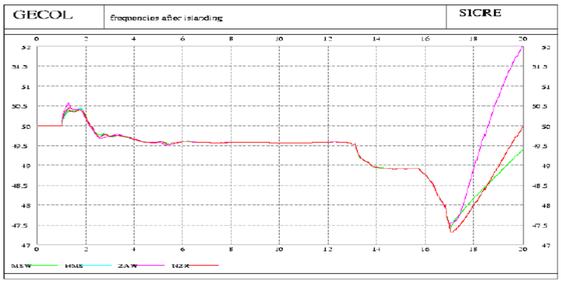

Figure 3 System frequencies during the blackout

B. Dynamic evolution

Generally, the dynamic performance of the network is presented in Figure 3. Figure 3 shows the frequencies of various bus bars following the occurrence of the fault. The dynamic evolution following the occurrence of the fault can be divided based on time into three periods.

1. First period (0-10s)

The first period, which is presented in Figure 4, starts with the fault occurrence which caused an immediate loss of four units in the west of Tripoli. This caused a loss of generation equal to 120 MW. At 0.8 s following the fault, three units were lost in the south of Tripoli, which caused a loss of generation equal to 237 MW. Two generation units were lost in the Zawia Plant at 5.5s. One second later, another unit in the same plant was lost. This period can be distinguished by a loss of generation amount equal to 848 MW. It is worthy of note at this stage that this type of fault is considered as extreme contingency, and it has very low probability of occurrence. It is noticeable that the frequency varies up to 49.6 Hz in this period for all the areas; such value is above the first stage of load shedding. It is also worthy of note that all units tripped in this period were due to auxiliary failures.

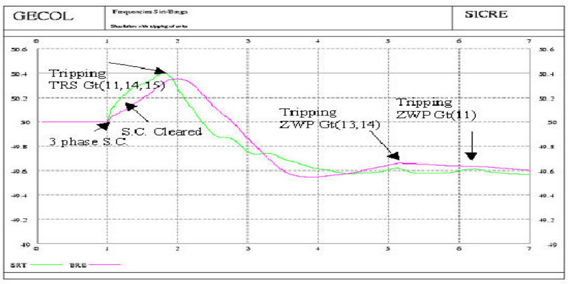

Figure 4 Sequence of events during the first stage

2. Second Period (7-12 s)

The second, which is presented in Figure 5, is characterized by a slow dynamic instability between the East and the West side of Libya. This kind of instability is due to a slow oscillation between the eastern and western generators with a slow increase of transfer power along a large distance.

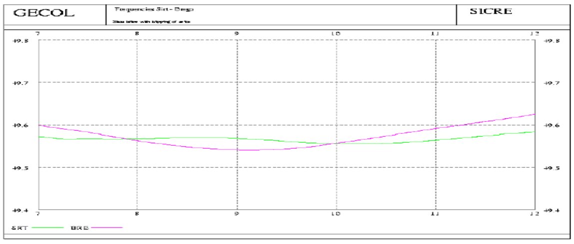

Figure 5 Sequence of events during the second stage

3. *Third Period (12s- end)*

It started with a fast drop in voltage in the interconnected line between the East and the West. This is due to a loss of synchronism between the East and the West. Therefore, the interconnection lines between the East and the West were tripped due to under voltage protection at 16.33s. At the same time, the Libyan Network was disconnected from the Egyptian Network. It is noticeable from Figure 6 that the eastern part of Libya survived; while the western part of Libya fell in a cascading manner by losing four units in the Homs plant. Two seconds following the separation of the East and the West of the network, the system dynamic, in terms of voltage and current related to Khoms machine , led to the under voltage and Over current generators protection near to the intervention settings. During this stage, two units in the Khoms plant were lost for reasons not completely clear. On the basis of event log, the most probable motivation is a "flame failure" for one and an unjustified intervention of the loss of excitation protection for the other. After these events, it is justified both for values and duration of the operation of the loss of excitation protections for the remaining two units.

Following the cascade tripping of Khoms generation units, the frequency drop was very fast with load shedding and system islanding. Such a stage is difficult to analyze because very small differences in the sequence of tripping and also defense plan activation can cause remaining generation units tripping for under frequency relay intervention. It reached the islanding stage at 48 Hz. Here, the islanding scheme played a decisive role at 19.34s where the network was split into three unstable islands. This led to a complete shutdown of the west.

As a general remark, in the case of rapid frequency decline, the proximity of the settings of under frequency relay for the units and islanding relay were not sufficiently able to assure good selectivity.

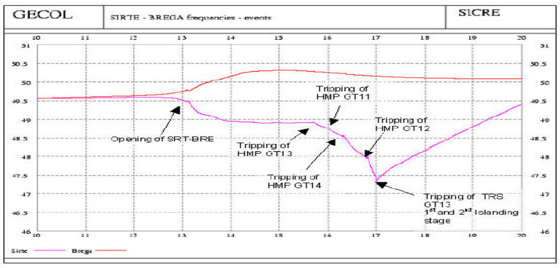

Figure 6 Sequence of events during the third stage

VI. CONCLUSION

The Libyan power system has been considerably developed during last years. Considerable number of high voltage transmission lines and substation are built. New power plants are added in order to match the increase in electrical power consumptions rate. However, due to the economical development, the increase electrical power consumption rate (ECR) is significantly high. This has emerged some difficulties in maintaining a balance between matching ECR and system security.

In this particular case , it is worthy of notice that the occurred transient stability problem was not due to electromechanical oscillation damping or fast transient stability due to short circuit of system fast variation in acceleration immediately after the consequence of units tripping. It was found that the instability is due to an angle opening between the West and the East where the maximum angle difference (about 90) was reached. The slow variation up to instability is largely dependent on the continuous operation of the frequency primary control trying to support the system until saturation of regulating energy in the most affected areas is reached. It is worth noting that the stability conditions for the Libyan system, characterized by a very long longitudinal structure, are influenced by many factors. These factors are frequency, primary control characteristics, the load typology, and power system stabilizer.

It is clear that the protection system of the generation units have plated a vital role to collapse the system. It seems that protection of the generation units have acted as apparatus protection rather than system protection. Proper protection system should be designed in a way to maintain the safe and operation of the power system as whole. They are not strictly related to protecting a specific apparatus being in danger due to its internal fault. In this sense the protection of generation units should be adjustment in away to keep the generation units connected to the grid as long as possible. It is worthy of note that the defense plan is useless if the generation unites can not operate in islanding situations

VII. RECOMMENDATIONS

Based on the above dynamic reconstruction and analysis the recommendations can be summarized in the following points:

1. The system should be monitored in terms of electromecanical phenomena.
2. The system should be reviewed in terms logic and setting for electrical supply of the auxiliaries of the gas turbine.
3. Co-ordination between grid and generation unit protections should be assured.
4. PSS gains and analysis of factors influencing the system stability should be reviewed.

5. The defense plan should be co-ordinated with the protective scheme and should be reviewed.
6. Tests on the thermal unit performance, to check their ability to face grid emergency conditions, should be conducted periodically.

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BIOGRAPHIES

Mahmud H. El-werfelli graduated from Al-fateh University (Tripoli- Libya) in Electrical Power Engineering in 2000 and obtained a Master's degree with distinction in 2005 from University of Newcastle upon Tyne in the same field. He worked for three years (2000-2003) as a planning engineer at General Electricity Company of Libya (GECOL). Currently, he is pursuing a PhD at University of Bath. The areas of interest are power system stability assessment and power system optimization problems using artificial intelligence.

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James Brooks graduated from the University of Bath in 2006 with a B.Eng. in Electrical & Electronic Engineering. He is now pursuing a Ph.D. at the University of Bath. The areas of interest are in dynamic stability of system with a large penetration of renewable power, AI and simulation.