الاتحاد العربي لمنتجي و ناقلي و موزعي الكهرباء
Arab Union of Producers, Transporters, and Distributors of Electricity

لجنة تنسيق تشغيل شبكات الربط الكهربائي العربي
Committee of Interconnected Arab Networks

(CIAN)

Major Interruptions (blackouts) Study

March 2006

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1. EXECUTIVE SUMMARY

Regarding to the forth meeting of the Committee of Interconnected Arab Networks that was held in Tunisia 18-19 May 2005, an Ad Hoc working group has been assigned to start actuating a comprehensive study relevant to the major interruptions (Blackout incidents) that happened across the members' Networks. The interruptions were classified as those causing loss of loads not less than 20 % of the concerned network loads. The main objective of the proposed study is to share the valuable information with regards to these interruptions between the Arab union of producers, transporters, and distributors of electricity. Following that, comprehensive analysis procedures are conducted so that valuable conclusions and recommendations can be drawn to reduce the occurrence of such major faults and to suggest for opportunities to enhance the performance and reliability of the concerned power systems. To verify the goal of the study objectives the following actions are implemented:

- Data information related to the power system major interruptions (Or blackouts) were collected. Number of fault records related to each country is listed below.

Country	No. of Interruption Records	Date of Interruption Record
Morocco	1	03/07/2000
Jordan	2	22/11/2003 – 09/08/2004
Egypt	1	24/04/1990
Bahrain	2	30/06/2004 - 23/08/2004
Saudi Arabia	2	03/08/2003 - 08/08/2003
Yemen	1	17/11/2000
Tunisia	2	30/06/2002 - 24/02/2004
Libya	1	08/11/2003
Syria	No Incidents Match the Blackout Criteria	

- Arrange the collected data information in a pre-defined fault analysis information sheet.
- Merge all fault analysis information sheets in one report.
- Draw conclusions and recommendations that may help reducing the possibility of the same fault incidents to be repeated.

The analysis procedures of the incidents conclude that:

- Twelve (12) different major blackout incidents have been recorded and collected from the Committee of Arab Interconnected Networks.
- About 42 % of the incidents are recorded as complete blackouts where 100 % of the system load was lost as a result of the incidents.
- Most of the incident causes are due to equipment performance that includes both malfunctioning and wrong settings while human errors were rare.
- The restoration time of the incidents ranges from 28 min minimum restoration time to 10-12 hrs maximum restoration time.
- Most of the recommendation actions taken by the utilities were stressing on adapting the performance of the equipment performance (setting, tests, and maintenance) and human performances (Training of operators, responsibilities, operation procedures and instructions).

2. REVIEW OF THE INCIDENTS

2.1 General Information of the Interruptions

- **<u>Morocco Incident</u>**

Name of Organization (Utility)	:	Office National de l'Electricité (ONE)
Transmission Voltage in Use	:	400, 225, 150, 60 kV
Total generation installed capacity	:	4620 MW
Maximum record peak load(MW/Date):	:	3340 MW / 21, June, 2005
Incident Location	:	EL-JADIDA /CT LASFAR
Incident Date / Time	:	3rd July 2000 / 15:00 GMT
Affected Load (% of the System Load):	:	52.2 %
System Load (% of the Annual Peak Load)	:	77.9 %
Type of day	:	Working day (Monday)
System configuration before the incident	:	Normal Configuration
Interconnection (Tie) lines State Before the Incident	:	In Service
Restoration time	:	05:08 (hh:mm)

On Monday July 3rd, 2000, during a short circuit test on unit no. 4 including the main transformer in EL JADIDA/ CT JORF LASFAR GIS power plant S/S with the incoming 225 kV feeder earthed, a flashover occurred on the Bus Bar Isolator of the unit and developed to a B.B fault which was cleared by differential B.B protection, caused a tripping of unit no. 2 (335 MW, 104 MVAR) and two 225kV transmission lines, the loading of the Spanish interconnection increased from 228 to 500 MW.

After 29 Sec. Unit no. 3 (335 MW, 80 MVAR) in EL JADIDA/ CT JORF LASFAR, which was connected to the unaffected B.B, tripped which increased the loading of the Spanish interconnection to 830 MW and the voltage over the all network started decreasing.

After 2.3 min. of unit 3 tripping, the loading of Spanish interconnection increased by 60MW, and the network suffered from voltage collapse which leads to a tripping of generating units and transmission lines and a power swing has occurred between the remaining units and lead to separation of the network into three islands:

- A Northern island connected to Spain,
- An eastern island connected to Algeria,
- And a Southern island (including Casablanca area) fully blacked out.

- **<u>Jordan Incident (1)</u>**

Name of Organization (Utility)	:	National Electric Power Company (NEPCo)
Transmission Voltage in Use	:	400, 132 kV
Total generation installed capacity	:	1650 MW
Maximum record peak load(MW/Date):	:	1387 MW / 30, August, 2003
Incident Location	:	Northern and eastern part of Jordan
Incident Date / Time	:	22nd November 2003 / 12:11
Affected Load (% of the System Load):	:	75 %
System Load (% of the Annual Peak Load)	:	77 %
Type of day	:	2nd Day of the Week End
System configuration before the incident	:	Normal Configuration
Interconnection (Tie) lines State Before the Incident	:	In Service
Restoration time	:	15 – 60 minutes

On 22nd November 2003, a phase-to-phase fault occurred on the Syrian Interconnection, the 400 kV double circuits Aqaba-Amman S. tripped out on the 2nd zone of main protection, the northern part suffered from generation capacity then the generation units in HTPS and Resha tripped out by the U/F and U/excitation protections affecting 75 % of the system load.

- **<u>Jordan Blackout Incident (2)</u>**

Name of Organization (Utility)	:	National Electric Power Company (NEPCo)
Transmission Voltage in Use	:	400, 132 kV
Total generation installed capacity	:	1650 MW
Maximum record peak load(MW/Date):	:	1515 MW / 07, July, 2004
Incident Location	:	Total Blackout Allover the Country
Incident Date / Time	:	9th August 2004 / 19:29
Affected Load (% of the System Load):	:	100 %
System Load (% of the Annual Peak Load)	:	85 %
Type of day	:	Working day
System configuration before the incident	:	Normal Configuration
Interconnection (Tie) lines State Before the Incident	:	In Service
Restoration time	:	Starting after 15 min from the Incident up to (2) hrs

On the 9th of August 2004, the (5 x 130 MW) Aqaba Thermal Power Station (ATPS) units tripped due to loss of fuel (N.gas), followed by tripping of the interconnection with Egypt then the Interconnection with Syria. As a result of such fault, a complete blackout incident has occurred causing complete loss of power.

- **<u>Egypt Blackout Incident</u>**

Name of Organization (Utility)	:	Egyptian Electricity Holding Company (EEHC)
Transmission Voltage in Use	:	500, 220, 132, 66kV
Total generation installed capacity	:	9200 MW
Maximum record peak load(MW/Date):	:	8000 MW / 24, April, 1990
Incident Location	:	Upper Egypt Zone
Incident Date / Time	:	24th April 1990 / 19:00
Affected Load (% of the System Load):	:	100 %
System Load (% of the Annual Peak Load)	:	95 %

Type of day	:	Working day (last night of Ramadan)
System configuration before the incident	:	Normal Configuration
Interconnection (Tie) lines State Before the Incident	:	No Interconnection exist
Restoration time	:	Six (6) hrs

On the 24th of April 1990, a complete blackout has been occurred causing 100 % of the system load to be lost. The blackout began with the forced outage of the 500KV double-circuit line between High Dam and Nag. Hamady. At this time, 1650 MW was transmitted on this line from High Dam power station toward Cairo. The tripping of this line causes power swing on the 132KV link between High Dam and Nag. Hamay, as a result this link tripped with the out-of-step relay protection. This situation formed two islands; the Southern Island that contained High Dam, and Aswan Dam power plants suffered from over generation, and the Northern Island started from Nag. Hamadi to the rest of Egyptian network suffered from under generation. The existing defense plan at this time could not handle this problem, so a complete blackout occurred as a result of tripping of all units in the Southern Island with the over frequency relays, and tripping of all units in the Northern Island with the under frequency relays.

- **<u>Bahrain Blackout Incident (1)</u>**

Name of Organization (Utility)	:	Ministry of Electricity and Water (MEW)
Transmission Voltage in Use	:	220, 66, 33kV
Total generation installed capacity	:	1849 MW
Maximum record peak load(MW/Date):	:	1632MW / 31, July, 2004
Incident Location	:	Alba / System
Incident Date / Time	:	23rd August 2004 / 8:32 AM
Affected Load (% of the System Load):	:	100 %
System Load (% of the Annual Peak Load)	:	79 %
Type of day	:	Working day
System configuration before the incident	:	Configured for Summer Peak operation
Interconnection (Tie) lines State Before the Incident	:	interconnection with alba with no flow through the interconnector
Restoration time (Major Load)	:	10- 12 hrs

On 23rd August, 2004, at 8:25 A.M. an important load in Aluminum Bahrain (ALBA) power system was rejected. System frequency immediately rose and speed governors operated to reduce generators output. System frequency dropped to 48:55 Hz so that the under-frequency load shedding scheme was activated and succeeded in restoring the frequency to 49.90 Hz. Unfortunately, for some minutes, system voltage rose to excessive value, and eventually, all spinning generators tripped on over-voltage related protection. AT 08:32 A.M. the total blackout of MEW power system happened, where 100 % of the system load (1288MW) was lost.

- **Bahrain Incident (2)**

Name of Organization (Utility)	:	Ministry of Electricity and Water (MEW)
Transmission Voltage in Use	:	220, 66, 33kV
Total generation installed capacity	:	1849 MW
Maximum record peak load(MW/Date):	:	1632 MW / 31, July, 2004
Incident Location	:	Isa town North primary substation
Incident Date / Time	:	30th June 2004 / 06:47 A.M.
Affected Load (% of the System Load):	:	240 MW (20.5%)
System Load (% of the Annual Peak Load)	:	1172 MW (71.8%)
Type of day	:	Working day
System configuration before the incident	:	Normal for Summer Operation
Interconnection (Tie) lines State Before the Incident	:	Interconnection with ALBA with no flow through interconnector
Restoration time	:	01.18 (hh.mm)

On the 30th of June, 2004, at 06:47 hrs, 220kV Bus Zone protection operated to trip all breakers on Busbar B1, causing a complete shutdown to Isatown North substation. The tripping caused a wide spread power shutdown to all connected areas. Following the incident, the following circuits were undergoing a cascading trip:

- T2262 at IsatownNorth , 220kV & 66kV Circuit Breakers (CBs.)
- IsatownNorth– UmmAlHassam, 220kV CBs at both ends.
- IsatownNorth– Rifaa, 220kV CB at IsatownNorth
- IsatownNorth – Waterfront No3, 220kV CB at IsatownNorth.
- Rifaa – College, 66kV CB at both ends.
- 220kV Bus coupler A1/B1 CB at IsatownNorth

After initial investigation, Heavy SF6 gas leakage was observed from insulating cone barrier of 220kV switchgear (CB and A1 Isolator) of T2262 at Isatown North substation. Further investigation revealed that insulating cone barrier had been severely damaged, consequently causing a 220kV Bus-fault.

- **<u>Saudi Arabia Incident (1)</u>**

Name of Organization (Utility)	:	Saudi Electricity Company (SOUTHERN REGION)
Transmission Voltage in Use	:	132, 33 kV
Total generation installed capacity	:	898 MW
Maximum record peak load(MW/Date):	:	903 MW / 03, August, 2003
Incident Location	:	Jazan Power Plant
Incident Date / Time	:	3rd August 2003 / 11:05
Affected Load (% of the System Load):	:	65.87 %
System Load (% of the Annual Peak Load)	:	94 %
Type of day	:	Working day (Sunday)
System configuration before the incident	:	Normal Configuration
Interconnection (Tie) lines State Before the Incident	:	There is no interconnection tie line
Restoration time	:	01:28 (hh:mm)

On 2003 August 03, at 11:05, Generator No.13 at Jazan CPS tripped on high MVAR demand. The system voltage eventually collapsed at 11:10, causing total blackout in the region causing a total loss of load (595 MW).

Restoration of supply commenced at 11:47 and continued through to 01:15 the following morning, when most of the load in the Jazan system was restored, with total load of 387 MW. Fourteen minutes later, at 01:29 of 2003 August 04, the Jazan system again experienced low voltage problems. Generators GT-2, GT-9, GT-10 and GT-12 (with total 104 MW output) tripped at Jazan CPS. Jazan Region was again blacked out.

Restoration of supply commenced at 01:44 and continued through to 05:58, when most of the load in the Jazan system (at total load of 441 MW), except Jazan Town S/S, was restored. Finally, Jazan Town S/S was normalized on 2003 August 05, at 06:10.

- **<u>Saudi Arabia Incident (2)</u>**

Name of Organization (Utility)	:	Saudi Electricity Company (WESTERN REGION)
Transmission Voltage in Use	:	380,110 kV
Total generation installed capacity	:	7995 MW
Maximum record peak load(MW/Date):	:	7143 MW / 08, August, 2003
Incident Location	:	Shoaiba Power Plant
Incident Date / Time	:	8th August 2003 / 03:31
Affected Load (% of the System Load):	:	31.31 %
System Load (% of the Annual Peak Load)	:	87 %
Type of day	:	Week end (Friday)
System configuration before the incident	:	Normal Configuration
Interconnection (Tie) lines State Before the Incident	:	There is no interconnection tie line
Restoration time	:	02:49 (hh:mm)

On 2003 August 08, at 03:31, a single phase to ground fault occurred on S-Phase of the South Aziziah (SAZ) – SWCC Shoaibah (SHB) 380 kV Line. The fault was rapidly cleared from the system in 50 msec (3 cycles). The fault caused a severe voltage dip in the system. The minimum voltage recorded at SAZ S/S was 0.4 PU of the nominal voltage. The voltage dip caused the generating units fuel pumps at Shoaibah Power Plant to drop out.

The change-over under voltage relays failed to reconnect the power supply to the fuel pumps. As a result, three (3) generating units tripped (while carrying about 1000MW) after 8.8 seconds from the transmission line fault. This amount of generation loss greatly exceeded the single contingency planning of West Operating Area (WOA). The system frequency dropped to a low level of 58.95Hz. At that level, three automatic under-frequency load shedding steps were activated, shedding of about 1080 MW.

About 11 seconds after tripping of the first three units, the remaining two (2) on-line units also tripped while carrying about 700 MW. This additional amount of generation loss caused further frequency drop to 58.77Hz. This also resulted in further automatic under-frequency load shedding of about 130 MW. These tripping caused the system frequency to drop further to 58.6 Hz and resulted in additional automatic under-frequency load shedding of about 400 MW. The system frequency remained low for long time. All area control centers had to manually shed about 336 MW to stop the frequency from further decline and improve.

At 03:36, about five (5) minutes after the initial transmission fault, **Steam Unit # 4** at Rabigh Power Plant tripped while carrying 260 MW. Steam combined cycles **Unit 2** tripped at 03:55 while carrying 28 MW and steam combined cycles **Unit 1** tripped at 04:04, while carrying 22 MW. At 06:20, all interrupted loads were restored, and the system normalized

- **<u>Yemen Blackout Incident</u>**

Name of Organization (Utility)	:	Public Electricity Corporation (PEC)
Transmission Voltage in Use	:	132 kV
Total generation installed capacity	:	645 MW
Maximum record peak load(MW/Date):	:	479.4 MW / 19, Sepember, 2000
Incident Location	:	Hiswa Power Station
Incident Date / Time	:	17^{th} November 2000 / 19:35
Affected Load (% of the System Load):	:	100 %
System Load (% of the Annual Peak Load)	:	88.6 %
Type of day	:	Week end (Friday)
System configuration before the incident	:	Normal Configuration
Interconnection (Tie) lines State Before the Incident	:	Interconnection lines are connected
Restoration time	:	5 hrs

On the 17^{th} of November, 2000, a major incident has been occurred as a result of multi-phase busbar fault within the 33kV SG at Hiswa power station, and due to delay of fault clearance contributed to additional loss of generation at Mansoura and Mukha power stations.

- **<u>Tunisia Blackout Incident (1)</u>**

Name of Organization (Utility)	:	Société Tunisienne de l'Electricité et du Gaz (STEG)
Transmission Voltage in Use	:	225, 150, 90 kV
Total generation installed capacity	:	2850 MW
Maximum record peak load(MW/Date):	:	1835 MW / 23, July, 2002
Incident Location	:	Complete blackout
Incident Date / Time	:	30^{th} June 2002 / 12:46
Affected Load (% of the System Load):	:	100 %
System Load (% of the Annual Peak Load)	:	71 %
Type of day	:	Week end (Sunday – Football world-cup final)

System configuration before the incident	:	Four transmission lines under maintenance, among which one important line of the 225 kV Tunis ring.
Interconnection (Tie) lines State Before the Incident	:	In service
Restoration time	:	50 minutes to 4 hours (total loads)

On the 30th of June, 2003, a trip by overcurrent protection of the second 225 kV line between Rades and Naassène (the first parallel line was under maintenance) has occurred. The result was:

- Overload and tripping of both 225 kV lines Goulette-Mnihla
- These tripping isolated the whole generation site of Rades (I & II)
- The loss of this important generation (737MW; 57% of total system load) lead to the separation of the Tunisian power system from the Algerian (and UCTE) one and to rapid frequency and voltage collapse.

The result of which was a total blackout within few seconds.

- **<u>Tunisia Incident (2)</u>**

Name of Organization (Utility)	:	Société Tunisienne de l'Electricité et du Gaz (STEG)
Transmission Voltage in Use	:	225, 150, 90 kV
Total generation installed capacity	:	3010 MW
Maximum record peak load(MW/Date):	:	2008 MW / 19, August, 2004
Incident Location	:	Partial blackout of Tunis Area
Incident Date / Time	:	24th February 2004 / 11:38 AM
Affected Load (% of the System Load):	:	547 MW (39.6 %)
System Load (% of the Annual Peak Load)	:	1389 MW (69 %)
Type of day	:	Working day
System configuration before the incident	:	Normal Configuration
Interconnection (Tie) lines State Before the Incident	:	In service
Restoration time	:	15 minutes to 45 minutes (total loads)

On the 24th February 2004, A tipping wagon touched a 90 kV line (Naassen - Grombalia1) at about 400 m from Naassen substation (resistive line fault evolving after few minutes in a bus bar fault). The main consequences were:

- Tripping of all tie lines with Algeria.

- Loss of generation units (Units 1 & 3 of Rades power station and total combined cycle IPP of RadesII) in the affected area. (615 MW)
- Voltage collapse in the north-east network and Cascade of line tripping: black-out in Tunis area and load relief in some other substations (547 MW).

- **Libya Incident**

Name of Organization (Utility)	:	General Electricity Company of Libya (GECOL)
Transmission Voltage in Use	:	220 kV
Total generation installed capacity	:	4700 MW
Maximum record peak load(MW/Date):	:	4005 MW / 25, Jan, 2006
Incident Location	:	Western area of Libya
Incident Date / Time	:	8th Nov. 2003 / 19:00:56
Affected Load (% of the System Load):	:	74.0 %
System Load (% of the Annual Peak Load)	:	69.6 %
Type of day	:	Working day
System configuration before the incident	:	Normal Configuration
Interconnection (Tie) lines State Before the Incident	:	two lines between eastern and western areas connected, two tie-lines between eastern area and Egypt connected
Restoration time	:	0.5 hour for main city, 6 hours complete restoration (entire network)

On Monday the 8th of November 2003 a major fault incident has occurred in the western area of Libya as a result of a short circuit on a 220/30 kV transformer in Tripoli west S/S. The main results of the incident were:

- Opening failure of circuit breaker and consequent fault removal in 2nd zone of the distance protections. The power lost at Tripoli West Power Plant was about 120 MW.
- After the short circuit clearing, a severe transient instability took place involving all the units of the system including units of the Eastern part.
- Cascade of tripping of generation units, system splitting and system shut down (74% of total loads).

Such disturbance was considered as an extreme contingency because of the fault duration and number of lost elements in the network (transmission lines and generation units) and affected loads.

2.2 Interruption Causes

Two categories of incident causes have been specified in this report, causes due to human errors, and causes due to equipment performance. Causes due to equipment performance are also categorized into two sub-causes, malfunctioning and wrong settings.

From the given incidents, it is noticed that, interruptions due to equipment performance is common for the whole incidents (100% of the incidents are initiated partially or totally throughout equipment performance factors) while just 25 % of the whole incidents were partially initiated by the human error factors. In brief description, Table I and Fig (1) indicate for the interruption causes percentage parties where:

- Malfunctioning is presented in 66.6 % of incidents (8 out of 12 incidents)
- Wrong setting is presented in 41.6 % of incidents (5 out of 12 incidents)
- Human performance is presented in 25 % of incidents (3 out of 12 incidents).

Table 1: Interruption Causes

Incident No.	Country	Interruption Causes		
		Equipment Performance		Human Performance
		Malfunctioning	Wrong setting	
1	MOROCCO	●		●
2	JORDAN (1)		●	
3	JORDAN (2)		●	
4	EGYPT		●	
5	BAHRAIN (1)	●		
6	BAHRAIN (2)	●		
7	SAUDI (1)	●		
8	SAUDI (2)	●		
9	YEMEN	●	●	●
10	TUNISIA (1)		●	●
11	TUNISIA (2)	●		
12	LIBYA	●		

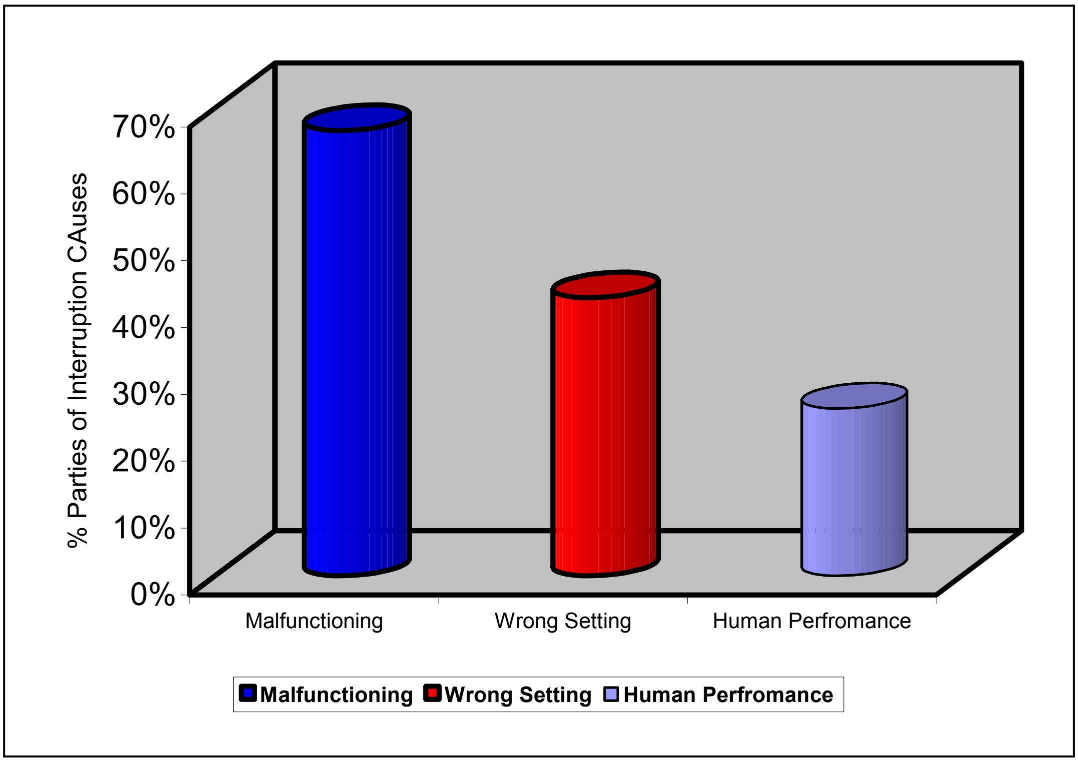

Figure 3.1: Contribution of Interruption Causes

2.3 Deficiencies During Emergency

2.3.1 Human/equipment performance during the development of blackouts incidents

Analysis procedures have been carried out to investigate the occurred blackout incidents. One of the analysis procedures is to follow the human and equipment performances during the development of the blackout incidents. Several factors are assigned by the committee members to follow the human/equipment performances. The following conclusions and observations have been drawn:

- Most of the incidents information during the fault are recorded and available in control rooms.
- Time span for operation response was short enough and accepted for most of the recorded blackout incidents.
- The majority of the blackout incidents introduce good coordination between entities (CCs, neighboring CCs, and within power producers).
- Accepted performance of operational procedures and instructions was maintained during most of the blackout incident.
- Technical tools in the control centers are available and used during most of the blackout incidents, while in some cases such technical tools were not available:
    - Where substations and power stations are not connected to SCADA system (YEMEN blackout incidents).
    - Or SCADA blocked (Morocco and Tunisia incidents)
- Preparedness of operators was sufficient for most of the blackout incidents while in some cases (YEMEN blackout incidents), preparedness of operators was weak where there is lack of qualified operators and training programs.

Table 2, shows detail information of the Human/Equipment performance during the development of blackouts incidents.

Table 2: Human/Equipment Performance during the Development Of Blackouts Incidents

Inc. No.	Country	Information available in Control Room	Missing Information	Time Span for Operation Response	Coordination between Entities				Operational Procedures or Instructions			Availability of Technical Tools in The Control Centers	Preparedness of operators
					Within the CC (or RCs)	Within the neighboring CCs	Within power producers	Within other operators	Appropriate	Sufficient	Correctly Followed		
1	MOROCCO	No information was available (SCADA blocked)	All information (system blocked)	Short Time	OK	OK	OK	-	-	YES	-	System blocked	OK
2	JORDAN	YES	-	Short Time	-	Good	Good	-	YES	YES	YES	Good	Good
3	JORDAN	YES	-	Short Time	-	Good	Good	-	YES	YES	90%	Available and Used	Good
4	EGYPT	YES	The excitation system at High Dam still on its automatic control	Good	Good	Good	Good	Good	No detailed documented emergency procedure was established			Appropriate	Good
5	BAHRAIN (1)	Yes	Nothing	4 min	Good	N/A	Good	Good	YES	YES	Alternate plane followed	Good	Good
6	BAHRAIN (2)	YES	Nothing	immediate	Good	N/A	Good	Good	YES	YES	YES	Good	Good
7	SAUDI (1)	YES	Nil	Good	Correctly followed	Correctly followed	Correctly followed	Correctly followed		Correctly followed	YES	OK	OK
8	SAUDI (2)	YES	Nil	Good	YES		YES	YES			YES	OK	OK
9	YEMEN	No. lack of SCADA information	Hiswa PS is not connected to SCADA system.		Good	Weak co-ordination due to lack of telecommunic ation	Good	Weak	No detailed documented emergency procedure was established			Weak, southern area substations and power stations are not connected to SCADA,	Weak, lack of qualified operators and training programs.

Table 2 (Continue): Human/Equipment Performance during the Development Of Blackouts Incidents

Inc. No.	Country	Information available in Control Room	Missing Information	Time Span for Operation Response	Coordination between Entities				Operational Procedures or Instructions			Availability of Technical Tools in The Control Centers	Preparedness of operators
					Within the CC (or RCs)	Within the neighboring CCs	Within power producers	Within other operators	Appropriate	Sufficient	Correctly Followed		
10	TUNISIA (1)	Sufficient to conclude that a blackout has occurred	Information about a small island (very important for the restoration plan) was missing.	Short (few minutes)	Good	Sufficient	Some pertinent information were not communicat ed	Good	YES	No, especially concerning information exchange between operators during emergency situations	YES	No real-time simulation tools	Not well prepared (trained) to face major interruptions
11	TUNISIA (2)	No (after about 15 min)	Information about the origin of the incident (bus bar fault in one substation)	Short (few minutes)	Good	Not sufficient	Good	Good	YES	YES	YES	YES	Sufficient
12	LIBYA	Yes (70 %)	-------	Fine	Ok	Ok	Ok	Ok	-------	-------	YES	Not Ok because CC and RCC are too old	Ok

2.3.2 Contribution of Other Items (Equipment / Human) In Development of the Blackout Incidents

Contribution of other items (Equipment / Human) in development of the blackout incidents has been also considered by the committee members to be taken in considerations in the analysis procedures. The assigned factors to be followed are the SCADA system, the telecommunication system, and any other factors having any contribution in developing the occurred blackout incidents. Data collection of such items reveals that:

- For most of the recorded blackout incidents the SCADA system did not introduce any contribution in development of the incidents.

- Telecommunication systems introduce a considerable contribution during some of the blackout incidents. As an example, incident No. 9 (YEMEN blackout incident), lack of telecommunications cause difficulties of quick response.

- Some other items rather than the SCADA system and telecommunications had considerable effects and contributions in the development of the blackout incidents. Optimizing/compromising protection relay settings, weakness of the transmission networks, and unexpected tripping of generation units are typical other factors that have an effect and contribution in developing the occurred blackout incidents.

Table 3, shows detail information of the blackout incidents contribution items (SCADA systems, Telecommunications and other items) and their contributions in the development of the recorded blackout incidents.

Table 3: Contribution of Other Items (Equipment / Human) In Development of the Blackout Incidents

Incident No.	Country	Contribution of Others Items (Equipment/Human) In Development of the Blackout Incidents		
		Computer System (SCADA)	Telecommunications	Other (specify)
1	MOROCCO	YES (System blocked)	No	
2	JORDAN (2)	No	No	
3	JORDAN (1)	No	YES	Protection
4	EGYPT	SCADA system is usually adopted for normal operation, not for blackout conditions	Good performance for the communication systems	
5	BAHRAIN (2)	Good	Good	
6	BAHRAIN (1)	Good	Good	
7	SAUDI	Nil	Nil	Nil
8	SAUDI	Nil	Nil	Nil
9	YEMEN	SCADA system is not covering the southern part, cause difficulties of quick response.	Lack of Telecommunications cause difficulties of quick response.	Difficulties to optimize the protection relay setting due to lack of high speed protection relays.

Table 3 (Continue): Contribution of Other Items (Equipment / Human) In Development of the Blackout Incidents

Incident No.	Country	Contribution of Others Items (Equipment/Human) In Development of the Blackout Incidents		
		Computer System (SCADA)	Telecommunications	Other (specify)
10	TUNISIA (1)	SCADA was blocked (state estimator not operational)	Telecontrol system saturated and obsolete. An important number of new substations not integrated in the telecontrol system.	• Overcurrent protections: correct tripping according to their settings: cascade of tripping. • Transmission network not strong enough to evacuate the installed power in Tunis area. • Due to a delay in execution of new reinforcements of transmission network, power system is operated close to its limits (especially during peak periods).
11	TUNISIA (2)	SCADA was too slow (state estimator not operational)	Loss of communication (telecontrol) with southern RCC	• Tripping of generation units • Tripping of some important 225 kV in Tunis area. • Blocking of some distance relays by FFM • Non directional earth fault protections tripping • Absence of fast bus bar protections in strategic substations • Too fast load restoration which lead to frequency collapse (48.492 Hz) and automatic load shedding
12	LIBYA	Not Ok	70 %	------------------

2.4 Deficiencies During Restoration Process

2.4.1 Human/Equipments Performance after the Blackout/During Restoration Process.

Some detailed informations of the restoration processes relevant to the introduced blackout incidents have been collected. Such valuable information are assigned by the committee members to be used as documentation and guidelines for defense actions to be followed in the future incidents. Human and equipment performances after the blackout incidents and during the restoration processes are investigated and reveal the following observations:

- There is a **lack of training and documentation** of the restoration philosophy and strategies after the blackout incidents occurred.
- For the introduced blackout incidents, there are considerable records of **Shortage of Generation** after the incidents occurred where there are 6 blackout incidents out of the total incidents (12 blackout incidents) subjected to shortage of generation.
- Some utilities have been suffering **problems to switch the transmission lines rapidly** during the restoration process (4 blackouts incidents out of the total eleven incidents) while others do not suffer problems to restore the transmission lines rapidly (8 blackouts incidents out of the total eleven incidents).
- There are no problems of controlling voltages during the restoration process for most of the recorded blackout incidents.
- Due to lack of required information during restoration process, two incident out of the total twelve incidents experienced technical problems. As an example, for the Incident No. 10 (TUNISIA blackout incident), a pertinent information about a small island was missing which was very important for the execution of the restoration plan.
- For some of the recorded blackout incidents, due to fast load restoration, there is a considerable problem of controlling frequency during the restoration process (4 blackouts incidents out of the total eleven incidents suffering problems of controlling frequency).

Table 4 shows more details about the human and equipment performances during the incidents.

Table 4: Human/Equipments Performance after the Blackout/During Restoration Process

Inc. No.	Country	Human/Equipments Performance After The Blackout/During Restoration Process											
		Restoration Philosophy			Preparedness of Operators	Available and Use of Technical Tools in the Control Center	Shortage of Generation	Inability to Switch Transmission Rapidly	Inability to Control Voltages	Lack of required information	Inability to Control frequency	Synchro nizing Problem	Other
		Appropriate	Sufficient	Correctly Followed									
1	MOROCCO	-	YES	-	NO	Insufficient (SCADA Blocked).	YES	No particular problem	No particular problem	System Blocked	No particular problem	No particular problem	-
2	JORDAN	YES	YES	YES	OK	YES	YES	NO	NO	NO	NO	NO	-
3	JORDAN	YES	YES	YES 90% of the Time	85%	OK	YES	YES	NO	NO	YES	YES	No emergency supply in the interconnection S/S
4	EGYPT	No written documentation strategies or philosophies existed in that time.			Did Not exist in that time	Good	NO	NO	NO	NO	NO	YES	
5	BAHRAIN (1)	YES	YES	YES (there was a change in plan)	Good	YES SCADA in use	NO	YES	YES	NO	NO	YES	No
6	BAHRAIN (2)	YES	YES	YES	Good	YES	NO	NO	NO	Cause of tripping for 66 KV feeder unknown	NO	NO	NO

Table 4 (Continue): Human/Equipments Performance after the Blackout/During Restoration Process

Inc. No.	Country	Human/Equipments Performance After The Blackout/During Restoration Process											
		Restoration Philosophy			Preparedness of Operators	Available and Use of Technical Tools in the Control Center	Shortage of Generation	Inability to Switch Transmission Rapidly	Inability to Control Voltages	Lack of required information	Inability to Control frequency	Synchronizing Problem	Other
		Appropriate	Sufficient	Correctly Followed									
7	SAUDI (1)	Nil	-	YES	NO	OK	YES	NO	NO	Nil	NO	YES	NO
8	SAUDI (2)	-	-	YES	Nil	OK	NO	NO	NO	Nil	NO	NO	Fuel pumping system & auto change over for auxiliary supply
9	YEMEN	-	No, a documented emergency procedure was not established.	With difficulties, due to lack of communications and qualified operators.	Lack of qualified operators and training programs.	Southern area substations and power stations are not connected to SCADA, and lack of telecommunication facilities.	YES around 10-15%	YES	NO	Southern area substations and power stations are not connected to SCADA	YES	YES	1-Loss of communication with some RTUs during switching 2-Public and management calls block the available telephone lines and disturbing the control engineers during the restoration.

Table 4 (Continue): Human/Equipments Performance after the Blackout/During Restoration Process

Inc. No.	Country	Human/Equipments Performance After The Blackout/During Restoration Process												
		Restoration Philosophy			Training lack for such situations - Preparedness of Operators	Availability and Use of Technical Tools in the Control Center	Shortage of Generation	Inability to Switch Transmission Rapidly	Inability to Control Voltages	Lack of required information	Inability to Control frequency	Synchronizing Problem	Other
		Appropriate	Sufficient	Correctly Followed									
10	TUNISIA (1)	Absence of tested, written and proved restoration philosophy			Training lack. Operators not well prepared (trained) to face major interruptions	Real-time technical (and simulation) tools not available. State estimator not operational	NO	In some areas due to over voltages	YES	• Information about a small island (very important for the restoration plan) was missing. • SCADA blocked • Substations operated locally	NO	YES	* Too many people (and anarchic received phone calls) in NCC and RCC during the restoration phase * Restoration was not well coordinated between operators
11	TUNISIA (2)	Absence of tested, written and proved restoration philosophy			Training lack. Operators not well prepared (trained) to face major interruptions	Real-time technical (and simulation) tools not available. State estimator not operational	NO	NO	NO	NO	Yes, due to fast load restoration which lead to frequency collapse and automatic load shedding	Yes, when switching on tie lines: * malfunction of synchronizing devices; * closing tie-line not coordinated between NCCs.	Restoration was not well coordinated between operators (NCC & RCC)
12	LIBYA	There was no restoration plan, restoration depended on operators experience			50 %	---	NO	NO	NO	NO	NO	NO	-------------------------

2.4.2 Performance of Other Items (Equipment / Human) During Restoration Process.

Information relative to the performance of other items (Equipment / Human) during restoration process have been also collected. Performance of human as well as equipment within the CC or the RCCs, within the neighboring CCs, with power producers, and within other operators was assigned and investigated by the committee members.

For most of the recorded blackout incidents, the performances of the human / equipment during the restoration process within the CC or the RCCs, within the neighboring CCs, with power producers were accepted and satisfactory. The only exception introduced by the incident No. 9 (YEMEN blackout incident) where restoration problems with the power producers (steam power plants) and within other operators (lack of qualified operators substations) were observed.

Table 5 shows more details of the performance of other items (Equipment / Human) within different relative links during restoration processes of the occurred blackout incidents

Table 5: Performance of Other Items (Equipment / Human) During Restoration Process

Incident No.	Country	Performance of others Items (Human/Equipments) during restoration process, cooperation and communication			
		Within the CC (or RCCs)	With neighboring CCs	With power producers	Within other operators
1	MOROCCO	No particular Problem	No particular Problem	No particular Problem	No particular Problem
2	JORDAN (1)	-	Good	Good	Good
3	JORDAN (2)	-	Good	Good	Good
4	EGYPT	Good	No interconnections exist in that time.	Good	Good
5	BAHRAIN (1)	Good	NA	Good	Good
6	BAHRAIN (2)	Good	NA	Good	Good
7	SAUDI (1)	Correctly followed	Correctly followed	Correctly followed	Correctly followed
8	SAUDI (2)	OK	OK	OK	OK
9	YEMEN		N/A response.	Restoration problems at steam power plants.	Lack of qualified operators at substations.
10	TUNISIA (1)	Good	Satisfactory	Good	Good
11	TUNISIA (2)	Not coordinated	Not coordinated when synchronizing both networks	Good	Good
12	LIBYA	OK	OK	OK	OK

3. LESSONS LEARNT – FURTHER ACTIONS

Most of the implemented actions taken by the utilities were stressing on adapting the performance of the equipment (setting, tests, and maintenance) and human performances (Training of operators, responsibilities, operation procedures and instructions.

Specifically, short and long term actions have been taken by the utilities against the blackout incidents, which reveal the following recommended actions**.**

- 60 % of the recommendation actions were specified as **long term actions** to be implemented.
- **Reviewing protection settings and updating grid protection** are the major actions recommended by most of the utilities.
- **Reinforcement of the existing transmission networks** is recommended as long term actions of network planning.
- **Defining different and accurate restoration plans** is recommended as a long term defense plan against future blackouts.
- To detect unexpected abnormal situations, **upgrading of control centers** and the SCADA systems are recommended.
- Defining guidelines documentations especially for **the restoration process philosophy** are recommended to ensure reliable execution of the **operational procedures and instructions** during the blackout incidents.
- **Using modern analysis tools to investigate** the blackout incidents are recommended so that documentation and guidelines can be taken as defense actions to be implemented against future incidents.

Tables 6 (a, b, and c) indicate different inventoried actions taken by the utilities after the blackout incidents have occurred.

Table 6a: Actions Taken By the Utility after the Event

Inc. No.	Country	Acquisition or use of real-time / off line tools		Protection systems		Network planning		Defense plans	
		Short term	Long term	Short term	Long term	Short term	Long term	Short term	Long term
1	MOROCCO	Remote control test	Control center upgrade	-	Upgrade grid protection	Split of Jorf 225 kV S/S into 2 S/Ss.	Re-inforcement of transmission network 4 S/S 400 kV 6 S/S 225 kV. Reinforcement of interconnection with spain new 400 kV cable.	Special protection system Load shedding depending on Tie line power flow	-
2	JORDAN (1)	-	Connecting an event recorder	-	Modified	-	-	-	-
3	JORDAN (2)	-	Modification of the protection setting of the Interconnection lines - Installing of Emergency Generator in the Interconnection Substation	-	-	-	-	-	Major load shedding in case of O/L of the Interconnection Line with Egypt
4	EGYPT	Collect all the available data from NECC and from all substation and power station logbook	Update the EMS/SCADA system, and tune all 150MW units and above under AGC	Review protection setting for lines and generating units	-	-	• Define restoration strategies. • Define different restoration plans and sequential steps.	Implement new load shedding scheme	Regular updating of load shedding scheme
5	BAHRAIN (1)	SCADA in use	Dynamic Study done for corrective Actions	Review of Protection Settings	Review by Consultants	Review of Summer Operation Network	Reinforcement of Network with6x220KV and16x66KV Substations	Implementation of Reactive Power Control Scheme	Review of Control philosophy of Gas Turbines

Table 6a (Continue): Actions Taken By the Utility after the Event

Inc. No.	Country	Acquisition or use of real-time / off line tools		Protection systems		Network planning		Defense plans	
		Short term	Long term	Short term	Long term	Short term	Long term	Short term	Long term
6	BAHRAIN (2)	SCADA in use	Dynamic Study of system behaviour	-	Protection of IsaTownNorth-UmmAlhassam was modified	Contengency Plan for Summer Operation		-	Network bulk point to be reinforced. Manufacturer to modify the design
7	SAUDI (1)	-	-	-	Implementation of under voltage & under frequency schemes		Installation of more generation & svcs	Review jazan power system to improve system reliability	-
8	SAUDI (2)	-	-	Install u/v protection on 480 v b/b - adjust o/c setting for units auxailry supply	-	Operate the auto recloser for cct saz to swcc shb at shb side instead of manual closing	-	Coating of over head line insulators to overcome bad weather conditions	-
9	YEMEN	Collect all the available data from NCC and from all substation and power station logbook	-	Review protection	-	-	-	-	-
10	TUNISIA (1)	Yes, off-line network simulations tools (PSS/E) available for dispatchers	PAS and EMS tools integrated in the new NCC project	Change of settings of some overcurrent protections	Total revision of power system protection philosophy and settings.	Organization of short-term network planning services more adapted to the requirements of reliability • New simulation tools (software, PCs) • Update forecast techniques and models	Acceleration of execution of new projects (reinforcements of transmission network)	Updated to face major incidents and outages (load shedding, tie lines wattmetric protections etc.)	Continuous update according to power system extension to face major incidents and outages
11	TUNISIA (2)	-	PAS and EMS tools integrated in the new NCC project	• Change of settings and replacement of some protections • Bus bar protections installed • Replacement of synchronising devices (and definition of best locations)	Complete revision of power system protection philosophy and settings	Short-circuits simulation to define best actions to reduce fault-currents	Acceleration of execution of new projects (reinforcements of transmission network)	Under voltage load shedding (to study)	Revised
12	LIBYA	New NCC and RCC are in installation stage		Adjustment		No		Defence plan study has been done with CESI co	

Table 6b: Actions Taken By the Utility after the Event

Inc. No.	Country	Training		Detection of abnormal situations		Organization (roles, responsibilities and authorities)		Operational procedures and instructions	
		Short term	Long term	Short term	Long term	Short term	Long term	Short term	Long term
1	MOROCCO	-	DTS in the new control center	-	Included in control center upgrade	Establishment of centralized unit	Restructuring of transmission sector	Improving documentation system	Certified quality management
2	JORDAN (1)	-	-	-		-	-	-	-
3	JORDAN (2)	-	-	-	Alarm in the control room in case of O/L of interconnection line with Egypt	-	-	-	-
4	EGYPT	-	Develop expert system for power restoration to be used as a training tool to support theoretical and actual training session.	-	Equip the EMS/SCADA system with the ASTA "Automatic System Trouble Analysis Program"	-	-	Establish documented guidelines for system restoration.	Develop expert system for power restoration to be used during actual blackout to implement the system assessment, and recommend sequential restoration steps.
5	BAHRAIN (1)	YES	DTS to be used for training staff	Yes, SCADA time-events logging	Annual contingency plans kept ready		Increase in Control Room Staff	Restoration Procedure to be reviwed	Regular review of Operation Procedures
6	BAHRAIN (2)	YES	YES	Installation of Partial Discharge sensors	Monitoring of Partial Discharge levels remotly	Monitoring Periods for Partial Discharge levels to be increased	Staff level to be increased	Yes/Followed	Yes/Followed
7	SAUDI (1)	-	-	-	-	-	-	-	-
8	SAUDI (2)	-	-	-	-	-	-	-	-
9	YEMEN	Induction course training was given for the operators	Planning for external course training	-	-	-	-	Establish a documented instructions to describe system restoration steps	-
10	TUNISIA (1)	External training of NCC and RCC dispatchers about control during major interruptions and restoration techniques	DTS in the new NCC project	Real-time alarms (thresholds etc.) continually updated	More real-time tools within the new NCC project	Information exchange between services more reliable (intranet, mails, fixed procedures etc.)	Communication circuits well defined in power system restoration reference document	Continually updated	Continually updated
11	TUNISIA (2)	-	-	-	-	Has to be improved especially during restoration process	-	Continually updated	Continually updated
12	LIBYA	Training of operators about the new CC SCADA, EMS	-	-	-	-	-	-	-

Table 6c: Actions Taken By the Utility after the Event

Inc. No.	Country	Actions related to restoration process (training measures, restoration philosophy etc.)		Communication with relevant parties		Coordination with network operators		Contingency analysis		Other Actions	
		Short term	Long term	Short term	Long term	Short term	Long term	Short term	Long term	Short term	Long term
1	MOROCCO	Defense plans (follow up and review)	-	-	-	-	-	Operational studies	Upgrade control center	-	-
2	JORDAN (1)	-	-	With the manufacturer	-	-	-	-	-	Performing a wide range dyn,amic behavior study	-
3	JORDAN (2)	-	-	-	-	-	-	-	Analysis of the incident by a consultant	Economic-secure operation was conducting	-
4	EGYPT	-	Develop expert system for power restoration to be used as a training tool to support theoretical and actual training session.	-	-	-	-	The case simulated using load flow, and dynamic simulation programs.	Develop expert system for power restoration to be used as a training tool to support theoretical and actual training session.	-	-
5	BAHRAIN (1)	YES	YES	YES	YES	YES	YES	Dynamic Study carried out	YES	All reactors were put in service	-
6	BAHRAIN (2)	YES	YES	With Manufacturer	With Manufacturer	YES	YES	YES	YES	All new HV circuits which to be commissioned should be tested before energize.	-
7	SAUDI (1)	-	-	-	-	-	-	-	-	-	-
8	SAUDI (2)	-	-	-	-	-	-	-	-	Modifying the auxiliary supply for pumping system to be from UPS not from the network.	-

Table 6c (Continue): Action Taken By the Utility after the Event

Inc. No.	Country	Actions related to restoration process (training measures, restoration philosophy etc.)		Communication with relevant parties		Coordination with network operators		Contingency analysis		Other Actions	
		Short term	Long term	Short term	Long term	Short term	Long term	Short term	Long term	Short term	Long term
9	YEMEN	Site visits were done for assessment of operator and equipment response	Planning for external course training	-	-	-	-	The case was simulated using load flow program	-	PB power consultant was called to analyse the event	-
10	TUNISIA (1)	Restoration process project started (work groups) to define guidelines	Restoration philosophy and process tested and adopted	-	Has to be more secure and reliable (avoid avalanche of communication calls)	Encourage the establishment of power exchange contracts	More reliable during normal and emergency situations	Possible manually (static only)	Possible manually and automatically: static and dynamic (new NCC)	Integration of some new substations and lines in the telecontrol system Real test of black-start capability of concerned units Quality approach implemented	Better and faster preparation, coordination and analysis of new projects (power system reinforcements) Revision of regulations for a suitable treatment for STEG Revision of STEG organisation Create a power system appraisal (expert) centre
11	TUNISIA	-	Restoration philosophy and process tested and adopted	Has to be improved in restoration phase	-	-	-	-	-	New NCC, RCC and telecommunication network project in progress adopted	-
12	LIBYA	-	-	-	-	-	-	-	-	-	New CC and RCC contract

4. GENERAL RECOMMENDATIONS

The detailed descriptions and analysis of the introduced incidents give raise to the need of certain recommendations. The recommendations might be useful to improve the overall system reliability and decrease opportunities of future incidents occurrence. The suggested recommendations are mainly used to improve some of electrical surrounding areas which include:

- Recommendations to **reinforce the existing transmission networks and improve reactive power compensation.**
- Recommendations to improve **the operation conditions of the transmission systems.**
- Recommendations to improve **defense plans.**
- Recommendations to improve **human performance in normal operation and during fault incidents.**
- Recommendations to improve **the restoration capabilities of the power system.**
- Recommendations to improve **pre and post fault analysis** (for all kinds of incidents and phenomena).

Reinforcing Existing transmission networks and improving Reactive Compensation

- Reinforce the existing transmission networks as long term actions taken by the network planning divisions.

Since reactive powers (MVAR) have a significant contribution to the system blackout during the fault condition, therefore the following supporting actions **are recommended**:

- Provide additional generation and install SVC for dynamic VAR/voltage support specifically at weak areas that frequently suffer voltage recovery problems**.**
- Based on comprehensive studies, shift or relocate the existing shunt reactors to right positions and install new shunt reactors.
- Keep the compensation devices connected in winter period as well as in summer period, switching on or out should be automatically according to the needs.

Improving the Operation Conditions of the Transmission Systems

To improve the operation conditions of the transmission systems, the following recommendations are suggested:

- To detect unexpected abnormal situations, upgrading of control centers and the SCADA systems, as well as communication tools and means **are recommended**.
- Investigate the actual capability of the existing generators to generate or absorb reactive power.
- Consider for the possibility of installing AGC systems (Automatic Generation Control).
- Perform periodically and when needed short and medium terms operational planning studies (load flow studies, contingency analysis, short circuit analysis, dynamic simulation studies) and adapt the operational procedures and network schemes accordingly. These studies and simulations need to be performed using high performance real time tools and off line software with very precise models for all power system components.
- Security (reliability) limits and operational procedures must be clearly established and strictly followed.
- Coordinate between supplying systems capabilities and expected demanding loads, exchange information and experiences between all parties (Generation, Transmission, and Distribution sectors). This will be useful to verify the maximum secure operating conditions and decrease the possibility of disturbance re-occurrence.
- Based on the results of this study, equipment performance (Malfunctioning and Wrong settings), as causes of interruptions, are common for the majority of incidents, so that **we recommend** for analyze and investigate with more details **protection settings, maintenance philosophy,** and **functional requirements** together with the existing system disturbances.
- Respect of high reliability standards in the planning, design and operation of power systems.

Improving Defense Plans

The detailed description of the introduced incidents showed that, the existing defense plans are not updated regularly and can not face major disturbances of the power systems especially at peak load conditions. So the following adaptation actions are highly recommended:

- Defense plans have to be reviewed on regular bases according to power system evolution (generation, loads, new transmission lines, new international tie-lines, recorded disturbances etc.). Special Protection Systems (SPS) should be studied and included in defense plans in order to preserve international or regional tie-lines.
- Immediate implementation or upgrading of under-frequency and under-voltage load shedding schemes after performing the required studies**.**
- Distribute equally the amount of the load to be shed at the different steps of the Automatic Under Frequency Load Shedding Scheme. In addition to that, manual load shedding might be significantly reduced or avoided completely.
- The rise in system voltage due to increasing the amount of load shed needs to be reviewed. It should be within the acceptable operational limits and not cause overvoltages in the system.

Improving Human Performance in normal operation and during Fault Incidents

Because the performance of the real-time operating staff in normal operation and during the incidents is important, we recommend investing more time, effort, and money to improve human performance as follows:

- Using modern analysis tools to investigate the blackout incidents (especially during emergency state) **are recommended** so that documentation and guidelines can be taken as defense actions to be implemented against future incidents. Expert systems and real-time automatic events analysis are of great support to the operators.
- In order to help the staff to optimize the system operation in normal situation as well as in exceptional incidents, intensive training sessions dedicated to new operators and senior operators should be **organized** and **conducted** regularly on a periodic basis. It

is recommended to use stored situations by means of DTS (Dispatcher Training Simulator) during the training sessions.

- Exchange of informations and experiences between real-time operators and operational engineers as well as managers throughout scheduled meetings and seminars **are highly recommended.**

Improving the Restoration Capability of the Power System

To improve the restoration capability of the transmission systems, the following actions **are recommended**:

- There is a lack of training and documentation of the restoration philosophy and strategies after the blackout incidents occurred, so that **we recommend** and stress for a unique agreed well documented Restoration Plan consisting of procedures and strategies to be executed by the real-time operators after system disturbances, outages, or blackouts have occurred.
- Carry out, when possible, scheduled simulated or real tests for the different phases of the Restoration Plan: black-start capabilities and dead-bus coupling, islanding tests to ensure reliable operation for the overall system protections, synchronization, operational procedures application and respect, human performance evaluation.
- Update the restoration plan and procedures according to power system evolution and new gained experiences, and recommendations.
- Perform regular restoration training sessions for power system operators (using DTS).

Improving Pre and Post fault Incident Analysis (for all kinds of incidents and phenomena)

Predictive actions are also recommended to decrease the possibility of future incidents to occur. The following actions **are recommended**:

- Perform full analysis studies relevant to the periodic data retrieval from the digital fault recording devices.
- Install permanent high resolution (high sampling frequency) time-synchronized (by GPS) disturbance recorders with communication capabilities and storage in all the transmission system substations and power plants where data could be useful for

further disturbance investigations and routine monitoring of all power system transient phenomena.

- Disturbance Analysis Working Groups should be established in order to study and investigate power systems disturbances, set recommendations and verify their implementation and follow up by operators. In that way, power system reliability is regularly reviewed, inspected and evaluated by network experts.

APPENDIX

Ad hoc working group members
(for studying major interruptions)

List of Ad Hoc Working Group Members

Name	Country	Company	E-mail	Telephone	
Chekib Ben Rayana	Tunisia	Tunisia Electricity & Gas Company (STEG)	cbrayana@steg.com.tn	+21698435845	Chairman
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