# THE ALLOCATION OF THE PRIMARY RESERVE AND POWER FREQUENCY CHARACTERISTIC OF THE EGYPT-JORDAN-SYRIA INTERCONNECTED POWER SYSTEM

**Mamoun Shehadeh**
**NEPCO**
**Jordan**

**Abeer Adaileh**
**NEPCO**
**Jordan**

**Abstract**

Power system utilities use primary reserve to withstand the disturbances facing the Egypt – Jordan – Syria interconnected power systems and to establish the steady state frequency. To ensure that the security of the interconnected power system and the operating frequency are maintained within the acceptable limits, the reserve quantity and response rate should be determined during the real time operation.

This paper discusses the determination of the power frequency characteristics and the power capacity contribution from each control area of Egypt – Jordan – Syria interconnected power systems.

Test results from the simulated conditions, and from the actual operation data have been evaluated to ensure that the power capacity contribution of each control area is within the theoretical approach.

**Keywords:** primary reserve, power frequency characteristic, contribution coefficient, generator droop.

## 1. Introduction

The Jordanian power system is now interconnected with Egypt and Syria which represents more than ten times its own load. One of the main requirements for keeping the integrity and stability of such interconnected power system is to maintain the system frequency within the operational standard limit during and after different cases of generators tripping, loss of load, and loss of main transmission line or tripping of the interconnection tie line.

This objective can be achieved by proper allocation of the primary reserve among the three interconnected parties (Egypt, Jordan and Syria). In the fact, the maximum demand of the interconnected areas in summer period is very high; each control area cannot keep the required primary reserve because of lack of its own generation and the high cost of the required reserve power.

On the other hand, significant and large amount of energy wheeling among the tie lines of the interconnected areas could be a case which requires the achievement of secure operation in case of tripping of the interconnected tie line.

## 2. Governor Speed – Load Characteristic

The electrical power system should reach a steady – state operating condition after a disturbance, and active power balance between power produced by the generators and consumed by the load should be provided to keep the system frequency close to the normal operating value. Three main concepts are playing an important role in the frequency stability (frequency regulation); generator-turbine inertia, primary reserve and governor speed–load characteristic.

The characteristic of a generator speed versus load explains the relationship of frequency regulation to load division. In the fact the controlled generator can operate in one of two controlled modes: isochronous mode (0 percent speed droop) and speed droop mode (100 percent speed droop).

In the isochronous mode the generator speed would remain constant isolated by increasing load, and the

m_shehadeh@nepco.com.jo

desired frequency will be maintained regardless of load changes if the capacity of the engine is not exceeded as illustrated in figure (1).

In the governor speed – droop mode the generator speed would drop until the maximum engine capacity is reached. The figure (2) illustrates the speed – droop governor curve which explains:

- To parallel the generator set, the speed setting should be on line (A) (no load speed equal bus frequency).

- When the speed setting is increased to line (B) the speed is constant but the load equals half load.

- When the generator set is fully loaded on line (C) and the main breaker of the generator is opened, the no load speed would be 4% above the synchronous speed.

In regulated machines the speed control mechanism is responsible for controlling the throttle values of the steam turbine or the gate position in hydro- turbines, and the mechanical torque is adjusted accordingly. This occurs under normal operating conditions and during disturbances. To be stable under normal conditions, the torque –speed characteristic of the turbine speed control system should have a droop characteristic. A typical droop or speed regulation characteristic is 5% in the United States and 4% in Europe.

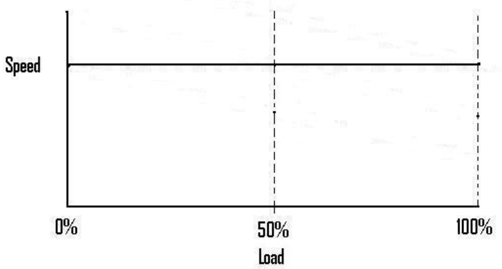


**Figure (1)**

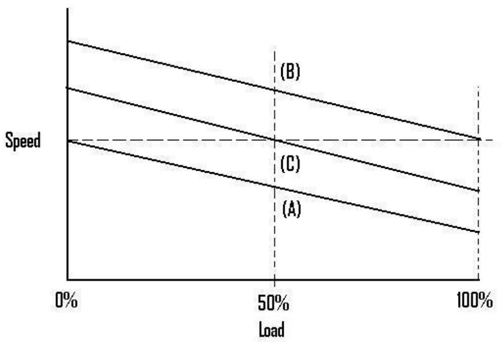


**Figure (2)**

The values of generators droop in Egypt, Syria and Jordan power systems are mostly typical to those in the United States and Europe (4% and 5%).

## 3. Power Primary Reserve

Each interconnected power system must satisfy specific conditions in its own area at each moment; the generation / consumption balance must be permanently ensured by each partner by putting into operation its own power stations and if necessary by activating load - shedding, and each party must help to compensate for the disturbance that may occur in proportion to its share of the total power output of the interconnected network at the time of the disturbance. In order to comply with these requirements, each partner must maintain power reserves, especially primary control reserve.
The purpose of the primary control system is to maintain a balance between generation and consumption, using turbine speed governors. As a consequence of the primary control action, frequency and power interchange may deviate from their reference values. The primary reserve is automatically activated within a matter of seconds (3-5 seconds) and continues until the inadvertent interchange is ended (30 seconds). The Dead Band of the governor plays main role in the Primary Load Frequency Control. As the effect of the Dead Band is detrimental to the electrical power systems, Dead Bands have to be cancelled or at least reduced as much as possible.

## 4. Primary Reserve Allocation

The both interconnected and isolated power systems cannot operate without reserves. The primary generating power reserves are needed for covering generation deficit in case of sudden outages of generating units. The suggested principle of determining primary reserves in different synchronous areas of Egypt-Jordan-Syria interconnected power system is based on the Joint Action. According to this principle each area must contribute to the correction of the disturbance (sudden outage of generating unit, outage of large transmission line, disconnection of the tie line...etc) in accordance with its respective contribution coefficient to primary control. The contribution coefficient of control area **(Ci)** is defined as the ratio of the control area generation including production for export **(Ei)** to the total generation of interconnected power system **( Eu )** and can be calculated according to formula :

**Ci = Ei / Eu**

Where $E_i$: electricity generated in the control area including electricity production for export.
$E_u$: the total sum of electricity production in all interconnected areas.

In fact this factor is completely theoretical and is used to determine the required reserve from each control area .The total and individual primary reserves of the Egypt-Jordan-Syria interconnected power system is determined on both experience and theoretical basis.

The reference event considered is the outage of largest generator (Kuraimat 650 MW in Egypt) or the tripping of the tie line between Syria and Jordan when Syria is exporting 650 MW to the neighboring countries.

The peak load of each control area of the Egypt – Jordan – Syria interconnected power system in year 2009 are 23000 MW, 2310 MW, and 7500 MW respectively. The exchange schedules between areas are limited due to lack of generation in each power system, which causes to put more expensive generation units in service. The outage of the largest generator (Kuraimat 650 MW in Egypt) during the peak time and without reserve will cause critical drop in the system frequency and may lead to activate the first stage of under frequency scheme in Egypt and Syria as illustrated in figure (3). To avoid such situation the primary reserve should be allocated between parties depending on the principle of Joint Action which says:" each control area must contribute to the correction of the disturbance in accordance with its respective contribution coefficient to primary control".
According to this principle the contribution coefficients for each control area of the Egypt – Jordan – Syria interconnected power system are 70%, 7%and 23% respectively.

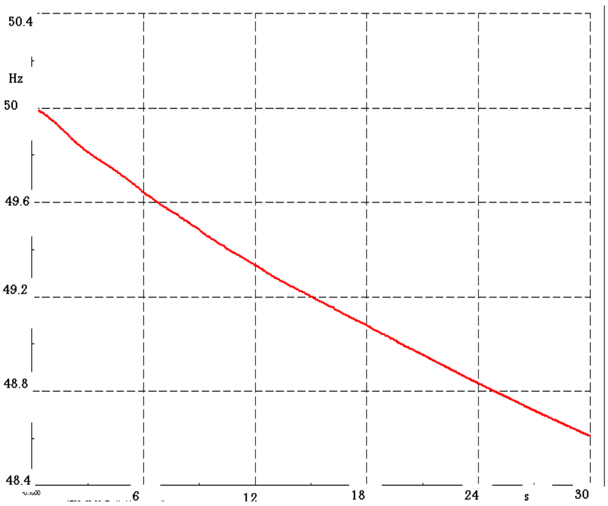

**Figure (3)**

The primary control reserve of each control area (power sharing) according to the calculated participation factors to withstand the outage of largest generator is defined according to the formula:

$$P_i = P_u \times C_i$$

The allocation of primary reserve between parties is defined:

$$P_{eg} = 650 \times 70\% = 450 \text{ MW}$$
$$P_{jo} = 650 \times 7\% = 45 \text{ MW}$$
$$P_{sy} = 650 \times 23\% = 150 \text{ MW}$$

The allocation of primary control reserves defined above is considered as a theoretical base, and the behavior of each control area of Egypt – Jordan – Syria interconnected systems should be analyzed depending on contribution factors defined before in case of any generation outages. Each control area should keep the required reserve during the real time operation to maintain system frequency within accepted limits after disturbances.

In this paper five disturbances (generation outages and tie line tripping) have been analyzed to evaluate the power sharing of each interconnected power systems and to define the power frequency characteristic for each control area, table (1) below shows the results of actual analysis of areas responses (power sharing) depending on the actual data collected from SCADA. The performance of each control area in response to primary control should be evaluated referring to the calculated values of primary reserve required from each control area.

| Element outage | Egypt Sharing | | Jordan Sharing | | Syria Sharing | |
|---|---|---|---|---|---|---|
| | Peg MW | Ceg % | Pjo MW | Cjo % | Psy MW | Csy % |
| Kuraimat 650MW (Egypt) | 330 | 51 | 44 | 7 | 131 | 20 |
| Zara 220 MW (Syria) | 131 | 60 | 17 | 8 | 41 | 19 |
| Aqaba 130 MW (Jordan) | 92 | 71 | 9 | 7 | 30 | 23 |
| Egypt-Jordan Tie Line interchange 180 MW to Jordan | 125 | 69 | 14 | 8 | 40 | 22 |
| Jordan-Syria Tie Line interchange 200 MW to Jordan | 127 | 64 | 16 | 8 | 47 | 23 |

**Table (1)**

The results show that the contribution coefficient of each control area of the Egypt – Jordan – Syria interconnected power system are closed to those coefficients defined in the theoretical base, which means that the response of the controlled areas to recover the power outage and frequency drop was as required in most cases.

In addition, the discussed five cases have been simulated using power system simulator DIgSILENT. The Load Flow and Dynamic Models for all three power systems have been prepared for all 5 disturbances and the simulation results are illustrated in table (2) below. The results show that the contribution coefficients of Egypt – Jordan – Syria interconnected power systems are closed to those defined in the theoretical calculations, and it is possible to decide from the comparison that the coefficients may vary as follows:

**$C_{eg}$ =[ 65% - 70%]**
**$C_{jo}$ = [ 6% - 8% ]**
**$C_{sy}$ =[20% - 24%]**

| Element outage | Egypt Sharing | | Jordan Sharing | | Syria Sharing | |
|---|---|---|---|---|---|---|
| | Peg MW | Ceg % | Pjo MW | Cjo % | Psy MW | Csy % |
| Kuraimat 650MW (Egypt) | 410 | 69 | 45 | 7 | 141 | 22 |
| Zara 220 MW (Syria) | 147 | 67 | 16 | 7 | 50 | 23 |
| Aqaba 130 MW (Jordan) | 92 | 71 | 8 | 6 | 32 | 24 |
| Egypt-Jordan interchange 180 MW to Jordan | 124 | 69 | 13 | 7 | 42 | 23 |
| Jordan-Syria interchange 200 MW to Jordan | 132 | 66 | 15 | 8 | 43 | 22 |

**Table (2)**

## 5. Power Frequency Characteristic

The power frequency characteristic of a control area of the interconnected power systems is the quotient of the power deviations responsible for the disturbance and the quasi-steady state frequency deviation caused by the disturbance and can be calculated by formula:

$$\lambda_i = - \Delta P_i / \Delta f \quad \text{MW/Hz}$$

It will be necessary to add power surplus or subtract the power deficit in the control area where the disturbance occurred, that why minus sign has been added to the formula above.

The Jordanian power system is interconnected to a system which represents more than ten times its own load. This is a new situation which requires an adaptation of the operating practices. One key point is the ability of the generating units in all three systems to control the frequency after disturbances. One of required measures is to adapt the dead bands of the generating units in all three systems to regulate the whole power balance of the interconnected system for smaller frequency deviation.

In order to calculate power frequency characteristic for each control area and for the whole interconnected power system the following procedures should be achieved:

### 5-1. Data collection:

- Frequency values before and after the disturbance (30 seconds readings).
- MW readings of Egypt – Jordan and Syria – Jordan Tie lines before and after the disturbance.
- Total generation of each control area before the disturbance.

### 5-2. Frequency Calculation:

- Frequency deviation **$\Delta f = f - f_o$** (where fo is the initial frequency before the disturbance and f is the average value of frequency between 10 and 30 seconds, **$f = (f_{10} + f_{30})/2$**.

### 5-3. Tie Lines MW Response:

- MW deviation of Egypt – Jordan and Syria – Jordan Tie lines (Average MW reading between 10 and 30 seconds). The total power response for covering the frequency after disturbance is the sum of power contribution from the generators in each control area and the total load dynamic response due to frequency deviation.

For example when Zara generation unit in Syria of 220 MW loading is tripped and the frequency decreased from 50.00 Hz to 49.935 Hz, while the Egypt – Jordan tie line loading is increased from 0 MW to 155 MW export to Jordan and the Syria – Jordan tie line loading is increased from 5 MW export to Jordan to 165 MW export to Syria. The total generation of Egypt, Jordan and Syria are (14000 MW, 2000 MW, and 5000 MW respectively).

Table (3) shows the result of calculation. The power frequency characteristic for the whole interconnected system for such event is 3385 MW/Hz , while for each control area of Egypt – Jordan – Syria system is 2384 MW/Hz , 231 MW/Hz and 769 MW/Hz respectively

**Incident: Tripping of 220 Mw in ZARA (Syria)**

| | Demand in MW | Frequency Before incident in Hz | Frequency After incident in Hz | Interconnection load before Incident in MW | Interconnection load after Incident in MW | generation lost or supply deviation in MW |
|---|---|---|---|---|---|---|
| Jordan | 2000 | 50 | 49.935 | 0 | -155 | 0 |
| Egypt | 14000 | 50 | 49.935 | 0 | 155 | |
| Jordan | 2000 | 50 | 49.935 | -5 | 165 | 0 |
| Syria | 5000 | 50 | 49.935 | 5 | -165 | 220 |

| | Actual Case | |
|---|---|---|
| lambda overall | $\lambda$ = 3384.62 | Mw/HZ |
| lambda Jordan | $\lambda$ = 230.77 | Mw/HZ |
| lambda Egypt | $\lambda$ = 2384.62 | Mw/HZ |
| lambda Syria | $\lambda$ = 769.23 | Mw/HZ |

**Table (3)**

For the five disturbances mentioned the Power frequency characteristics have been calculated and the results are shown in table (4) below:

| Element Tripping | λ Eg MW/Hz | λJo MW/Hz | λSy MW/Hz | λall MW/Hz |
|---|---|---|---|---|
| **Kuraimat 650MW (Egypt)** | 2222 | 211 | 699 | 3132 |
| **Zara 220 MW (Syria)** | 2134 | 240 | 689 | 3063 |
| **Aqaba 130 MW (Jordan)** | 2100 | 195 | 766 | 3061 |
| **Egypt-Jordan interchange 180 MW to Jordan** | 1910 | 222 | 710 | 2842 |
| **Jordan-Syria interchange 200 MW to Jordan** | 1999 | 250 | 731 | 2980 |

**Table (4)**

Power frequency characteristics **λi** for control areas of Egypt – Jordan – Syria interconnected systems vary between [(1900-2200 MW/Hz), (200-250 MW/Hz), and (690-760 MW/Hz) respectively and (2850-3100 MW/Hz) for the whole interconnected system **λall**.

The power contribution from each control area can be defined depending on the power frequency characteristics of each control area and the power frequency characteristic of the whole interconnected system and can be calculated as follows:

$$\lambda_i = C_i \times \lambda_{all}$$

Table (5) below shows the calculated contribution coefficients for each control area of Egypt – Jordan – Syria interconnected system depending on results shown on table (4) and on the above equation:

| Element Tripping | C eg % | Cjo % | Csy % |
|---|---|---|---|
| **Kuraimat 650 MW (Egypt)** | 71 | 7 | 22 |
| **Zara 220 MW (Syria)** | 68 | 8 | 22 |
| **Aqaba 130 MW (Jordan)** | 67 | 5 | 24 |
| **Egypt-Jordan interchange 180 MW to Jordan** | 61 | 7 | 23 |
| **Jordan-Syria interchange 200 MW to Jordan** | 64 | 8 | 23 |

**Table (5)**

The results shown in table (5) are closed to the calculated contribution coefficients of each control area of Egypt – Jordan – Syria defined in the theoretical calculation that means in all 5 cases the response of each area was close to the requirements.

## 6. Conclusions

The contribution coefficients of each control area of Egypt – Jordan – Syria interconnected system in relation to the correction of a disturbance are: [(60-70%), (6-8%), (22-24%)] respectively. The power frequency characteristics of each control area of Egypt – Jordan – Syria interconnected system in relation to the correction of a disturbance are: [(1900-2200 MW/Hz), (200-250 MW/Hz), and (690-760 MW/Hz)] respectively.

## 7. References

[1]-"Frequency control in a Market Environment "IARNOTT,A BOSE,NCUKALEVSKI,JLA FRANCE, T RUSIN, N SINGH.CIGRE.Paris.2002.

[2]-"Operational Studies for the Interconnection of the Power Systems of the EIJST Countries Phase2: Turkey – SYRIA –JORDAN- EGYPT"EDF generation and Transmission, IPES Services- Power System Projects April 2001.

[3]-"Ground Rules Concerning Primary and Secondary Control of Frequency and Active Power within the UCPTE-April 1998".

[4]-"Stability of a Power System under Normal Operating Conditions"Prof.F.J.AL-AZZAWI, Amman-Jordan 1997.

[5]-"DIgSILENT Power Factory Manual Version 14.GmbH, Gomaringen, Germany, 2009".