The impact of electrical interconnection between countries on the stability of electrical power systems

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***Abstract*— Because power systems are operated closer to critical limits, environmental constraints limit transmission network expansion, the need for long-distance power transfers has grown, and operators share less in the supervision and operation of power systems, management of power systems has become more difficult than before. The problems of power systems instability are a major concern in many countries and many blackouts have been reported, where the reason has been the instability of frequency in electrical stations. The purpose of this study is analyzing the impact of electrical interconnection between Arab countries in supporting the stability of frequency in the Syrian electrical grid, where has used program (PSS/E) for comparing the behavior of the Syrian electrical system before and after the electrical interconnection.**

***Keywords*— Frequency, Spinning reserve, Interconnection, PSS/E.**

I. INTRODUCTION

Interconnecting the electric power systems of several countries has many benefits (postponing or avoiding the building of new power plants entirely. This can be achieved by sharing power across interconnected grids without impacting their security and reliability; reducing the need for reserve power to meet demand changes, reducing operating costs; benefiting from the establishment of generating stations in the most economically feasible locations due to the availability of cheap and surplus fuel that is difficult to export or difficult to store in one of the interconnected countries; reducing in the general level of environmental pollution in the region). Fig.1 shows the most important electrical interconnection projects in the Arab countries that have been implemented during the past two decades [1],[2]:

1. The eight countries interconnection project (the yellow color, Fig.1).

2. The Maghreb countries interconnection project (the red color, Fig.1).

3. The gulf cooperation council (GCC) power grid interconnection project (the green color, Fig.1).

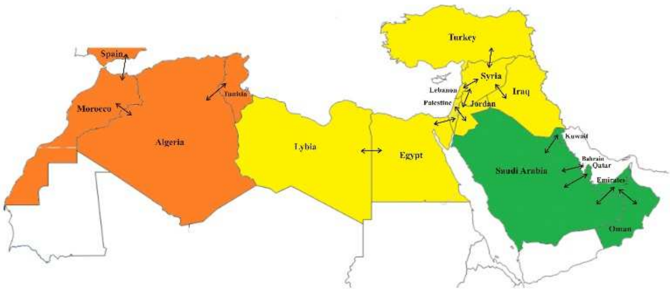

Fig. 1. The map of the main three interconnection project grids in the Arab countries.

Since the article is about the Syrian electrical power system, the study will be about the eight countries interconnection project (the yellow color).

This project involves interconnecting the electrical grids of Egypt, Iraq, Jordan, Libya, Lebanon, Palestine, Syria, and Turkey as shown in Fig.2. This project is symbolized by the first letter of the names of the eight countries (EIJLLPST).

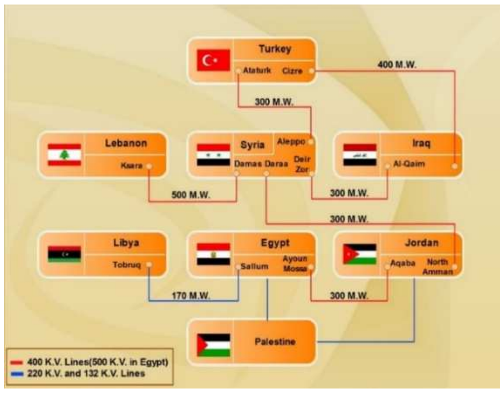

Fig. 2. The countries of the project (EIJLLPST).

It began as a five-country interconnectivity project including Egypt, Iraq, Jordan, Syria, and Turkey, expanded to six countries when Lebanon joined, and then expanded to eight countries when Libya and Palestine joined in. The Egyptian-Jordanian electrical interconnection is the first project that has been implemented to interconnect an electricity grid at 400kV in Jordan and 500kV in Egypt [3, 4].

The implementation of this project began in 1993 and entered service in 1998 and in the same year, the electrical connection between Egypt and Libya was activated, although this interconnection was set at 220kV, not 400kV [5]. Two other connection projects followed, one of them was to interconnect the Syrian grid to the Jordanian grid and entered service in 2001, And the other is to interconnect the Syrian grid to the Lebanese grid, which entered service in 2009 [6].

II. OVERVIEW

A. The Syrian electrical grid

In the Syrian electrical grid, there are 16 electrical stations with different types of generation (combined cycle - steam - gas - diesel). Fig.3 shows the distribution of these stations, noting the electrical interconnection with neighboring countries at voltage 230 kV and 400 kV. Fig.4 shows the percentage generation of these stations, where the total generation capacity is estimated at 9 GW [1].

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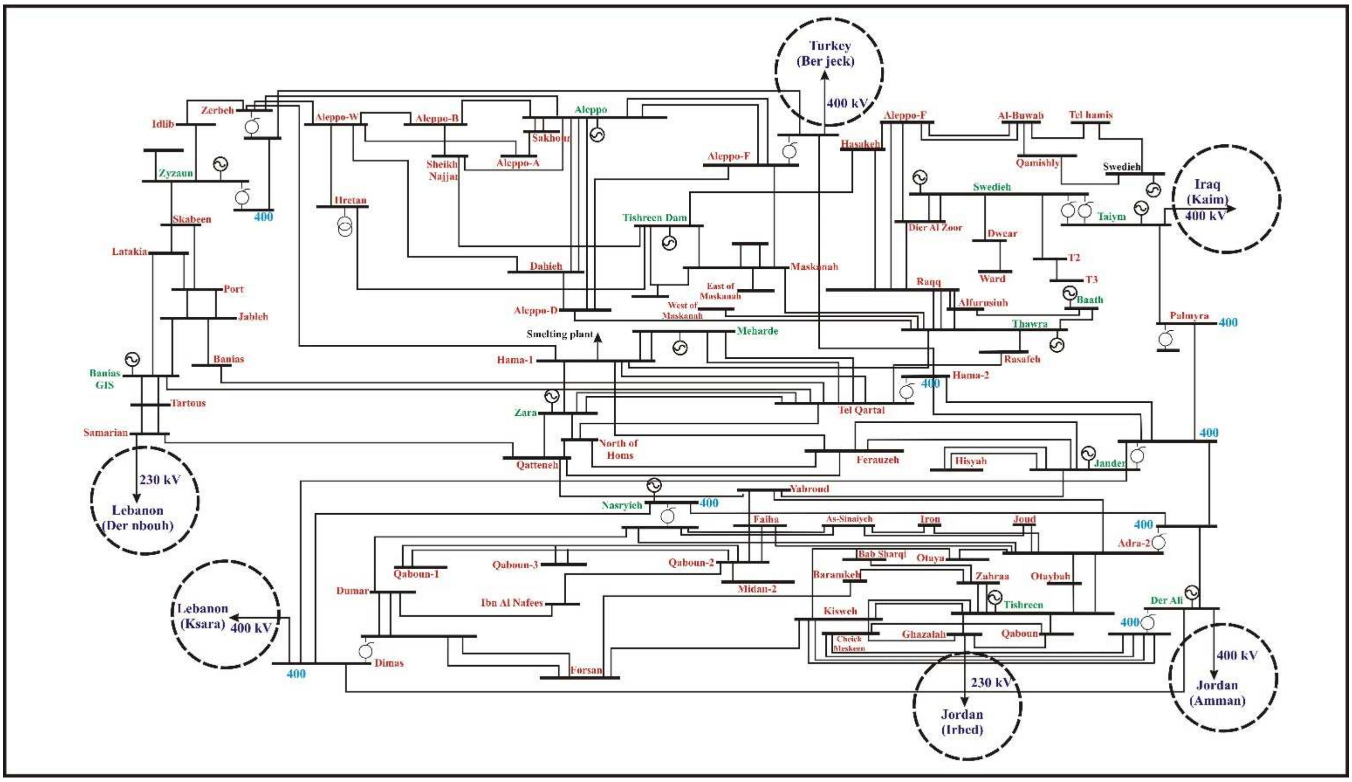

Fig. 3. Distribution of Syrian electrical stations.

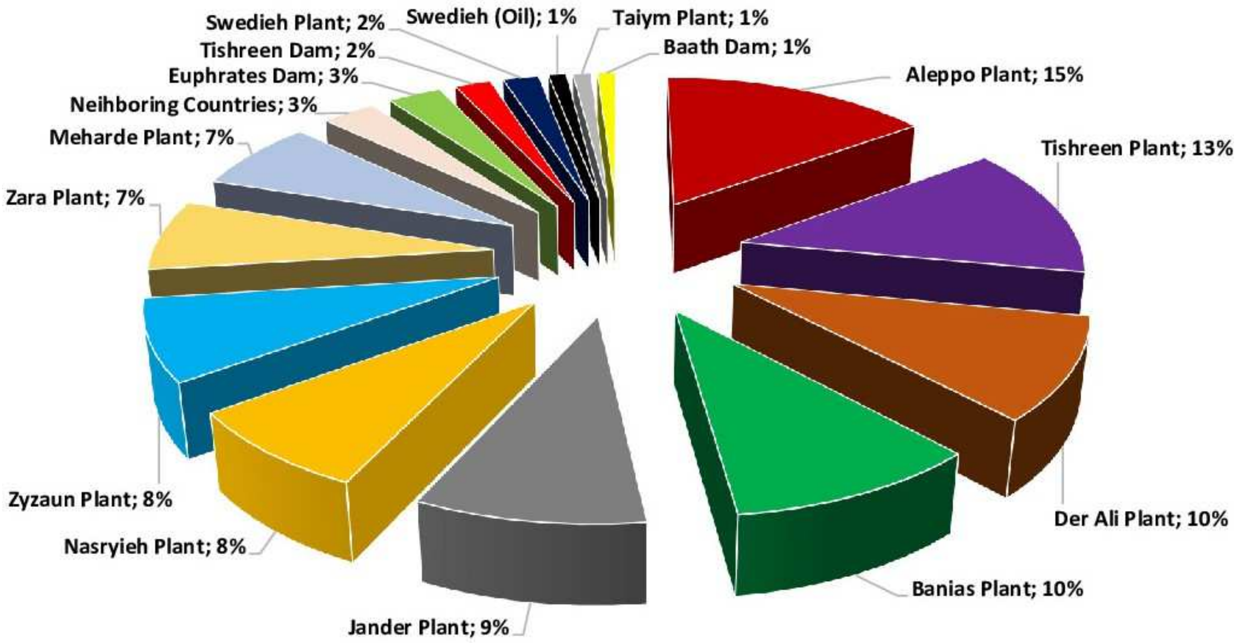

Fig. 4. Percentage of the generation units contribution to cover the capacity of the Syrian electrical grid.

TABLE I. UNDERFREQUENCY PROTECTION IN SUBSTATIONS AT VOLTAGE 66KV IN SYRIA.

Frequency (Hz)	City	Location of underfrequency protection	Load (MW)	Time over (sec)
49	Damascus	Transformer 66/20 kV (Adra)	21	0.5
		Transformer 66/20 kV (Midan 2)	3	0.5
		Transformer 66/20 kV (Dumar)	12	0.5
		Transformer 66/20 kV №.1 (Kisweh)	14	0.5
	Hama	Line Suruj 66 kV (Hama 1)	15	0.5
		Line Hama 2- Hama 3 №.1 (Hama 2)	32	0.5
	Aleppo	Transformer 66/20 kV №.1 (Aleppo-H)	30	0.5
		Transformer 66/20 kV №.2 (Aleppo-H)	18	0.5
	Latakia	Line Banias-Sheikh Badr	25	0.5
		Line Banias-Qadmus	7	0.5
		All of outputs 20kV	8	0.5
	Deir Al Zoor	Transformer 66/20 kV №.1 (Dier Al Zoor plant)	20	0.5
	Hasakeh	Transformer 66/20 kV №.1 (Hasakeh plant)	23	0.5
		Transformer 66/20 kV №.2 (Qamishly)	20	0.5
		Transformer 66/20 kV №.3 (Qamishly)	30	0.5
	Daraa	Line Sanamayn 66kV	22	0.5
		Transformer 66/20 kV №.2 (Cheick Meskeen)	8	0.5
		Transformer 66/20 kV №.1 (Cheick Meskeen)	10	0.5
		Transformer 66/20 kV №.1 (Nawa)	8	0.5
	Total(1)		326	
48.90	Damascus	Transformer 66/20 kV №.1 (Qaboun 2)	10	0.5
		Transformer 66/20 kV №.2 (Dumar)	12	0.5
		Transformer 66/20 kV №.2 (Forsan)	14	0.5
		Transformer 66/20 kV №.1 (Midan 2)	2	0.5
		Transformer 66/20 kV №.2 (Kisweh)	22	0.5
		Transformer 66/20 kV №.2 (Bab Sharqi)	7	0.5
	Hama	Transformer 66/20 kV №.1 (Hama 1)	21	0.5
		Transformer 66/20 kV №.1 (Hama 2)	10	0.5
	Aleppo	Transformer 66/20 kV №.2 (Aleppo-H)	30	0.5
		Transformer 66/20 kV №.2 (Aleppo-F)	12	0.5
	Latakia	Transformer 66/20 kV №.1 (Banias)	12	0.5
	Idlib	Transformer 66/20 kV №.2 (Idlib)	16	0.5
	Deir Al Zoor	Transformer 66/20 kV №.2 (Dier Al Zoor plant)	20	0.5
		Line Mayadin 66kV (Dier Al Zoor plant)	30	0.5
	Hasakeh	Transformer 66/20 kV №.2 (Hasakeh)	23	0.5
		Transformer 66/20 kV №.1 (Qamishly)	13	0.5
		Line Qahtaniyah 66kV (Qamishly)	15	0.5
	Daraa	Transformer 66/20 kV №.2 (Nawa)	8	0.5
	Total(2)		277	
	Damascus	Transformer 66/20 kV №.1 (Forsan)	10	0.5
		Transformer 66/20 kV №.3 (Kisweh)	17	0.5
		Transformer 66/20 kV №.2 (Bab Sharqi)	8	0.5
	Hama	Transformer 66/20 kV №.2 (Hama 1)	20	0.5
	Aleppo	Line Aleppo 66kV (Aleppo-H)	20	0.5
	Idlib	Line Al Dana 66kV (Idlib)	40	0.5
	Deir Al Zoor	Line Suwar 66kV (Dier Al Zoor plant)	20	0.5
	Total(3)		135	
48.70	Damascus	Transformer 66/20 kV №.1 (Bab Sharqi)	10	0.5
	Total(4)		10	
48.60	Damascus	Line Al Hamah 66 kV (Dumar)		0.5
	Hama	Line Sheikh Khloof 66 kV (Hama 1)		0.5
		Transformer 66/20 kV №.2 (Hama 2)		0.5
	Raqqa	Transformer 66/20 kV №.1 (Raqqa plant)		0.5
	Total(5)		98	
	Total		846	

B. The program used in the study (PSS/E):

Power **S**ystem **S**imulation for **E**ngineering (PSS/E) is a collection of programs that may be used to investigate the performance of a power system's transmission network and generation in both steady-state and dynamic conditions.

Usually, in this program two main simulations are used one for steady-state analysis and the other for dynamic simulations. PSS/E can be used to make calculations easier for a variety of studies, including power flow and related network functions, optimal power flow, balanced and unbalanced faults, network equivalent construction, dynamic simulation [7].

The program consists of three sub-programs:

1. Psslf: It is concerned with the steady-state of the network. The following information is entered into the electrical network in the program (generation units-transformers-transmission lines - loads of busbars) to the program and saved as file (.sav).

The busbars of (generators-transformers-or loads) are numbered, and in the case of the Syrian grid, a specific numbering pattern is followed, the busbar consists of five numbers from left to right.

The first number indicates the following voltage:

Number (1): less than 20 kV.

Number (2): 20 kV.

Number (3): 230 kV.

Number (4): 400 kV.

Number (5): 500 kV.

Number (6): 66 kV.

The second number indicates the region where the busbar is located. In the case of the Syrian grid, there are five regions:

Number (1): Southern region.

Number (2): Central region.

Number (3): Coastal region.

Number (4): Northern region.

Number (5): Eastern region.

The third, fourth and fifth number indicates to number of busbar. For example, in Der Ali plant there is busbar 41220:

Number (4): 400 kV.

Number (1): busbar is located in the southern region.

Number (220): Number of busbar.

2. Pssds4: It is concerned with the dynamic simulation of the network, and here is loading a (.sav) file that was produced from the first program (loading electrical network to be tested). After that, any test we want can be executed, such as disconnecting (busbar, transformer, load...) and get file (.out) contains curves that show the change of the curves of (frequency, rotor angle, voltage, power...) and this file can only be read by the third program.

3. Pssplt: It is a program that shows the results of tests on the network by opening the file (.out) that resulted from the second program.

C. The Importance of the Spinning Reserve

Spinning reserve [8] (r) defines the relative difference between the maximum power capacity of the system and the actual load:

$$r = \frac{\sum_{i=1}^{N_G} \mathrm{P}_{ni} - \mathrm{P}_L}{\mathrm{P}_L} \qquad (1)$$

A simple expression for the local droop of the generation characteristic can be obtained by assuming that the droop of all the units which are not fully loaded are approximately identical, that is:

$$\left.\begin{aligned} &(\rho_i = \rho)\,\&\left(\mathrm{K}_i = \mathrm{K} = \frac{1}{\rho}\right) \\ &p = \frac{\sum_{i=1}^{R} \mathrm{P}_{ni}}{\sum_{i=1}^{N_G} \mathrm{P}_{ni}} \end{aligned}\right\} \qquad (2)$$

For the units operating at their limits, $(\rho_{i=\infty})\&(K_i = 0)$Under these conditions [9]:

$$\left.\begin{aligned} \Delta\mathrm{P}_\mathrm{T} &= -\sum_{i=1}^{N_G} \mathrm{K}_i \mathrm{P}_{ni} \frac{\Delta f}{f_n} = -\sum_{i=1}^{j} \mathrm{K}_i \mathrm{P}_{ni} \frac{\Delta f}{f_n} \cong -\mathrm{K}\sum_{i=1}^{j} \mathrm{P}_{ni} \frac{\Delta f}{f_n} \\ \Delta\mathrm{P}_\mathrm{T} &= -\mathrm{K}_p \sum_{i=1}^{N_G} \mathrm{P}_{ni} \frac{\Delta f}{f_n} = --\mathrm{K}_p (r+1)\mathrm{P}_L \frac{\Delta f}{f_n} \end{aligned}\right\} \qquad (3)$$

Dividing by P_L gives:

$$\left.\begin{aligned} &\frac{\Delta\mathrm{P}_\mathrm{T}}{\mathrm{P}_L} = -\mathrm{K}_\mathrm{T} \frac{\Delta f}{f_n} \\ &\frac{\Delta\mathrm{P}}{\mathrm{P}} = \frac{\Delta f}{f_n} \end{aligned}\right\} \qquad (4)$$

Where:

$$\left.\begin{aligned} &\mathrm{K}_\mathrm{T} = p(r+1)\mathrm{K} \\ &\rho_\mathrm{T} = \frac{\rho}{p(r+1)} \end{aligned}\right\} \qquad (5)$$

For a given load, equation (4) represents the linear approximation of the nonlinear generating characteristic. The local droop ρ_T increases as the spinning reserve decreases. At the limit, both the coefficients r and p are 0 and $\rho_\mathrm{T} = \infty$, when the load P_L equals the system producing capacity. This corresponds to all the generating units being fully loaded [10].

p :number of poles;

f :nominal frequency;

P_L: real power absorbed by a load or total system load;

K_i: reciprocal of droop for the ith generating unit;

K_p: the gain of power system stabilizer;

K_T: reciprocal of droop for the total system generation characteristic;

ρ: static droop of the turbine–governor characteristic;

ρ_T: droop of the total system generation characteristic;

$\sum_{i=1}^{N_G} \mathrm{P}_{ni}$: is the total of all the generating units in the system's power ratings;

$\sum_{i=1}^{R} P_{ni}$: is the sum of the power ratings of all the units operating on the linear part of their characteristics.

TABLE II. ADDED UNITS TO CREATE SPINNING RESERVE IN THE SYRIAN ELECTRICAL GRID

Name of station	Units	Spinning reserve (r)
Jander	combined cycle	1 x 150 MW
Der Ali	combined cycle	1 x 250 MW
Tishreen	Steam	1 x 200 MW
Swedieh	combined cycle	2 x 150 MW

r=900 MW represents about (10%) of the total generation capacity (9 GW) in the Syrian electrical system.

III. RESULTS AND ANALYSIS

The impact of electrical interconnection in supporting **p**ower **s**ystem **s**tability (*PSS*) for frequency(*f*) in Syria will be studied through a comparison between independent and Interconnected grid.

For a comprehensive study of the frequency stability in the Syrian electrical grid, four electrical plants were selected in four different regions (Der Ali, Jander, Aleppo, Taiyam), shown in Fig .3. Supposedly, there was a fault in Der Ali and Tishreen plants, for example in the gas pipelines feeding these two stations. This led to a fault on the busbars of these two plants at voltage (20-230)kV:

- Busbar of Der Ali plant (21224, 21225, 21226).

- Busbar of Tishreen plant (31141, 31142, 31143, 31144, 31147, 31148, 31149).

The impact of these faults will be studied at (*PSS, f*) in busbars (45920 pink, 44670 blue, 42400 red, 41220 green).

The response of a power system to a power imbalance caused by the tripping of a generating unit can be divided into four stages Fig.5 [11]:

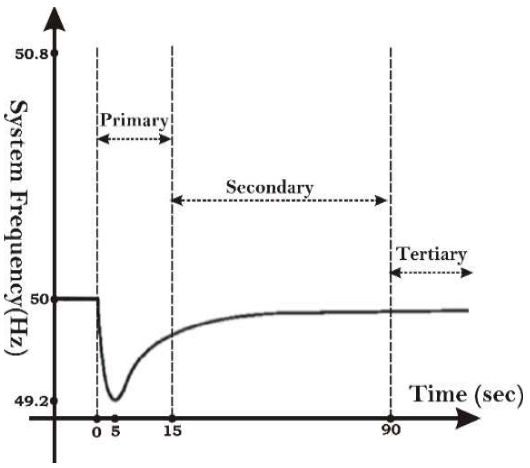

Fig. 5. The Time of each stage when an imbalance power occurs

Stage I (Rotor swings in the generators); Stage II (Frequency drop); Stage III (Primary control by the turbine governing systems); Stage IV (Secondary control by the central regulators).

A. Independent grid:

- *Stage I (r=0)*: using table I of underfrequency [12-15] protection in substations of the Syrian grid, we applied stage I which disconnected at (f=49 Hz). (PSS/E) program is used to describe this situation, and the resultant curve is shown in Fig.6. It is noticeable that the frequency didn't fall less than (f=47.5 Hz), but rather it stabilized at (f=47.7 Hz). Consequently, there will be no collapse or blackout in the electrical grid.

- *Stage II (r=900 MW):* the value of the frequency (f=47.7 Hz), at which the electrical network has stabilized is very low. Using the table I, applied stage II, which disconnected at (f=48.5 Hz). (PSS/E) program is used to describe this situation, and the resultant curve is shown in Fig.7. It is noticeable that the frequency stabilized at (f=49.7 Hz) (very acceptable value) , thus no need for stage III, IV.

B. Interconnected grid:

- *Stage I (r=0):* using table I , applied stage I which disconnected at (f=49 Hz). (PSS/E) program is used to describe this situation, and the resultant curve is shown in Fig.8. It is noticeable that the frequency stabilized at (f=48.9 Hz) not the value (f=47.7 Hz) in Fig.6.

- *Stage II (r=900 MW):* using the table I, applied stage II, which disconnected at (f=48.5 Hz). (PSS/E) program is used to describe this situation, and the resultant curve is shown in Fig.9. It is noticeable that the frequency stabilized at (f=49.8 Hz) (very acceptable value) [16-18] , thus no need for stage III, IV.

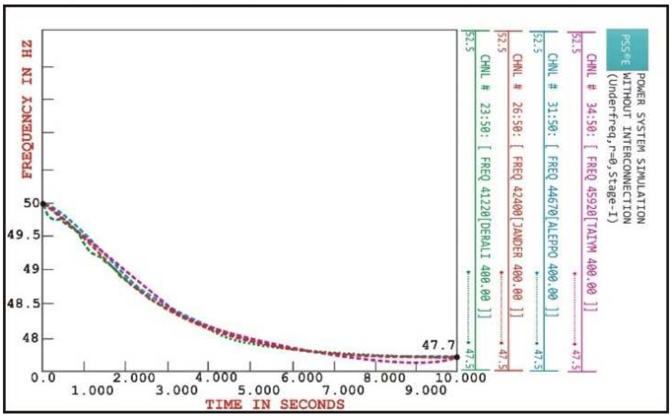

Fig. 6. Frequency behavior (The Independent grid, Stage I).

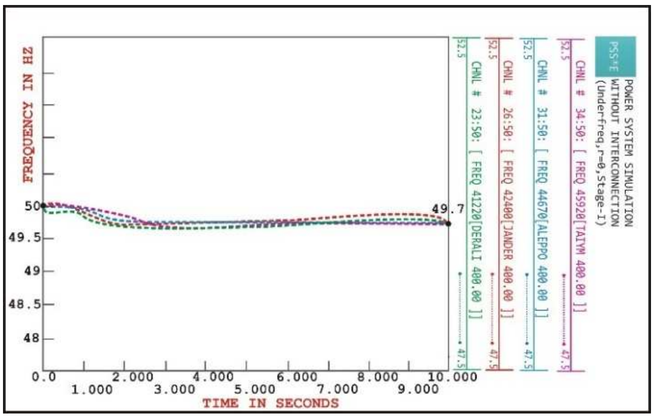

Fig. 7. Frequency behavior (The Independent grid, Stage II).

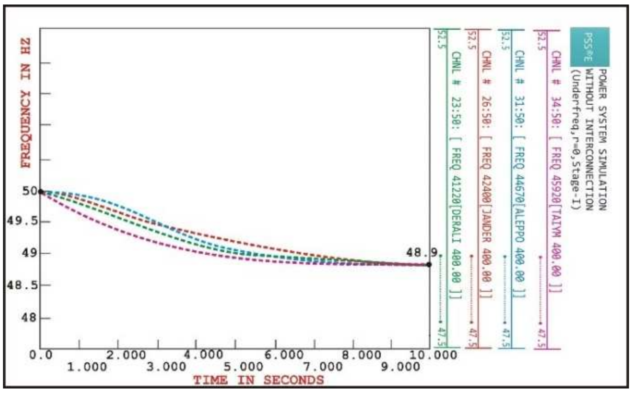

Fig. 8. Frequency behavior (The Interconnected grid, Stage I).

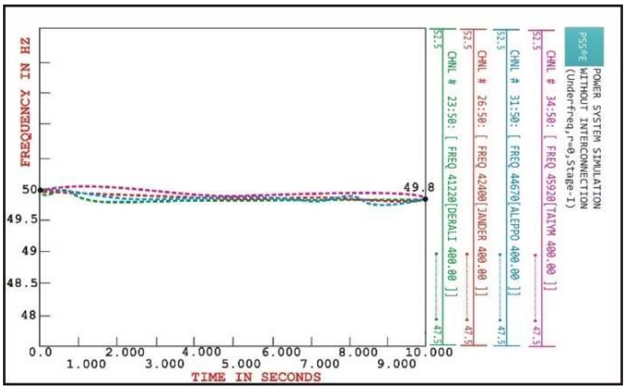

Fig. 9. Frequency behavior (The Interconnected grid, Stage II).

It has been It is noticed from the figures and table III:

1. The role of electrical interconnection contributed compensation for the reduction in the spinning reserve;
2. Supporting the stability of the frequency through the power imported through the interconnecting lines during emergency situations.
3. Preventing the frequency from falling to the limit values.
4. The role played by Stage I and Stage II in avoiding the frequency drop to the value 47.5 Hz (-5%) and thus avoiding the occurrence of total blackouts.

As a result of the electrical interconnection, the Syrian electrical grid became more balanced, better static and dynamic stability.

TABLE III. THE FREQUENCY VALUES BEFORE AND AFTER ELECTRICAL INTERCONNECTION

Grid	Independentd	Interconnected
Stage I	47.7 Hz	48.9 Hz
Stage II	49.7 Hz	49.8 Hz

IV. CONCLUSION

This research paper has discussed the importance of electrical interconnection for Arab countries, for example, given the domestic circumstances in Libya and Syria tie lines can help provide power needs until generating capacity is repaired and upgraded. This paper confirmed the close relationship between the generated power and frequency in equation (4) ,where the frequency deviations were reduced from 4.6% to 0.4%. Finally it is recommended to activate Automatic Generation Control (AGC) in the Syrian Grid instead of the manual operator, this contributes to the speed of work of Stage I and Stage II with high efficiency.

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