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Study of Impact of the Main Parameters of Synchronous Generators on the Dynamic Stability in the Syrian Power System

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***Abstract*—The importance of interconnection between electrical power systems has increased, largely due to the dependence of the whole world on electricity and ease of transfer between its countries vast, in addition to their economic and technical benefits. In this research, the dynamic impact of the interconnection on the rotor angle stability for Synchronous Generators, located on the Syrian network, were analyzed through the dynamic simulation of the power system. The none linear equations were built, then use the program PSS®E (Power system simulation), to identify the determinants of the system and determine critical fault clearing times of three-phase faults on the 400 and 230 kV. In addition, to identifying the angular revolving generators, thus to verify the stability whether it is on the independent network within the Syrian electrical system or as part of the five countries interconnection project.**

***Keywords*—Electrical Interconnection, transmission lines, power transposed, stability, rotor angle**

I. INTRODUCTION

The types of electrical system stability are classified according to its main determinants:(Rotor angle of generator-Voltage of busbar- Frequency of electrical system)[1].The study will be conducted about rotor angle stability

The dynamics of a power system are characterised by its basic features given below [2],[3]:

1-Synchronous tie exhibits the typical behaviour that as power transfer is gradually increased a maximum limit is reached beyond which the system cannot stay in synchronism, i.e., it falls out of step.

2-The system is basically a spring-inertia oscillatory system with inertia on the mechanical side and spring action provided by the synchronous tie wherein power transfer is proportional to sinδ or δ (for small δ, δ being the relative internal angle of machines).

3-Because of power transfer being proportional to **sinδ**, the equation determining system dynamics is nonlinear for disturbances causing large variations in angle **δ**.

II. FORMATION OF THE MATHEMATICAL MODEL:

The mathematical model in the general case includes all the basic elements of an electrical power system:

(Excitation systems - Generators - Transmission lines - Transformers -Loads etc...).

A-Excitation Systems: It is classified into three broad categories based on the excitation power source [4] :(DC excitation systems- AC excitation systems- Static excitation systems). The different types of excitation systems, but in the Syrian electrical system are represented by one model of the type SEXS. Fig.1 below illustrates the block diagram of a simplified exciter system. SEXS model represents no specific type of excitation system, but rather the general characteristics of a wide variety of properly tuned excitation systems. SEXS model is particularly useful in cases where an excitation system must be represented and its detailed design is not known[5],[6].

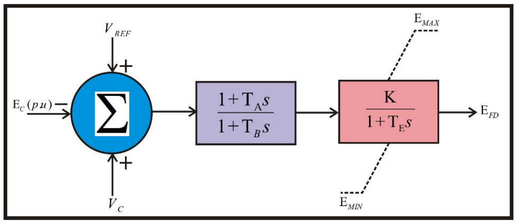

Fig. 1. Simplified Excitation System in PSS/E.

K: the gain.

T_E: time constant.

E_{MIN},E_{MAX}: are a basic representation of the excitation source.

T_A,T_B: time constants, which provide the transient gain reduction needed to allow satisfactory dynamic behavior with high steady-state gain.

SEXS model is the most common exciter model used in order to perform analysis and producing generator main field voltage **E_{FD}.** According to data [7] were taken from the Syrian Ministry of Electricity, the parameters of the excitation systems model of the type SEXS are given as follows:

TABLE I. THE PARAMETERS OF THE EXCITATION SYSTEMS MODEL OF THE TYPE SEXS.

K	T_B	T_A/T_B	E_{MIN}	E_{MAX}	T_E
[20-100]	[5-20]	[0.05-1]	0	[3-6]	[0-0.5]

B-Generators: The GENRSA and GENROE generator types are used [8].

The generator model to represent the salient pole unit is the PSS®E model GENSAE, shown in the block diagram in Fig.2. This is a 5th order dynamic model with the saturation function represented as a geometric (exponential) function [9].

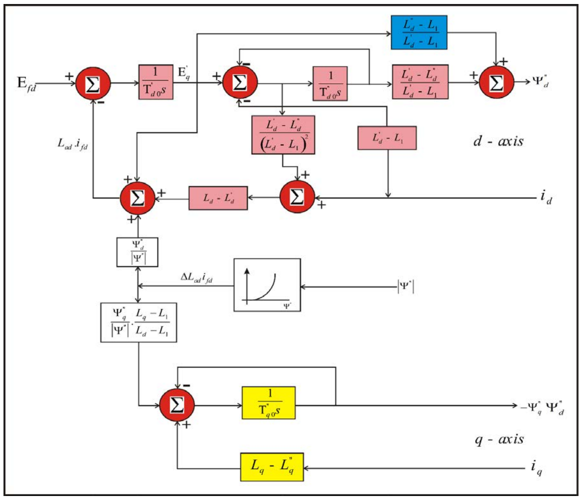

Fig. 2. Block Diagram for the PSS/E Model GENSAE (salient pole).

The generator model to represent the round-rotor unit is the PSS®E model GENROE, shown in the block diagram in Fig.3. This is a 6th order dynamic model with the saturation function represented as a geometric (exponential) function [9].

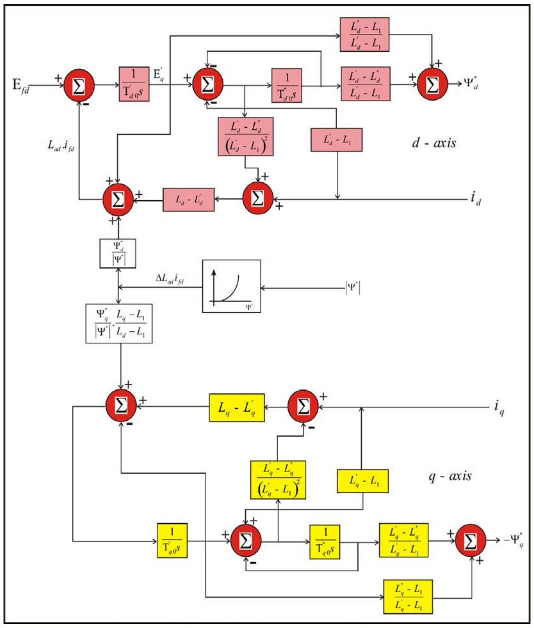

Fig. 3. Block Diagram for the PSS/E Model GENROE (round-rotor).

C-Transmission lines: The electricity can be distributed in the grid with AC or DC technology. The power systems used here are only using AC technology. PSS®E uses a model to represent the transmission line called π – equivalent [8]:

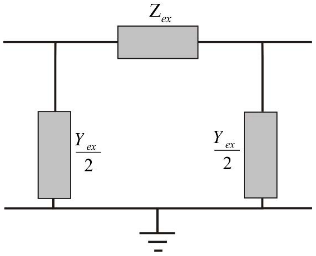

Fig. 4. π -equivalent circuit for a transmission line.

D-Transformer Modeling: The transformers used in the Syrian electrical system are two and three winding transformers [8],[10].

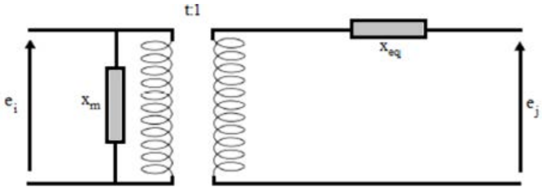

Fig. 5. two winding three-phase positive sequence transformer model with tap changer.

In PSS®E the transformer terminal voltages ei and ej both depends on:

X_m: the magnetizing reactants.

X_{eq}: the equivalent reactance.

T: the tap position.

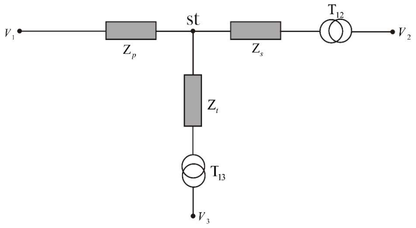

Fig. 6. The equivalent circuit of the three winding transformer.

E-Load Modeling: Load models differ according to their parameters (Current-Active power-Reactive power) and the relationship of these parameters to the frequency of the busbars, according to the equations[8]:

$$\left.\begin{aligned} &I_p + jI_q = \left(I_{p0} + jI_{q0}\right)\left(\frac{\omega}{\omega_0}\right)^k \\ &P = P_0\left(\frac{\omega}{\omega_0}\right)^m \\ &Q = Q_0\left(\frac{\omega}{\omega_0}\right)^n \end{aligned}\right\} \qquad (1)$$

I_p: the real part of the current load.

I_q: the imaginary part of the current load.

I_{p0}: the real part of the current load at the reference value of voltage and frequency.

I_{q0}: the imaginary part of the current load at the reference value of voltage and frequency.

k,m,n: constants depend on the reference value of voltage and frequency

In this study a simplified representation of the electrical power system known as the classical model[11] will be adopted. Assumptions of this model:

- The damping is neglected.
- The mechanical power is constant.
- The synchronous machines are modelled as constant voltage sources behind the transient reactance.
- The coincidence between the mechanical rotor angle of each machine and the voltage behind the machine reactance.
- Loads are represented by impedances (admittances).

Based on the Assumptions, the swing equations of an electric power system containing m nodes and n buses will be derived as in the Fig.7[12]:

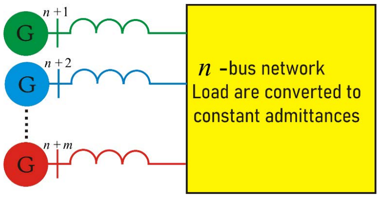

Fig. 7. Power system representation for transient stability analysis (multi-machine).

In order to study the stability of power system, some of the following pre-calculations must be done:

1- Assume the electrical power base (Sbase=100 MVA).

2- The machine currents prior to disturbance are calculated from:

$$\left.\begin{aligned} I_i &= \frac{S_i^*}{V_i^*} = \frac{P_i - jQ_i}{V_i^*} \\ i &= n+1\dots\ \dots n+m \end{aligned}\right\} \tag{2}$$

Vi: The Voltage of the node i.

Pi: The total of active power in the node i.

Qi: The total of reactive power in the node i.

The generator armature resistances are usually neglected and the voltages behind the transient reactance are then obtained:

$$E_i^{'} = V_i + jX_d^{'} I_i \tag{3}$$

3-All load are converted to equivalent admittances by using the relation:

$$Y_{i0} = \frac{S_i^*}{|V_i|^2} = \frac{P_i - jQ_i}{|V_i|^2} \tag{4}$$

4-The node voltage equation with node 0 as reference for this network:

$$I_{bus} = Y_{bus} V_{bus0} \tag{5}$$

I_{bus}: vector of the injected bus currents.

V_{bus0}: vector of bus voltages measured from the reference node**.**

5-From [12] we can find:

$$P_{ei} = \sum_{j=1}^{m} |E_i^{'}||E_j^{'}||Y_{ij}|\cos\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{6}$$

The swing equation with damping neglected, for machine i becomes:

$$P_{mi} = \frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} + \sum_{j=1}^{m} |E_i^{'}||E_j^{'}||Y_{ij}|\cos\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{7}$$

Y_{ij}: elements of the faulted reduced bus admittance matrix.

H_i: inertia constant of machine **i** expressed on the common MVA base.

We introduce here state variables to convert each second order swing equation by two coupled first order differential equation.

$$\left.\begin{aligned} &\frac{d\delta_i}{dt} = \Delta\omega_i \\ &\frac{d\Delta\omega_i}{dt} = \frac{\pi f_0}{H_i}\left(P_{mi} - P_{ei}^{f}\right) \\ &i = 1+n\dots\dots\dots n+m \end{aligned}\right\} \tag{8}$$

Usually, one of the generators is used as a reference and the phase angle difference is plotted for all generators based on this reference. If the phase angle differences are not increasing, then it is said that the system is stable, but if these differences are increasing, then this means that the system is not stable.

III. DYNAMIC REPRESENTATION OF THE SYRIAN ELECTRICAL POWER SYSTEM

The data[13] will be taken from the Syrian Ministry of Electricity about (power stations-transmission lines- loads) as input data for program PSS®E [14] as files **.raw**[15].

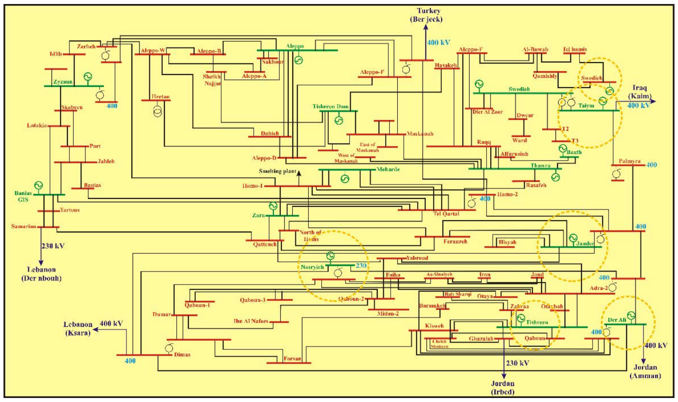

Fig. 8. The one-line scheme of the Syrian electrical grid for voltage (230-400) kV.

The dynamic representation of the Syrian electrical power system for a three-phase short circuit will be studied at the substations with changing the fault clearing time in the range (100-600) msec and determining the Critical Fault Clearing Time (CFCT)[16],[17] for all plants in the Syrian electrical power system at 230 kV and 400 kV before and after interconnection. Then, some faults will be made in the Syrian electrical system and in some electrical systems of the interconnection countries as: (Three-phase short circuit at 400 kV busbar-disconnecting(Trip) some transmission lines-Unexpected out of service for generating units).

IV. THE EIGHT COUNTRY INTERCONNECTION PROJECT (NAMED EIJLLPST)

This project[18],[19] involves interconnecting the electrical grids of Egypt, Iraq, Jordan, Libya, Lebanon, Palestine, Syria, and Turkey as shown in the Fig.9:

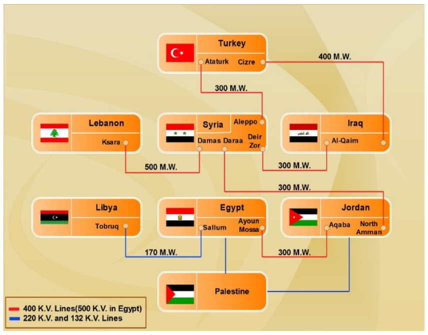

Fig. 9. The Diagram of electric interconnections in the project (EIJLLPST).

The transmission networks between these countries have been interconnected at a (500-400-220) kV, in addition to a 13 km submarine cable at 400 kV, it interconnects between Al-Aqaba power station in Jordan and Taba power station in Egypt[20].

V. DETERMINATION OF CRITICAL FAULT CLEARING TIME IN THE SYRIAN ELECTRICAL POWER SYSTEM

Critical Fault Clearing Time (CFCT)is the critical time or maximum time needed by the synchronous generator to maintain the condition of the generator remains in synchronization. The principle followed in determining (CFCT) is to impose a three-phase short circuit at bus, and the fault was disconnected after (X msec), the process was repeated with a new fault time…….. until we get (CFCT).

TABLE II. THE CRITICAL FAULT CLEARING TIMES OF THREE-PHASE SHORT CIRCUIT FOR SOME POWER STATIONS BEFORE INTERCONNECTION.

BUS		Power Stations	CFCT (msec)
№,	***NAME***		
55599	NASRG01 15.0	Nasryieh 230	200
55607	JANDGT01 15.0	Jander 230	200
55639	TAYHGT01 10.5	Taiym 230	200
55836	DIRALIGT01 20.0	Der Ali 400	400
55837	DIRALIGT02 20.0		
55579	SWDPT01 10.5	Swedieh 230	200
55589	TISHGT01 15.0	Tishreen 230	200

TABLE III. THE CRITICAL FAULT CLEARING TIMES OF THREE-PHASE SHORT CIRCUIT FOR SOME POWER STATIONS AFTER INTERCONNECTION.

BUS		Power Stations	CFCT (msec)
№,	***NAME***		
55599	NASRG01 15.0	1-Nasryieh 230	250
55607	JANDGT01 15.0	2-Jander 230	200
55639	TAYHGT01 10.5	3-Taiym 230	200
55836	DIRALIGT01 20.0	4-7-Der Ali 400	500
55837	DIRALIGT02 20.0		
55579	SWDPT01 10.5	5-Swedieh 230	200
55589	TISHGT01 15.0	6-Tishreen 230	200

VI. CHECKING GENERATOR STABILITY AND PLOT ROTOR ANGLE CURVES

ST-1: Fig.10 shows rotor angle curve Nasryieh generating unit (NASRG01), before interconnection with (EIJLLPST). When occurs Three-phase short circuit(3phs) at bus 55599 of Nasryieh power plant. For different Fault Times (FT)= (100-200-250) msec. It is noticeable from the plot (blue curve) that Nasryieh power plant Out-of-phase synchronization (OOPS) for FT=250 msec therefore, CFCT=200 msec.

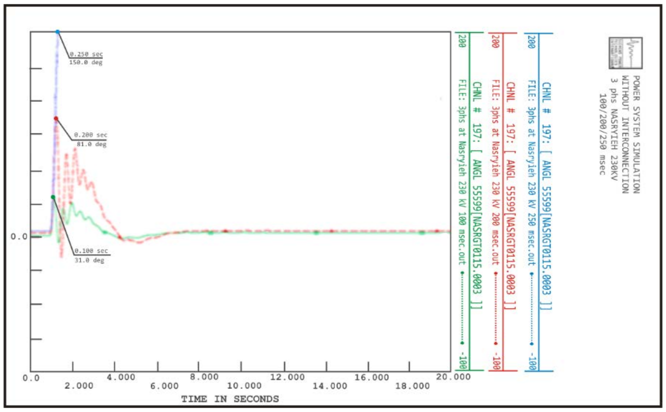

Fig. 10. Rotor angle of Nasryieh power plant for different (FT) before interconnection.

ST-2: Fig.11 shows rotor angle curve Nasryieh generating unit (NASRG01), after interconnection with (EIJLLPST). When occurs Three-phase short circuit(3phs) at bus 55599 of Nasryieh power plant. For different Fault Times (FT)= (100-200-300) msec. It is noticeable from the plot (blue curve) that Nasryieh power plant Out-of-phase synchronization (OOPS) for FT=300 msec therefore, CFCT=250 msec.

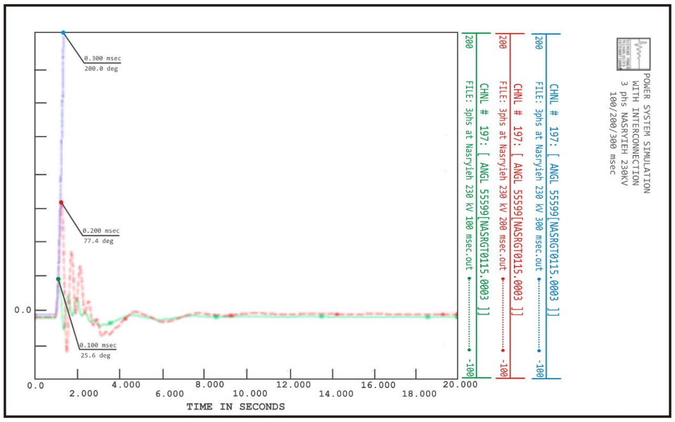

Fig. 11.Rotor angle of Nasryieh power plant for different (FT) after interconnection.

By comparing Figures (10) and (11), we notice an improvement CFCT for (3phs) of the Nasiriyah power plant after interconnection with (EIJLLPST) from 200 to 250 msec.

ST-3: Fig.12 shows rotor angle curve of generating units of (Jander- Taiym- Der Ali- Swedieh) power plants, before interconnection with (EIJLLPST). When occurs Three-phase short circuit (3phs) at bus 55579 of Swedieh power plant. For Fault Time (FT)= 200 msec. It is noticeable from the plot (green curve) that Swedieh power plant Out-of-phase synchronization (OOPS).

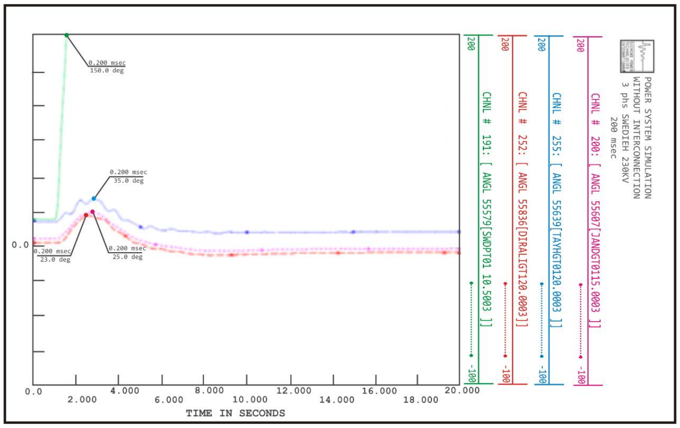

Fig. 12. Rotor angle of (Jander- Taiym- Der Ali- Swedieh) power plant (FT=200msec) before interconnection.

ST-4: Fig.13 shows rotor angle curve of generating units of (Jander- Taiym- Der Ali- Swedieh) power plants, after interconnection with (EIJLLPST) and power transposed 700 MW. When occurs Three-phase short circuit(3phs) at bus 55579 of Swedieh power plant. For Fault Time (FT)= 200 msec. It is noticeable from the plot (green curve) the oscillation of the unit generating of Swedish and got back to their normal state after fault application (Stable), this indicates the role of interconnection in restoring stability after faults.

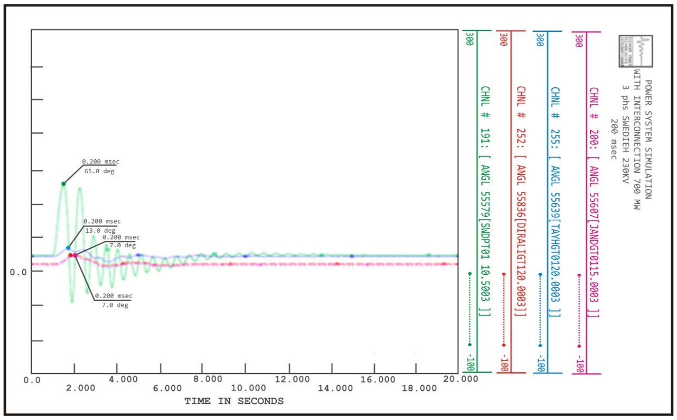

Fig. 13. Rotor angle of (Jander- Taiym- Der Ali- Swedieh) power plant (FT=200msec) after interconnection.

ST-5: Fig.14 shows rotor angle curve of Der Ali generating unit (DIRALIGT01), before interconnection (red curve) and after interconnection (green curve) with (EIJLLPST). When occurs three-phase short circuit(3phs) at bus 55836 of Der Ali power plant and trip of the transmission line (Der Ali-North of Jordan) 400 kV. For Fault Time (FT)= 200 msec. Power transposed (PT=300 MW). It is noticeable from the plot (red curve) that Der Ali generating unit (DIRALIGT01) Out-of-phase synchronization (OOPS) this is because:(A large imbalance of power in the failure node- Low electrical power generated- The voltage drop that becomes approximately equal to zero in the failure node) which leads to:(Generator acceleration during the failure period- The decrease in power coming from the interconnecting line as a result of the trip). This shows the positive impact of interconnection on the angle stability of (DIRALIGT01).

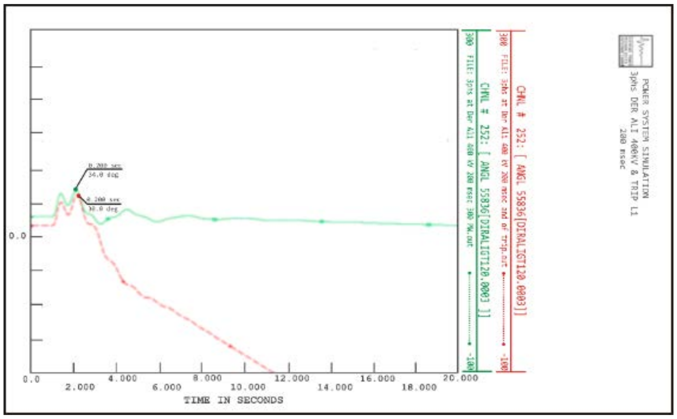

Fig. 14. Rotor angle of (DIRALIGT01, FT=200msec, PT=300MW) before and after interconnection.

ST-6: Fig.15 shows rotor angle curve of Der Ali generating unit (DIRALIGT01), before interconnection (blue curve) and after interconnection (red and green curve) with (EIJLLPST).

When occurs three-phase short circuit(3phs) at bus 55836 of Der Ali power plant. For Fault Time (FT)= 200 msec. Power Transposed:

(PT1, PT2) = (300MW, red curve) , (700 MW, green curve).

It is noticeable from the plot:

- When increase in the power transposed, there is a clear improvement in the rotor angle of GT01.
- Although the interconnection network contributes to feeding the failure node but, it contributes to increasing (Short-circuit power-reliability of busbar) which leads to the enlargement of the stabilization area after failure.

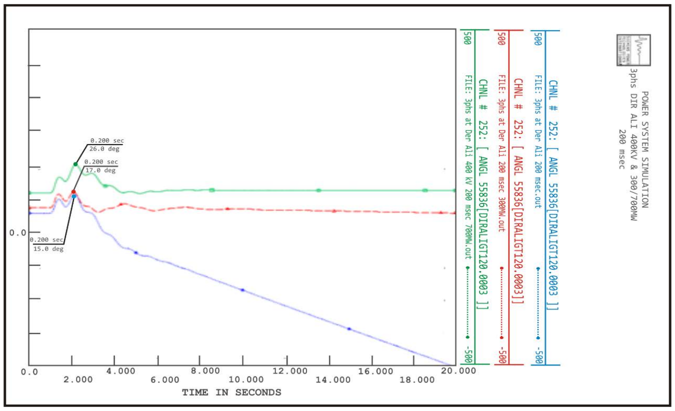

Fig. 15. Rotor angle of (DIRALIGT01, FT=200msec, PT=300 and 700MW) before and after interconnection.

ST-7: Fig.16 shows rotor angle curve of Der Ali generating unit (DIRALIGT01), after interconnection with (EIJLLPST). When occurs Three-phase short circuit(3phs) at bus 55836 of Der Ali power plant. For Fault Time (FT)= 200 msec. Power transposed (PT=700 MW). Then the recurrence of the same failure, but with a drop of generation unit (KURM1-600 MW) in Egypt. It is noticeable from the plot (red curve) the oscillation of GT01 and does not get back to their normal state after fault application and fall out of step due to no synchronism between electromagnetic and mechanical torques as a result of the negative impact of the sudden drop of KURM1.

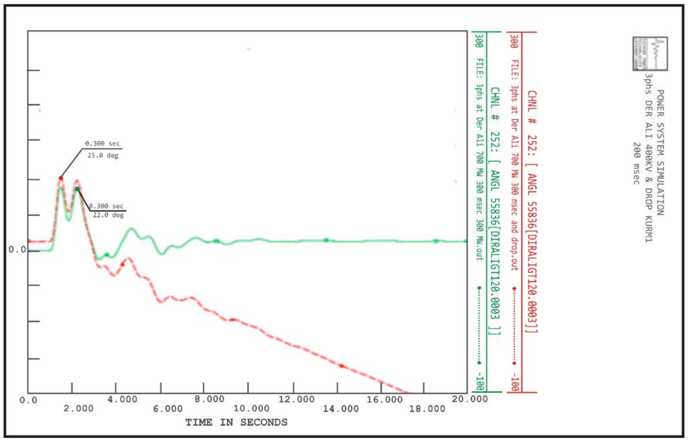

Fig. 16. Rotor angle of (DIRALIGT01, FT=300msec, PT=700MW, drop KURM1) after interconnection.

VII. CONCLUSIONS:

1. It was found that there is an increase in CFCT for units of generation in the Syrian electrical system because of: Activating the interconnection- Increasing power transposed (PT) this lead to enlarge the post-fault stabilization area.

2. It was found that faults that occur on one of the electrical systems (Egypt in our study) participating in the interconnection network may negatively impact the transient stability of the other electrical systems.

3. Before starting to interconnect electrical systems to the Syrian electrical system, it is recommended to conduct in-depth dynamic studies on the entire system to show the impact of the interconnection on the system's parameters and taking into account the increase in Power transposed and choosing the appropriate protections for interconnection lines.

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