Impact of the New Gabl El-Zite Wind Farm Addition on the Egyptian Power System Stability

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Abstract—
Due to the continuous yearly increase in the Egyptian system electric load, in addition to the present days high price of the fuel, it is planned to exploit the renewable energy sources. A new wind farm of the power 2300 MW is planned to be erected in the year 2017 at Gabl El-Zite site on the red sea coast and it will be added with the present 517 MW connected farm located at Zaafrana site for feeding the system loads. In this paper the effect of the Zaafrana and Gabl El-Zait wind farms penetration on the Egyptian power system stability will be conducted. Also the effect of this penetration on the thermal limits of the system transmission system will be covered. The MATLAB-Simulink software package is used for carrying these studies.

***Keywords*— Voltage Stability, Angle Instability, Doubly-Fed Induction Generator, Fault Ride-Through, Egyptian power System.**

I. INTRODUCTION

Owing to the rapid increase of the global population, uneven distribution of resources energy and the non-renewable nature of fossil fuels, the importance of renewable energy resources is obvious. Further, growing environmental concerns and attempts to reduce dependency on fossil fuel resources are bringing renewable energy resources to the mainstream of the electric power sector. Among the various renewable resources, wind power is assumed to have the most favourable technical and economical prospects [1-3].

According to the new energy policies regarding the share of renewable energy, the European Union raises its target to 20%. Germany and Spain raise their targets to be more than 40%. As well in Egypt, the Supreme Council for Energy raises the target to 20%. However, as the penetration of wind energy resources increases, the impact of wind turbine generators on power system dynamic behaviour exaggerates. These impacts obviously differ from that of the conventional synchronous generators. It is therefore very important and imperative to study their effects on the stability of power system networks and to emphasize the methodologies to avoid their massive problems. These problems, when occur, impact significantly the performance of the system overall grid and may result in the synchronous instability or the system total or partial blackouts.

In [4] the authors carried out the stability studies of the IEEE 9-bus power system assuming different penetration values of the FSIG-based wind farm, and it is found that the FSIG affect negatively on the system voltage stability because of the reactive power absorption and also the critical clearing time much smaller than that with the conventional synchronous generators. In [5] the dynamic modelling of the DFIG was covered. Also, the Fault Ride-Through capability of the DFIG was covered considering both the crowbar and the DC-chopper circuit and it is found that the DC-chopper circuit can protect the rotor converter from excessive over current resulting from grid faults. Also, the reactive power support capability of the DFIG was discussed and it is found that the DFIG can support the grid voltage by generating the required reactive power within its thermal limits. The power system stability analysis of the power system considering high penetration of the DFIG based wind turbine, considering 16-bus test system was discussed in [6]. It is found that the system lose its angle and synchronous stability while the DFIG can maintain its rotor speed stabilityand system voltage stability. Also the critical clearing time during terminal faults is greater than that when the conventional synchronous generator is used.

The aim of the paper is to carry out the Egyptian power system stability studies of the system with the connected Zaafrana wind farm. Furthermore, the system stability studies are repeated assuming different power values penetrated from the new connected wind farm located at Gabl El-Zait and which is completely erected during the coming five years. Also the penetration effects on the thermal limit of the transmission system are carried out.

II. CONFIGURATION OF THE EGYPTIAN POWER SYSTEM NETWORK

It is known that the Egyptian transmission system network is composed of an interconnected 220 kV and 500 kV unified two networks. The system generated electric power is obtained, nowadays, from a 25 main conventional steam power stations, the High-dam hydraulic power station, in addition to the Zaafrana wind power station. Further, during the coming five years, a new wind farm will be erected at Gabl El-Zait, and it will be connected with the Egyptian power system. Eliminating some of the system non-generator

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buses, the Egyptian reduced power system network, which is composed of 27 generators, 157 lines, and 77 buses, is shown in Fig. 1. Values of the lines resistances, inductances, capacitances, in addition to the lines power limits are obtained from the Egyptian National Control Centre.

III. Configuration of the DFIG

The basic configuration of a DFIG driven by a wind turbine is shown in Fig. 2, where the turbine is connected to the DFIG through a low-speed and a high-speed two shafts and a gearbox in between. The wound rotor induction machine in this configuration is fed from its both stator and rotor sides, where the generator stator is directly connected to the grid while its rotor is connected to the grid through a variable frequency ac/dc/ac converter (VFC), which consists of two four-quadrant insulated-gate bipolar transistor (IGBT) pulse width modulation (PWM) converters connected back- to-back by a dc-link capacitor.

In order to deliver an electrical power with constant voltage and frequency to the utility grid for a wide operating range of speed, from sub-synchronous to super-synchronous speeds, the power flow between the generator rotor circuit and the grid must be controlled in both magnitude and direction. Connecting the rotor with the grid, via a four-quadrant ac-to-ac converter, enables decouple control of the generator active and reactive powers. Also, the variable frequency rotor voltage permits the adjustment of the rotor speed to match the optimum operating point at any practical wind speed.

The Rotor Side Converter (RSC) and the Grid Side Converter (GSC) control circuits are shown in Fig. 3, where the RSC control system consists of two basic control loops for the active and for the reactive powers P and Q, respectively. The GSC is used for keeping DC-link voltage of capacitor constant regardless of the magnitude and direction of rotor power as well as controlling the GSC output reactive power especially in case of the grid disturbance [7-9].

IV. Stability studies of the Egyptian power system with the connected Zaafrana wind farm

As a first step for the Egyptian power system stability studies, it is considered the system reduced network with the connected wind farm, as shown in Fig. 1. Next, the system load flow computations are carried out for the system by using the Newton-Raphson method. From the obtained results it is found that the power penetrated into the system from the wind farm cannot exceed, due to the lines thermal limits, the value 230 MW.

Now, in order to penetrate the wind farm installed power capacity (517 MW) with maintaining the lines thermal limits, it is found, from the load flow computations that a new 220 kV double-circuit transmission line should be added to the system network lines and used for connecting Sokhna and Katamia buses (the Egyptian ministry of electricity already begun to establish this line).

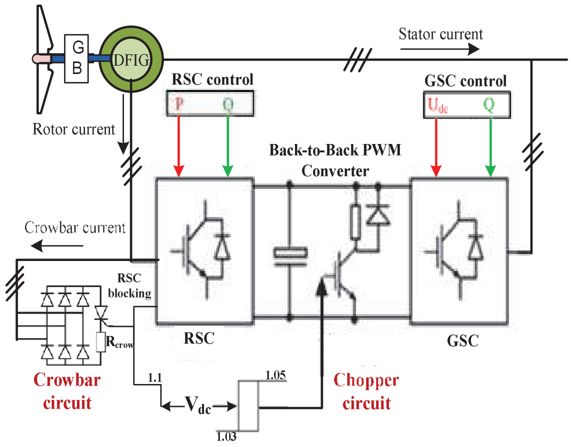


Fig. 2 Configuration of a DFIG wind turbine

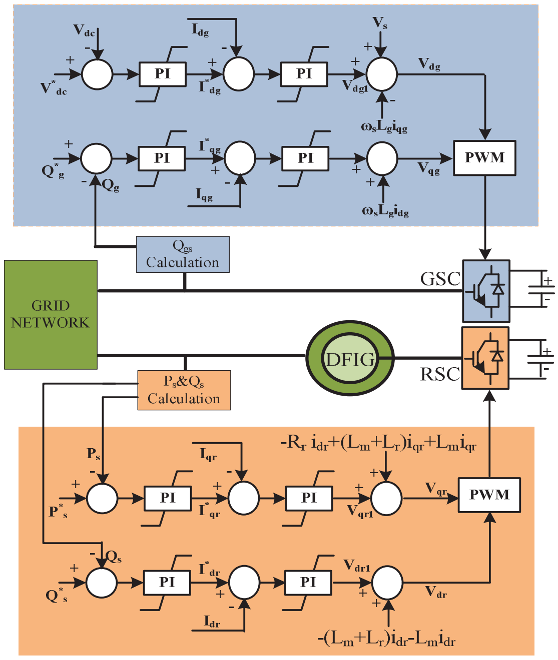


Fig. 3 Basic control loops for the RSC and GSC

Next, each of the system synchronous generators are represented by using the two-axis model, and it is considered the effects of both the generator excitation and speed governor systems. Also wind farm is represented, in this paper, by an equivalent DFIG with the equivalent power.

Finally, considering the Egyptian power system with the new proposed transmission line, the system stability computations are carried out assuming a 3-phase short circuit fault to occur at a point close to the farm external bus (i.e. El-Sokhna bus). From the obtained stability results, it is found, referring to Fig. 4, that the system can maintain its synchronous, voltage, and frequency stability when the fault is cleared not later than 0.20 sec (10 Hz) from the fault instant.

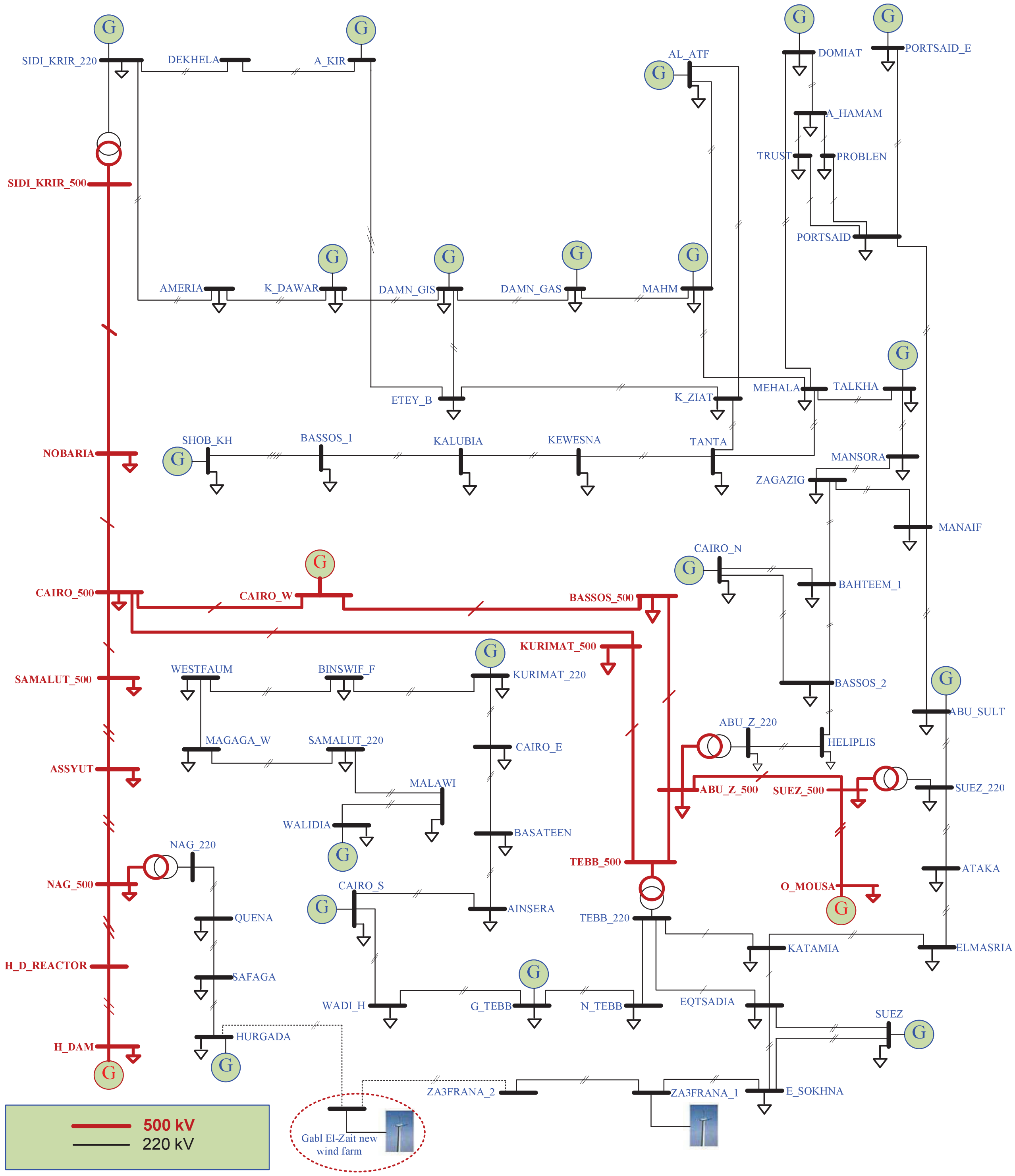
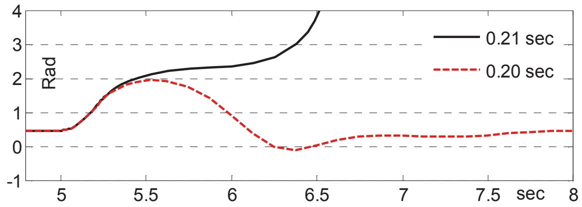
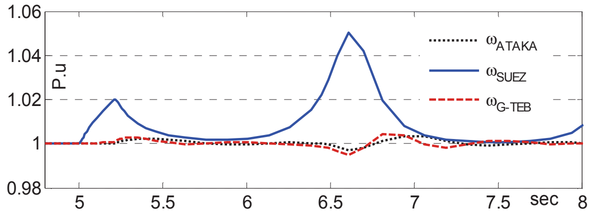


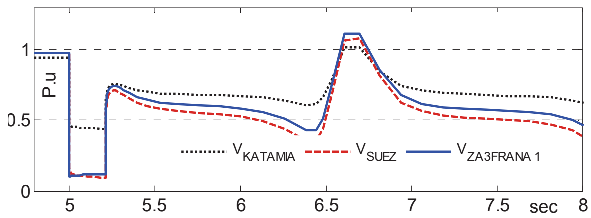
Fig. 1 The Egyptian power system reduced network.



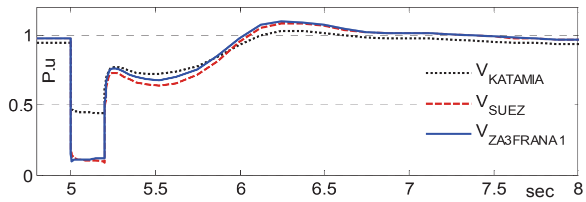
a- Variations of the relative angle of the Suez station equivalent generator with respect to Nobaria reference generator



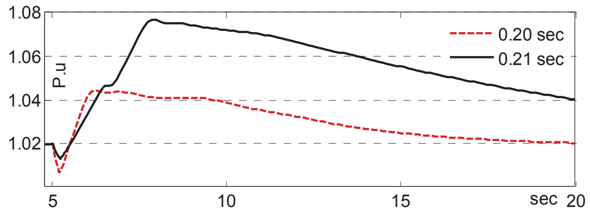
b- Variations of the rotor speeds for some of the system synchronous equivalent generators assuming the fault period of 0.21 sec.



c- Voltage variations at some of the Egyptian system buses assuming a fault period of 0.21 sec



d- Voltage variations at some of the Egyptian system buses assuming a fault period of 0.2 sec



e- Variation of the DFIG rotor speed assuming two fault clearing times.

Fig. 4 Response of some of the Egyptian power station equivalent generators assuming a 3-phase short circuit fault to occur at El-Sokhna bus when the Zaafrana wind farm penetrated power equals 517 MW.

V. Stability studies of the Egyptian power system with the connected Gabl El-Zait new wind farm

Due to the continuous yearly increase in the Egyptian system electric load by about 6%, in addition to the present days high price of the fuel, needed for the system steam power stations, the Egyptian government planned to exploit the renewable energy sources. Therefore a number of small rated power wind farms were erected in Egypt during the last twenty years.

Furthermore, during the incoming four years, a new large power wind farm will be constructed at Gabl El-Zait site, on the coast of the Red Sea. The total installed power of the farm will reach, when it is completely constructed, the value of 2300 MW (about 10 % of the Egyptian network).

As a first step in stability studies of the Egyptian system with the connected new Gabl El-Zait farm, the system load flow computations are carried out to get the most suitable bus to which the farm should be connected such that it can penetrate its installed power value with maintaining the lines thermal limits.

Now, assuming that each of the Egyptian system loads is increased, yearly, by the constant ratio 6.0 %, the system load flow computations are carried out considering both of the zaafrana and new Gabl El-Zait two wind farms. Assuming different penetrated power values from the Gabl El-Zait farm, the system stability studies are carried out in different four case studies as follows:

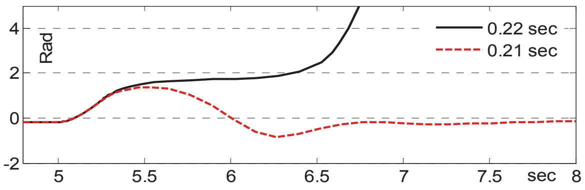
A. Case study 1:

Referring to data obtained from the Egyptian National Control Centre ENCC, a two 220 kV double-circuit transmission lines, which are being under construction, will be used for connecting the new farm with the Egyptian power network at Zaafrana-2 and Hurgada buses, see Fig. 1.

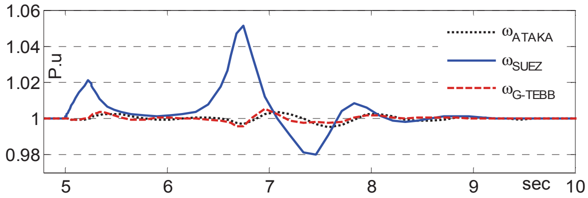
Now, in this case, the system stability studies are carried out assuming the new farm to be connected with the Egyptian system only at the Zaafrana-2 bus via one of the under construction lines.

Taking the Nobaria bus as a slack bus, and assuming that the power of 517 MW is penetrated from the Zaafrana farm (see section IV). The system load flow computations are carried out. It is found that, the thermal limit for the line connecting the Sokhna and Katamia buses will be exceeded when the new farm penetrated power value is larger than 300 MW.

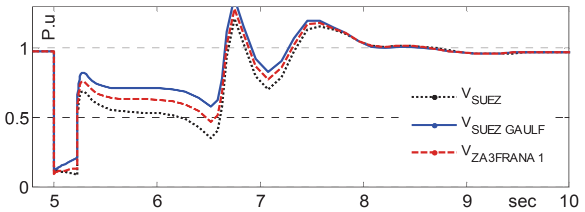
Assuming the new farm penetrated power is equal to 300 MW, when a 3-phase short circuit fault occurs at a point very close to Sokhna bus to which the Zaafrana farm is connected with the considered system, the stability computations are carried out. The obtained stability results are depicted in Fig. 5, from which it can be shown that, despites the system maintains its voltage and frequency stability it will lose its synchronous stability when the fault duration is larger than 0.21 sec.



a- Variations of the relative angle of the Suez station equivalent generator with respect to Nobaria reference generator



b- Variations of the rotor speeds for some of the system synchronous equivalent generators assuming the fault period of 0.22 sec



c- Voltage variations of some of the Egyptian system buses assuming a fault period of 0.22 sec

Fig. 5 Response of some of the Egyptian power station equivalent generators assuming a 3-phase short circuit fault at El-Sokhna bus when the Zaafrana and Gabl El-Zait wind farm output power are 517 and 300 MW, respectively.

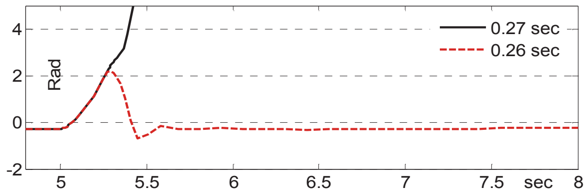
B. Case study 2:

In this case, it is assumed that the new farm is connected with the Egyptian system only at the Hurgada bus via one of the under-construction two lines. From the obtained load flow computations, it is found that the power injected from the new farm cannot exceed, due to maintaining the thermal limit for the line connecting the Hurgada and Safaga buses, the value of 650 MW, as shown in table 1.

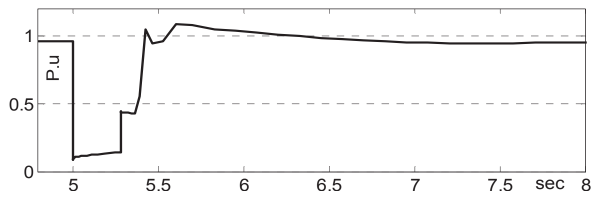
TABLE 1:

FROM	To	No. of circuit	MVA per circuit	Thermal limit MVA/circuit
SAFAGA	QUENA	2	195.1567	274
HURGADA	SAFAGA	2	231.3869	229
HURGADA	SUEZ GULF	2	322.4657	366

Now, considering the under-construction line, used for connecting the Gabl El-Zait farm with the Egyptian system at Hurgada bus, and assuming the output power from the Gabl El-Zait farm to be equal 650 MW, the system stability studies are carried out when a three-phase short circuit fault occurs at

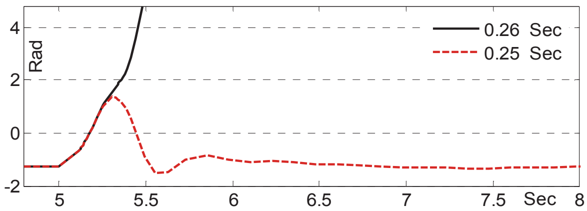


a- Variations of the relative angle of the Hurgada station equivalent generator with respect to Nobaria reference generator

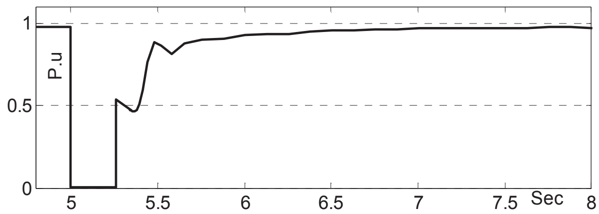


b- Voltage variations at Gabl El-Zait wind farm terminal assuming a fault period of 0.27 sec

Fig. 6 Response of some of the Egyptian power station equivalent generators assuming a 3-phase short circuit fault at Hurgada when the Zaafrana and Gabl El-Zait wind farm output power are 517 and 650 MW, respectively.



a- Variations of the relative angle of the Hurgada station equivalent generator with respect to Nobaria reference generator



b- Voltage variations at Hurgada bus assuming a fault period of 0.26 sec

Fig. 7 Response of some of the Egyptian power station equivalent generators assuming a 3-phase short circuit fault to occur at Hurgada bus when the Zaafrana output power equals 517 MW and without the new farm addition.

a point very near the Hurgada bus. It is found, referring to Fig. 6 that clearing the assumed fault after a period longer than 0.26 sec the system will lose its synchronous stability.

Now, considering the same assumed fault condition, given in present case study, the stability computations are repeated for the system without the new farm addition. It is found, referring to Fig. 7 that the system synchronous stability will be lost when the fault clearing occurs after 0.26 sec instead of 0.27 sec, when the new farm is added, from the fault instant. This essentially means that adding the new farm, the system stability will not affected whereas the power values of 650 MW is penetrated into the system that farm is added.

C. *Case study 3:*

In this case, the considered system load flow computations are repeated assuming the new farm to be connected with the system network at both of the Hurgada and Zaafrana-2 buses via the new under-construction two lines. It is found, from the obtained results, that the new farm injected power can be increased to the value 830 MW before the power flows in the line connecting Sokhna and Katamia buses exceeds its thermal limit, as given in table 2.

TABLE 2

FROM	To	No. of circuit	MVA per circuit	MVA Thermal limit
E-SOKHNA	KATAMIA	2	230.1655	229
ZA3FRANA_2	SUEZ_GAULF	2	148.776	366
EQTSADIA	KATAMIA	2	225.4615	229

Now, when the new farm penetrates the power of 830 MW into the Egyptian system, it is assumed that a 3-phase short circuit fault is occurred at the Sokhna bus. From the stability obtained results, it is found that the system will lose its synchronous stability when the assumed fault is cleared after 0.21 sec from the fault instant, as shown in Fig. 8.

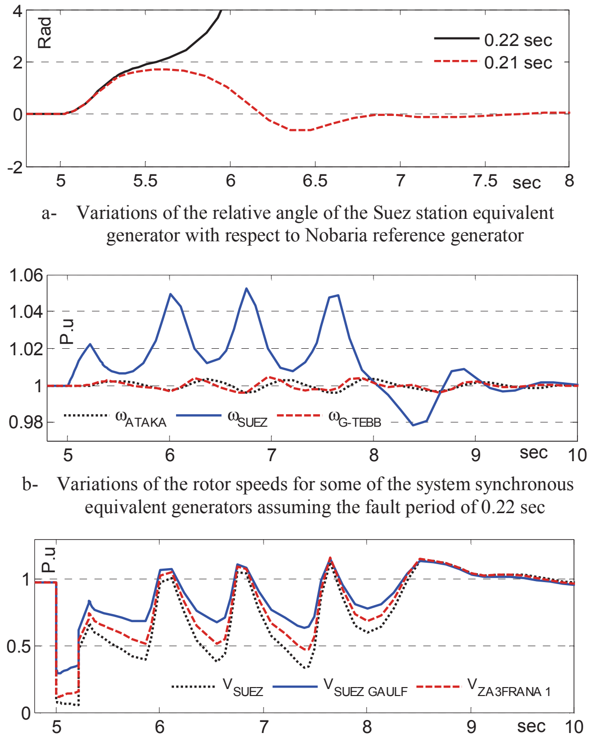
Now, considering the same fault location, a comparison of the critical fault clearing time obtained for the present case with that for the Egyptian system before the new farm addition (see Fig. 4), it can be noted that the two times are nearly equal. This implies that the new farm addition does not affect the considered system stability despite the power of 830 MW will be penetrated into the system after adding that farm.

Now, assuming the short circuit fault to occur at the Hurgada bus, instead of the Sokhna bus, the system stability studies are repeated. It is found that the fault duration can be increased to the value 0.27 sec before the system loses its synchronous stability, as shown in Fig. 9.

D. *Case study 4:*

In order that the new farm penetrated power value can be increased to 2300 MW (i.e. the farm installed power capacity), it is found from the system load flow studies that a new 500 kV double-circuit transmission line (having a thermal limit of 1732 MW per circuit) should be constructed and used for connecting the farm with the Egyptian system network at the Kurimat-500 bus. The suggested line and the two under construction transmission line between new farm and Zaafrana-2 and Hurgada buses can transmit the new farm capacity power without exceeding the thermal limit of any of the system transmission lines.

Now, considering the under-construction 220 kV two lines connecting the new wind farm with the Egyptian network at the Zaafrana-2 and Hurgada buses, in addition to the new 500 kV proposed line, the system stability studies are carried out.

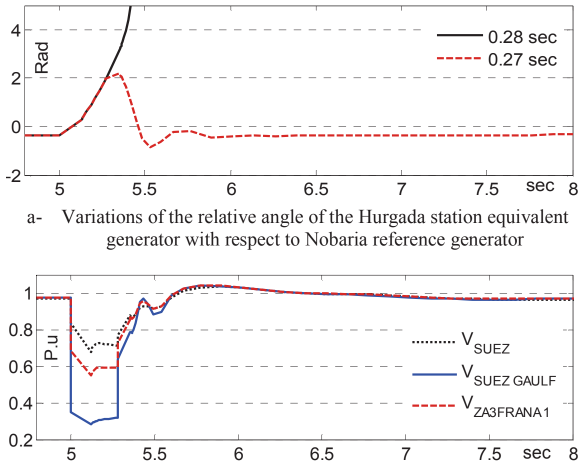


a- Variations of the relative angle of the Suez station equivalent generator with respect to Nobaria reference generator

b- Variations of the rotor speeds for some of the system synchronous equivalent generators assuming the fault period of 0.22 sec

c- Voltage variations at some of the Egyptian system buses assuming a fault period of 0.22 sec

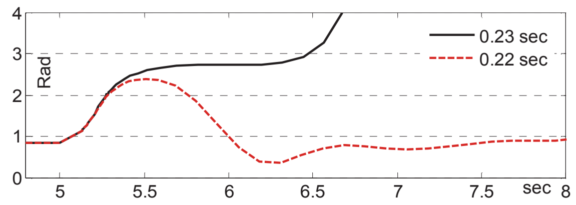
Fig. 8 Response of some of the Egyptian power station equivalent generators assuming a 3-phase short circuit fault at Sokhna bus when the Zaafrana and new farm output powers are 517 MW and 830 MW, respectively.



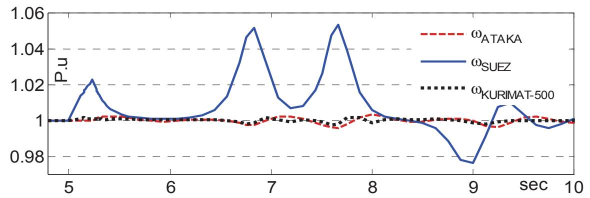
a- Variations of the relative angle of the Hurgada station equivalent generator with respect to Nobaria reference generator

b- Voltage variations of some of the Egyptian system buses assuming a fault period of 0.28 sec

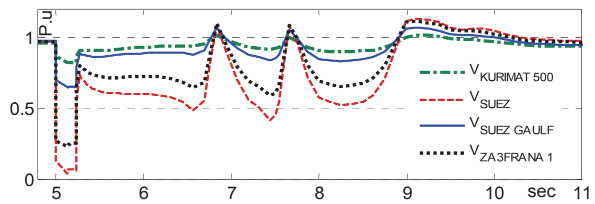
Fig. 9 Response of some of the Egyptian power station equivalent generators assuming a 3-phase short circuit fault at Hurgada bus when the Zaafrana and new farm output powers are 517 MW and 830 MW, respectively.



Variations of the relative angle of the Suez station equivalent generator with respect to the Nobaria reference generator

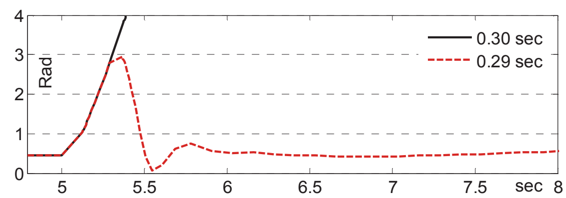


Variations of the rotor speeds for some of the system synchronous equivalent generators assuming the fault period of 0.23 sec.

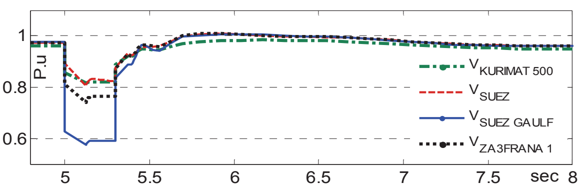


Voltage variations at some of the Egyptian system buses assuming the fault period of 0.23 sec

Fig. 10 Response of some of the Egyptian power station equivalent generators assuming a 3-phase short circuit fault at Sokhna bus when the Zaafrana and new farm output powers are 517 MW and 2300 MW, respectively.



Variations of the relative angle of the Suez station equivalent generator with respect to the Nobaria reference generator



Voltage variations at some of the Egyptian system buses assuming the fault period of 0.30 sec

Fig. 11 Response of some of the Egyptian power station equivalent generators assuming a 3-phase short circuit fault at Hurgada bus when the Zaafrana and new farm output powers are 517 MW and 2300 MW, respectively.

Assuming a 3-phase short circuit fault to occur at Sokhna bus, it is found, referring to Fig. 10, that the system will lose its synchronous stability when the considered fault duration is larger than 0.23 sec.

Now, it is assumed that the considered fault is occurred at the Hurgada bus, instead of the Sokhna bus, and the system stability computations are repeated. Referring to Fig. 11, it is found that the system synchronous stability can be maintained when the fault is cleared before 0.30 sec from the fault instant.

Comparing the critical clearing time values for the previous cases can be summarized in table 3 and 4. From table 3 and 4 it can be shown that increasing the new farm injected power to 2300 MW by adding suitable lines will not affect the time value during which the fault can be sustained with maintaining the system stability.

TABLE.3

Critical clearing time for a 3-phase short circuit at hugada bus for different penetration of the new wind farm

New wind farm output (MW)	0	650	830	2300
C.C.T (sec)	0.25	0.26	0.27	0.29
Figure No.	Fig. 7	Fig. 6	Fig. 9	Fig. 11

TABLE.4

Critical clearing time for a 3-phase short circuit at El-Sokhna bus for different penetration of the new wind farm

New wind farm output (MW)	0	300	830	2300
C.C.T (sec)	0.20	0.21	0.21	0.22
Figure No.	Fig. 4	Fig. 5	Fig. 8	Fig. 10

VI. Conclusions

It is considered, in this paper that the Egyptian power system with the connected 517 MW wind farm located at the Zaafrana site on the Red sea coast in addition to the new 2300 MW wind farm which will be erected at Gabl El-Zite site, about 100 Km from Zaafrana. This new farm will be completely constructed in the year 2017. From the load flow and stability studies considering either the connected Zaafrana wind farm, or both of this farm and new Gabl El-Zait wind farm, it is obtained the following main conclusions:

1) In order that the connected Zaafrana farm can inject its installed power capacity value (that is 517 MW) into the Egyptian power system, with maintaining all the power flow in the system lines to be behind their thermal limits, a new 220 kV double-circuit transmission line should be erected and used for connecting the Sokhna and Katamia two buses.

2) Using the two under-construction 220 kV double-circuit new lines for connecting the Gabl El-Zait new wind farm with the Egyptian system at both Hurgada and Zaafrana-2 buses, the Gabl El-Zait new wind farm can deliver, due to the thermal limits of the system lines, the power value of 830 MW only to the Egyptian system.

3) For increasing the Gabl El-Zait new farm penetrated power to the value 2300 MW with delivering the power of 517 MW from the Zaafrana farm to the Egyptian system, it is necessary to construct a new 500 kV double-circuit transmission line between the Gabl El-Zait new wind farm and Kurimat-500 bus in addition to the two under construction lines.

4) Considering the Egyptian system with the connected Zaafrana farm and the added Gabl El-Zait new farm, it is found that the system loses its synchronous stability with maintaining its both voltage and frequency stability when a short circuit fault at any of two assumed locations.

5) Increasing the power penetrated into the Egyptian system from Gabl El-Zait new farm does not affect the system voltage and frequency stability. Further, the critical fault clearing times of the 3-phase short circuit at the system buses is increased with increasing the new wind farm output power as listed in table.4 and 5.

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