Stability Analysis of Western Libyan Electric Network with Connected Wind Energy generators

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Abstract

Constantly increasing demand for electricity due to growing of population and industrial development, is putting power industry on great pressure of increasing the power generation.

Increasing demand potentially causes deterioration of the environment due to the combustion of fossil fuels to meet the energy generation needs. Continuing of adding new generation capacity while keeping carbon dioxide (CO2) emission at minimum level requires extensive modifications to the existing power systems. There is great interest at present in expanding the use of distributed generation, as distributed generation (DG) units comprise renewable and non-renewable sources.

Wind energy is depending on the injected power from the wind speed, therefore, fluctuations in wind velocity can affect branch power flows, and network stability, It is widely known that transient stability also is an important aspect in designing and upgrading the electric power system, and angular stability assessment of wind power generator is one of the main issues in power system security and operation. The angular stability for the wind power generator is determined by Critical Clearing Time (CCT).

This research presents and analyze the effect of wind power on the transient fault behavior and investigated the impact of wind generation on power system performance by increasing gradually the rate of wind power penetration and changing the location of wind resources. It is necessary to estimate the maximum level of wind energy that will not affect the stability of the power system.

The power system stability analysis for Libyan Western Network is considered as a case study where the fault test is created on different busses, and determine the critical clearing time (CCT), as an index for stability.

The simulation analysis was established on the Libyan western network by ETAP software.

Keywords: Transient Stability, Wind energy, Three Phase Fault, Critical Clearing Time (CCT) Wind Penetration

1. Introduction.

The demand of power is escalating in the world of electricity. This growth of demand triggers a need of more power generation. DG uses smaller-sized generators than does the typical central station plant, distributed generators are usually small scale generators located close to consumers.

Distributed generation is an electric power source, connected to the grid at distribution level voltages, serving customers on-site or providing support to a distribution network. Distributed generation (DG) becomes more reliable and economically feasible, to serve different purposes and offer more possibilities to end-users, such as:

• improving availability and reliability of electric power.

• Peak load shaving.

• Energy cost savings.

• Selling power back to utilities or other users.

• Reactive power compensation.

• Mitigation of harmonics and voltage sag.

The generation technologies can be classified into renewable and non-renewable. This classification means that DG is not a synonym for Renewable Energy Source. The DG technologies based on renewable are:

- Wind.

- Photovoltaic and solar thermal.

- Ocean (tidal and marine current).

- Hydro (small).

Wind power is a renewable energy resource that has the potential to become one of the crucial energy resources in many countries, because it is pollution free and powered by the abundant availability of wind. However, the wind power cannot be integrated randomly into the Western Libyan grid, due to its fluctuating nature of the wind turbine. Wind turbine fluctuation leads to a decrease in the efficiency of the power system to maintain the balance between the generation and demand.

This paper will focus on the type of the variable-speed wind turbine directly-driving multi-pole permanent magnet synchronous generator (PMSG) to studying its impacts on the Libyan Western Electric Network stability, and analyses the transient response of the system by considering different clearing time as an index for stability performance, and by increasing gradually the rate of wind power penetration with changing the location of wind resources [1].

2. System Modelling.

2.1Wind Energy Conversion.

Wind Energy Conversion The wind consists of a source that generates wind speed signal to be applied to the wind turbine. The kinetic energy is given by:-

$$E = \frac{1}{2} m v^2 \quad (1)$$

The wind power is given by

$$P_m = \frac{1}{2} \rho S^3 \quad (2)$$

Where m is the air mass, ρ is the air density, S is the covered surface of the turbine, v is the wind speed

2.2 Wind Turbine.

The Wind turbine is able to convert the wind energy to mechanical torque. The mechanical torque of the turbine can be calculated from mechanical power, the turbine extracted from wind power. The wind speed after the turbine is not zero. The power coefficient of the turbine is used. The pitch angle and tip speed is a function of the power coefficient. The Wind turbine is applied to convert the Wind energy to mechanical torque [2] .

$$T_m = \frac{\rho \; S \; C_P(\lambda, \beta) v^3}{2\omega} \quad (3)$$

Where Tm is electromechanical torque , ρ air density, S covered surface, C_P power coefficient , λ tip speed ratio, β blade pitch angle and v is the wind speed .

2.3 Wind Turbine (WT) Technology Description.

The WT technology that has been used in this study is the variable-speed WT equipped with synchronous generators, Permanent magnet synchronous generator (PMSG), and the rotor shaft is coupled directly to the generator, which means that no gearbox is needed; The PMSM has 1.65 MW of active power capacity [2] .

The main description of the permanent magnet synchronous machine characteristics is as follows:

1. Strong, compact and less weight.

2. Copper loss due to the current flow which is the largest loss in case of the induction machine is approximately half that of the induction motor.

3. High efficiency in case of a permanent magnet synchronous machine compared to the induction [2].

The generator is connected to a three-phase inverter which rectifies the current from the generator to charge a DC-link capacitor .The DC-link feeds a second three-phase inverter which is connected to the grid through a transformer.as shown in figure (1), the variable speed of WT generator with full conversion power converters.

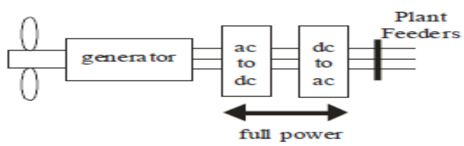

Figure (1): Variable Speed Wind Turbine Generator with Full Conversion Power Converter [2].

2.3 Permanent magnet synchronous Generator (PMSG) Model.

Dynamic model of the PMSG is obtained from the two phase synchronous reference frame, which the q axis is 90 degree ahead of the d axis with respect to the direction of rotation. The synchronization between the d-q rotating frame is maintained by a phase locked loop as shown figure (2)[2].

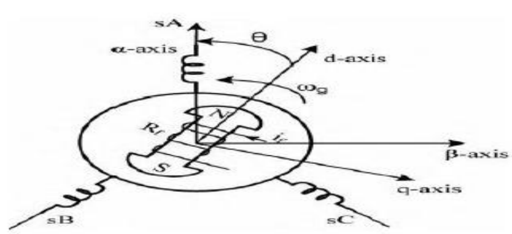

Figure (2) shows the DQ reference frame model used in a salient -pole synchronous machine[2].

The mathematical DQ model for the PMSG is given as follows:

$$v_d = R_s i_d + \frac{di_d}{dt} L - \omega_e L i_q \tag{4}$$

$$v_q = R_s i_d + L \frac{di_q}{dt} \omega_e L i_d + \varphi_m \omega_e \tag{5}$$

The general mechanical equation of the machine is

$$\frac{dw_r}{dt} = \frac{T_m - T_e}{J} - \frac{Bw_r}{J} \tag{6}$$

Where

$$K_t = \frac{3}{4} P \varphi_m \tag{7}$$

$$T_e = K_t i_q$$

The mathematical model of PMSG is

$$\frac{di_d}{dt} = -\frac{R_s}{L} i_d + \frac{P}{2} i_q \omega_r - \frac{1}{L} v_d \tag{8}$$

$$\frac{di_q}{dt} = -\frac{R_s}{L} i_q - \frac{P}{2}\left(i_d - \frac{\varphi_m}{L}\right) \omega_r - \frac{1}{L} v_q \tag{9}$$

$$\frac{d\omega_r}{dt} = \frac{T_m}{J} - \frac{K_t i_q}{J} - \frac{B\omega_r}{J} \tag{10}$$

Where:

v_d is Direct axis voltage, v_q is quadratic axis voltage, i_d is direct axis current, i_q is quadratic axis current, R_s is the stator resistance, ω_e is the electrical speed, L_d is the direct axis inductance, L_Q is the quadratic axis inductance, φ_M is the permanent magnet flux linkage, T_m is the electromechanical torque, B is damping coefficient, J is moment of inertia, ω_r is the rotational speed.

3. System of Study Description and methodology.

This research aims to study the impacts of wind generation penetration on power system stability, considering Libyan Western Electrical Network as a study case.

The Libyan Western Electric Network (220kv) system is considered for checking its behavior using the known load flow methodology for system power flow analysis, and applying stability studies during wind energy generation to check its impacts on the Western Area Electric Network 220kv system.

The Western area is divided to geographical regions connected together by 220kv transmission and have the following power station generation according to 2015 General Electricity Company of Libya (GECOL) planning program.

- Zawia power plant (STCC; GTCC).
- Rowis power plant (Gas unit).

- Tripoli west (steam unit).
- Tripoli south (Gas unit).
- Sidi Banour (GTCC).
- Homs power station (Gas unit).
- Misurata power station (GTCC,STCC,Gas) units.
- Gulf power station (steam units).
- Ubari power station (Gas unit)[under installation].
- Milita power station (STCC) expected to be construction.
- Wind energy power station (in Mesallata city) considered.
- Wind energy power station (in Tarhona) considered.

All information about modelling of synchronous generators, their excitation ,and turbine governing control equipment for wind turbine generators are shown in table (1) ,that consider to be installed on the network for checking its penetration impact.

The maximum loading of year 2015 is collected for (GECOL) planning department including the data for stability study.

Table(1) wind turbine data and general characteristics .

General Characteristics Twt-1.65/82	
Wind turbine model	TWT-1.65/82
Wind turbine class	III B
Nominal power	1.617 Kw
Rotor diameter	82 m
Hub height	70 m
Number of blades	3 blades
Range of Rotor speed at power production	6 to 19 r.p.m
Cut-in Wind speed	3,5 m/s
Nominal Wind speed (density=1.225 kg/m3)	12 m/s
Cut-out Wind speed	20 m/s of average 10 min
Range of temperature operation	-10 ºC a 40 ºC
Swept area	5.281 m2
Power density	0,3125 Kw/m2
Pitch	Variable
Generation type	Synchronous, variable speed
Nominal voltage	690 V
Nominal intensity	1.700 A
Frequency of grid	50 Hz
Total weight	245.000 Kg
Orientation of the rotor	Upwind

4 Case Studies and Analysis .

To study the Impacts of the wind generation penetration on system transient stability the following steps are considered, which will be followed to end up with a fruitful conclusions , using load flow analysis with stability analysis.

Step I: Considering the western area electrical network without any penetration of wind generation connected **as the base study**.

- Applying three phase fault on certain point on 220kv buses by using transient stability studies, and analyses the transient response of the system, by considering different clearing times as an index for stability .this base case will be taken as a reference for comparison when applying wind energy penetration.

Step II:

Considering wind energy penetration to the grid at some places where these generators expected to added according to the information available for wind streams.

- Connecting wind generators each of size 1.65MW and adding the penetration power in steps while checking its impacts on the transient system stability, in one location and doing the same above procedure .And discussing the case results.

Connecting wind generators in more than one location and repeating the same procedure and discussing the case results.

Step III:

Integrate wind energy at different placed in the grid to end up with a conclusion for impacts of wind energy on transient stability of the network.

4.1 Case I: Base Case.

In this case the transient system stability is studied without any penetration of wind generation considering fault at different location of the considered grid.

Scenario I: load flow results of the system at maximum forecasted load of year 2015.

In this case, the overall load is 8213.583MW, the generation sum up to 8361.396MW. The voltage profiles at all the system buses are generally within limit (+/- 5%) during maximum load and the overall network losses is (P Losses =147.814 Mw) .

Scenario II: Applying three phase fault at different location and check for critical clearing time (CCT) that assures the system stability

- Applying three phase fault at khoums switching bus .The results shows that the system is stable at CCT of 1.2 second in figures .(3.a,b).

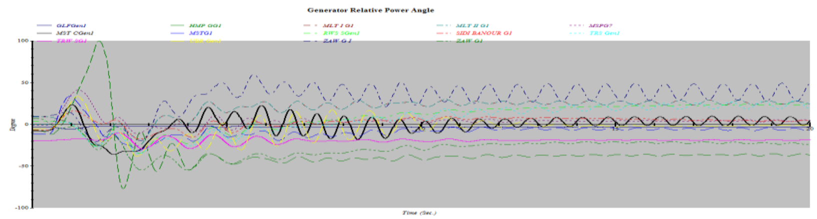

Fig.(3. a) Relative Rotor angle for a fault at (Khoms) of (1.2 sec.).

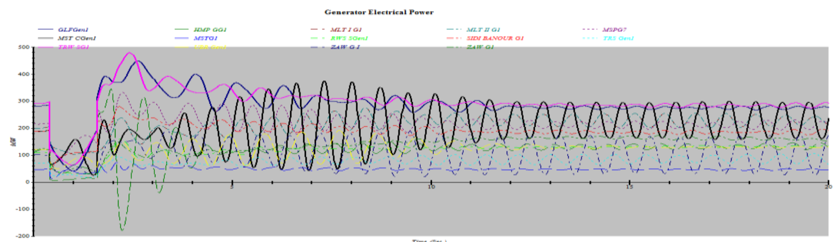

Fig.(3. b) generator electrical power for a fault at (Khoms) of (1.2 sec.).

When increase the CCT to 1.3 second, the system is going to be Unstable as shown in figures (4.a,b).

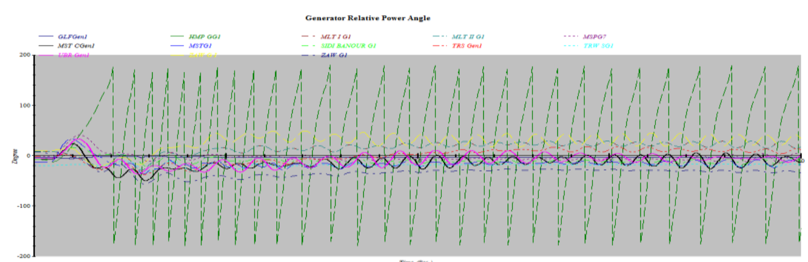

Fig.(4.a) Relative Rotor angle for a fault at (Khoms) of (1.3 sec.)

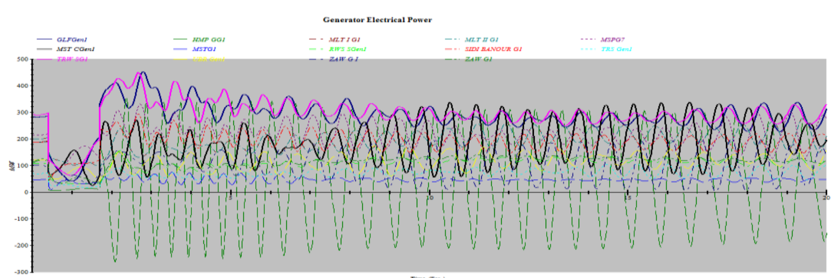

Fig.(4.b) generator electrical power for a fault at (Khoms) of (1.3 sec.).

4.2 Case II: Wind power is placed in Mrada (Mslata).

Wind farm with 50MW power installed on 30kv Mrada , Contains 30 Wind Turbines.

- **Scenario I :**load flow results of the system at maximum forecasted load of year 2015.

In this case, the overall load is 8213.345 MW, the generation sum up to 8362.418MW. The voltage profiles at all the system buses are generally within limit (+/- 5%) during maximum load and the overall network losses is (P Losses =149.074 Mw)

- **Scenario II:** Applying three phase fault at different location and check for critical clearing time CCT that assures the system stability.

- Applying three phase fault at khoms switching bus. The results shows that the system is stable at CCT of 2 second as shown in figures (5.a, b).

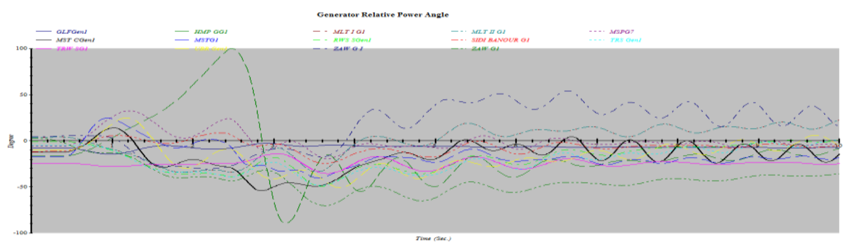

Fig.(5 a). Relative Rotor angle for a fault at (Khoms) of (2 sec.).

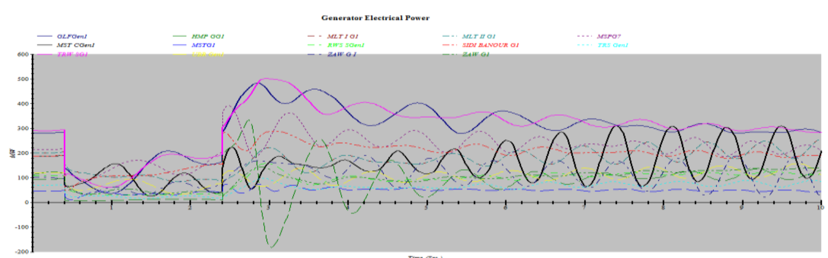

Fig.(5.b). generator electrical power for a fault at (Khoms) of (2 sec.)

The behavior of the Wind generator (W.G) during fault and after fault clearing as shown in figures (6.a,b,c).

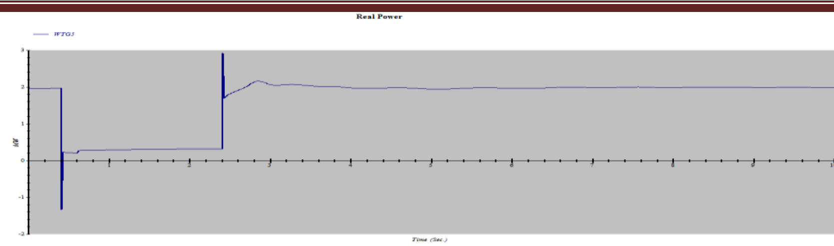

Fig.(6.a) W.G. Real Power output.

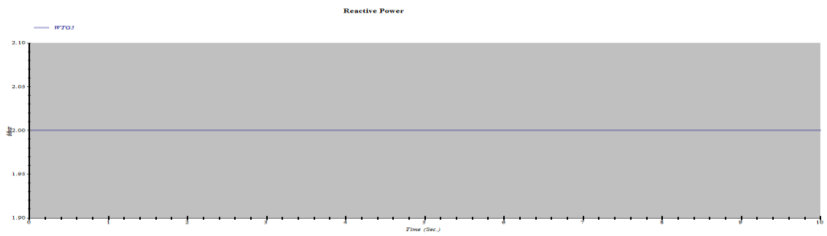

Fig.(6.b) W.G. Reactive Power output.

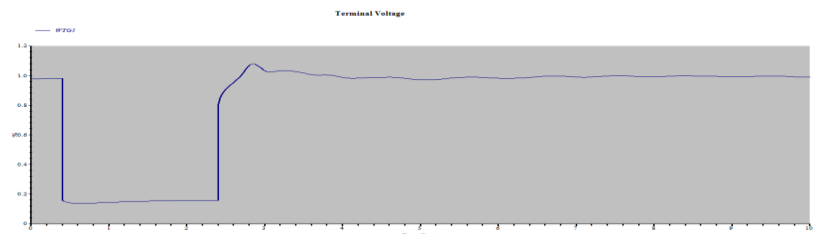

Fig. (6.c) W.G Terminal voltage.

- The effect of wind power on the oscillations is investigated by gradually increasing the rate of wind source penetration while observing the transit behavior of system, effect to the angular stability, changing the fault locations first at Abukmash 220kv bus bar, and second at saraj 220kv the results are summarized in Table (2).

Table (2). Changing the fault locations and results of CCT with stability conditions

Wind power is placed in Mrada				
Cases	Installed capacity of Wind sources (MW)	3ϕfault Khoms Switching	3ϕfault Abkmash	3ϕfault Sraje
Case II.A	50MW	2 stable	More than3S stable	More than3S stable
		2.1 unstable		
Case II.B	100MW	4.2 stable	More than5s stable	More than5s stable
		4.3 unstable		

Case II.C	150MW	4.2 stable	More than5s stable	More than5s stable
		4.3 unstable		
Case II.D	175MW	2 stable	More than3s stable	More than3s stable
		2.1 unstable		
Case II.E	200MW	1.4 stable	More than3s stable	More than3s stable
		1.5 unstable		

4.2.A Case Discussion.

As concluded discussion the results shows that :-

- When the fault is close to the W.G Plant location the CCT is increased as the W.G power generated is increased from 50MW to 150MW CCT increased from 2 second to 4.2 second, when power generation is increased over 150MW the CCT is retarded to be 2 seconds and less, which means that the stability region with W.G connected is limited within penetration size of the energy.
- Results shows that the system stability is independent on the CCT .i.e .CCT has no effect on system stability with Wind Generator Plant connected since the fault location is far away from wind source.

4.3 Case III: Wind power is placed in Tarhona.

- **Case III.A:** Wind farm with 50MW power installed on 30kv Tarhona , Contains 30 Wind Turbines.

- The effect of wind power on the oscillations is investigated by gradually increasing the rate of wind source penetration while observing the transit behavior of system, effect to the angular stability, changing the fault locations first at Abukmash 220kv bus bar, and second at saraj 220kv station the results are summarized in Table (3).

Table (3) Case results with Tarhona Location

Wind power is placed in Tarhona				
Cases	Installed capacity of Wind sources (MW)	3ϕfault Khoms Swiching	3ϕfault Abkmash	3ϕfault Sraje
Case II.A	50MW	2 stable	More than 3S stable	More than 3S stable

		2.1 unstable		
Case II.B	100MW	4.2 stable	More than 5s stable	More than 5s stable
		4.3 unstable		
Case II.C	150MW	4.2 stable	More than 5s stable	More than 5s stable
		4.3 unstable		
Case II.D	175MW	2 stable	More than 3s stable	More than 3s stable
		2.1 unstable		
Case II.E	200MW	1.3 stable	More than 3s stable	More than 3s stable
		1.4 unstable		

4.3. A Case Discussion.

As a concluded discussion the results shows that:-

- When the fault is close to the W.G Plant location the CCT is increased as the W.G power generated is increased from 50MW to 150MW from 2 second to 4.2 second, when power generation is increased over 150MW the CCT is retarded to be 2 seconds and less, which means that the stability region with W.G connected is limited within penetration size of the energy .
- Fault far away from W.G Plant location, the W.G penetration have not effect on stability.

4.4 Case IV: Integrate Wind power is placed at both Mrada and Tarhona.

In this case Marda and Tarhona are integrated wits same procedure , and results shown in table (4).

Table (4). Case results with Mrada and Tarhona

Wind power is placed both in Mslata-Tarhona				
Cases	Installed capacity of Wind sources (MW)	3ϕfault Khoms Swiching	3ϕfault Abkmash	3ϕfault Sraje
Case IV.A	150MW+50MW	4.1 stable	More than 5s stable	More than 5s stable
		4.2 unstable		

Case IV.B	150MW+100MW	4 stable	More than 5s stable	More than 5s stable
		4.1 unstable		
Case IV.C	150MW+150MW	4.1 stable	More than 5s stable	More than 5s stable
		4.2 unstable		
Case IV.D	150MW+200MW	4.1 stable	More than 5s stable	More than 5s stable
		4.2 unstable		
Case IV.E	200MW+150MW	1.2 stable	More than 3s stable	More than 3s stable
		1.3 unstable		

4.4. A Case Discussion.

In this case the W.G is fixed at Mrada and increased in step at Tarhona the CCT is fixed at 4.1 second and the system is stable and the penetration is increased to be 350MW on both connections.

But when the penetration is increased in Mrada to 200MW and 150MW at Tarhona the stability index is reduced and CCT is reduced to 1.2 second.

5 Conclusions.

This thesis investigates the impact of wind generation on transient stability. and the impact of a power penetration of wind energy on The Libyan Western Electric Network (220kv) was studied.

It has mainly focused on the assessment of the angular stability by determinate a critical clearing time (CCT) at selected buses after simulating a three-phase fault. Then, the location is ranked according to their corresponding CCT, where the higher CCT refers to higher stability for the system.

The center of interest of this study is to check the oscillation of a group of generators during a fault and analyzed by observing the transient behavior for the following cases:-

- Changing a wind source location.
- Increasing gradually a rate of wind sources penetration.

In order to study the impacts of the wind power over the angular stability of power system, a three-phase symmetrical fault is assumed then the CCT is calculated, and compared to the case without wind source and others cases where a wind source is connected to test system at different Buses.

If wind generation improves transient stability margins or if the impact is rather negative. The answer depends on location of wind resourcesand the problem has to be analyzed individually for each case.

Wind power plant is connected to system through a transmission line on different buses for evaluating their effect to the angular stability, and location selected in the Western network such as:

1. Wind power is placed inMrada.
2. Wind power is placed in Tarhona.
3. Compare the effect of penetration for each case.

- When the fault is close to the W.G Plant location the CCT is increased as the W.G power generated is increased from 50MW to 150MW at Mrada and Tarhona from 2 second to 4.2 second ,when power generation is increased over 150MW the CCT is retarded to be 2 seconds and less, which means that the stability region with W.G connected is limited within penetration size of the energy.
- Fault far away from W.G Plant location ,the W.G penetration have not effect on stability
- Integrate Wind power is placed at both Mrada and Tarhona, W.G is fixed at Mrada and increased in step at Tarhona the CCT is fixed at 4.1 second and the system is stable and the penetration is increased to be 350MW on both connection. But when the penetration is increased in Mrada to 200MW and 150MW at Tarhona the stability index is reduced and CCT is reduced to 1.2 second. The results are concluded in table (5).

Table (5) Results from the simulations for the angular stability on different locations.

<table>
<tr><td colspan="4">Without wind</td></tr>
<tr><td rowspan="3">-</td><td>CCT 3ϕfault Khoms Swiching</td><td>CCT3ϕfault Abkmash</td><td>CCT 3ϕfault Sraje</td></tr>
<tr><td>1.2 stable</td><td rowspan="2">More than3s stable</td><td rowspan="2">More than3s stable</td></tr>
<tr><td>1.3 unstable</td></tr>
</table>

Wind power is placed inMrada			
Installed capacity of Wind sources (MW)	3ϕfault Khoms Swiching	3ϕfault Abkmash	3ϕfault Sraje
50MW	2 stable	More than3S stable	More than3S stable
	2.1 unstable		
100MW	4.2 stable	More than5s stable	More than5s stable
	4.3 unstable		
150MW	4.2 stable	More than5s stable	More than5s stable
	4.3 unstable		
175MW	2 stable	More than3s stable	More than3s stable
	2.1 unstable		
200MW	1.4 stable	More than3s stable	More than3s stable
	1.5 unstable		
Wind power is placed in Tarhona.			
50MW	2 stable	More than3s stable	More than3s stable
	2.1 unstable		
100MW	4.2 stable	More than5s stable	More than5s stable
	4.3 unstable		
150MW	4.2 stable	More than5s stable	More than5s stable
	4.3 unstable		
175MW	2 stable	More than3s stable	More than3s stable
	2.1 unstable		
200MW	1.3 stable	More than3s stable	More than3s stable
	1.4 unstable		
Wind power is placed both inMslata-Tarhona			
150MW+50MW	4.1 stable	More than5s stable	More than5s stable
	4.2 unstable		
150MW+100MW	4 stable	More than5s stable	More than5s stable
	4.1 unstable		
150MW+150MW	4.1 stable	More than5s stable	More than5s stable

	4.2 unstable		
150MW+200MW	4.1 stable	More than5s stable	More than5s stable
	4.2 unstable		
200MW+150MW	1.2 stable	More than3s stable	More than3s stable
	1.3 unstable		

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