International Journal of Electrical and Computer Engineering (IJECE)
Vol. 10, No. 1, February 2020, pp. 91~104
ISSN: 2088-8708, DOI: 10.11591/ijece.v10i1.pp91-104

PSS/E based placement wind/PV hybrid system to improve stability of Iraqi grid

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Article Info

Article history:

Received Apr 20, 2019
Revised Aug 16, 2019
Accepted Aug 29, 2019

Keywords:

Busbar fault
Dc chopper
PSS/E
PV/wind hybrid
Stability

ABSTRACT

Proper employment of Hybrid Wind/ PV system is often implemented near the load, and it is linked with the grid to study dynamic stability analysis. Generally, instability is because of sudden load demand variant and variant in renewable sources generation. As well as, weather variation creates several factors that affect the operation of the integrated hybrid system. So this paper introduces output result of a PV /wind via power electronic technique; DC chopper; that is linked to Iraqi power system to promote the facilitating achievement of Wind/ PV voltage. Moreover, PSS/E is used to study dynamic power stability for hybrid system which is attached to an effective region of Iraqi Network. The hybrid system is connected to Amara Old bus and fault bus is achieved to that bus and the stability results reflects that settling time after disturbance is not satisfactory. But, it is found that PV/wind generation system influences Iraqi grid stability to be better than that with only PV generation and the latter is better than stability of the grid that is enhanced with only wind generation. These results represent an important guideline for Iraqi power system planner.

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1. INTRODUCTION

Now wind, and solar energy technology has promising applications as renewable energy (RE) resources as employed to meet arising energy needs. These types of generators vary in generation capacity from hundreds in kilowatts to some megawatts [1, 2].Supply changing dictates the operating schedules of wind and solar sources. Power electronics integration between the two energy types-wind and solar-makes it possible to stabilizes electrical output. Where inverters; DC/ AC converters; are connected to the source for feeding AC loads, while choppers; DC/DC converters; are used to feed DC loads.

The energy produced by wind is cube the speed of it and the suitable site is considered according to monthly speed variation, covering a year. Although knowing annual wind variation in a site is vital, but it is not enough to consider the economic feasibility of installing wind turbine [3, 4]. The data emphasize that wind power capacity is very low thus peak demand can't be met. For that, wind energy can be an additional generation to the more dependable means to provide the desired demand [5].

Photovoltaic (PV) energy is developed rapidly in its usage because this energy is clean, safe, long life and maintenance is low [6, 7]. PV cells convert 15% of sun energy [8]. PV system converts sunlight to DC power which is transformed to AC power; that is relevant for domestic usage; by connecting an inverter to the system [9].

Devices that are made of semiconductor materials can operate at high AC voltages, which can be inverters, rectifiers, or any interface systems, that enhance hybrid systems performance. Researches integrated them to develop hybrid systems [10, 11]. Power electronics are also employed to process the generated wind power to synchronize power specifications of the related grid; like frequency, voltage, etc [12, 13].

J. M. Espi, Jaime castello [14] introduces optimized design for the capacitance of the convertor that is used in back-to-back dc link as part of wind power generation system. Dynamic conditions and switching ripple are combined to optimize the capacitance value of the DC-link beside the required voltage regulation compensator. PV panel, beside a suitable size of battery deliver DC power to the controller. The rotor power is delivered by PV panel as soon as the speed of wind is low [15]. Grid that utilizes RE resources like solar or wind needs controlling stability; through different control methods; that adjust variant in load and supplied energy. Jelena Stanojevic**,** Ana Djordjevic, and Milos Mitrovic [16] studied the effect of BESS; within a hybrid grid of two diesel generators of 200KW; on the electrical grid. The first 200KW is (WTG) and the second is (PV) system.

Bruno Wanderley Franca, Andre Ramos de Castro, and M. Aredes [17] assessed system performance applying altered wind speed and PV that are connected through Synchronverter to power system. It studies increasing performance by controlling inertia. The controller of the three phase back to back power converter is connected to the turbine to produce the specified voltage. Umer Akram, Muhammad Khalid, and Saifullah Shafiq [18] present a method for the optimized capacity of the wind- solar energy, and the energy storage is comprised of battery and supercapacitor, which is employed in microgrid. To meet the energy demand, batteries are charged by photovoltaic (PV), and wind generators.

Battery storage system is a support source to improve generated power transmission or distribution in wind farm. Typically energy storage device includes a converter to control its output power. Power converter acts as an inverter when transmitting DC power to AC grid, and as rectifier when transmitting AC power to DC side. Power converter could control its operation to deliver or absorb power [19]. Herlambang Setiadi, Awan Uji Krismanto, and N. Mithulananthan [20] examine the effect of battery energy storage system; which is installed with large PV plant; on small angle stability of a hybrid power system.

In both terminals of the voltage controller; i.e. DC link terminals; stability limits are calculated. Rectifier in machine side controls dc link which suffers ripple currents which is twice the frequency of the grid [21]. Reactive power at the rectifier and inverter sides are discretely controlled; i.e. at rectifier side, reactive power is controlled such that generator's power loss is minimized or terminal voltage of the generator is kept constant; whereas at inverter side, reactive power is controlled to zero or to the required value without limit violation of converter rating [15].

PSS/E is a conventional package, from which that involves of power system displays convergence progress. Hybrid system linked to ac grid could be simulated using PSS/E analyzing power system load flow; that is performed facilitating numerical analysis [22]; which is essential for transient stability analysis.

Most of researches that discuss renewable energy system connection to Iraqi grid didn't use hybrid system besides using off grid simulation softwares which do'nt represents the actual behavior of the grid. In this paper PSS/E package is used to simulate Iraqi grid to observe the actual performance of the grid. This package provides all types of wind generators and can interconnect it with PV generation system using Python script that deals with dynamic simulation and modeling frequency events such as loss of wind/PV generation or loads. In this paper Iraqi grid stability is observed for three phase and single phase fault with incorporating only wind system firstly, only PV system secondly and finally with hybrid system incorporation.

Generating electricity using wind power is not utilized till now in Iraq, while this country can be assessed to have the opportunity of using it especialy with its good road and electrical infrastructure network that will make wind power more feasible. Beside wind power, implementation of solar energy projects in Iraq with locations of good grid connection and on flat land to avoid shadows, forming a hybrid wind/ PV system will improve the stability of Iraq grid which suffers of frequent total shut down especialy at summer.

Developments of Iraqi transmission grid is influenced by Power demand and Generation fuel availability and location, thus using hybrid energy presents great solution for grid development problems which is the objective of this paper. In the east of the country where the highest wind source, local features and climatic properties sort the wind regime suitable for wind development beside the great solar potential. Thus Amara was our choice to develop the case study, where the hybrid system is linked to 132 grid through (Amara Old) busbar. This paper represents the first study; in the ministry of electricity; of utilizing hybrid energy in Iraq.

This paper is organized as follows; Section 2 describes wind and solar models besides explaining connection method of hybrid system to ac grid as a proposed solution of stability problems. Wind framework in PSS/E is described in Section 3, whereas Section 4 defines PV framework in PSS/E approach.

Section 5 studys the wind/ PV model. Section 6 clarifies the dynamics stability algorithm using PSS/E approach. The case study is in Section 7, and obtained results in Section 8; is concluded in Section 9.

2. SYSTEM MODELLING

PV, wind and dc chopper mathematical models are important requirements to improve control technique; despite their models are familiar today, they are defined here for completeness.

2.1. Wind model

Wind energy generates high electrical power which is proportional to wind speed and other variants as shown in (1):

$$P_m = \frac{1}{2}\rho A C_P v^3 \tag{1}$$

Where:
P = Air density (Kg/m3)
A = Swept area by the rotor (m2)
C_P = Power coefficient of the wind turbine
V = wind speed (m/s)

Voltage change in dc-link capacitor is kept constant since it depends on the grid power (P_g) and the rotor power (P_r).

$$P_{dc} = P_r - P_g = CV_{dc}\frac{dV_{dc}}{dt} \tag{2}$$

But

$$P_{dc} = V_{dc}I_{wind} = CV_{dc}\frac{dV_{dc}}{dt} \tag{3}$$

Then:

$$I_{wind} = C\frac{dV_{dc}}{dt} \tag{4}$$

$$C\frac{dV_{dc}}{dt} = I - i_{dc} \tag{5}$$

$$I_{wind} = I - i_{dc} \tag{6}$$

The Figure 1 shows a wind generator connected to three phase rectifier that is associated with a filter; capacitor (C); causing a subsequent dc output current I_{dc} in the DC side.

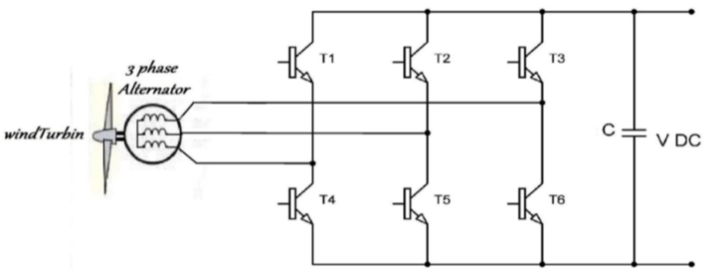

Figure 1. Wind generator with 3 phase rectifier

Power DC with neglected loss is:

$$P_{dc} = V_{dc}I_{dc} = 3I_L V_L \cos\phi \tag{7}$$

For unity power factor the equation becomes:

$$V_{dc}I_{dc} = 3I_L V_L \quad (8)$$

$$\text{Where } V_{dc} = \frac{3\sqrt{3}V_{ph}}{\pi} = \frac{3V_{line}}{\pi} \quad (9)$$

Maximum DC ripple voltage is between angle 30^o and 90^o so the dc voltage range is.

$$\frac{3\sqrt{2}V_{line}}{2\pi} \leq V_{dc} \leq \frac{3\sqrt{2}V_{line}}{\pi} \quad (10)$$

So the Dc wind current depends on (6) and (10)

$$I_{wind} = I - 0.74 i_{dc}$$
$$I_{wind} = I - 1.48 i_{dc}$$

It is essential to control V_{dc} change that is supplied by wind generators, thus DC chopper is used to achieve this control as shown in Figure 2.

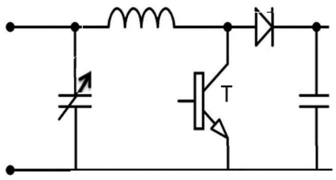

Figure 2. Boost DC chopper

2.2. Modeling of PV system

Many researches beside this research consider (4) in their models but here PV panels are connected to DC busbar via boost converter. The photovoltaic (PV) current I_{pv} which also represents load current is:

$$I_{pv} = I_d - I_{cell}\left[\exp\frac{qV}{akT} - 1\right] \quad (11)$$

Where,
I_d = the diode current I_{cell} = the saturation current of the diode q= electron charge =1.6×10^{-19} Coulombs a = curve fitting or diode ideality constant K= Boltzmann constant = 1.38×10^{-23} joule/°KT= temperature on absolute scale (°K).

Solar panels are in series forming a string which is connected in parallel with other strings to form an array; connected to the boost chopper as shown in Figure 3.

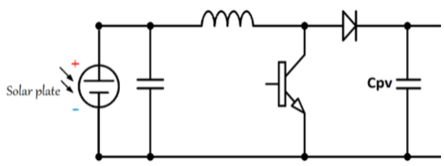

Figure 3. Solar array with boost chopper

Output current, output voltage of solar module with its mathematical model was derived in [23]. Boost dc-dc converter adjust PV output voltage to be constant.

$$V_{pv} - V_{dc} = L_{pv}\frac{dI_{pv}}{dt} \quad (12)$$

$$\frac{dI_{pv}}{dt} = \frac{V_{pv} - V_{dc}}{L_{pv}} \quad (13)$$

It is important to know that dc chopper could be operated in off-MPPT or on-MPPT which depends on system's power balance.

$$(dI_{pv})_{closed} = \frac{V_{pv}DT}{L_{pv}} \quad (14)$$

$$(dI_{pv})_{open} = \frac{(V_{pv}-V_{dc})(1-D)T}{L_{pv}} \quad (15)$$

$$V_{dc} = \frac{V_{pv}}{1-D} \quad (16)$$

$$(I_{pv})_{max} = I_{pv} + \frac{V_{pv}DT}{2L_{pv}} \quad (17)$$

$$(I_{pv})_{min} = I_{pv} - \frac{V_{pv}DT}{2L_{pv}} \quad (18)$$

2.3. Hybrid PV/wind to AC grid

The Figure 4 illustrates the hybrid resultant DC voltage that enforces the power system through three phase inverter. According to grid synchronization, ac grid's terminal voltage initiates tracking the effective voltage. As voltages match occurs, grid connectivity can be held; representing Mode 1 extension. Related to Mode 2, voltage of dc bus depends on boost chopper and the interlinking converter provides the ac-bus.

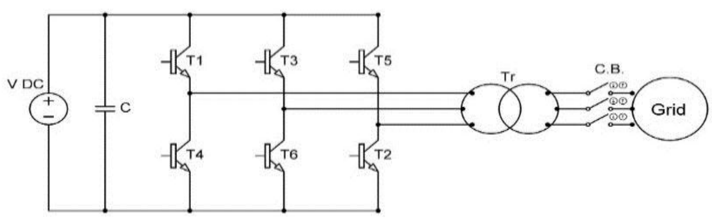

Figure 4. Hybrid system connected to AC grid

Converter current is calculated by (19):

$$I = I_{wind} + I_{pv} \quad (19)$$

Power of the converter can be calculated as:

$$S_t = P + jQ = \frac{3}{2}V\,i_p - j\frac{3}{2}V\,i_q \quad (20)$$

Considering that the grid voltage, V, is constant. By controlling i_p and i_d, active and reactive power can be controlled, respectively.

3. WIND IN PSS/E

PSS/E 34.0 [24] Generic wind turbine Generators are classified as:

a. Type 1. Conventional Induction Generator
WT1 PSS®E stability model is established to mimic wind turbine performance employing conventional induction generator which is in direct connection with grid.

b. Type 2. Wounded rotor Induction Generator with Variable Rotor Resistance
WT2 PSS®E stability model is established to mimic wind turbine performance employing wounded rotor induction generator controlled by variable rotor resistance.

c. Type 3. Doubly-Fed Induction Generator (DFIG)
WT3 PSS®E stability model is established to mimic wind turbine performance employing (DFIG) with its rotor terminals is controlled by an attached power converter.

d. Type 4. Full Size Converter Unit
The WT4 PSS®E stability model is established to mimic wind turbine performance employing generator in connection with grid through power converter. PV plant model is based on this model type.

WT4 consists of two modules: converter/ generator and electrical control as shown in Figure 5. Converter control module calculates injected current to the grid based on electrical control commands of active and reactive power; and the two current components- I_p and I_q are processed under low/ high voltage condition.

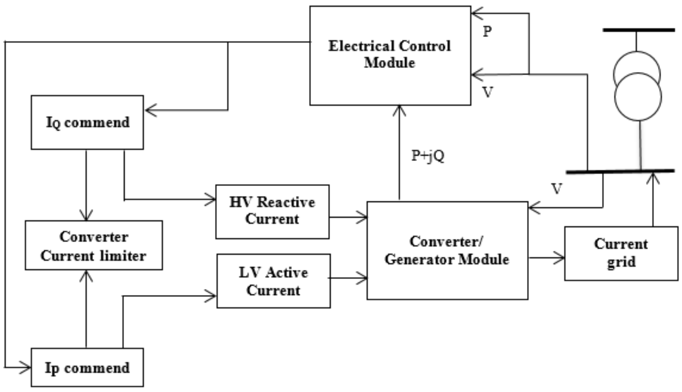

Figure 5. WT4 module connection to the grid

Reactive control computes reactive current for different options of control: remote bus voltage, power factor, and reactive Power control [25]. Active control is to keep balance between machine and grid power by changing active injected current consequently i.e. injected active power is compared with the reference power accordingly injected active component current is changed. Converter current limiter is used to update converter's active and reactive current component.

4. PV in PSSE

PSS/E 34.0 [24] PV models are designed just as wind models with PVGU; as generator/converter model, PVEU; as electric control model, PANEL; as mechanical model, and IRRAD as pitch model. PVGU model calculates injected current to grid depending on PVEU model commands of active and reactive power as they represent part of converter control model. PSS®E recent versions developed stability model of photovoltaic unit such that to simulate PV plant performance which is connected thru power converter to grid as shown in Figure 6. The model is subject to universal type WT4 of wind model; beside solar irradiation effect on output changes can also be simulated.

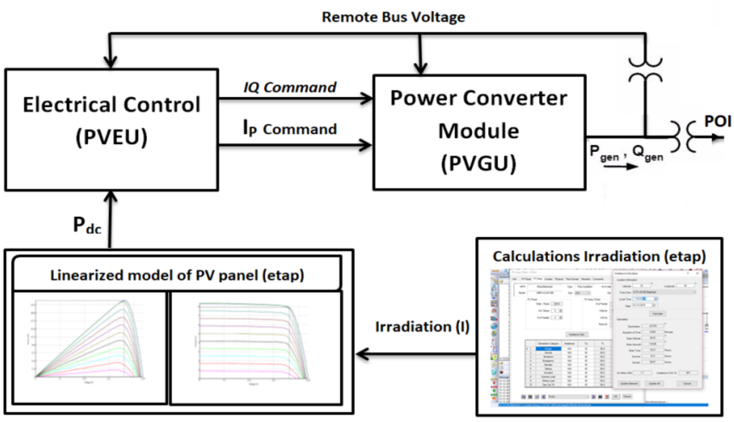

Figure 6. PV solar module connection to the grid

5. STUDY OF PV/WIND SYSTEM MODEL

In the power flow raw data, wind machine control mode which are contained of four options as following: not a wind machine, standard QT/ QB limits, Q limits based on WPF and fixed Q based on WPF [24]. PV machine is identified as wind machine giving it the characteristics of WT4, and Python is used to enter the dynamic's characteristics like fault type with its time occur and how it is connected to grid.

- 0 if the grid of power system is not contained a wind machine, as well as, power factor is ignored.
- 1 if the grid of power system is contained wind or PV machine with standard QT/QB limits.
- 2 if there is found wind machine with Q limits based on WPF but, power factor is used in sitting of machine's reactive power limits. Set the limits of reactive power as [Qmin, Qmax] to control remote bus voltage for wind machine. Such as in the third and fourth types of wind machine, but the forth type is decoupled from the grid by a power converter.
- 3 if there is wind machine with fixed Q based on WPF but, power factor is also used in setting of machine's reactive power limits too and set based on the specified power factor and on the machine's active power setting. Moreover, negative value may be specified when the wind control mode is (3) of the Power Flow Raw Data File. Such as in the first two types of wind machine IC index from 101-107 is respectively included one of wind modules type which are generator, electrical control , mechanical control, pitch control, Aerodynamics , wind Gust Ramp, and Auxiliary control.

PV is detached from the grid through a power converter which is attached to grid, for that, wind control model is 2, i.e. remote bus voltage is controlled by wind machine within the reactive power range (Q_{min}; Q_{max}). Machine reactance is assumed to be infinite. PV equivalent model is users' decision; whether panels number or how many converters are lumped to the represented machine in load flow model. If N converters are lumped, then original converter M_{BASE} must be multiplied by N. Users' also responsible to provide suitable equivalent corresponding plant feeders, transformers, and collectors.

6. STUDY OF DYNAMICS STABILITY USING PSS/E

For the purpose of starting the studies of the stability of the electrical system, the following procedures should be prepared:

a. Preparation of successful power flows and the conversion of loads and generation through (POWER FLOW).
b. After this procedure, the power flow file is converted into a formula that can be used in the stability studies, after that the file is saved in a similar name to the power flow file with the addition of CNV (* _Cnv. Sav).
c. Call the file (DYRE) which contains all components of the generating unit by going to (File) then select (Open) and choose (* .dyr).
d. Choose the appropriate solution parameters to study the stability by clicking on the "dynamics" we choose (Simulation) and then choose the command (Solution Parameters) shows a dialog box in which can change the delta value to (0.001).
e. Selection of monitoring channels, will obtain (Snapshot). After completion of these steps, the file is ready for the studies of stability, but these steps must be followed to make sure that the file is suitable for stability studies.
f. When applying a fault on a transmission line, through the command (Disturbance) we choose (Line fault) and shows us a dialog box called (Apply a line fault).
g. Then return to the state of application of the state of stability and through the (Dynamics) go to (simulation) then choose (Perform Dynamics) which shows a dialog box called (Perform Dynamics Simulation). Then increase the time of the crash to the time of the steady state.
h. An increase of the error after executing it with the opening of the error on the relay through the command (Disturbance) then from choose (Clear fault).
i. This study is running for a period longer than (10 seconds) after removing the error. In the order of (Dynamics), after that select (simulation) and then go to (Perform simulation). Stability study analysis can be started showing distinct illustrations that display these incidents effect on electrical system parts and show graphs in (file) and (New) (Plot Book) with converting information bar to (Plot Data).
j. The file can upload with an (.out) Extension, which contains the channels to be monitored.
k. After uploading file, any channel can monitor previously identified. Therefore, possible to start analyzing the studies of the stability by dragging the channels to be studied in (a drag & drop method) to a plot book. Figure 7 shows how to incorporate PV machine to grid and studying the dynamic of system using PSS/E.

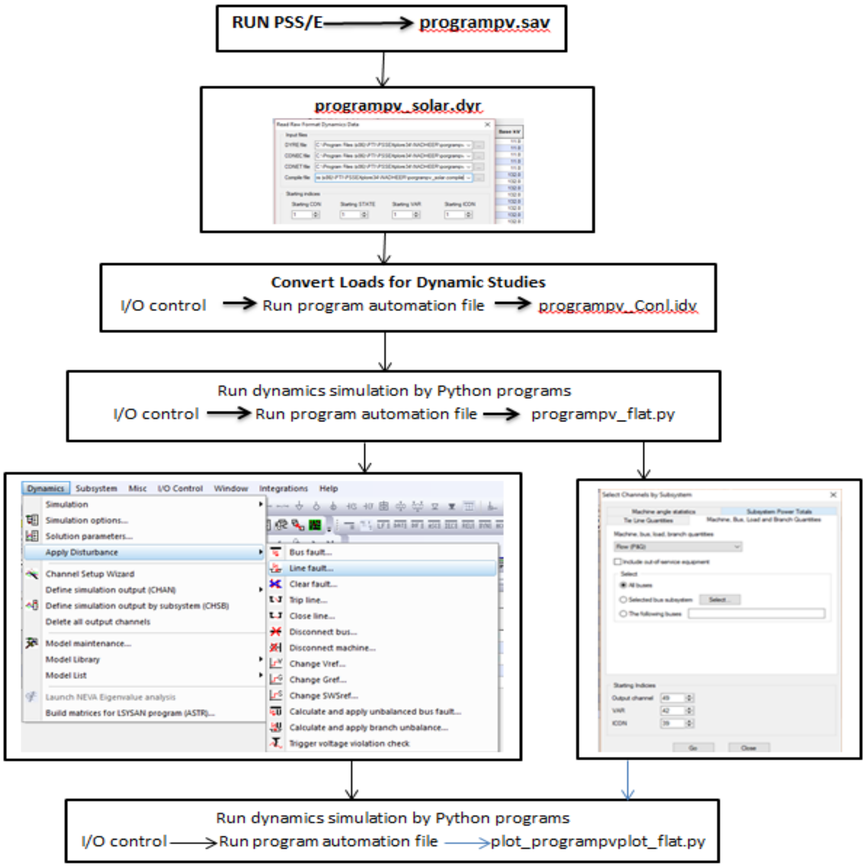

Figure 7. Flow chart of dynamic simulation

7. CASE STUDY

This study presents the potential for the renewable energy development in Iraq, specifically considering commercial wind and solar power. Iraq average wind speed is low, that limits the widespread use of wind energy. However, in the east of Iraq especially in Amara where good road is there, wind speed is high beside electrical infrastructure network make wind power more viable. On other hand, In Iraq there is an auspicious solar source. Thus an assessment could shows that grid interconnection with photovoltaic system is officially feasible giving good regulatory mechanism. This study focused to Amara which has total generation of 225MW and city demands; for this year 2019; are shown in Table 1. The solar irradiance (PD), solar energy (ED) and available wind speed (V) in Amara is shown in Table 2. Amara governorate has fourteen busbar of 132 Kv. Figure 8 shows the load flow of Amara Old (26302) busbar connected to other buses; before hybrid system interconnection. When three phase and single phase fault at Amara Old occurs; before hybrid system incorporation; the short circuit currents of Amara Old and linked buses are as follows in Table 3.

Table 1. Amara energy and power demands [17]

Governorate	Energy demand at consumer end (GWH)	Peak demand at consumer end (MW)	Energy demand at 132KV substation end (GWH)	Peak demand at 132KV substation end (GWH)
Amara	1806	326	1981	358

Table 2. Amara wind speed and solar irradiance and energy

Location	Height (m)	Parameters of measured quantities		
		V (m/s)	PD (W/m2)	ED (KWh/m^2)
Amara	60	6.5358	170.0043	1483.9
	90	7.2536	231.7114	2022.5
	120	7.8103	288.3992	2517.3

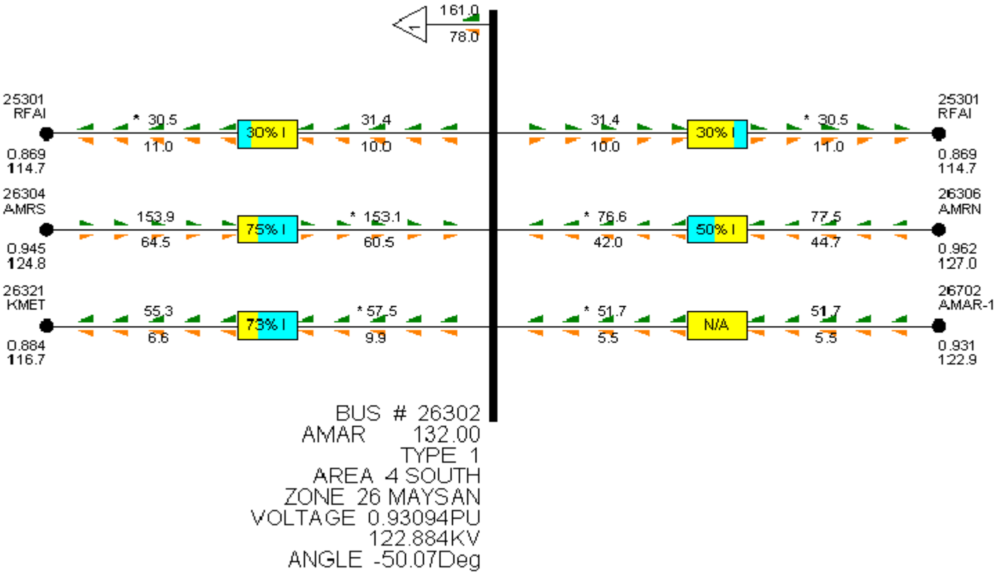

Figure 8. (Amara old) load flow

Table 3. Buses fault current before including hybrid

Bus name and number	3 Phase Fault Current (A)	Single Phase Fault Current (A)
ALGB (26301)	1472.7	1792
Amara (26302)	9996.8	9854
NAMR(26303)	9771.7	9011
AMRS(26304)	11348.1	11390
BZRG(26305)	5490.4	6668.4
AMRN(26306	10515.7	11823
KMET(26321)	2302.9	2788.5

8. RESULTS

Since loading is restricted by stability considerations; thus it is important to maintain system stability of Iraq grid which suffers of blackouts. So the proposed solution is to develop grid stability by connecting hybrid system to AMRW 26315 AC busbar via 13.6/132 kV transformer. Figure 9 represents hybrid/ Grid connection. The software WAsP version 9.1 is used to measure the developed power for Amara wind speed (7.8m/s), and the resultant power was 825 kW as in Figure 10.

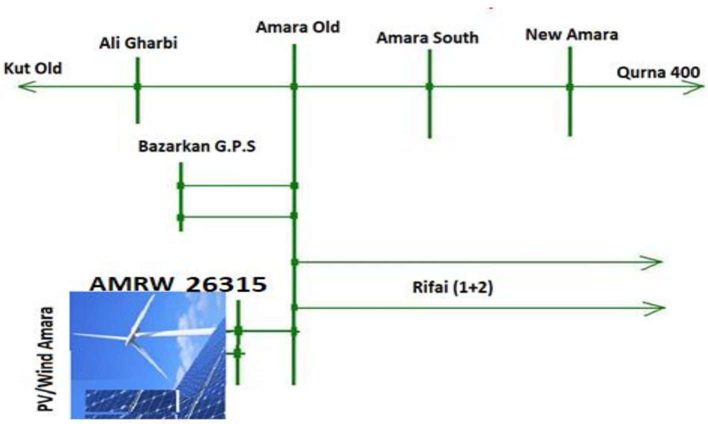

Figure 9. Hybrid system connection to (Amara Old) busbar

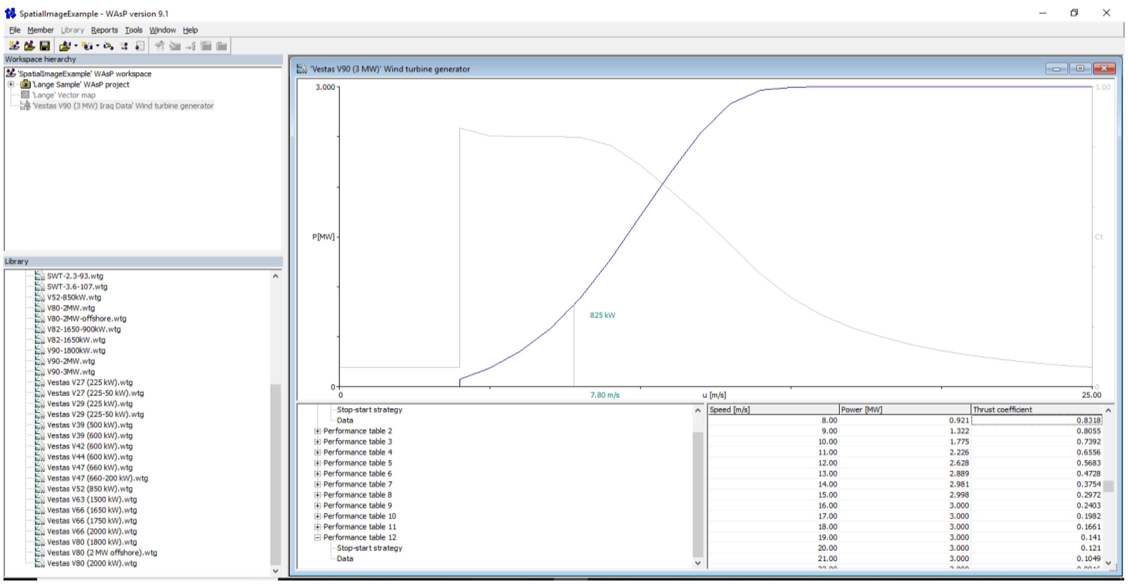

Figure 10. Turbine generated power using WAsP

The dynamic study of Iraqi system connected to hybrid energy sources is simulated using PSS/E. It is important to tell that wind speed was 7.6m/s at fault execution time, thus wind generated power is 0.75 MW. Short circuit currents of three phase and single phase faults at (Amara Old), at time t = 1sec., and lasted 0.15sec.; is shown in Table 4 after hybrid system addend.

Table 4. Buses fault current after including hybrid

Bus name and number	3 Phase Fault Current (A)	Single Phase Fault Current (A)
ALGB (26301)	1402.37	1392
Amara (26302)	11062.3	10123.2
NAMR(26303)	8766.7	7652
AMRS(26304)	9879.8	10456.5
BZRG(26305)	5490.4	6668.4
AMRN(26306	9867.6	9987.5
KMET(26321)	2153.9	2622.5

It is evident that short circuit currents after adding hybrid system are less for most buses of Amara governorate. While fault current of case study bus (26302) is increased especially in single phase fault, this represents expected behavior because of generating units increase at that bus. This comparative result is illustrated in the charts in Figure 11 for three phase and single phase short circuit currents.

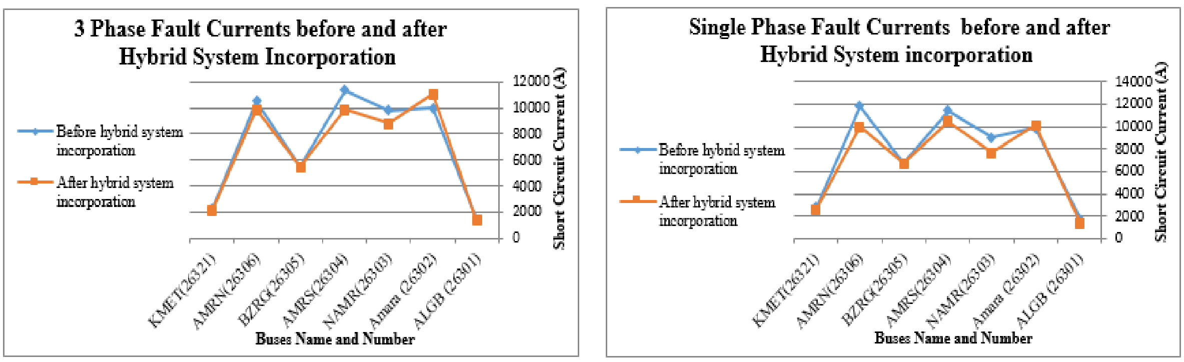

Figure 11. Fault Currents before and after hybrid system incorporation for
(a) Three phase fault, (b) Single phase fault

The Figure 12 shows (power/time) system response to various kinds of sources. The system has been designed to withstand the N-1 contingency which means that the system will operate normally even if one of the high voltage transmission lines tripped or one of the generating units tripped. Maximum power, minimum power, and settling time information can be summarized in Table 5. Settling time of wind for power is the worst but combing it with PV improves results.

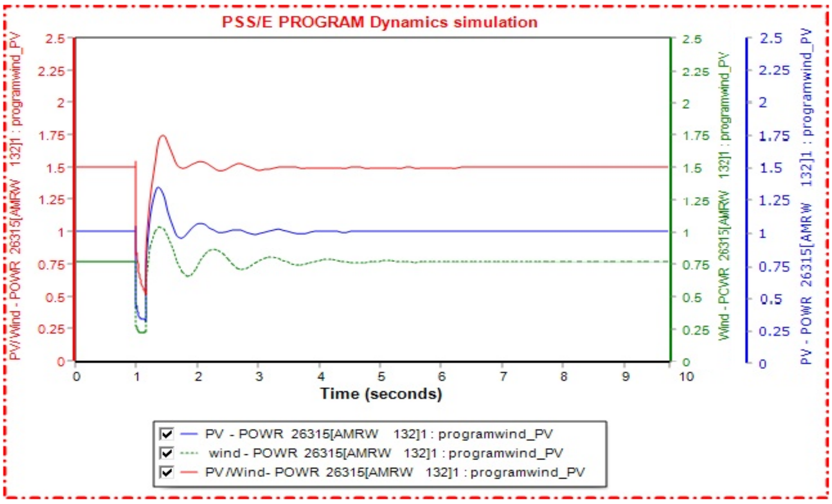

Figure 12. Power response of (Amara Old) fault

Table 5. Disturbance information

Source Type	Steady state power (PU)	Max power (PU)	Max Power difference (PU)	Min power (PU)	Min Power difference (PU)	Settle time (sec)
pv	1	1.351	0.351	0.279	0.721	4.2
wind	0.75	1.124	0.374	0.248	0.502	4.5
Pv/wind	1.5	1.75	0.25	0.518	0.982	3.3

It is supposed for hybrid installation that wind system power factor is 0.9; at 132kV connecting point; for leading and lagging performance. Figure 13 clarifies volt ampere reactive (VAR/Time) response of the system for bus fault with all kinds of sources.

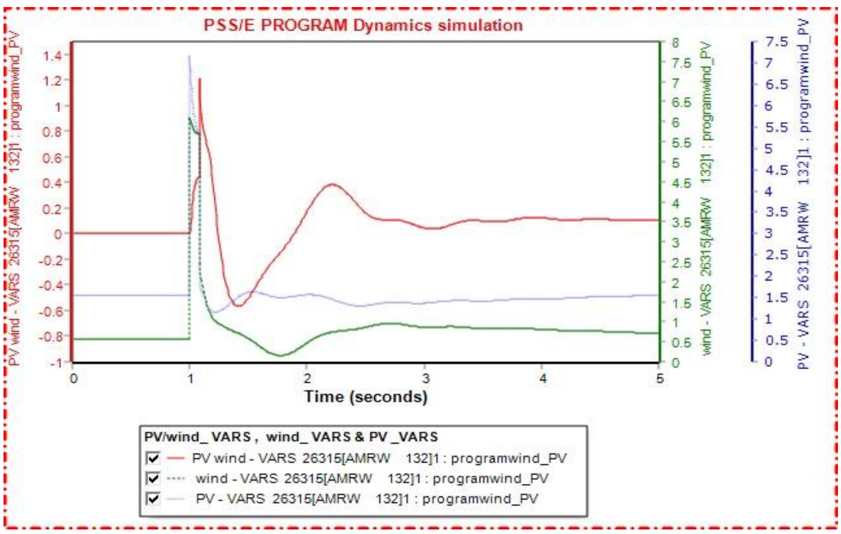

Figure 13. VAR response for (Amara Old) disturbance

Fault presented in the case of wind or PV, settling time taken after fault 1.65sec and 1.53sec respectively. Whereas response to disturbance of hybrid system is the worst because it takes (2.45sec) after fault to settle to about 5%, but from other point of view it is best in delivering zero VARs. During fault, hybrid generation reduces injected active power to grid in order to offer reactive power the ability of injection. For wind system this result in rotor speed up and with longer last of fault, pitch mechanism could be respond and consequently active power may be decreased after fault. Due to fault with pv/wind, (Amara Old) bus voltage falls down to 0.75pu until the fault is cleared. Voltage reaction is illustrated in Figure 14 as fault is cleared; an obvious transient in voltage curve is noticed with maximum value of 1.12pu.

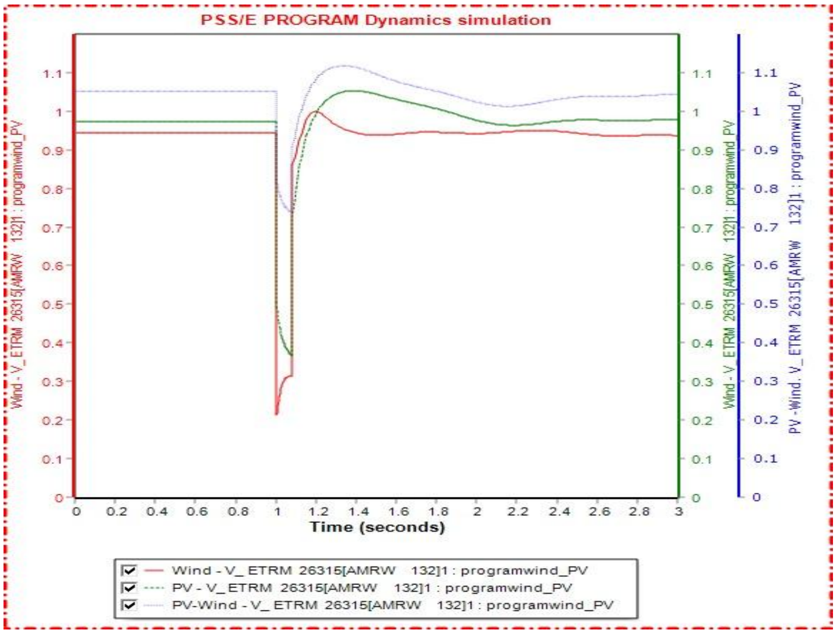

Figure 14. Voltage dynamic response for (Amara Old) fault

Also dynamic simulation mimics voltage, power factor, and frequency response of hybrid system at terminal as in Figure 15 which shows less voltage transient, angle never gets back to its steady state value, and frequency rises by 0.55pu and its settling time is 2.2s after fault.

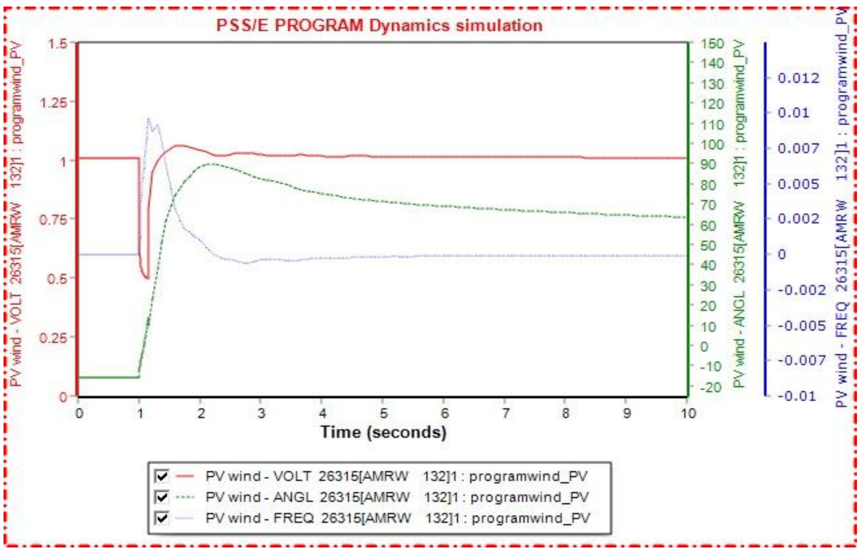

Figure 15. Terminal dynamic response to (Amara Old) fault

9. CONCLUSION

The main goal of this paper is to investigate the dynamic characteristics of Iraqi power system with enhanced hybrid system. AC/DC interlinking is found to be stable and grid synchronization is facilitated ensuing power balance in spite of generation kind's variety. Several parameters could affect the maximum hybrid output and consequently system transient characteristic; such as change of wind speed or solar irradiance, beside the height of propellers of wind energy system and if solar system is supported with sun tracking system or not. The indicated results reflect the actual system output level and dynamics study with a satisfactory performance that could be used as reference base for Iraqi grid development planners.

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