STEADY STATE ANALYSIS OF GRID-CONNECTED AC/DC HYBRID MICROGRID USING MATLAB/SIMULINK

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Abstract

This paper presents a model of grid-connected hybrid ac/dc micro grid. The proposed system consists of a variable-speed and direct-drive wind generator, wind-side converter, solar array, dc-dc converter and grid interface inverter. All the generation units are connected to a distribution system to operate in grid-connected mode. The grid interface inverter transfers the energy drawn from the wind turbine and PV array into the grid by keeping common dc voltage constant. Dynamic models for each system component were developed and used for steady state simulation. The influence of the system operation was simulated at steady state in both ac and dc sides using Matlab/Simulink. The simulation results show the dynamic behaviour of the wind/PV system.

Keywords: Hybrid; Microgrid; Grid-Connected; Detailed Modelling.

Introduction

Due to the critical condition of industrial fuels such as oil, gas and others, the development of renewable energy sources is continuously improving and becoming more important nowadays. Moreover, these resources are abundant in nature, eco-friendly, and recyclable. Many renewable energy sources like sun, wind, water and tides are there. Among these renewable sources solar and wind energy are the world's fastest growing energy resources. With no emission of pollutants, energy conversion is done through wind and pv cells Lipsa P. (2012), Nabil A. (2006).

Day by day, the demand for electricity is rapidly increasing and the available base load plants are not able to supply electricity demand. So, these energy sources can be used to bridge the gap between supply and demand during peak loads.

It has been reported that in weak grids, the wind/solar hybrid system is better than single wind or PV generation since it suppresses rapid change in the output power of the single source such as the wind turbine system Kurozumi et al (1998).

The entire hybrid system comprises of pv and the wind systems as shown in Figure (1).

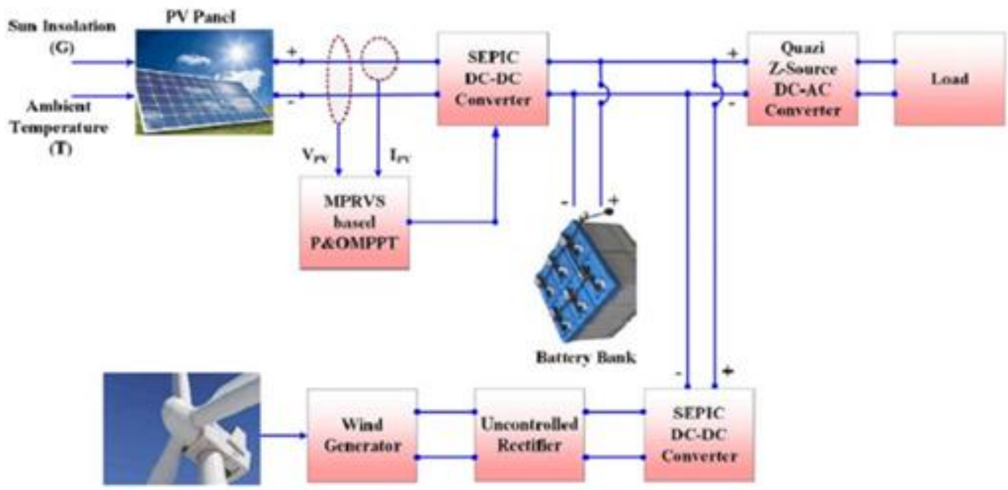


Figure (1): Block Diagram of Hybrid System.

Hybrid renewable energy systems (hres) have been widely recognized as an efficient mechanism to generate electrical power because of their high reliability, low running cost with flexibility to operate in grid-connected Lipsa P. (2012). This paper presents a modelling and simulation of grid-connected AC/DC microgrid (mg). The system is composed of a wind turbine, photovoltaic cells and an ultra-capacitor for energy storage. The generation units are connected to a distribution system to operate in grid-connected mode.

Modelling of DC Microgrid

Photovoltaic power generation system is composed of photovoltaic array, which can convert light energy into direct current, and through the DC inverter it can converted to AC power which is connected to the grid. In this section, a generalized model for DC mgs, as in Figure (2), and interconnected dc mgs considering aforementioned control loops are presented QobadShafiee et al (2005).

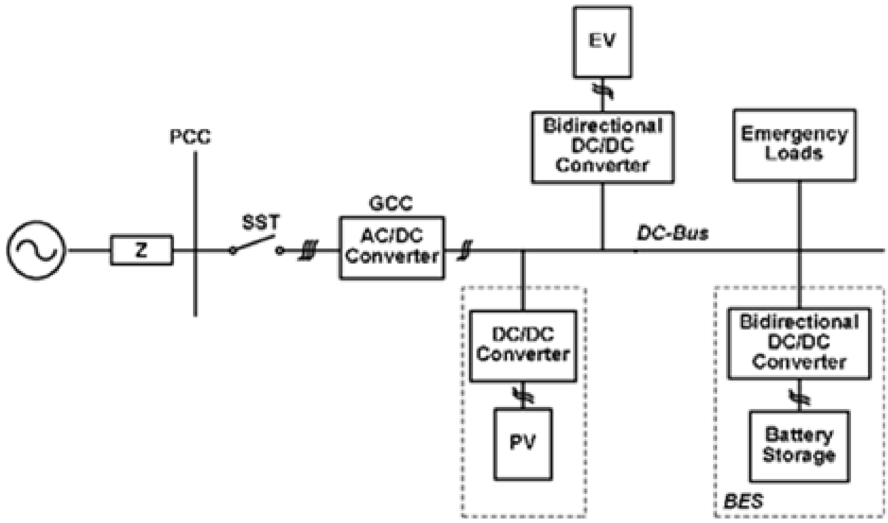


Figure (2): Structure of The DC Microgrid.

A. Mathematical Model for Photovoltaic Cell

The equivalent circuit of a PV cell is shown in Figure (3-A). The current source Iph represents the cell photocurrent. Rsh and Rs are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. Practically, pv cells are grouped in larger units called pv modules and these modules are connected in series or parallel to create pv arrays which are used to generate electricity in pv generation systems. The equivalent circuit for pv array is shown in Figure (3-B) XuanHieu (2009).

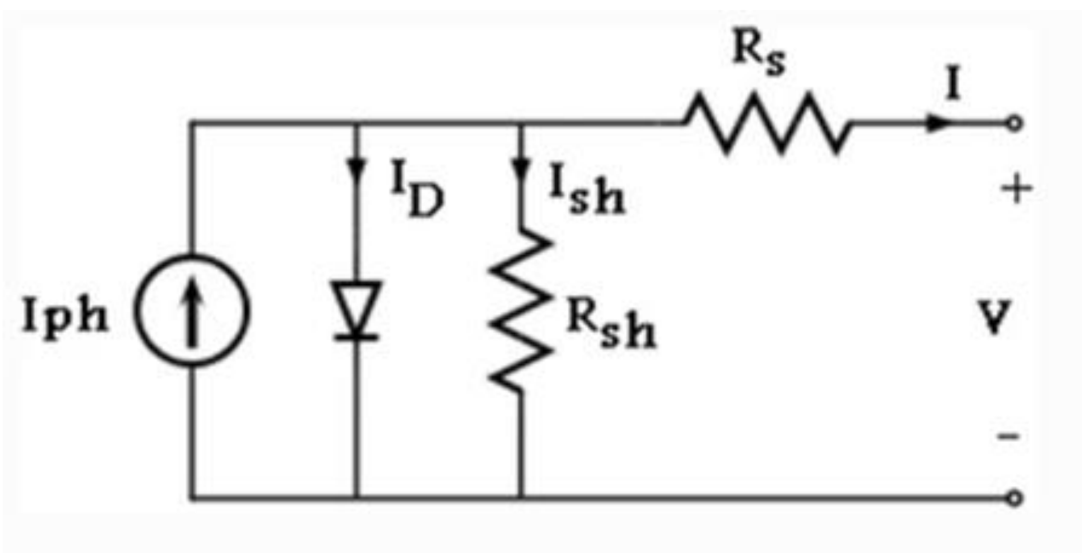


Figure (3-A): The Equivalent Circuit of a PV Cell.

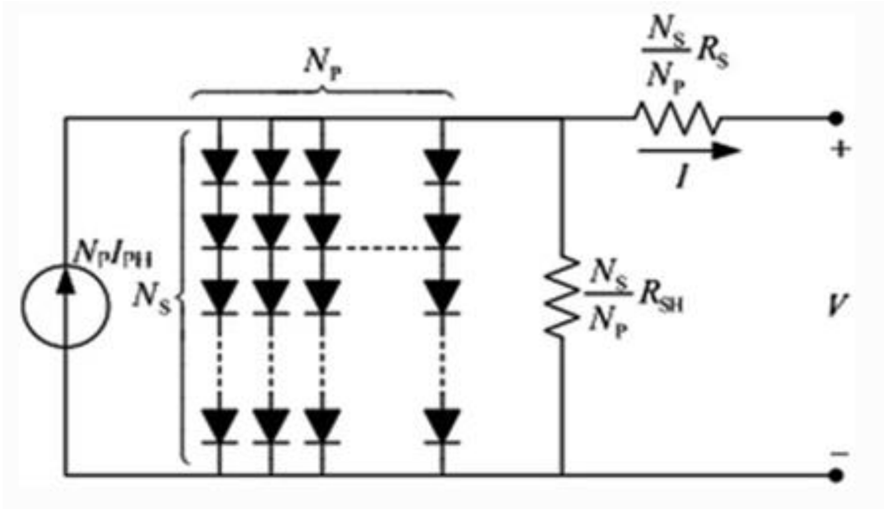


Figure (3-B): The Equivalent Circuit for pv Array.

The voltage–current characteristic equation of a solar cell is module photo-current Iph:

$$\mathbf{I_{Ph} = [I_{Sc} + K_I(T - 298)] * \frac{I_R}{1000}} \qquad (1)$$

Here,

Iph: photo-current(A);

Isc: short circuit current (A);

Ki: short-circuit current of cell at 25 °C and 1000 W/M2;

T: operating temperature (K);

Ir: solar irradiation (W/M2).

Module Reverse Saturation Current Irs :

$$\mathbf{I_{rs} = I_{sc} \Big/ \left[Exp\left(q \frac{V_{Oc}}{N_S KnT} \right) - 1 \right]} \qquad (2)$$

Here,

Q: electron charge, = 1.6 × 10−19c;

Voc: open circuit voltage (V);

Ns: number of cells connected in series;

N: the ideality factor of the diode;

K: Boltzmann’s Constant, = 1.3805 × 10−23 J/K.

The module saturation current i0 varies with the cell temperature, which is given by:

$$\mathbf{I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 Exp\left[\frac{q * E_{g0}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right]} \qquad (3)$$

Here,

Tr: nominal temperature = 298.15 K;

Eg0: band gap energy of the semiconductor, = 1.1 eV;

The current output of PV module is:

$$\mathbf{I = N_P * I_{Ph} - N_P * I_0 * \left[Exp\left(\frac{\frac{V}{N_s} + \frac{I * R_S}{N_P}}{N * V_t}\right) - 1\right] - I_{Sh}} \qquad (4)$$

with

$$\mathbf{V_t = \frac{K * T}{q}} \qquad (5)$$

and

$$\frac{\mathbf{I_{Sh} = v * N_P / N_S + I} * \boldsymbol{R_s}}{\boldsymbol{R}_{\mathbf{Sh}}} \qquad (6)$$

Here:

Np: number of Pv modules connected in parallel;

Rs :series resistance (Ω);

Rsh: shunt resistance (Ω);

Vt :diode thermal voltage (V).

The electrical specifications of the proposed PV model including the PV manufacturing datasheet are listed in Table (1).

Table (1): Electrical Specification for Solar Panel at 25 °C, 1000w/M2

Parameters	Value
Maximum power rating Pmax	220W
Rated current Impp	5.37A
Rated voltage Vmpp	41.0V
Short circuit current Isc	5.75A
Open circuit voltage Voc	48.6V
Number of Cells per module	36
Number of series connected modules per string	15
Number of parallel strings	67

B. Sizing PV Plant

Photovoltaic (PV) modules are sized using wattage determined under standard test conditions (Stc). This is the manufacturer's specified nameplate wattage and represents module output as measured under very controlled factory conditions. Specifically, Stc is 1000 W/M2 (Solar Irradiance) and 25oc (Module Temperature). The Design Criteria for Pv module are based on the manufacturer's data which illustrated in Table (1).

The rated voltage and current at maximum power point (Vmpp, Impp) 41.0 V and 5.37a respectively result in 220w (Pmpp) power output for each Pv module at Stc. From the results obtained, it is found that A 220.8 Kwp solar photovoltaic power plant can be developed on 1475.5m2 Area. The required numbers of pv modules are obtained as follows:

$$NO._{PV}\ modules = \frac{P_{pv}}{P_{mpp}} \qquad (7)$$

$$NO._{pv} = \frac{220800}{220} = 1004\ PV\ modules$$

Using the effective area and the module area

$$NO._{pv}\, modules = \frac{effective\ area}{module\ area} \qquad (8)$$

$$NO._{pv}\, modules = \frac{1475.5}{1.244} = 1186\ modules$$

In order to form a solar photovoltaic power plant 1186 modules are connected in a series-parallel combination (15 in series and 67 parallel) Shawnee R. (2013).

C. Maximum Power Point Tracking (MPPT)

Consequently, the mppt is an algorithm embedded in the charge control units used to extract the maximum power available from the pv unit under certain conditions. It is called the voltage at which the pv unit can produce the maximum energy (maximum power point) or the peak of the energy voltage. The maximum energy varies with solar radiation, ambient temperature, and solar cell temperature XuanHieu (2009). These mppt algorithms are necessary in mpp photovoltaic applications for the solar panel.

Over the past decades, many methods have been developed and deployed on mpp David S. (2010). Among these technologies, p & o algorithms are the most popular. This technology can be easily implemented.

D. Ultra-Capacitor Energy Storage System

1. Ultra-Capacitor (Uc) Model

The model consists of an ideal capacitor, a series resistance Esr and a parallel resistance Epr. Esr is small and simulates heat losses and charge/discharge voltage transient mutation in charging/discharging process. Epr is a large resistance representing the current leakage effect and impacts long-term energy storage.

2. Control System

The ultra-capacitor energy storage system is composed of the ultra-capacitor, a bi-directional dc/dc converter and a control system. The configuration should enable the ultra-capacitor to operate in the bi-directional mode. Figure (4) represents the control system for the bi-directional converter. The primary objective is to maintain the common dc-link voltage constant Zhen guo Chu (2010). In this way, no matter whether the ultra-capacitor is charging or discharging, the voltage at the dc bus will be stable and with reduced ripple in the capacitor voltage Tomas P (2003), Sindhu K (2012).

When the voltage at the dc bus is lower than the reference, switch s2 is activated and the converter works as a boost circuit; when dc bus voltage is higher than the reference, s1 is activated and the converter works as a buck circuit. At steady state, the input voltage and the output voltage satisfy the relationship.

$$\mathbf{V_{Dc} = \frac{V_{Uc}}{1 - D_1} = \frac{V_{Uc}}{D}} (\boldsymbol{boost})$$

$$\boldsymbol{V_{uc} = D_2 V_{dc}} \qquad (\boldsymbol{buck})$$

Where d is the duty cycle of the switching signal.

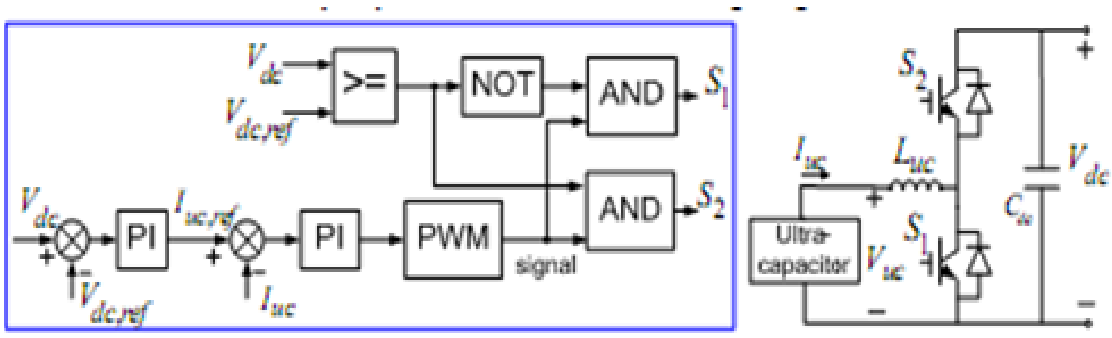


Figure (4): B i-Directional dc/dc Converter Control.

Modelling of Ac Microgrid

With the use of power of the wind, wind turbines produce electricity to drive an electrical generator. Usually wind passes over the blades, generating lift and exerting a turning force. Inside the nacelle, the rotating blades turn a shaft then goes into a gearbox. The gearbox helps in increasing the rotational speed for the operation of the generator and utilizes magnetic fields to convert the rotational energy into electrical energy. Then the output electrical power goes to a transformer, which converts the electricity to the appropriate voltage for the power collection system Sindhu K (2012). A wind turbine extracts kinetic energy from the swept area of the blades. The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time.

1. Model of Wind Generator

Simplified model of Dfig is shown in Figure (5). The rotor of induction machine is connected to the grid with a back-to-back voltage source converter that controls the excitation system.

This most significant feature enables sub synchronous and super synchronous operation speeds in generator mode and adjustable reactive power generation QobadShafiee et al (2005), Sindhu K. (2012).

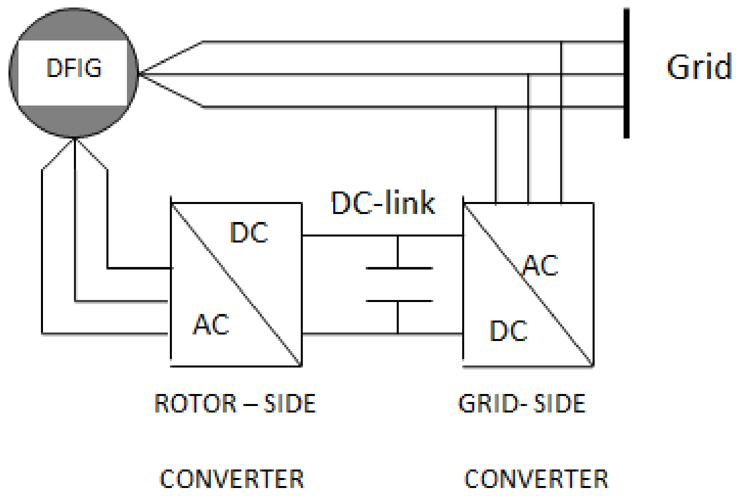


Figure (5): Dfig Detailed Model.

Grid connected induction generator (dfig) develops their excitation from that of the grid. The generated power is fed into the supply system when the ig is made to run above that of the synchronous speed. Machines having cage type rotor feeds only through the stator part and mostly operates at low negative slips. On the other hand, wound type rotor machine can feed power through the stator as well as rotor part to the bus over a wide range of speed and it is known as doubly fed induction machine.

2. Dc-Link Voltage

The dc link voltage capacitor connected on dc side acts as a dc voltage source. Its steady state value for mid-level output power can be modelled as in Figure (1). It is believed that a better-tuned controller would result in improved results. More complex controllers could also be added to improve the response Ali B (2011), Shawinee R (2013), Tomas P (2003).

3. Mathematical Model

Under constant acceleration, the kinetic energy of an object having mass *m* and velocity *v* is equal to the work done, *w* in displacing that object from rest to a distances under a force *f* .

$$E = W = Fs$$

According To Newton’s Law, We Have:

$$F = Ma$$

Hence,

$$E = Ma \times S \qquad \textbf{(9)}$$

Using the third equation of motion:

$$\upsilon^2 = U^2 + 2as$$

We get:

$$A = \frac{(\upsilon^2 - u^2)}{2s}$$

Since the initial velocity of the object is zero, i.e.

U = 0, we get:

$$A = \frac{\upsilon^2}{2s} \qquad \textbf{(10)}$$

Substituting it in equation (10), we get that the kinetic energy of a mass in motions is:

$$E = \frac{1}{2} M v^2 \qquad \textbf{(11)}$$

The power in the wind is given by the rate of change of energy:

$$P = \frac{dE}{dt} = \frac{1}{2} v^2 \frac{dm}{dt} \qquad \textbf{(12)}$$

as Mass Flow Rate is given by:

$$\frac{dm}{dt} = \mathrm{Pa} \frac{dX}{dt} \qquad \textbf{(13)}$$

And the rate of change of distance is given by:

$$\frac{dX}{dt} = v$$

We get:

$$\frac{dm}{dt} = \mathrm{P}av$$

Hence, from equation (13), the power can be defined as:

$$\mathrm{P} = \frac{1}{2} \mathrm{Pa}\upsilon^3 \qquad \textbf{(14)}$$

If the rotor diameter is d, the area of the disc subtended by the rotor is:

$$A = \frac{\pi d^2}{4}$$

Thus the power available from the wind is

$$P = \frac{1}{2}\rho\frac{\pi d^2}{4}v^3 = \frac{\pi}{8}\rho d^2 v^3 \qquad \textbf{(15)}$$

From eqns. (5) and (6), keeping everything constant except for the wind speed, we can get the power ratio:

$$\frac{P(v)}{P_0(v)} = \left(\frac{v}{v_0}\right)^3 \qquad \textbf{(16)}$$

Thus doubling the wind speed leads to an increase in the wind power by a factor of 2^8.

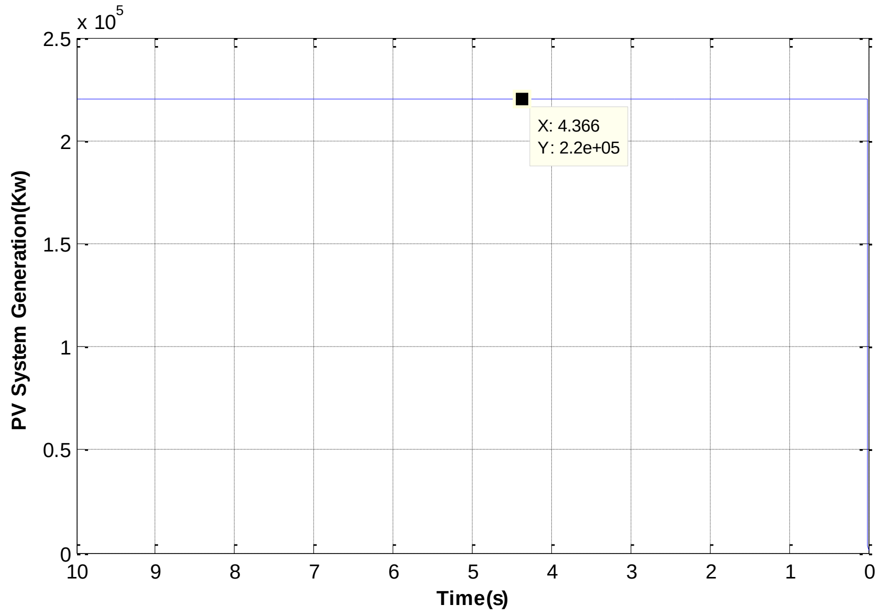
Grid-Connected Hybrid Ac/Dc Microgrid Simulations

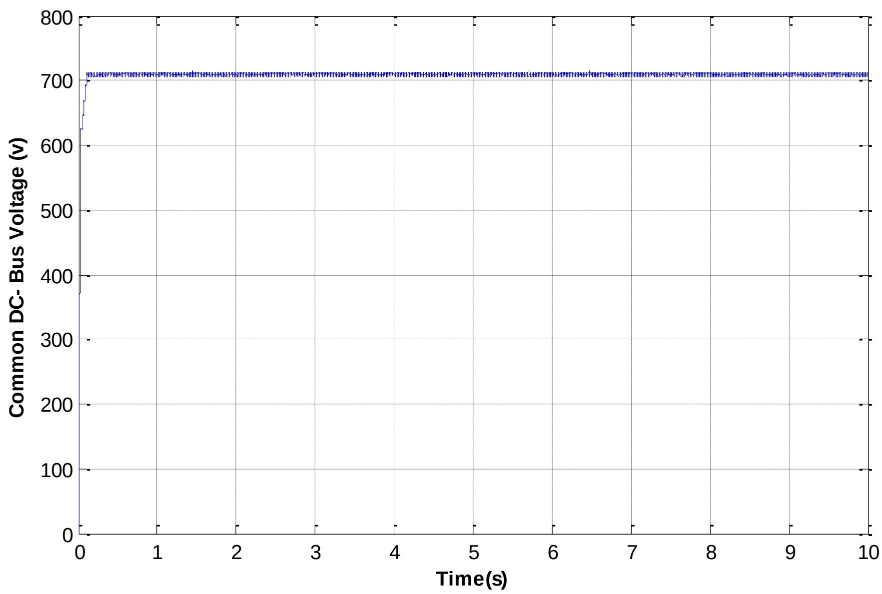
The model of the complete grid-connected hybrid ac/dc Microgrid system is implemented using Matlab/Simulink. Based on this test-bed several cases are simulated including steady-state operation.

The wind system has 60kw nominal power, the wind turbine operates at a nominal wind speed of 15 m/s, with a generator rotor speed of 1.2 pu , and the pv system has a maximum power rating of 220.8 kw with solar irradiance of 1000 w/m2 and an operating temperature of 298k Sharad W (2009), Eung-Sang et al (2016), Zhen Guo Chu (2010).

Steady State Operation

At steady state, all distributed generation units are operating at their nominal point and supply power to the loads and grid, and the PV system sufficient power for the loads and grid, and the ultra-capacitor energy storage system are inactive, i.e. neither charging nor discharging. Figure (6) shows the simulation results. From the Figures, it is evident that all distributed generating units reach the steady-state operation after a short period of time. The figure of the active power for the five loads illustrates that three distributed generation units have enough power to supply the local loads, while the loads far from the distributed generation.


x 10^5
PV System Generation(Kw)
X: 4.366
Y: 2.2e+05
Time(s)


Common DC- Bus Voltage (V)
Time(s)

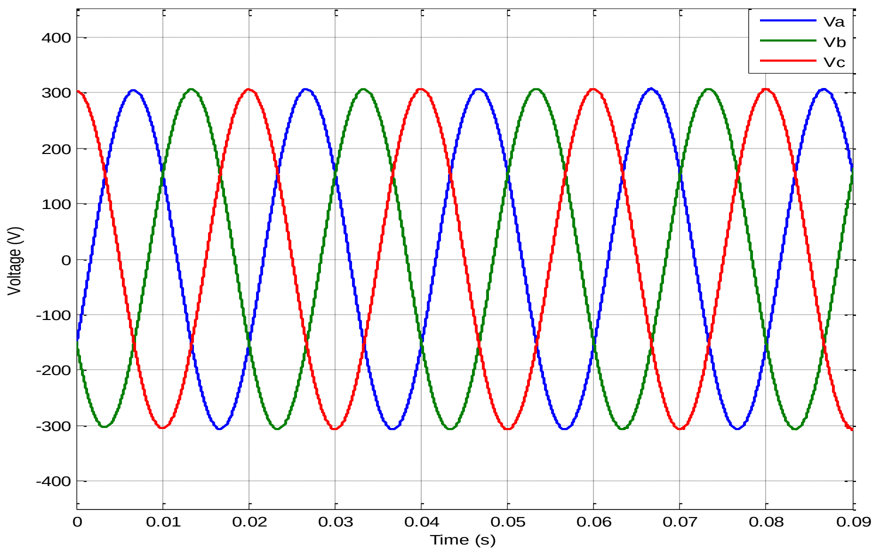
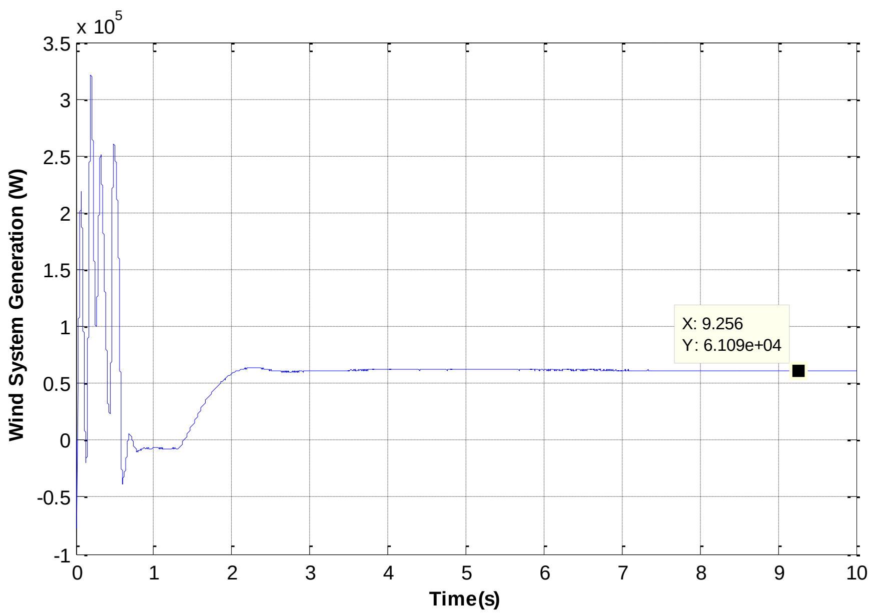
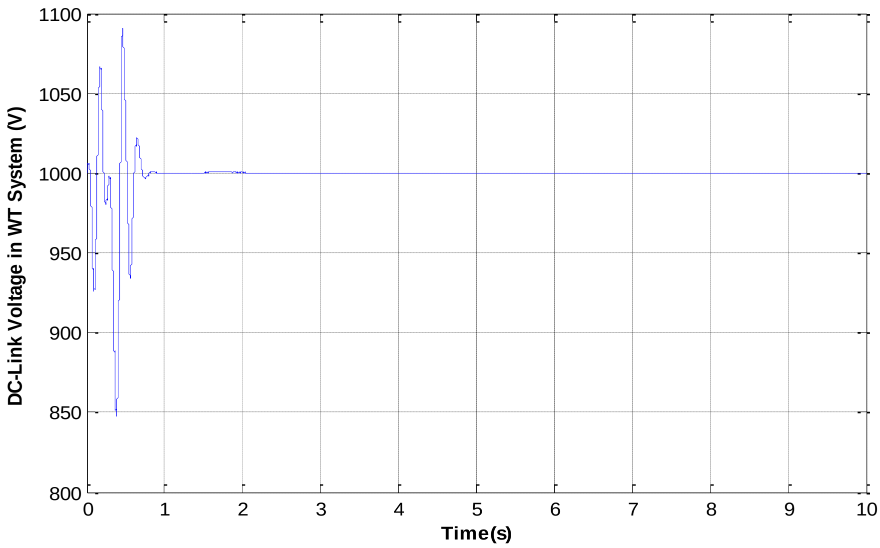
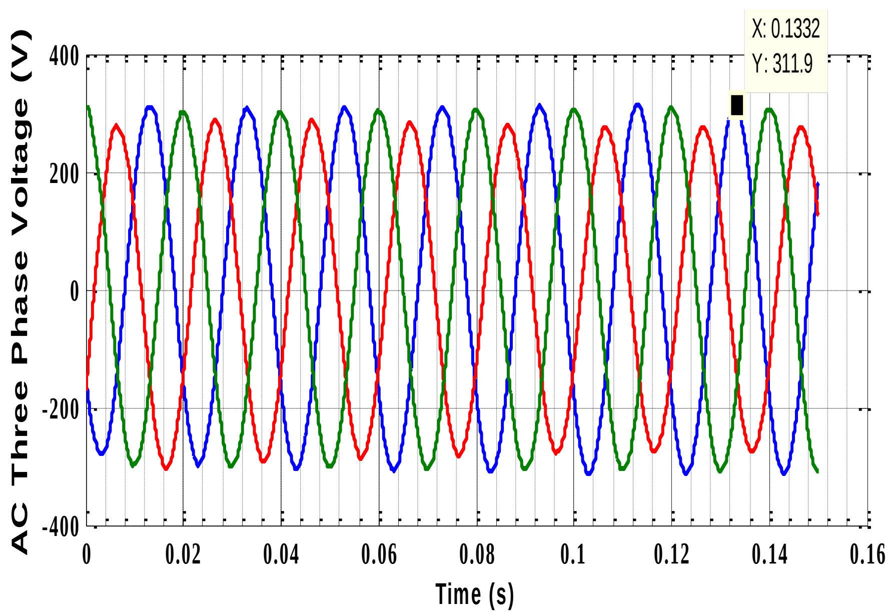


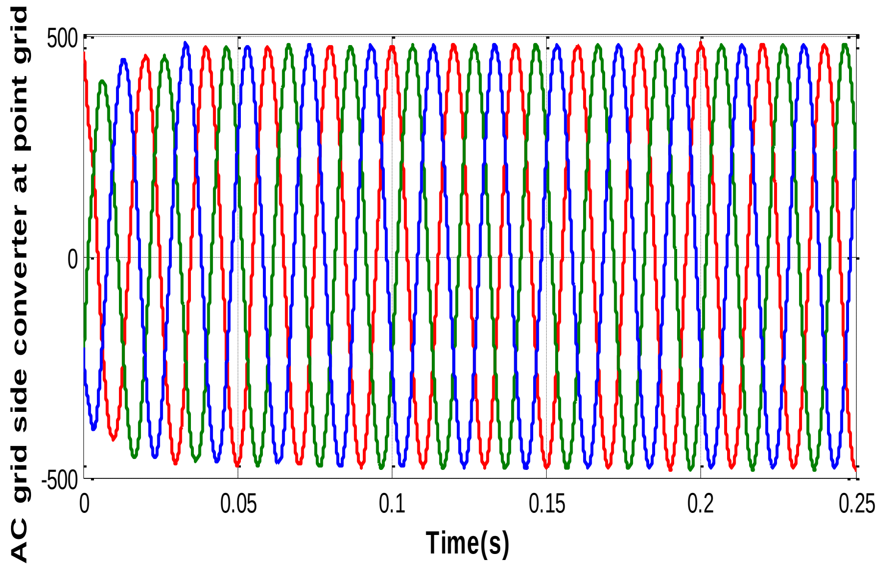
Figure (6): Three Phase Inverter Output Voltage Simulation Result.

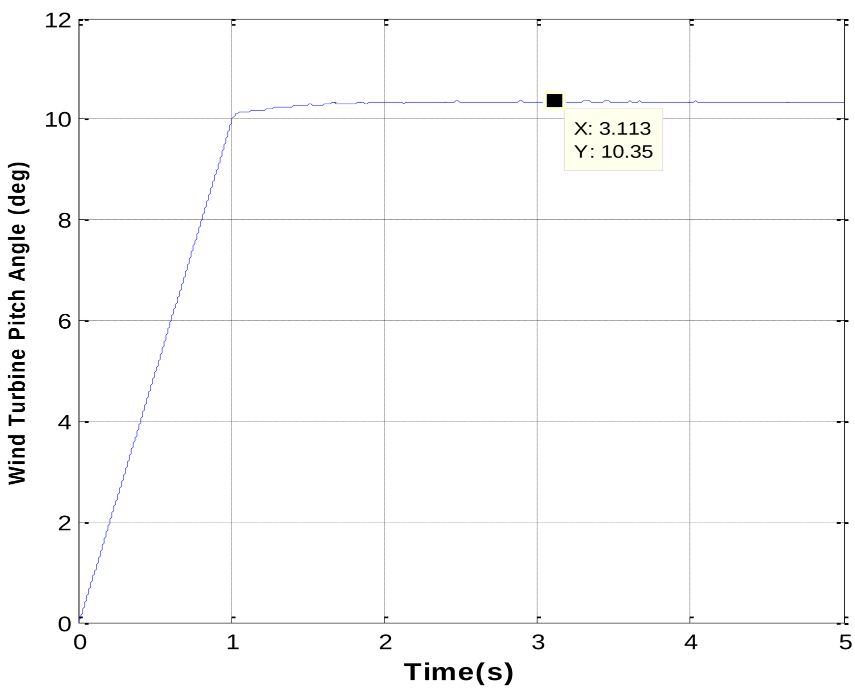
(a) Dc microgrid: pv system generation, common dc-bus voltage.

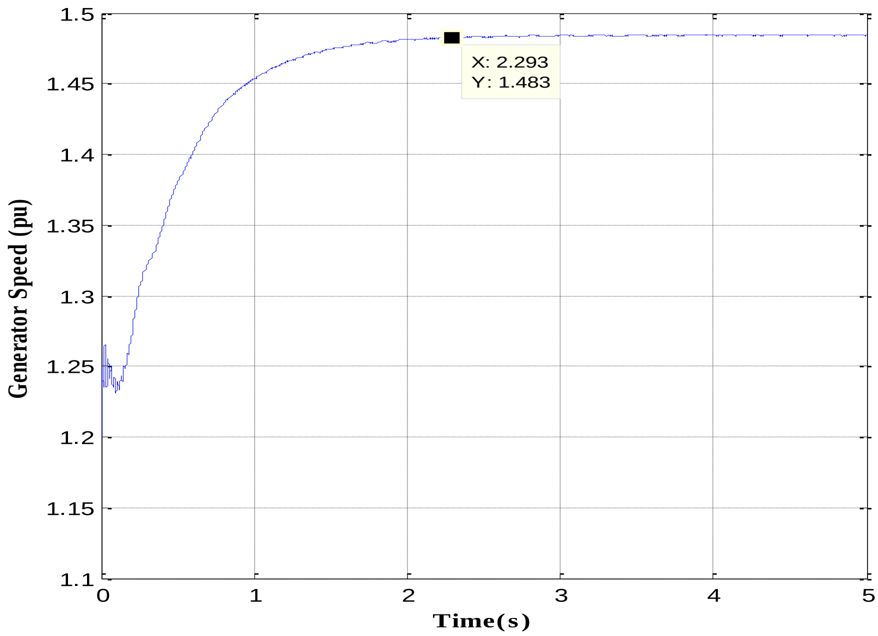



DC-Link Voltage in WT System (V)
Time(s)
1100
1050
1000
950
900
850
800
0
1
2
3
4
5
6
7
8
9
10


AC Three Phase Voltage (V)
Time (s)
X: 0.1332
Y: 311.9
400
200
0
-200
-400
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16


AC grid side converter at point grid
500
0
-500
0
0.05
0.1
0.15
0.2
0.25
Time(s)


Wind Turbine Pitch Angle (deg)
12
10
8
6
4
2
0
0
1
2
3
4
5
Time(s)
X: 3.113
Y: 10.35



(b) Wind generation system: ac grid side converter at point grid, dc-link voltage, wind system generation (w), wind turbine bitch angle, and generator speed.

Conclusion

The limited supply of fossil fuels and the desire to reduce the amount of greenhouse gases produced are two of the best arguments for the use of renewable energy sources. The paper shows how the renewable sources are integrated to the grid and are able to supply the power to the grid. The hybrid system is an emerging renewable energy concept that may play an important role in meeting future energy needs. The behaviour of grid connected PV/Wind system under steady state operation has been investigated. At steady state speed of 15m/S and radiation 1000 W/m^2, the generation units operate stably and provide power for the loads. The obtained results showed that the system responds very well in these situations.

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