Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444
Volume 3, Issue 6, June-2016

A Review paper on Wind and Solar Hybrid Generation for Standalone System

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Abstract- *Combined utilization of renewable energy sources are becoming more popular nowadays. Based on that, this is a review paper of hybrid renewable energy systems like wind and solar hybrid generation inclusion with battery storage system. Paper gives the ideas about the design and implementation of wind and solar hybrid generation system. Paper also consists of derived equations for the hybrid system by which getting maximum power at different weather conditions. This paper also highlights the future trends for this system, which give easiest solution for power generation.*

Keywords: Hybrid Renewable Energy Systems *(HRES), PV system and Battery storage system.*

I. INTRODUCTION

At present, there is a main issue related to dependency on fossil fuel and environmental issues. So the main object is to reduce the dependency on fossil fuels and to protect the environment by research work. Two strategies that can be followed to reduce dependence on fossil fuel [1]. The first strategy is based on reducing energy consumption by applying energy savings programs and second is to achieve this goal by consists of using renewable energy sources. Also, there is an unavailability of grid power to the remote places and no proper rural electrification is developed. So, Renewable resources and clean alternative energy power generation technologies give better attraction because of having several advantages like, less dependency on fossil fuel, availability of the resources which are free of cost with no pollution and environmental friendly. Renewable energy sources, such as wind, solar, micro hydro (MH), biomass, geothermal, ocean wave and tides, and clean alternative energy sources, such as fuel cells (FCs) and micro turbines (MTs), have become better alternatives for conventional energy sources [2, 3]. However, in compare to conventional energy sources, renewable energy sources are less used because of their uncertainty, intermittency due to dependence on weather and high initial cost. At present, the research work is going on renewable energy resources at worldwide to develop renewable energy materials, decrement in cost and increasing it's efficiency.

To overawe the intermittency and insecurity of renewable sources and to provide a cheap, unfailing and constant supply of electricity, a altered arrangement that take part these renewable energy sources and use them in a hybrid system mode is predictable by many researchers. The energy from renewable resources is available in lavishness but alternating in nature, hybrid combination and addition of two or more renewable sources make best consume of their operating characteristics and advance the system routine and effectiveness.
Hybrid Renewable Energy Systems are composed of one renewable and one conventional energy source or more than One renewable with or without conventional energy sources, that works in standalone or grid connected mode [1].

Hybridization of different alternative energy sources can match each other to some level and attain higher total energy efficiency than that could be attained from a single renewable source. Multi source hybrid renewable energy systems, with proper control, have great latent to provide higher class and more consistent power to consumers than a system based on a single source. Due to this feature, hybrid energy systems have trapped global exploration consideration.

The presentations of hybrid energy systems in distant and remote areas are more related than grid connected systems. In addition, the application of hybrid systems is becoming standard in distributed generation or micro-grids, which newly have excessive anxiety. Due to improvements in renewable energy equipment which have enhanced their efficacy and compact the cost, and spreads in power electronic converters and automatic controllers which increase the operation of hybrid energy systems and cut repairs necessities, these development made hybrid systems real-world and reasonable. Hybrid energy systems are now becoming an integral part of the energy planning process to supply previously unelectrified remote areas [2]. Various hybrid energy systems have been installed [6,7] in many countries over the last decade, resulting in the development of systems that can compete with conventional, fuel based remote area power supplies [5] in many applications.

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The strategic procedure of hybrid energy systems needs the choice and sizing of the best appropriate arrangement of energy sources, power taming devices, and energy storing system together with the application of an efficient energy communication approach [4]. The choice of the appropriate grouping from renewable technology to usage a hybrid energy system be subject to the accessibility of the renewable resources in the position where the hybrid system is planned to be fitted. In adding to convenience of renewable sources, other features may be taken into account for correct hybrid system project be contingent on the load supplies such as, consistency, greenhouse gas releases during the predictable life cycle of the organization, efficacy of energy alteration, land necessities, financial phases and public influences [4, 5]. The unit sizing and optimization of a hybrid power system show a significant role in determining the consistency and expensiveness of the system.

II. DESIGN OF HYBRID RENEWABLE ENERGY SYSTEMS

1.1 Energy Resources

Since the invention of first engine in 17th century, energy consumption has been highlighted due to different causes, such as political, economic, world population based, requirements of new technologies in use.

Persistent increase in the energy demand has caused to seek new energy resources in the world. New alternative energy resources have been also utilized to minimize the energy deficit [10]. This deficit biased trend shows also how our country does depend on foreign energy suppliers. The World Energy Production/ Consumption Profile is show in Figure 1.

Neutral current in three-phase power systems is often thought to be only the result of the imbalance of the phase currents. With electrical network, very high neutral currents have been observed even when the phase currents are balanced. Unbalanced and non-linear loads on 3P4W system causes excessive neutral current and the problems related to the excessive current in the neutral conductor are [15]:

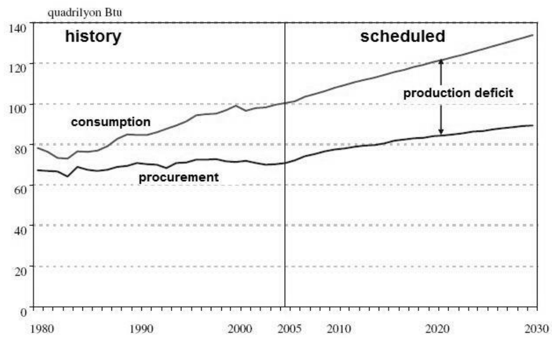

Fig. 1. World Energy Production/ Consumption profile [11]

Energy resources are classified into two groups: primary unrenewable and secondary-renewable resources, with respect to change in quantitative.

1.1.1 Unrenewable Energy Resources

Unrenewable energy resources are the ones that decay partially or vanish with the time or needs decades for reuse, such as oil, coal and coal derivatives, natural gas, wood and radioactive atoms (uranium).

1.1.2 Renewable Energy Resources

Renewable energy resources are the ones that are persistently available and renewing itself with the time. Industrialization and increasing world population has remarked the use of renewable energy resources. Solar power, wind power, biomass, tide power, wave power, geothermal power is known ones.

1.2 Solar Power

Solar panels are the medium to convert solar power into the electrical power. Solar panels can convert the energy directly or heat the water with the induced energy. PV (Photo-voltaic) cells are made up from semiconductor structures as in the

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computer technologies. Sun beam is absorbed with this material and electrons are emitted from the atoms that they are bounded. This release activates a current. Photovoltaic is known as the process between beam absorbed and the electricity induced. With a common principle and individual components, solar power is converted into the electric power.

Solar batteries are produced by waffling p-n semiconductors. A current-volt characteristic of the PV in the darkness is very similar to that of diode. Under beam, electron flow and current occurs. In closed-loop, PV current passes through the external load. While in open-loop, the current completes the circuit through the p-n diode structure [12].
Solar batteries can be represented with an equivalent circuit of a current source, a resistor and a diode in parallel, and an external load-resistor [13], as seen in Figure 2.

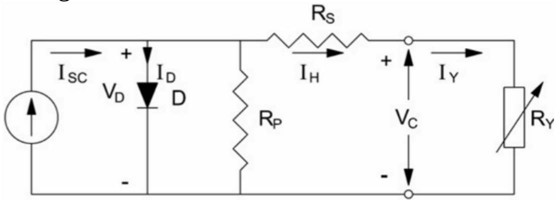

Fig. 2. Equivalent circuit of solar battery

It is possible to insert AC-DC converter, charger, accumulator, extra power source, and controller depending on the design differences in operational and functional specifications [14]. Solar system could be categorized into two types:
Line-independent systems: These are established in absence of line electricity to provide electricity. Since the current in these systems are DC and it must be also available overnight, energy is stored in accumulators, DC-Batteries. In case of AC-Supply requirements for the appliances, it is possible to use DC-AC invertor [14].
Line-dependent systems: These systems do not need DC Batteries, since the energy is served to the demand with the help of an invertor. Line electricity is being switched in use in case of insufficient sun beam [14].

1.3 Wind Power

Wind turbines are used to convert the wind power into electric power. Electric generator inside the turbine converts the mechanical power into the electric power. Wind turbine systems are available ranging from 50W to 2-3 MW. The energy production by wind turbines depends on the wind velocity acting on the turbine. Wind power is used to feed both energy production and consumption demand, and transmission lines in the rural areas.

Wind turbines can be classified with respect to the physical features (dimensions, axes, number of blade), generated power and so on. For example, wind turbines with respect to axis structure: horizontal rotor plane located turbines, turbines with vertical or horizontal spinning directions with respect to the wind. Turbines with blade numbers: 3-blade, 2-blade and 1blade turbines.
On the other hand, power production capacity based classification has four subclasses [7].

- Small Power Systems
- Moderate Power Systems
- Big Power Systems
- Megawatt Turbines.

III. DESIGN AND IMPLEMENTATION OF DOMESTIC SOLAR-WIND HYBRID ENERGY SYSTEM

Hybrid systems are the ones that use more than one energy resources. Integration of systems (wind and solar) has more influence in terms of electric power production. Such systems are called as “hybrid systems”.

Hybrid solar-wind applications are implemented in the field, where all-year energy is to be consumed without any chance for an interrupt. It is possible to have any combination of energy resources to supply the energy demand in the hybrid systems, such as oil, solar and wind. This project is similar with solar power panel and wind turbine power. Differently, it is only an add-on in the system.

Photovoltaic solar panels and small wind turbines depend on climate and weather conditions. Therefore, neither solar nor wind power is sufficient alone. A number of renewable energy expert claims to have a satisfactory hybrid energy resource if both wind and solar power are integrated within a unique body.

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In the summer time, when sun beams are strong enough, wind velocity is relatively small. In the winter time, when sunny days are relatively shorter, wind velocity is high on the contrast. Efficiency of these renewable systems show also differences through the year. In other words, it is needed to support these two systems with each other to sustain the continuity of the energy production in the system.

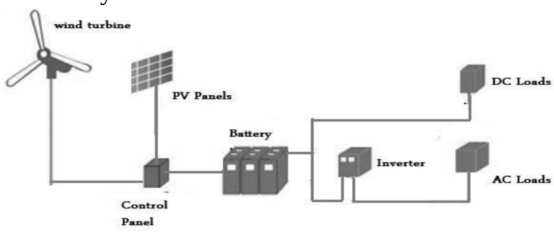

Fig. 3. Hybrid system

In the realized system, a portion of the required energy for an ordinary home has been obtained from electricity that is obtained from the wind and solar power. Experimental setup for the domestic hybrid system consists of a low power wind turbine and two PV panel. Depending on the environmental conditions, required energy for the system can be supplied either separately from the wind or solar systems or using these two resources at the same time is in show Figure 3. Control unit decides which source to use for charging the battery with respect to condition of the incoming energy as seen in Figure 4.

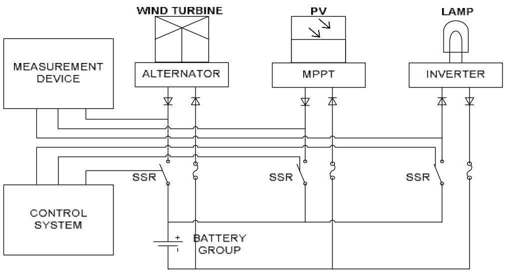

Fig. 4. System block diagram

Wind turbine first converts the kinetic energy to mechanical energy and then converts it to the electricity. The wind turbine in the system consists of tower, alternator, speed converters (gear box), and propeller. and a picture of the constructed hybrid system is show in Figure 7.

The kinetic energy of the wind is converted to the mechanical energy in the rotor. The rotor shaft speed, 1/18, is accelerated in the reduction gear and then transmitted to alternator. The electricity that comes from the alternator can be directly transmitted to DC receivers as well as it can be stored in the batteries.

The solar panels in the system convert the day light directly in to electricity. The properties of the PV module (PM 065, Solen Energy Corporation) in the system are given in the Table 1.below.

Table 1. PV module properties

PMAX (WP)	65
MPP Voltage (V)	16.5
MPP Current (A)	3.94
Open Circuit Voltage (V)	20
Short Circuit Current (I)	4.50

The solar panels can generate major amount of electricity even in the cloudy weathers.

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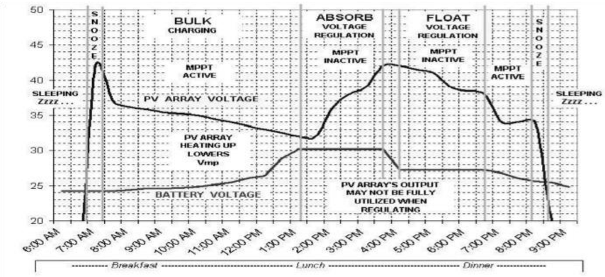

Fig. 5. Typical day in the Life of a MPPT controller charging Batteries [8]

MPPT regulates the energy coming from these panels and ensures a continuous high power generation. The current from the MPPT is used to charge the batter [8]. The system layout for MPPT charge controller (60 PV MPPT Charge Controller, Out Back) is shown in Figure 5.

Control card controls the microprocessor by processing the information coming from all the components in real time. Measurement card simultaneously measures the current and the voltage values of the wind, solar, and invertor systems. They operate according to line-isolated Hall-Effect principle. In addition, these sensors have high precision (99.2 %), high linearity, high band width, and low response time features [8].

The current sensors used in the system are LTS-25 from LEM Company. They also operate according to Hall-Effect principle and have unipolar voltage feature. Measurement range is expanded. Solid state relays for switching the wind turbine, solar panels, and invertor system are capable of conducting high currents with low supply voltages [9].

The batteries in the system provide to store the electricity that is generated from the wind or the solar power. Any required capacity can be obtained by serial or parallel connections of the batteries. The battery that provides the most advantageous operation in the solar and wind power systems are maintenance free dry type and utilizes the special electrolytes. These batteries provide a perfect performance for long discharges.

The storage and usage of the electricity that is generated from the wind and solar power are controlled in the real time control system. In the domestic type hybrid system, the storage of the electricity from the wind turbine and solar panels is achieved by control card, measurement card and connection card is show in Figure 6.

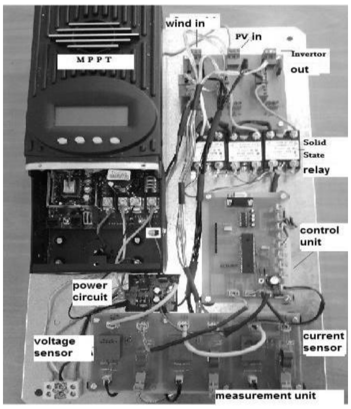

Fig. 6. Control system

Control card controls the microprocessor by processing the information coming from all the components in real time.
Measurement card simultaneously measures the current and the voltage values of the wind, solar, and invertor systems.
A semiconductor (tristor or transistor) with low operating power and low triggering voltage is connected to the input of the system and triggers another semiconductor with high operating power and low triggering voltage. Thus, the relay can switch on/off more quickly than the conventional relays. It is used because of the properties like spark free operation and long operation life.

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Fig. 7. A picture of the constructed hybrid system

Invertor in the system is used to convert the direct current to 220V alternative current. External invertors can use 12V and 24V direct current from the batteries and by converting it to 220V alternative current, they provide a safe operation for any electrical device. Depending on the output voltage, invertors have different output waves like square wave, modified sinusoidal wave and exact sinusoidal wave. Invertors with the exact sinusoidal wave output is used in the system. Linetech Cotek 300W exact sinusoidal invertors that can automatically turn off in case of the overload, overheating, and high-low battery voltage is used in the system. This inventor can operate to devices up to 300W and has a 400W surge rating.

IV. PV SYSTEM MODELLING AND SIMULATION

Different components of the standalone solar site can be simulated with general blocks and Equivalent electrical circuits. The first level of the simulation model is given in Figure 9. As it can be seen there are five main blocks in this model. While Solar Irr simulates solar irradiance, PV Array simulates an array of PV modules. In addition, the block with the name of Boost-Type Converter provides the simulation of DC-DC converter. Battery and Load blocks, respectively, Simulate a stack of lead-acid battery cells and the load profile.

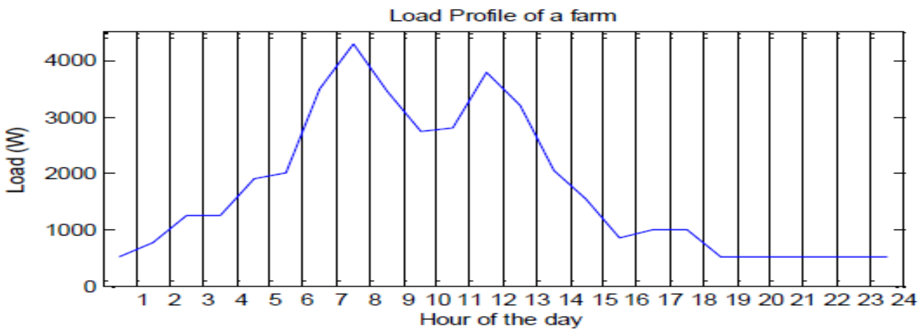

Fig. 8. Load profile [19].

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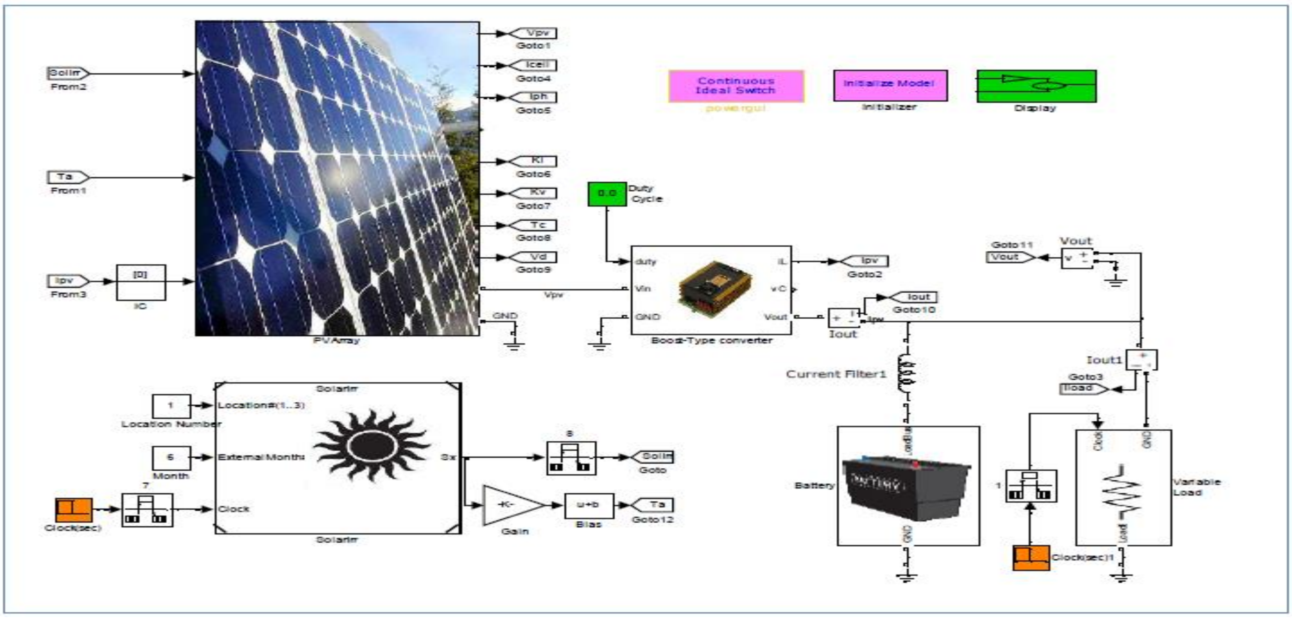

Fig. 9. First level of the simulation model [20]

Solar irradiance simulation

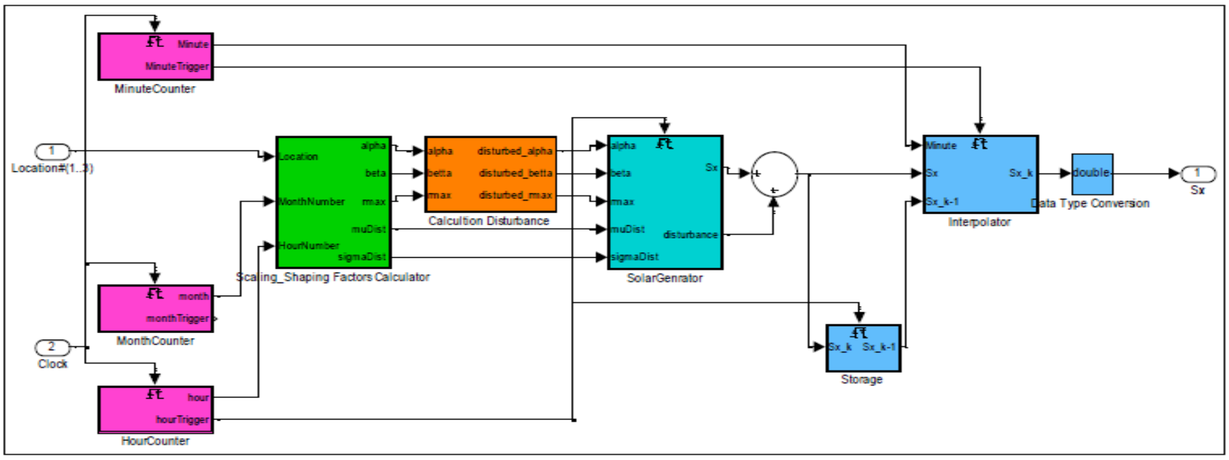

Fig. 10. Solar irradiance generator module.

The simulation proposed in this paper for solar irradiance is based on the hourly stochastic model. Although, there are inaccuracies in fitting solar irradiance into beta distribution still there are two advantages the simulation can benefit from stochastic modelling.

The main advantage of stochastic modelling of solar irradiance is its simplicity for simulation. Once the shape parameters are learned for all hours of the year, the value of insolation can be generated easily by using random generators. Another advantage of generating random values for solar irradiance is that uncertainties due to cloud shading or incident angle are intrinsically taken into account and the generated values of the solar irradiance are directly fed into the PV cell. In calculation of the shape parameters for hourly solar irradiance, the meteorological sample data available from British Atmospheric Data Centre (BADC) [18] between 1990 and 2010 have been used. The calculated shape parameters load into lookup tables and used to generate random values for hourly solar irradiance (Figure 10).

There are two challenges in simulating the insolation coupled with other components. First, it causes the simulation to be multi-rate. While the time step for all components is small enough to simulate the system dynamics, the simulation rate of the solar irradiance is one hour, which is significantly higher. In this study, this challenge has been overcome by feeding a separate clock to *Solar Irr* block (Figure 9). Second, singularity can occur during simulation by hourly step-wise solar irradiance. An interpolator has been employed to solve this problem with linearizing the transition of solar irradiance between hours.

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PV Array simulation

A modified version of the equivalent electrical circuit proposed by Villalva, Gazoli and Filho [3] is used for simulating PV array. Figure 9 illustrates this model including a current source controlled, where I_m is the sum of the photocurrent, I_{ph}, and the diode current, I_d. The proposed circuit is modified by adding a new block to simulate the PV cell temperature, T_c. The PV cell temperature has been simulated using the state-space block and its output is then fed into the *PV Array* block.

The PV identification method proposed by Villalva, Gazoli abd Filho [3] with the following modifications is adopted in this work.

- The norm of error has been changed to the difference of both the voltage and current at the MPP with the values provided by the manufacturers.
- The step size of R_s declines dynamically due to decreasing the norm of error.
- A nonlinear transform has been applied to R_s improving the speed of MPP search algorithm.

Although the PV array as a component can be simulated with its equivalent electrical circuit, there is still a challenge in its connection to DC-DC converter. Since the PV array is an instantaneous system, its connection to the converter casts an algebraic constraint on the converter which is not solvable with ordinary ODE integrators. It requires employing a DAE integrator to simulate such a system directly. In the present study, however, a combination of an ordinary integrator coupled with a Newton type method, which solves the algebraic constraints, have been employed. It requires using a small step-size for the simulation (i.e. 10^{-8} sec.) and setting manually a consistent initial value.

Individual sources of the hybrid systems have to be operated at a point that gives the most efficient generation. In fact, this may not be occur due to that the load sharing is often not linked to the capacity or ratings of the sources. Several factors decide load sharing like reliability of the source, economy of use, switching require between the sources, availability of fuel etc. Therefore, it is desired to evaluate the schemes to increase the efficiency to as high level as possible.

DC-DC converter simulation

Figure 10 shows the simulation circuit of the boost-type DC-DC converter including pulse width modulation (PWM) block and ideal switches. Evidently, the simulation of the converter has not been simplified with averaging approach, instead it has been modelled according to a hybrid system. The transistors are replaced with two ideal switches for simplicity's sake. However, to prevent cases in which both switches are opened causing the inductor to be disconnected, a snubber resistor has been added to *Ideal Switch1*.

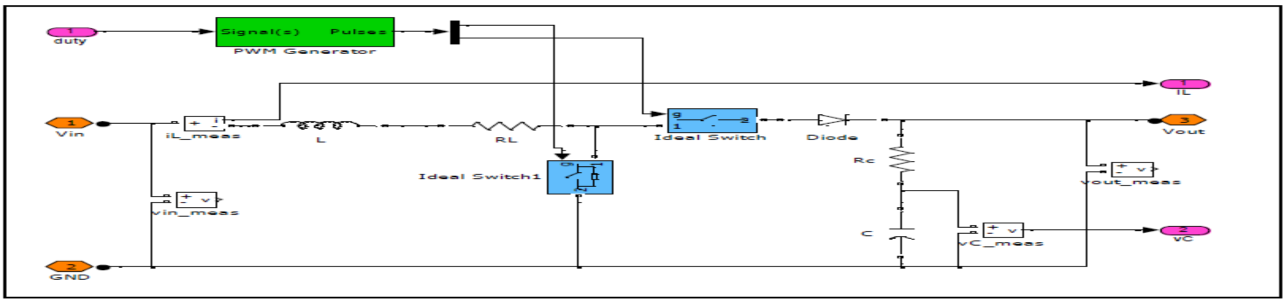

Fig. 11. Electrical circuit of boost-Type DC-DC converter module.

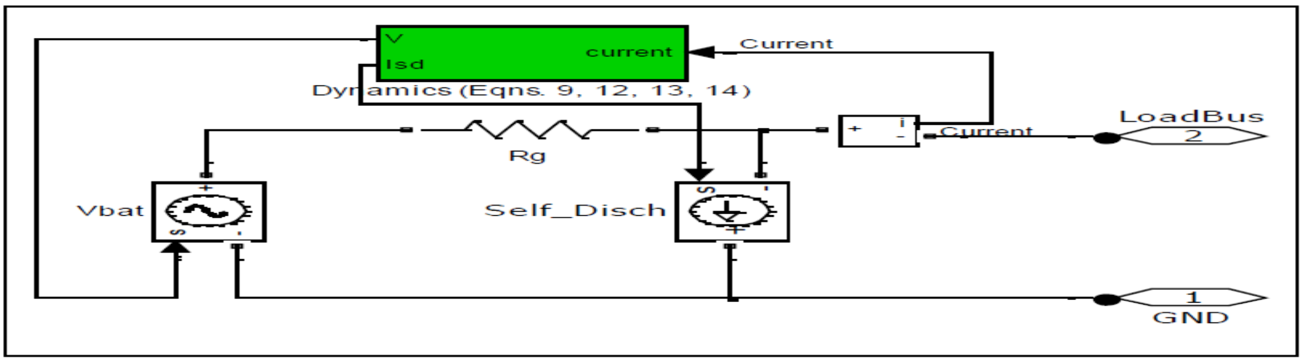

Fig. 12. Equivalent electrical circuit for lead-acid battery module

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Battery simulation

The lead-acid battery is modelled with its equivalent electrical circuit as shown in Figure 11. The voltage source is controlled by the block called Dynamics. For simplicity, the self-discharge rate approximated as the constant loss equals to of its charge per day and the temperature effect is ignored. As in the PV array, connecting the battery to the DC-DC converter introduces certain algebraic constraints leading to a DAE-based system. In this case, the system can be simulated by reducing the step-size of simulation and adding a slight R-L element (Figure 9).

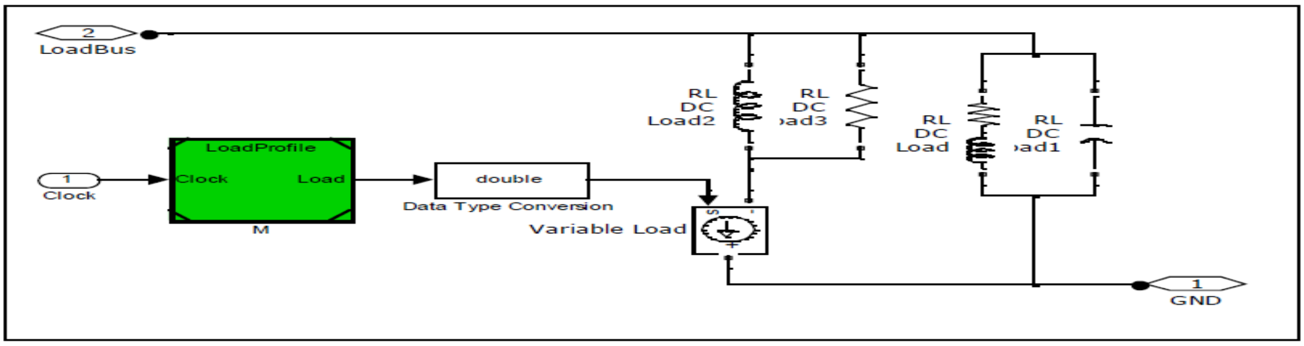

Fig. 13. DC load module

Load profile simulation

The DC load has been modelled as an electrical circuit. It consists of an optional constant RLC load coupled with a variable load. In Figure 12, it can be seen that the load profile has been modelled using a current source controlled by the profile values, which are loaded into a lookup table. A series inductor filter has been added to the model to suppress the sudden changes of variable load.

Simulation Results

MATLAB/SIMULINK environment was used to simulate the model given in Figure 9 for a 24- hour period. The built-in algebraic loop solver and the Sim Power Systems toolbox in SIMULINK can integrate the model of the solar branch of HRES. However, it also requires applying small step-size of simulation and an initial condition block (IC) across the loop. Table 2 lists the simulation parameters including the day of the year, PV array configuration including the PV module name and number of modules in parallel, duty cycle of the converter, battery parameters, and the type of the load profile. The model includes no DC-DC converter controller as it is a generic simulation platform for any controller. The effect of this controller in changing the duty cycle can be simulated manually.

Table 2. Simulation parameters

Parameter	**Value**
Date	1st June
PV model	KC200GT
N_{pvp}	10
D	50%
Battery Rated Capacity	550 Ah
Battery Nominal Voltage	48 VDC
Load profile	Farm
Sampling time	1×10^{-8} sec
PWM Frequency	$100\times10^{3}\ Hz$

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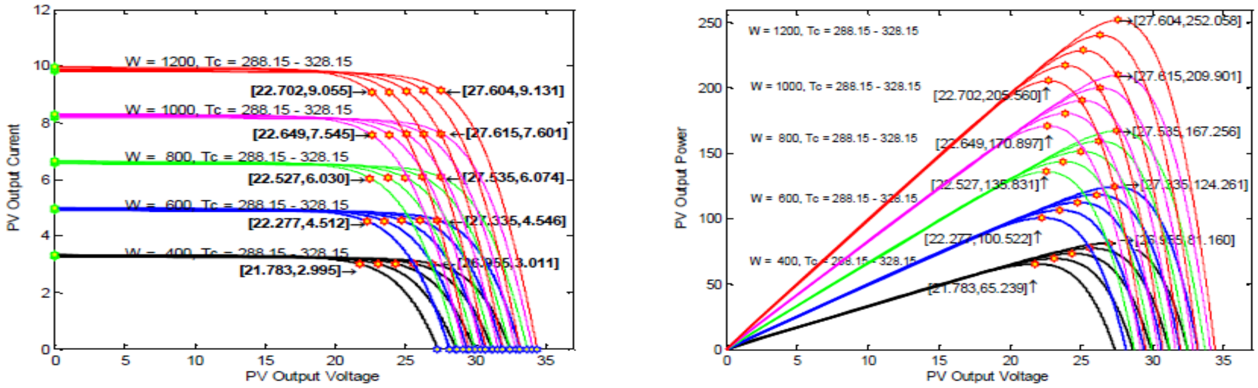

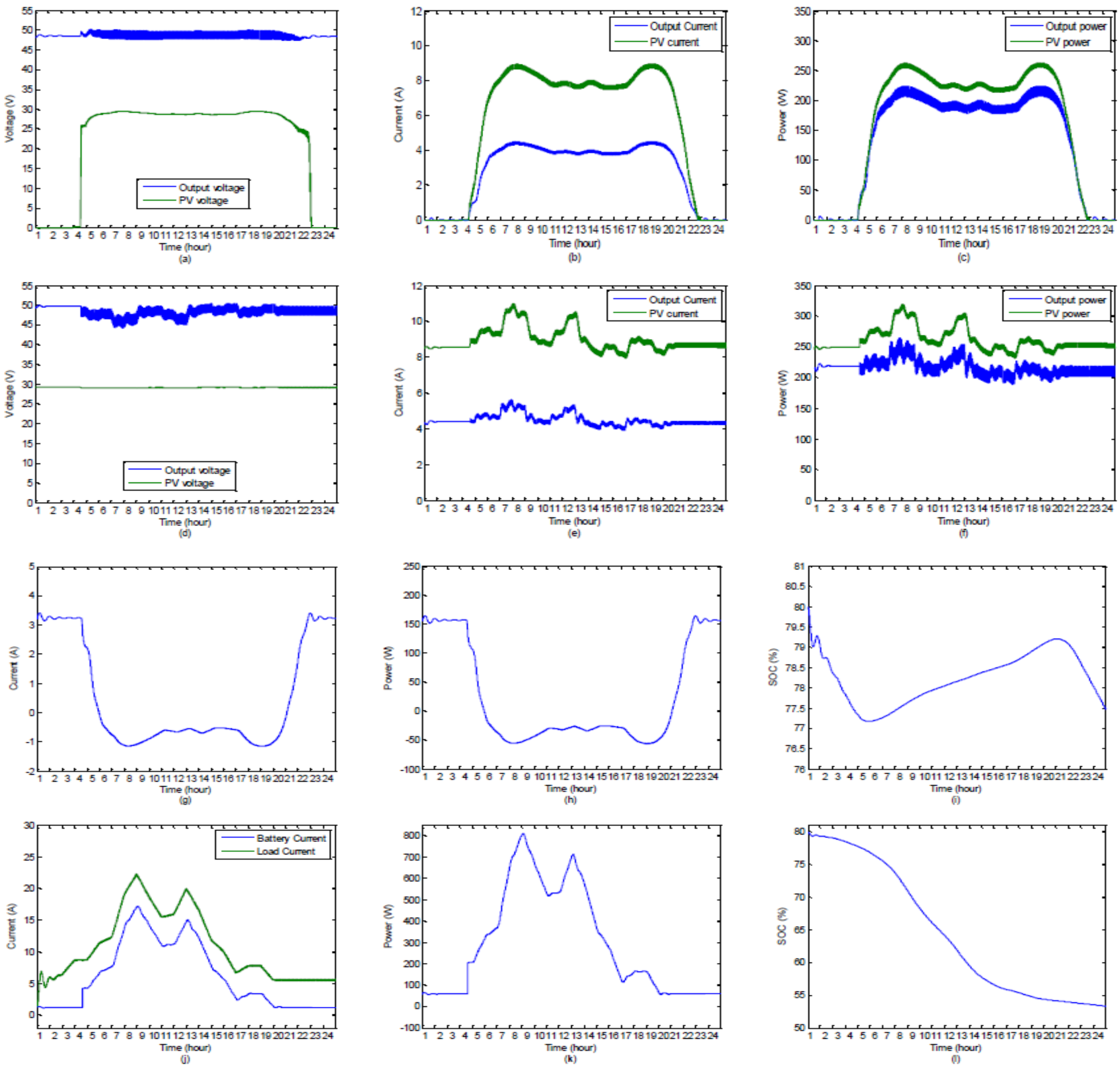

Fig. 14. (a) Output voltage, (b) output current, and (c) output power of the PV and the DC-DC converter for constant load with variable insolation. (d) Output voltage, (e) output current, and (f)output power of the PV and the DC-DC converter for variable load with constant insolation. (g) Current, (h) power, and (i) SOC of the battery for constant load with variable insolation. (j) Current, (k) power, and (l) SOC of the battery for variable load with variable insolation.

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V. WIND SYSTEM MODELLING AND SIMULATION

In this research, physical model of the wind energy conversion system with doubly-fed induction machine connected to grid of distribution system is implemented in Matlab Simulink software. The system models constituting elements of the system separately and also considers interrelationship among different elements within the system, where type and structure of the model is normally dictated by the particular requirements of the analysis, e.g. steady-state, fault studies, etc. Indeed, due to the importance of more realistic production of the behaviour of doubly-fed induction machine, it is intended to adopt physical model rather than functional model in order to accurately assess performance of doubly-fed induction machine in the event of fault particularly in determining whether or not the generator will trip following a fault. Fig.15 shows induction machine stator currents and grid-side converter currents, while Fig.4 shows the wind turbine model. In order to simulate the overall of the system, distribution power system with distributed generation including wind energy conversion system is also illustrated in Fig.17.

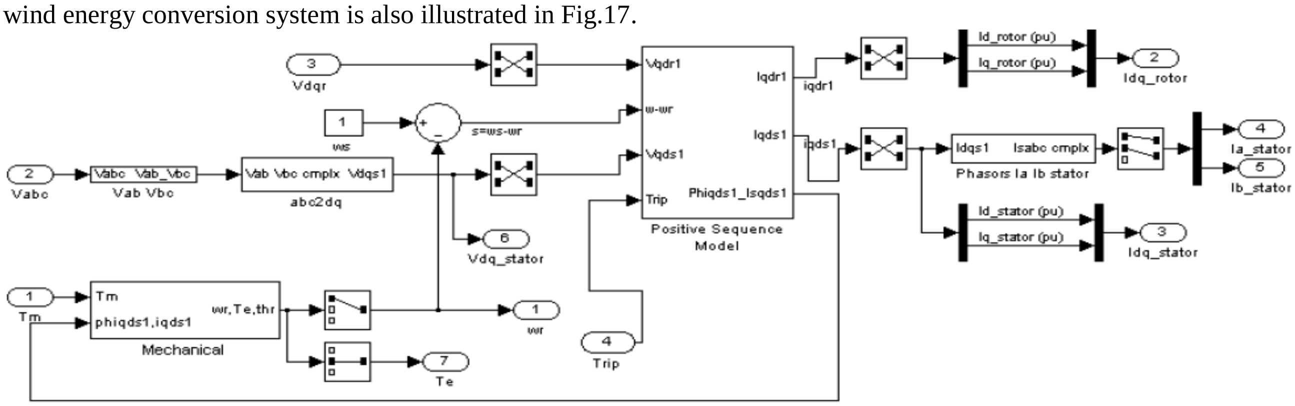

Fig.15. Induction machine stator currents and grid-side converter currents

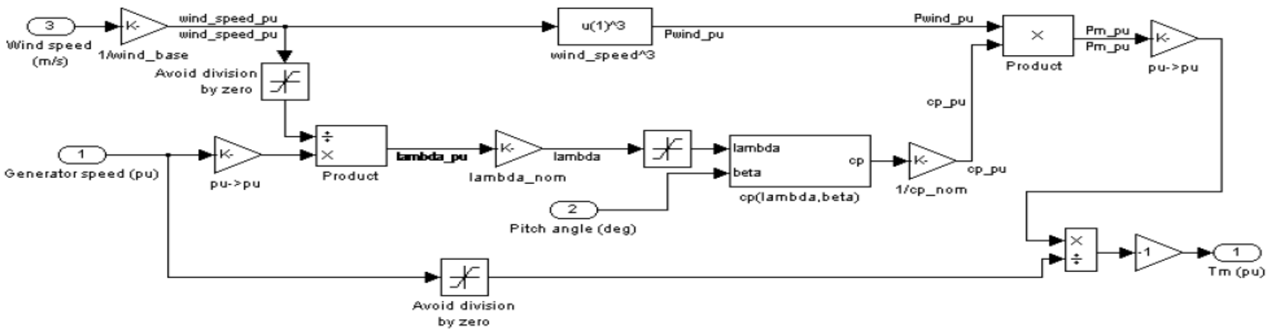

Fig.16. Wind turbine model.

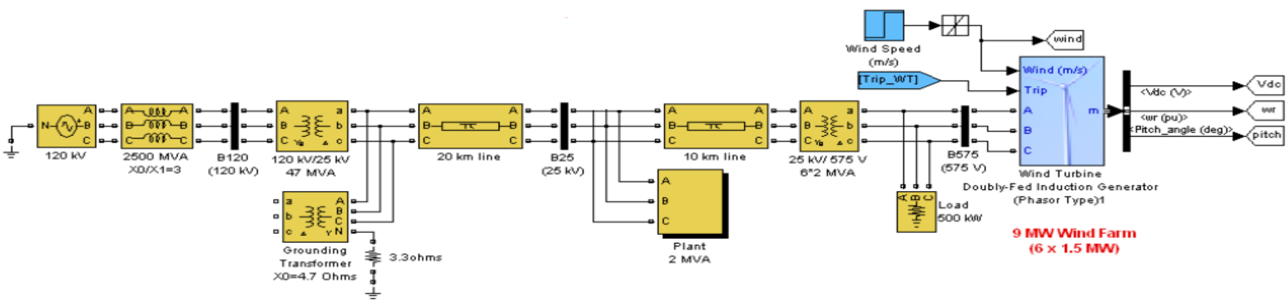

Fig.17. Wind energy connected to a distribution system.

Simulation of Turbine Response to a Change in Wind Speed

In this section, the turbine response to a change in wind speed is observed. Initially, wind speed is set at 8 m/s, and then at t = 5s, wind speed increases suddenly at 14 m/s. Fig.6 shows the waveforms associated with this simulation. At t = 5s,

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the generated active power starts increasing smoothly (together with the turbine speed) to reach its rated value of 9 MW in approximately 15s. Over that time frame the turbine speed increases from 0.8 pu to 1.21 pu.

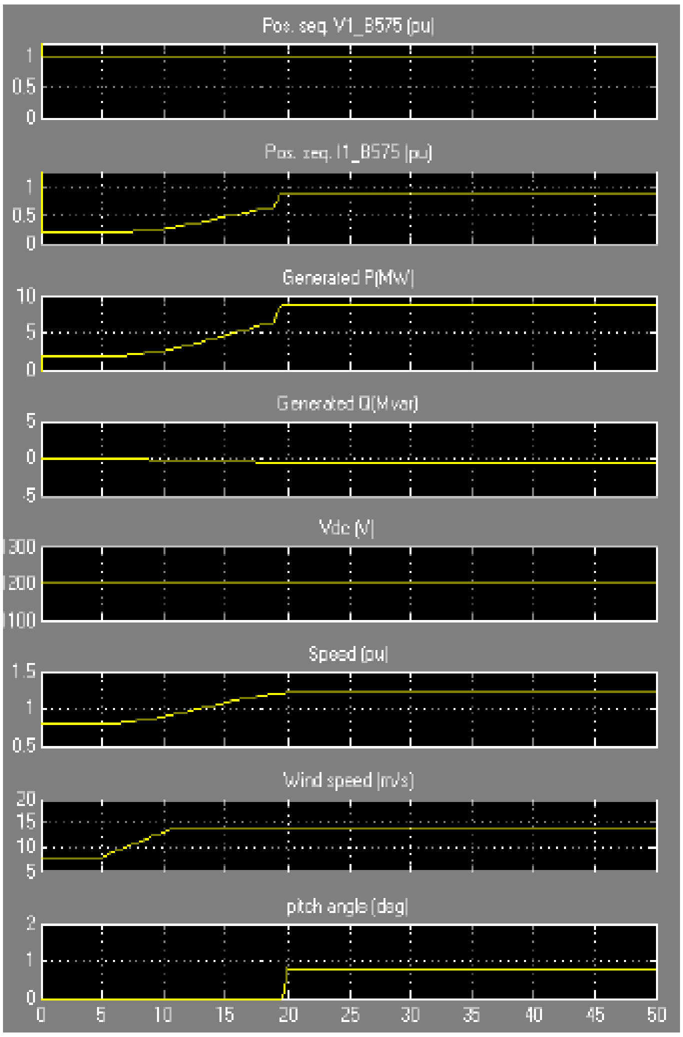

Fig.18. Waveforms for a gust of wind in voltage regulation mode.

Initially, the pitch angle of the turbine blades is zero degree and the turbine operating point follows the red curve of the turbine power characteristics up to point D. Then the pitch angle is increased from 0 deg to 0.76 deg to limit the mechanical power.

The voltage and the generated reactive power is also observed. The reactive power is controlled to maintain a 1 pu voltage. At nominal power, the wind turbine absorbs 0.68 MVar (generated Q=-0.68 MVar) to control voltage at 1pu. If the mode of operation is changed to Var regulation with the Generated reactive power Qref set to zero, the voltage increases to 1.021 pu when the wind turbine generates its nominal power at unity power factor.

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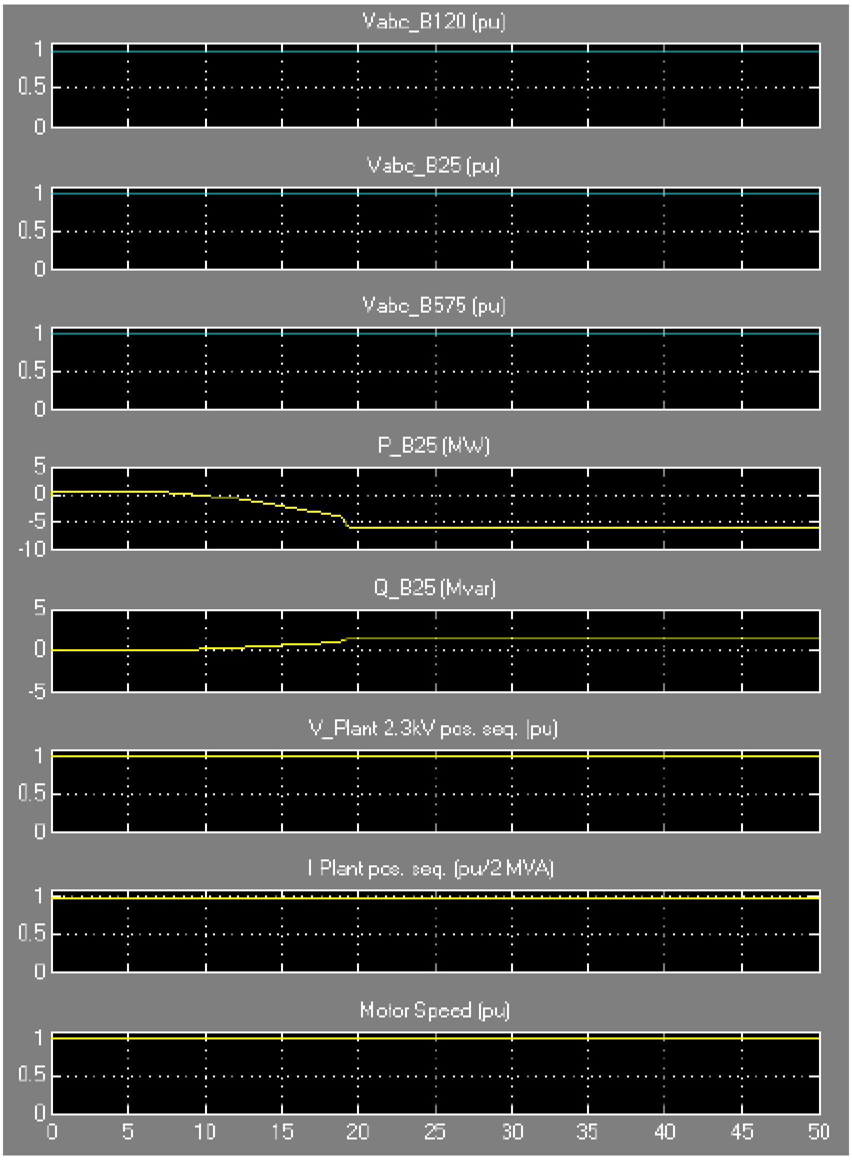

Fig.19. Waveforms for a gust of wind in Var regulation mode.

VI. CONCLUSION

This paper provides a summary of available different approach for system configuration of hybrid system are presented. Simulation and Waveforms for wind and solar hybrid technologies have been shown. The comprehensive list of references at the end of paper is included further research.

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