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Power Control For Hybrid Renewable Energy System

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Abstract:This paper is focused on the study of conventional PI controller for the power control of inverter supplied from a hybrid renewable energy system. It is composed of two renewable energy sources (wind turbine and photovoltaic - PV - solar panels).Renewable energy sources are known to support system hydrogen generation hence, the newly developed idea is the ability to supply the load without any compensation by the wind turbine or PV panel's solution in offing. Although photovoltaic panels are used as popular renewable energy sources, two major problems they encounter depending on power production are with solar irradiation and surplus energy storage. These problems can be solved by using other renewable energy sources and storage systems such as electrolyzer, hydrogen storage tank, fuel cell and battery.

Key Words:Electrolyzer, Battery Bank, Fuel cell, Photovoltaic panel, Wind turbine, Maximum power point tracking (MPPT), DC-DC Converters, EMS

1.0 Introduction:

Hybrid Renewable Energy System (HRES) combines two or more renewable energy resources with storage, in order to fulfil the demand of an area.Using a singular form of renewable energy, such as solar PV, to supply a rural area is possible, however no electricity will be generated when sunlight is not available and therefore no electricity will be supplied during that time. If more than one independent source is employed for energy generation, for example a combination PV panels and wind turbines, the energy demand generation can be split between these two sources and therefore the system depends less on one intermittent energy source.[11] This improves energy supply security. To make the system further reliable, energy storage must be added to the system to store energy in times of excess generation and supply energy in times of a lack of generation.Hybrid Renewable Energy Systems, using a combination of energy sources and storage are preferred in the area of rural electrification. Nowadays many houses in rural and urban areas use hybrid systems. Many isolated island try to adopt this kind of technology because of the benefits which can be received in comparison with a single renewable system. This specific hybrid system present many benefits. More specifically for a wind or solar hybrid system the assessment is focused on the wind and solar potential of the region.Based on conventional source of energy are rapidly depleting and the cost of Energy is rising, photovoltaic and wind energy becomes a promising alternative source.Among its advantages are that it is:

1) Continuous power can be supplied to the consumers.
2) Pollution free;
3) Distributed throughout the earth
4) Recyclable.
5) Hybrid solar-wind can be made available to the for away consumers at economical rate from the utility saving hydraulic energy.

1.1 Topologies used

HRESs present a common DC bus to which all the energy sources are connected. The most used topologies are the parallel hybrid and series hybrid. In the parallel hybrid topology, all the energy sources are connected to the common DC bus through DC-DC power converters, whereas, in the series hybrid topology, some energy source (commonly some energy storage device) is directly connected to the common DC bus without DC-DC power converter. An energy efficiency analysis of the commonly used series and parallel hybrid topologies in hybrid power systems[1]

Configuration with battery support

Using bi directional buck boost dc dc converter in which boost converter 12 v into 24v and buck convert 24v to 12v.

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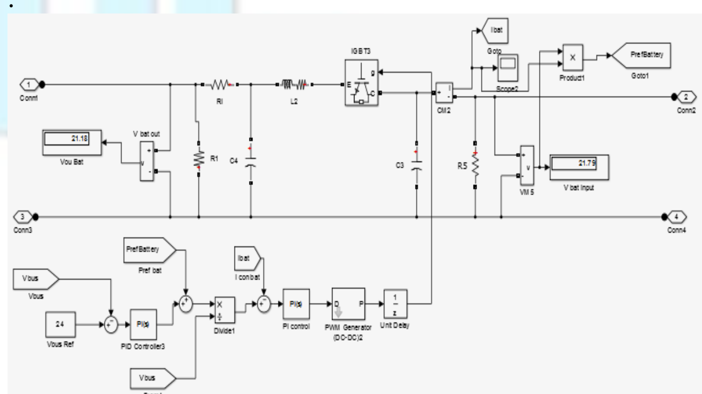


Fig 1.Configuration with hydrogen support

2. Proposed Methodology

HRES is the combination of two or more renewable energy systems here the Hybrid system consists of a photovoltaic panel, wind turbine, proton exchange membrane fuel cell (PEMFC), electrolyzer, power convertor and a three-phase variation load Figure -2[2] The load supplied is based on the photovoltaic panel and wind turbine, while the fuel cells are back-up for compensating possible power load shortage.

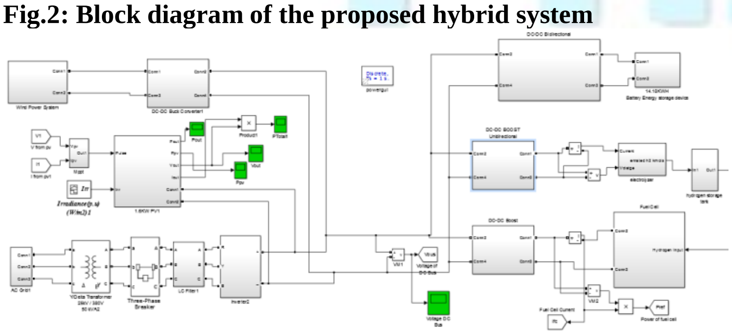
Primary energy sources are commonly wind turbine/s and PV solar panels (renewable energy sources), which operate whenever there is wind speed and/or solar irradiance and also the energy storage devices commonly used are batteries, and hydrogen systems (fuel cell, electrolyzer and hydrogen tank), which has received considerable attention in recent years].

In the hydrogen system, the electrolyzer produces the hydrogen, which is stored in a tank to supply the fuel cell. The excess of renewable energy can be stored in the battery or as hydrogen produced by the electrolyzer, whereas the deficit of renewable energy can be provided by the battery and/or fuel cell.

The surplus of power produced will be stored in a hydrogen tank by an electrolyzer system when the PV panel and wind turbine produce more power than required. Photovoltaic panels are used as popular renewable energy sources, two major problems they encounter depending on power production are with solar irradiation and surplus energy storage.

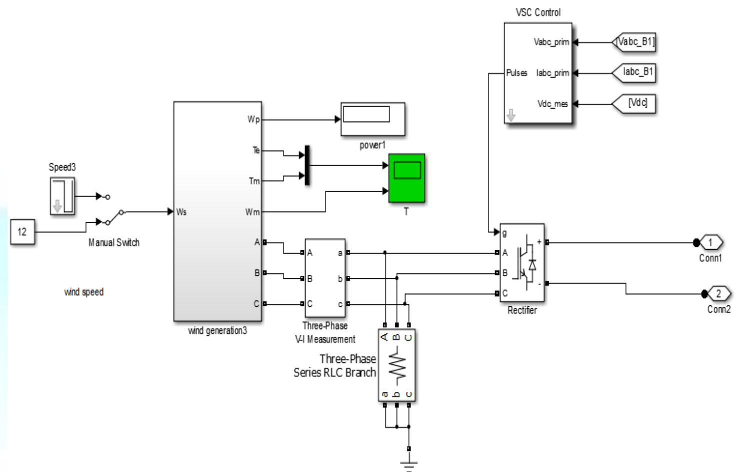
Renewable energy sources are known to support system hydrogen generation. Therefore, the newly developed idea is the ability to supply the load without any compensation by the wind turbine or PV panels solutions in offing. Although photovoltaic panels are used as popular renewable energy sources, two major problems they encounter depending on power production are with solar irradiation and surplus energy storage. These problems can be solved by using other renewable energy sources and storage systems such as electrolyzer, hydrogen storage tank, fuel cell and battery.Due to high efficiency, fast response, flexibility and modular structures, a combination of electrolyzer, hydrogen tank with fuel cell is the best choice for a hybrid system that uses photovoltaic panels and wind turbine system.

Fig.2: Block diagram of the proposed hybrid system



SOURCE MODELING

Fig 3) Wind Power System



Wind is proving to be a very successful source of renewable energy as it still is able to provide a high amount of energy, while the cost not being too much higher than other traditional sources of energy generation shown in fig. 3.Wind turbines of different types can range from generating power of 1kW to 7MW and therefore can be suited to whatever load size is needed to be supplied. As with PV panels, MPPTs are used to ensure that the maximum power that can be produced by the wind turbine at the particular wind conditions is produced. MPPTs for wind turbine systems are very similar to those discussed for PV panels and therefore will not be discussed again with regards to wind turbines.

The wind turbine needs to be modelled to ascertain the power added to the hybrid renewable energy system by the wind turbine(s) at the given wind speeds and tower heights. This will ensure that the system is accurately designed.

2.1 Modelling Wind

A wind turbine has a very distinct wind-power curve, which is shown in figure. As can be seen from figure there is a very detailed relationship between the speed of the wind and the power that the wind turbine generates.

Once wind speed has been properly modelled or enough accurate data is obtained, the power generated by the wind turbine can be estimated. [8]

Energy is generated between

a) cut-in wind speed (V_{ci})

b) cut-out wind speed(V_{co}).

Between the rated wind speed, V_r, and the cut-out wind speed the power generated remains constant.

Wind energy systems convert kinetic energy of wind into electrical energy or use it to do other work, [vi]. The kinetic energy of air of mass m moving at speed v can be expressed as

E = $\frac{1}{2}$ mv^2……………………………………(1)

m = ρAvt……………………………………..(2)

The power of wind is given by

P_w= $\frac{1}{2}\rho$ Av^3…………………………………..(3)

The specific power or power density of a wind site is given as

P_{den} =$\frac{1}{2}$ ρv^3…………………………………..(4)

Where, ρ: Air density. A: Rotor swept area. d: Distance (m). m: mass of air =air density*volume= ρ*A*d. v: Distance/time (m/s). The actual power extracted by the rotor blades from wind is the difference between the upstream and the downstream wind powers,[4]

P_w =$\frac{1}{2}$ ∗ $K_m(v^2 - v_o^2)$……………………………(5)

Where V is the upstream wind velocity at the entrance of the rotor blades, V_0 is the downstream wind velocity at the exit of the rotor blades. Km is the mass flow rate, which can be expressed as

K_m = ρA $\frac{v+v_o}{2}$……………………………………..(6)

P= $\frac{1}{2}\left[\rho A \ \frac{v+v_o}{2}\right]$ $(v^2 - v_o^2)$………………………..(7)

Let C_p= $\frac{1}{2}\left(1+\frac{v_o}{v}\right)\left[1-(1-\frac{v_o}{v})^2\right]$………………..(8)

P =$\frac{1}{2}\rho A v^3 C_p$…………………………………(9)

Cp is called the power coefficient of the rotor or the rotor efficiency.

P_m= .5 $\rho A C_p$ (α,β) v^3………………………….(10)

λ: The tip speed ratio and β: Pitch angle.

T_m = $\frac{P_m}{\omega_r}$………………………………………(11)

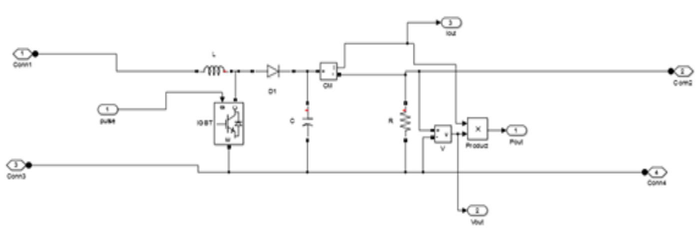


Fig4. Circuit of dc-dc boost converter

The DC/DC converter regulates unregulated DC voltage obtained by PV arrays and wind system.

The DC-DC boost converter is based on the equations 1-4.

D= 1-$\frac{V_{in}}{V_{out}}$…………………………………… (12)

R = $\frac{V_{out}^2}{P_{in}}$……………………………………… (13)

L= $\frac{D(1-D)^2 R}{2*f_s}$………………………………… (14)

C ≥ =$\frac{V_{out} * \ D}{R*f_s \ *\Delta V_{out}}$…………………… (15)

Where

D is the duty cycle,

V_{in}: is the input voltage,

V_{out}: is the output voltage,

R is the load resistance and

f_s : is the switching frequency.

PI controller is used to get regulated output voltage from the boost converter.

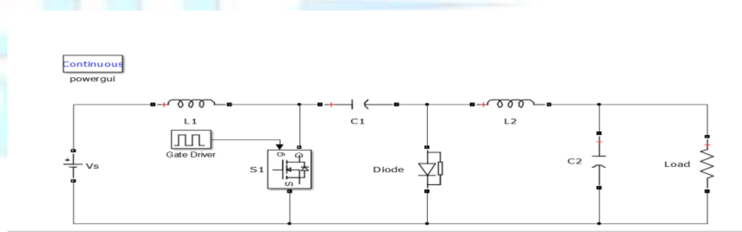


Fig5. Circuit of dc-dc CUK converter

The CUK converter can step the voltage either up or down, depending on the duty cycle shown in fig. 5.

The CUK converter contain the series inductors at both input and output, hence it has much lower current ripple in both circuits.

The average output voltage can be calculated in term of the switch duty cycle.

D = on time duration of switch/ total switching time period

Duty cycle = – $\frac{V_o}{V_S - V_o}$……………………… (16)

Output voltage (V_o) = –$V_s\left[\frac{D}{1-D}\right]$ …………………… (17)

The equation used in dc-dc CUK converters are

$V_o = \frac{D\,V_{in}}{(1-D)}$……………………………………...... (18)

$L_i = \frac{D\,V_{in}}{(\Delta I_{Li})f_s}$………………………………….... (19)

$L_o = \frac{V_o(1-D)}{(\Delta I_{Lo})f_s}$…………………………………… (20)

$C_i = \frac{D}{\{(Rf_s)(\frac{\Delta V_{ci}}{V_o})\}}$……………………………….… (21)

$$C_o = \frac{1-D}{\{(8L_o f_s^2)(\frac{\Delta V_{co}}{V_o})\}} \ldots\ldots (22)$$

Where
f = switching frequency
ΔI = peak to peak ripple current I (assuming 10% of I)
ΔI = peak to peak ripple current I (assuming 10% of I)
ΔV= voltage ripple (assuming 5% of V)
D = duty cycle
DC-DC power converters have a fixed output reference and ensure that such voltage is always delivered, no matter what the input is; some others can have a variable output reference, which can be therefore set depending on the current need of the device the power converter is used in. The regulated DC output of boost converter is fed to the VSI which is connected to the grid through LC filter.

2.3 MPPT TECHNIQUE used

Perturb and observe (P&O) MPPT method is the most commonly used method in commercial PV products. The P&O MPPT method uses trial and error in that the controller adjusts the reference output power of the inverter up fractionally and monitors the output power of the system. If the power increases, the controller will once again adjust the reference output power fractionally upwards and again monitor the output. [9]

Calculation For Power Output From Different Source:
Power Output from Wind Source: The speed of wind is a random process; therefore it should be described in terms of statistical methods. The wind speed data were recorded near the ground surface. To upgrade wind speed data to a particular hub height, the following equation is commonly used
V= V_i-(H/Hi)α ………………………….(23)
Where: v-wind speed at projected height, H
V_i-wind speed at reference height, Hi
α - Power-law exponent (- 1/7 for open land).
Let m = Mass (in kg) of the air in the hypothetical cylinder which radius is equal to the vane length
v = the velocity of air in m/s.
So kinetic energy
E = m u2 / 2………………………………..(24)
Power output Pw = (v2/2) × dm/dt
= ρ× (v2/2) × dQ/dt= ρ× (v3/2) ×A …………………(25)
Where: Q = Au = volume of air ρ = 1.2 (kg/m3)
(at mean sea level)
Pw = 0.6 A u3 pa = Pw /A = 0.6u3 = power density (in W/m2)

2.4Electrolyzer Model

An electrolyzer is a well-known electrochemical device utilizing electrical current to decompose water into hydrogen and oxygen. It consists of several electrolyzer cells connected in series. The current in comparison to voltage feature of an electrolyzer depends on its working temperature according to Faraday's law, the production rate of hydrogen in an electrolyzer cell is directly proportional to the transfer rate of electrons at the electrodes, which in turn is equivalent to the electrical current in the circuit Expressed in the following equation,[7]

$$nH_2 = \frac{\eta F . n_n . ie}{2F} \ldots\ldots (26)$$

nH_2= Hydrogen production rate, mol s-1,
ηF = Faraday's efficiency,
n_c = the number of electrolyzer cells in series
i_e = electrolyzer current [A]
F = Faraday constant [C kmol−1]
The ratio between the actual and the theoretical maximum amount of hydrogen produced in the electrolyzer is known as Faraday efficiency. Assuming that the working temperature of the electrolyzer is 40 °C, Faraday efficiency is expressed by

$$\eta F = 96.5 \times e^{\frac{0.09}{i_e} - \frac{75.5}{i_e^2}} \ldots\ldots (27)$$

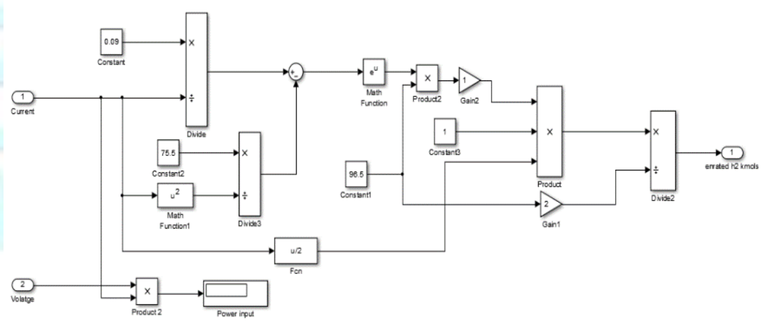


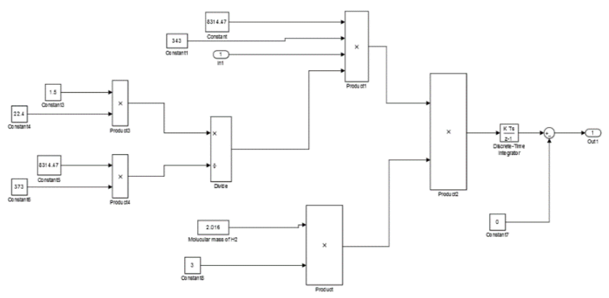
fig 6) Hydrogen Storage Tank
One of the hydrogen storage techniques is physical hydrogen storage, which include using tanks to store either compressed hydrogen gas or liquid hydrogen shown in fig 6. The produced hydrogen storage is stored in the tank whose system dynamics can be expressed as follows:

$$P_b - P_{bi} = z \times \frac{N_{H_2}\, RT_b}{M_{H_2} V_b} \ldots\ldots (28)$$

P_b= Pressure of tank pascal
P_{bi} =Initial pressure of the storage tank pascal
R= universal (Rydberg) gas constant(J/kmol K)
T= Operating temperature (K)
V_b=Volume of the tank m^3

Z= Compressibility factor as a function of the pressure,
P=Pressure, V_m=molar volume, T=Temperature
This model directly calculates the tank pressure using the ratio of hydrogen flow to the tank.mpression motor were ignored in the dynamic model, the Simulink model .

Hydrogen storage is depicted in Fig.7



2.5 Inverter modelling and control

The fundamental types of control can be classified into two categories: current control and voltage control. When the inverter is connected to the network, the network controls the amplitude and frequency of the inverter output and the inverter operates in current control mode.

The classical current control can lead to other control methods can be obtained such as active and reactive power control/voltage control. If the network being power injected is not available due to improper network parameters, the inverter will autonomously supply the load; consequently it adequately supplies the alternative voltage in amplitude and frequency and it is not affected by network blackouts.

In this case, the inverter will control the voltage. The 50 Hz frequency is assured by a phase-locked loop (PLL) control. The grid converter is a full-bridge IGBT transistor-based converter and it normally operates in inverter mode such that the energy is transferred from the hybrid source to the utility grid and/or to the load. When the system is operating in grid-connected mode, the PLL tracks the grid voltage to ensure synchronization; but when the system enters in islanding mode of operation, the VSI can no longer track the grid characteristics. As the PLL for the VSI changes the frequency which is sent to the pure integrator for angle calculation by switching between the frequency from the filter and that from another fixed reference.

The PLL for the VSI is the main catalyst for the re-synchronization and re-closure of the system to the Utility once disturbances have passed. The frequency from the filter is used during the grid-connected mode.

3 Simulation Result and discussion

Matlab software package is used in all simulation accomplished here which shows results obtained for voltage and current wave form, on the ac side supplied to the grid. The main objective of the control scheme is to supply constant power to grid and gird connected load. It is done by using different power converter which converts unregulated supply into regulated supply.In simulation model there is use of buck as well as boost converter. The power obtained from wind turbine system is of large amount and unregulated so maintaining it constant we used the dc-dc buck converter which step down voltage level and maintained the constant voltage at the dc bus and power obtained from PV panel is less so there is used of dc-dc boost converter which step up the voltage level and maintain the constant voltage level.

The inverter model has been used to convert dc supply into ac supply. In order to minimize the current converter error conventional PI controllers tuned by PSO. Throughout this simulation, the dynamic response of the inverter studied under two different operating condition.Thus,the HRES are simulating under several changes (by step and slope) in the reference of active and reactive power injected into the grid,and a grid voltage sag considered.In both cases, as it will be shown below,the EMS is responsible for overseeing the HRES,controlling the system devices in order to produce the power demanded by the grid.All the results have been validated in several simulations.

In simulation modelling there is use of buck,boost converter for controlling the unregulated power and converting it into regulated power supply and then compare it with CUK converter and found that CUK converter has continuous input and outpit current. Voltage and Current changes in the low frequency domain better performances than other current mode control techniques, Such as the hysteretic or the peak current-mode control.Output voltage can be either greater or less than input voltage.It reduces the overshoot of a converter and settling time.

4.Simulation Results

1. With buck and boost converter

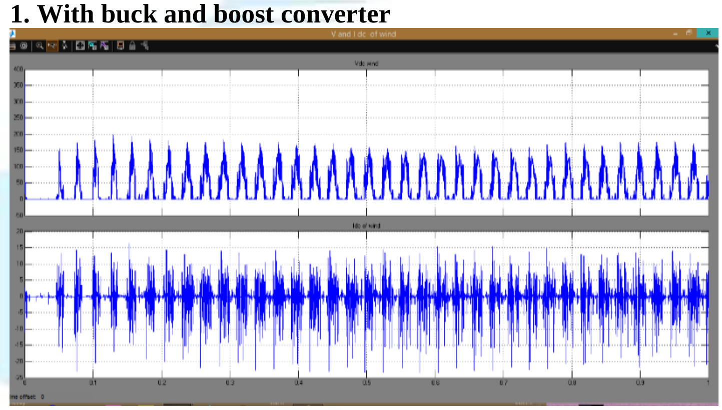


Fig.8 Output voltage and current of wind power system

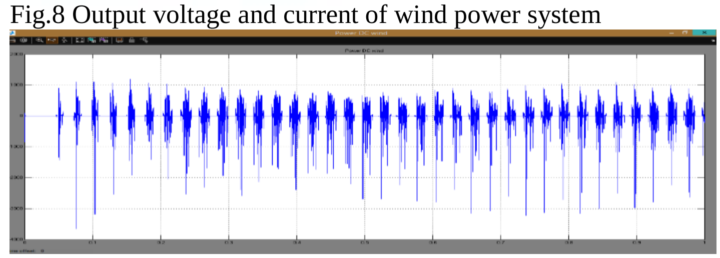


Fig.9Power output of wind power system

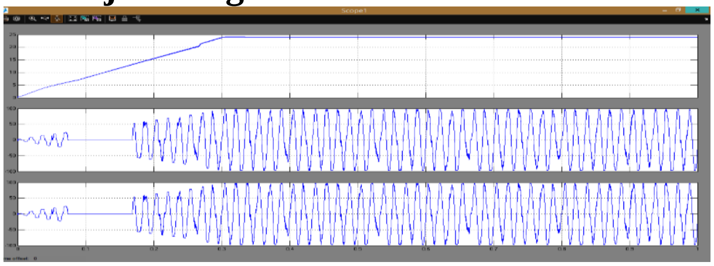


Fig10. Voltage at Dc bus, inverter and at load

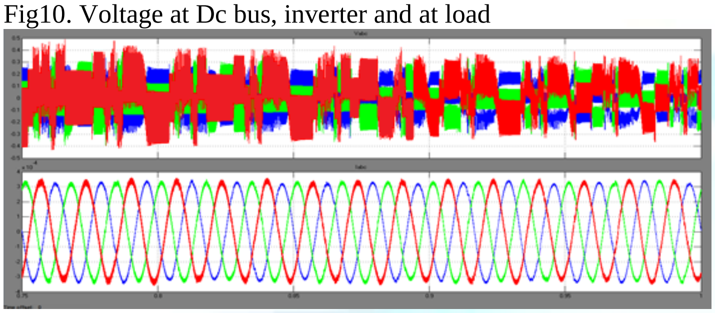


Fig.11 VI measure at ac grid

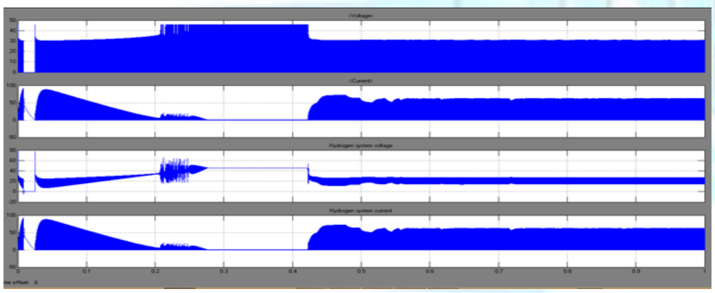


Fig.12 Hydrogen system output

2. With CUK converter

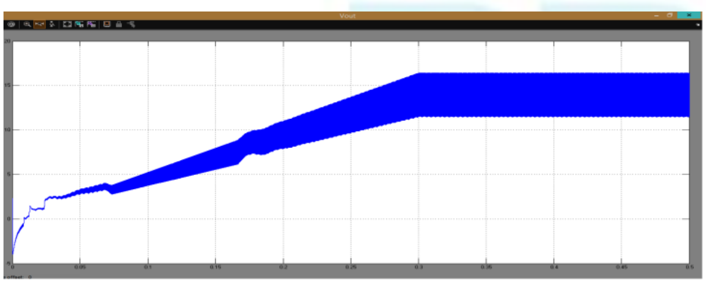


Fig.13 Power output of solar system

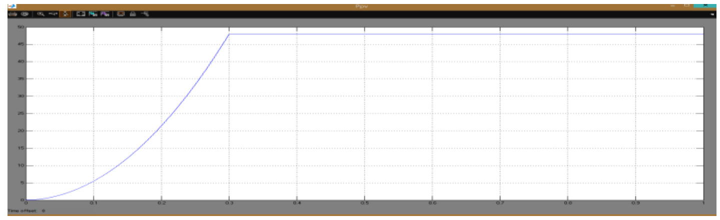


Fig.14 Output power of PV Panel

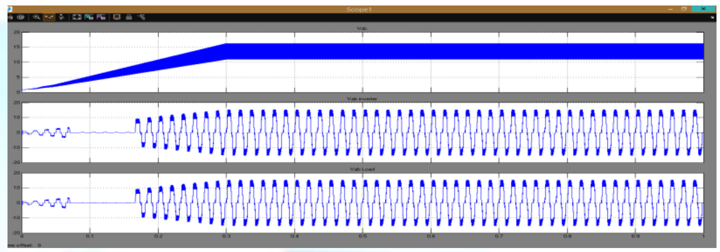


Fig.15 Voltage at DC bus ,inverter and at load

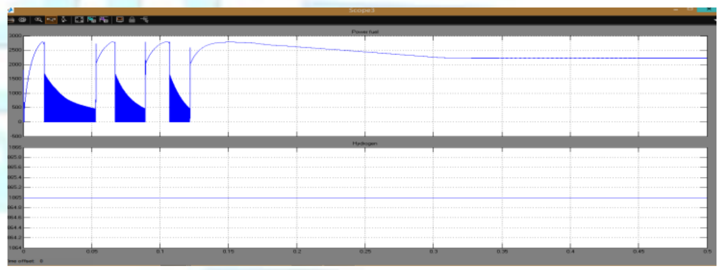


Fig.16 Hydrogen system output

5. Conclusion

This work provides a summary of available approaches and methodology for harnessing renewable energy resources in terms of research and development. Detailed literature survey has been presented on integrated/hybrid systems based power generation covering unit sizing, cost optimization, and energy flow management. The presented literature review facilitate interested researchers in the design and power management of integrated/hybrid RE energy systems with focus on energy sustainability. The present work mainly includes the grid tied mode of operation of hybrid system. The models are developed for all the converters to maintain stable system under various loads and resource conditions and also the control mechanism are studied.

The dynamic performance of Hybrid Wind/photovoltaic power systems are studied for different system disturbances like load variation, wind speed variation and different irradiation. The simulation results shows that, using CUK converters other than buck and boost have a better control of power through grid-connected hybrid energy system.

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