MODELLING OF A HYBRID RENEWABLE ENERGY CONVERSION SYSTEM

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Abstract

A hybrid renewable energy conversion system based on solar panels and wind turbine is designed and analysed in this paper. Each separate energy conversion system is controlled either using pure PI controller or extended PI controller that has auxiliary controllers such as Perturb and Observe algorithm. The solar farm model is constituted by connecting 170W photovoltaic (PV) panels serially and energy conversion is performed with maximum power point tracking (MPPT) algorithms in buck converter. The MPPT algorithm utilized in the control step of converter is developed using Perturb and Observe (P&O) that is extended with PI controller. The wind energy conversion system (WECS) is designed with a permanent magnet synchronous generator (PMSG), and the AC-DC conversion stage is constituted with an uncontrolled full-bridge rectifier. All the converter outputs are connected to busbar over interphase transformers (IPT). The DC bus-bar voltage is supplied to a full bridge inverter to generate three-phase AC voltages at the output of inverter. The three-phase inverter is controlled with sinusoidal pulse width modulation (SPWM) scheme which is developed with phase shifted carrier signals. Measurement results and obtained three phase voltage are analysed in detail.

Keywords: Wind energy, solar energy, distributed generation, hybrid renewable energy system, energy conversion.

1. Introduction

The utilization of renewable energy sources are intensively increased since the fossil fuels have limited reserves and their outcomes are mostly harmful gases. Although the renewable energy sources draw nonlinear characteristics when compared to nuclear and thermal energy sources, they do not have any pollution effect to environment. The most widely used renewable energy sources in electricity generation are solar, wind, hydraulic and tidal sources. Ackermann et al. describes the distributed generation as “distributed generation is an electric power source connected directly to the distribution network or on the consumer side of the meter” [1]. The distributed power generation systems based on renewable energy sources such as photovoltaic (PV) cells, wind turbines, fuel cells, and micro-turbines is experiencing a rapid development to meet the energy demand all around the world [2]. Nowadays, the wind energy as a renewable energy source itself is the most preferred natural energy source. In particular, wind energy that commonly used in high power requirements is used either in island mode or in grid connected mode. It is a dependent energy source to weather conditions since the generated power will vary according to wind speed in island mode applications. Therefore, other energy resources may be added to wind energy system in order to ensure the sustainability of energy supplied to load when wind is insufficient. Another widely used renewable energy source besides the wind is solar energy. It is also a dependent energy source similar to wind since the generated energy is depended to several season conditions such as irradiation angle, panel temperature, and irradiation levels. Consequently, the spare energy can be stored to charge systems.

Chen et al. presented a Simulink model of a system that is comprised by wind and solar energy sources. In the study, authors also used a fuel cell to support ultra capacitor model when the wind speed and solar irradiation are insufficient where the capacitor is used to store excessive part of the generated energy [3]. Hirose et al. presented an application of island mode that is comprised by wind and solar energy. In order to ensure energy flow continuity to load, battery bank and a diesel generator is added to hybrid system. However, a dump load is connected to the system to be used when the battery bank is fully charged and the power obtained from wind turbine and solar panels exceed the demand. The overcharge of battery bank is prevented by controlling this dump load. Therefore, lifetime of battery bank is improved and the continuous metering process of current and voltage is eliminated [4]. Guo et al. presented a hybrid grid-connected system that is constituted with fuel cell and wind turbine and is controlled by fuzzy PI observer in Simulink where the total harmonic distortion rate is obtained lower than 5% properly to international standards and reacts to dynamic load variations rapidly [5,6].

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In this paper, a distributed generation system is designed by modelling a solar energy plant and a wind turbine model that are developed in Simulink. The designed model is handled in three main subsections as solar energy conversion system, wind energy conversion system and DC-AC energy conversion part. the renewable energy conversion systems are used to harvest generated energy in DC busbar and then converted to AC by a three-phase full-bridge inverter. The proposed hybrid renewable energy conversion system (HRECS) is introduced in terms of design and analysis in the following sections.

2. HRECS Design

The proposed HRECS consists of wind energy conversion system (Permanent magnet synchronous wind turbine generator, uncontrolled full bridge rectifier and PI-controlled buck converter), solar energy conversion system (solar panels, MPPT and PI-controlled buck converter), IPT, SPWM controlled full bridge inverter and three-phase transformer. Each output of the energy conversion systems are combined through IPT to fixed DC link voltage for required input voltage of full bridge inverter. The proposed HRECS is illustrated in Fig. 1.

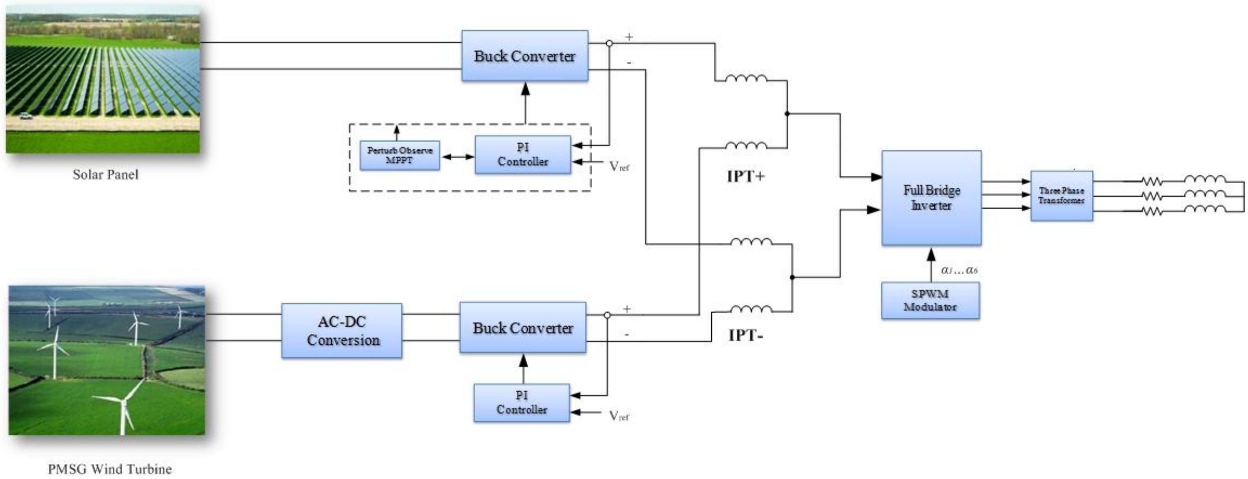
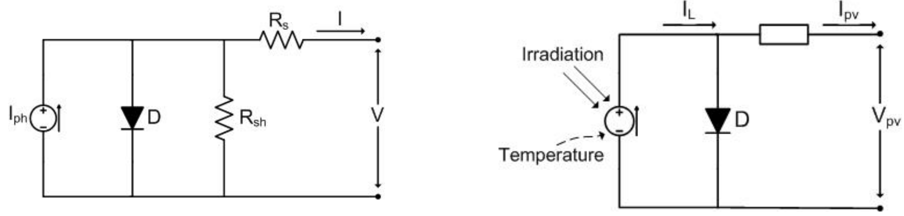


Figure 1. Graphical representation of the proposed HRECS

2.1. PV panels

Photovoltaic (PV) cells are the structures that are made of semiconductor materials and convert sunlight directly into electrical energy and forms PV panels. The equivalent electrical circuit of PV cells consist of a current source, diode and resistors in series and parallel connected as shown in Figure 2.a. Figure 2.b shows the state of the simplified equivalent circuit.



(a) (b)

Figure 2. Photovoltaic cell, (a) equivalent circuit, (b) simplified circuit

The current source generates current as a function of the sun rays and heat [3,8]. The current of PV panel is determined using (1);

$$I_{pv} = I_{ph} - I_p[e^{q(v_{pv}+i_{pv}R_s)/(\eta.k.T)}] - \frac{v_{pv}+i_{pv}.R_s}{R_{sh}} \qquad (1)$$

where,

i_{pv}, v_{pv} : current and voltage at the output terminals of the photovoltaic cells,
I_{ph} : photocurrent,
q : electron charge,
η : quality factor of n-p junction,
k : Boltzman constant, $1.38x10^{-23}$ J/K,
T : ambient temperature, K

Solar panel efficiency is the ratio of actual DC output with generated maximum power of panel at maximum irradiation level (1000W/m^2). The losses in this case are listed as the panel surface impurities, the unavailability of full sunlight, panel temperature, the angle of solar irradiation and losses on the equivalent DC circuit elements [7]. The number of serially connected PV panel is also can be fixed using PV model in the modelled system. The main parameters of the PV panel are set according to NE-170UC1 solar panel of Sharp which has maximum power out about 170W [9]. The modelled PV panel interface allows to adjust the parameters such as open circuit voltage (V_{oc}), maximum power voltage (V_{pm}), short circuit current (I_{sc}), and maximum power current (I_{pm}). The solar panel models are controlled according to various irradiation values in a way that models the daily solar state. Each of solar panels are applied different irradiation levels between 600 W/m^2 and 1000 W/m^2 at the same time. The value of output power obtained from solar panels kept at the highest possible level using MPPT. The PI controlled buck converter is used to maintain constant output voltage of solar panel. The Simulink model of Solar panels and converter are seen in Figure 3.

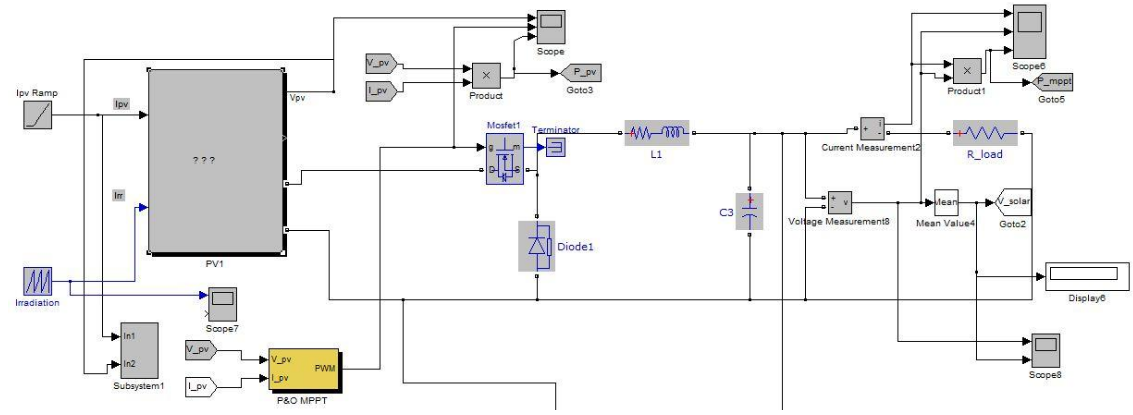


Figure 3. PV panel and buck converter Simulink model

2.2. Wind turbine

In the study, a 2 kW PMSG model is designed for wind energy conversion system (WECS) where the Simulink design is seen in Figure 4. Energy conversion process is performed with this model at constant wind speed (9 m /s). The wind turbine model is constituted using a wind-torque conversion interface and a PMSG. The generated three-phase AC output voltages of PMSG are converted to DC with an uncontrolled full bridge rectifier. Due to the input of the rectifier is variable it causes variations on the output. In order to stabilise the DC line voltage, a DC-DC converter is used at the end of rectifier in buck converter topology. The buck converter of wind energy conversion system is controlled by a PI controller that tracks the reference voltage and adjusts the output voltage to reference value. The power output of wind turbine vary depending on many parameters such as wind speed, air pressure, pitch angle and so on.The power of wind turbine is determined using (2);

$$P_m = \frac{1}{2} C_p(\lambda, \beta) \cdot \rho \cdot A \cdot v^3 \tag{2}$$

where,

P_m : mechanical output power of wind turbine,
C_p : Coefficient of performance,
λ : Pitch angle (degree),
β : Peak velocity ratio,
ρ : Air density (kg/m^3),
A : Rotor swept area (m^2),
v : Velocity of wind (m/s)

2.3. IPT and full bridge inverter

All the DC output voltages are connected over interphase transformers (IPT) in order to unify DC lines. Another energy conversion part of HRECS is constituted by a full bridge inverter that generates three-phase AC voltage owing to sinusoidal pulse width modulation (SPWM) controlled switching. The modelled full bridge inverter is commutated at 5 kHz switching frequency acquired by a unique carrier triangular signal.

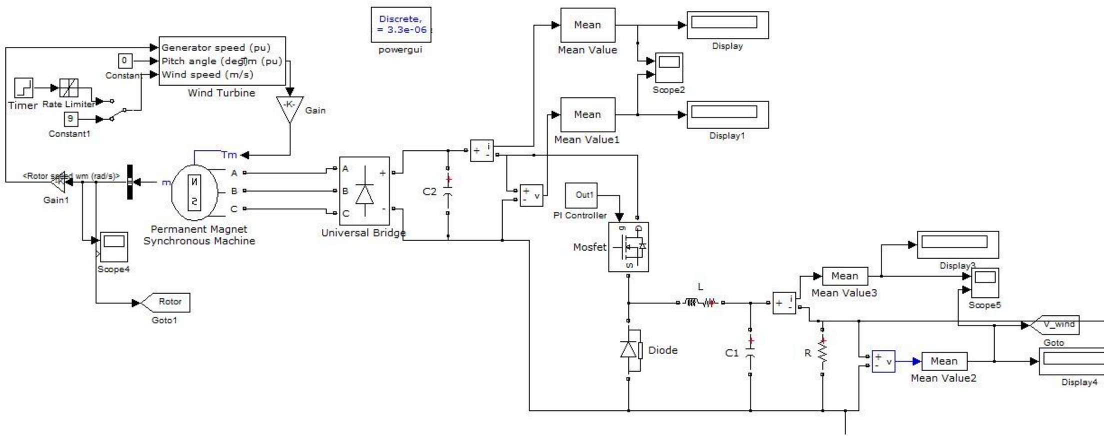


Figure 4. Simulink model of wind energy conversion system

The modulation index value which is the proportion of peak value of modulating signal (V_{ref}) to carrier (V_{tri}) defines the operating area as linear or over-modulation according to being less than 1 or more than1 as given in (3). The modulation index is set to optimal value at 0.8 as proposed in [10]. In SPWM control technique, the line voltages (V_{AB}, V_{BC}, V_{CA}) are obtained in linear modulation range as given in (4) and defined using (5) for the over-modulation range;

$$m_i = \frac{V_{ref}}{V_{tri}} \tag{3}$$

$$V_{AB} = V_{BC} = V_{CA} = m_i \frac{\sqrt{3}V_d}{2} \qquad 0 < m_i \leq 1 \tag{4}$$

$$\frac{\sqrt{3}V_d}{2} < V_{AB} = V_{BC} = V_{CA} < \frac{4}{\pi}\frac{\sqrt{3}V_d}{2} \qquad m_i \geq 1 \tag{5}$$

A sample switching order and generated phase voltage are shown in Figure 5 as indicating modulator signals which are compared in the SPWM modulator block of model in the first curve, S_1 switching signal for the upper switch of one of phase legs in the second curve, S_4 switching signal for the lower switch of one of phase legs in the third curve, and the output phase voltage of inverter in the last curve. The mi value of modulator is set to 0.8 adjusting the proportion of modulating sinusoidal signal to triangular carrier at 500 Hz. The output line frequency is adjusted to 50 Hz due to predefined frequency of modulating signal. The line voltage measured at the output of inverter is seen in the last curve of Figure 5 namely Fig.5. (d) when the inverter is controlled at 0.8 mi.

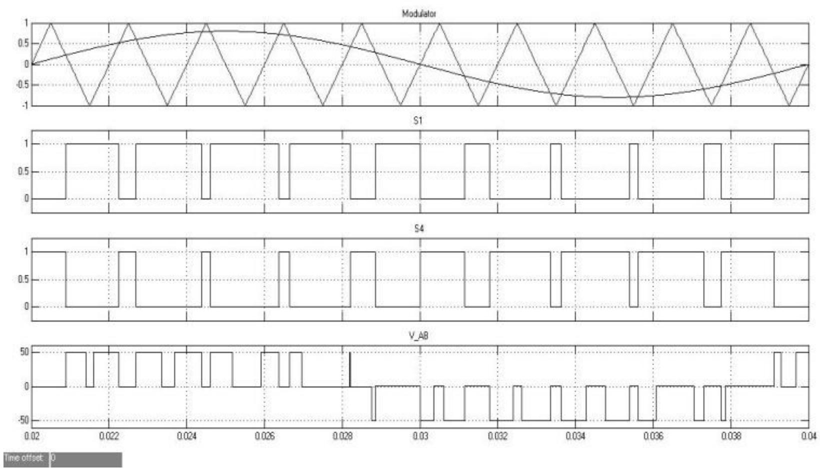


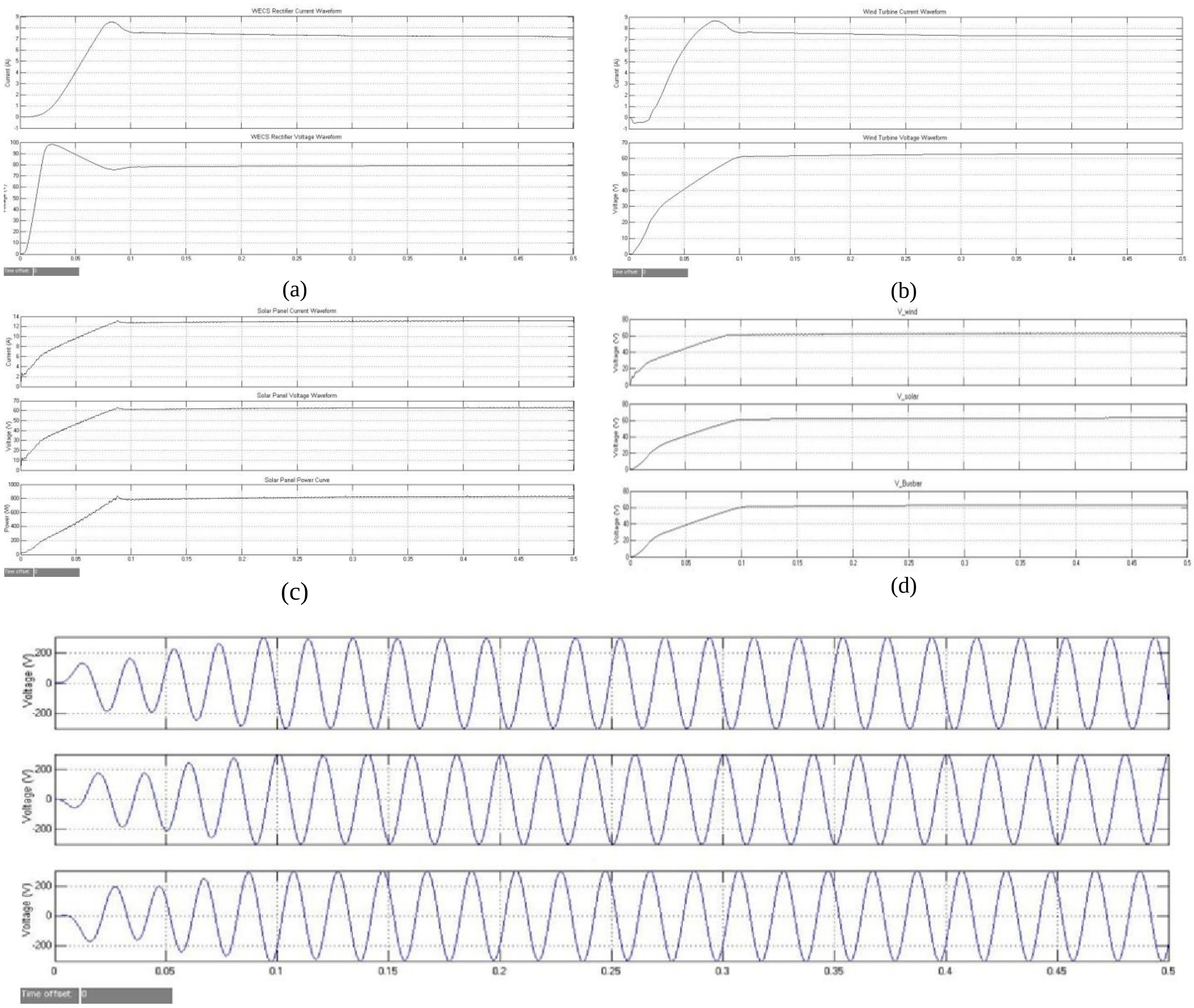
Figure 5. Ideal SPWM patterns for three phase inverter (m_i=0.8); a) carrier (500Hz) and modulating signal (50 Hz) b) S_1 switching signal c) S_4 switching signal d) ac output voltage

The switching signals generated in the modulator block are applied to full-bridge inverter block which is constituted in Simulink as seen in Figure 1. The phase outputs of inverter are obtained at +50 V, 0 V, and –50 V levels in this

Simulink sample. The output of inverter is compensated with a three-phase transformer. The analysis results of the full bridge inverter are also seen in the following section.

3. Simulation Results

The waveform analyses of the entire system are seen in Figure 6. The generated AC output of wind turbine is converted to DC with an uncontrolled full bridge rectifier. The DC outputs of rectifier are seen in Fig. 6.a where the current and voltage are stabilised up to desired value in 0.1 s. It is seen that output current of rectifier is equal to output current of wind turbine, while the voltage values are generated at proper values in wind turbine. The DC output voltage is decreased to required value with PI controlled Buck converter as seen in Fig. 6.b. The current and voltage levels of solar panel are depicted in Fig. 6.c where the upper curve illustrates the current value and lower curve shows the voltage while the power curve is illustrated in the last order. The stabilised DC voltage levels of wind turbine, solar panel, and bus-bar are seen in Figure 6.d respectively. The total DC voltage obtained from bus bar over interphase transformers is applied to the full bridge inverter. The root mean square (RMS) phase output voltages are seen in Fig. 6.e where voltages draw a stabilised output at 0.09 s.



(a) (b) (c) (d) (e)

Figure 6. Waveform analysis of the proposed HRECS, (a) WECS rectifier current and voltage, (b) WECS current and voltage, (c) solar panel current, voltage, and power, (d) output voltages of wind, solar and bus-bar voltage, (e) RMS phase voltages

The total harmonic distortion ratio of phase voltage (THDv) is measured as 0.69% at the output of inverter as seen in Fig. 7. The measured THD spectrum proves that almost all the side band harmonics are eliminated due to SPWM modulator introduced in [11] of authors. The THDv value of the whole system also presents proper values of IEEE 509-1992 standards [6].

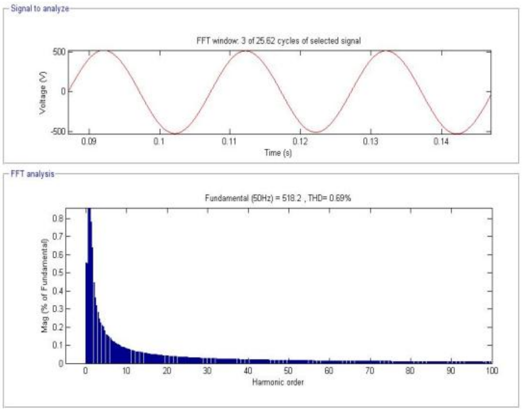


Figure 7. Voltage THD spectrum of inverter

4. Conclusions

The study proposed in this paper introduces a hybrid renewable energy conversion system in detail. Most widely used renewable energy sources are modelled separately and collected together to build a distributed generation system in the graphically presented Simulink model. The DC bus-bar connection prevents the intersection of separate power levels to each other and enables the energy conversion system to perform in a stable way. The generated phase voltages verify that the modelled distributed generation system draws an efficient conversion with total harmonic ratio of voltage (THDv) at 0.69%. The proposed system will be extended by adding fuel cell and ultra capacitor applications in future works. In addition to this, the energy storage and damp load features will be added to the developed Simulink model. The results of ongoing experimental studies will also prove the efficiency of proposed system in real time too.

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