

Multi-input DC-AC Inverter for Hybrid Renewable Energy Power System

Mohd Azman Rosli, Nor Zaihar Yahaya, Zuhairi Baharudin

Department of Electrical and Electronic Engineering, Petronas University of Technology, Malaysia

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ABSTRACT

The objective of this paper is to design a multi-input dc-ac inverter integrated photovoltaic array, wind turbine and fuel cell in order to simplify the hybrid power system and reduce the cost. The output power characteristics of the photovoltaic array, wind turbine and fuel cell are introduced. The operational principle and technical details of the proposed multi-inputdc-ac inverter is then explained. The proposed inverter consists of a three inputflyback dc-dc converter and a single phase full bridge dc-ac inverter. The control strategy for the proposed inverter to distribute the power reasonably to the sources and it achieved a priority of the new energy utilization is discussed. This multi-input dc-ac inverter is capable of being operated in five conditions and power delivered to the aload can be either individually or simultaneously. First to third condition occurs when the power delivered from either renewable energy sources individually, fourth condition happens when power is demanded from two sources simultaneously, and finally when power are available from three sources simultaneously. The proposed inverter has been simulated by employing NI Multisim 12.0 circuit simulator.

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Corresponding Author:

Nor Zaihar Yahaya,
Department of Electrical and Electronic Engineering,
Universiti Teknologi Petronas,
Bandar Seri Iskandar, Tronoh 31750, Perak, Malaysia.
Email: norzaihar_yahaya@petronas.com.my

1. INTRODUCTION

The development of alternative energy sources is continuously increasing because of the limited conventional energy sources such as oil, gas and others. Nowadays, the conventional energy sources are currently decreased and future will collapse. Moreover, environmental concerns such as global warming are becoming increasingly serious and require significant attention and planning to solve. Renewable energy (RE) sources are the answer to these needs and concerns, since they are available as long as the sun is burning and because they are sustainable as they have no or small impact on the environment. With the development of RE technologies, the cost of the photovoltaic (PV) arrays, wind turbines (WT) and fuel-cells (FC) are expected to decrease in future and they are gaining prominence as they are more energy efficient, reduce pollution and serve as a promising solution to the toughest energy crisis faced during the recent years.

In Malaysia, RE sources such as solar and wind energy conversion are serious consideration because the potential for both of this energy generation depends on the availability of the solar and wind resources that varies with location. Energy efficiency and renewable energy under the Eight Malaysia Plan (2001-2005) and Ninth Malaysian Plan (2006-2010) are focused on targeting for renewable energy to be significant contributor and for better utilization of energy resources. An emphasis to further reduce the dependency on petroleum provides for more effort to integrate alternative source of energy [1].

A hybrid renewable energy generation system (HREGS) combines more than one energy source. The main advantage of implementing HREGS is the enhancement of reliability of the system used and also

can reduce the battery size. Nowadays, these systems are important and better than conventional systems. In order to accommodate different renewable energy sources, the concept of multi-input inverter have been proposed. Some literatures has paid attention to HREGS recently. Most of the multi-input converters are based on multi-input DC-DC boost converter [2], [3], [4], [5] and most of the multi-input inverters consists of a buck/buck-boost fused multi-input DC-DC converter and a full-bridge DC-AC inverter [6], [7]. The main disadvantages of these topologies are complexity in operation at wide variable input voltage from different energy sources to produce a constant output voltage to the load. This inverter is used in several stages in power conversion which increases the number of power switches and components and complicated control system. These disadvantages increase the cost, size and weight of the hybrid system and the control become difficult.

The objective of this paper is to propose a multi-input DC-AC inverter for hybrid PV, WT and FC power system which consists of a multi-input DC-DC flyback converter and a single phase full-bridge DC-AC inverter in order to produce a constant output voltage from the different energy sources. As the power from PV and wind sources is intermittent, a charge controller is used to provide uninterrupted supply to the converter while the power from FC source is same voltage levels and constant. The advantages of the proposed multi-input DC-AC inverter are: i) simple configuration, ii) high extendibility and flexibility, iii) increase the efficiency and reliability of the inverter in a lower cost and less size, and iv) suited for hybrid renewable energy application with more than two input sources.

2. PROPOSED HYBRID SYSTEM

The use of separate single input inverters in HREGS leads to relatively complex configuration, high cost and low integration. As an alternative, multi-input inverter is used to reduce complexity; improve power density and reduce the cost of hybrid power systems [8]. Figure 1 shows the block diagram of proposed multi-input dc-ac inverter in HREGS. It consists of a three input flyback dc-dc converter and a single phase full bridge dc-ac inverter. The Maximum Power Point Tracking (MPPT) is dedicated to extract the maximum power point from photovoltaic array and wind turbine by using perturbation and observation of MPPT. The optimum fuel cell operation range is set by Proton Exchange Membrane Fuel Cell (PEMFC) and charging or discharging of battery is operated by the charge controller.

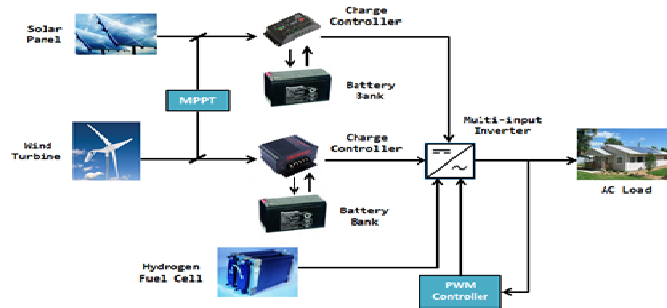


Figure 1. Block diagram of proposed multi-input dc-ac inverter application for HREGS

The power output from renewable energy sources will be regulated by the three input flyback dc-dc converter utilizing Pulse Width Modulation (PWM) control scheme to the power switches. Then, the dc power output from the converter will be stabilized by the single phase full bridge dc-ac inverter using Sinusoidal Pulse Width Modulation (SPWM) control to achieve the input output power flow balance. The expected output from the inverter is 240 V AC, 50Hz frequency and 250W power output.

3. RENEWABLE ENERGY SOURCES

3.1. Photovoltaic Array

The photovoltaic array is constructed by many series or parallel connected solar cells [9], [10]. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. The equivalent circuit of the general model which consists of a photo current, a diode, a parallel

resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow is illustrated in Figure 2.

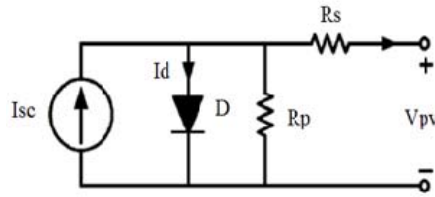


Figure 2. The equivalent circuit of a solar cell

The most common model used to predict energy production in photovoltaic cell modeling is the single diode circuit model [11]. This equivalent circuit models the general form the equation that relates current and voltage in a photovoltaic cell as given in Eq. (1) to Eq. (3).

$$I_{pv} = I_{sc} - I_0 \left(e^{\frac{q(V+IR_s)}{kT_c}} - 1 \right) - \frac{V + IR_s}{R_p} \quad (1)$$

$$V_{pv_{cell}} = V_d - R_s \cdot I_{pv} \quad (2)$$

$$V_{pv} = N_s \cdot V_{pv_{cell}} \quad (3)$$

where, I_{pv} is solar cell current (A), I_{sc} is light generated current (A), I_0 is diode saturation current (A), q is electron charge (1.6×10^{-19} C), k is Boltzmann's constant (1.38×10^{-23} J/K), T_c is cell temperature in Kelvin (K), V_{pv} is solar cell output voltage (V), R_s is solar cell series resistance (Ω), R_p is solar cell shunt resistance (Ω) and N_s is number of cells in series.

A number of approaches for cells and modules parameter determination can be adopted using the datasheet of parameters specified by manufacturer or measured. The performance of solar cell is normally evaluated under the standard test condition (STC), where an average solar spectrum at AM 1.5 is used, the irradiance is normalized to 1000W/m², and the cell temperature is defined as 25 °C.

3.2. Maximum Power Point Tracking Algorithm

In order to utilize the maximum output power from the photovoltaic array and wind turbine, an appropriate control algorithm is adopted. Generally, the maximum power point tracking efficiencies (η MPPT) of the three common algorithms for photovoltaic array are shown in [12]. Perturbation and observation method is one of the most commonly used [13]. The perturbation of the output power is achieved by periodically changing (either increasing or decreasing) the controlled output power. The perturbation and observation method is applied to determine the changing direction of the load because the output power of the photovoltaic array and wind turbine are not constant.

3.3. Wind Turbine

Wind turbines convert the kinetic energy present in the wind into mechanical energy by means of producing torque. Among various types of wind turbines, the permanent magnet synchronous wind turbine, which has higher reliability and efficiency, is preferred [14], [15]. The available power of wind energy system is given in Eq. (4).

$$P_{wind} = \frac{1}{2} \rho A V_{wind}^3 \quad (4)$$

Where, ρ (kg/m³) is the air density and A is the area swept out by turbine blade in (m²), while V_{wind} is the wind speed in (m/s). To describe a wind turbine power characteristic, this Eq. (4) describes the mechanical power generated by the wind. The equation is governed by Eq. (5).

$$P_m = \frac{1}{2} \rho A V_{wind}^3 C_p(\lambda, \beta) \quad (5)$$

Where, ρ is the air density (kg/m^3), A is the area of the turbine blades (m^2), V is the wind velocity (m/s), and C_p is the power coefficient. The power coefficient (C_p) is a nonlinear function that represents the efficiency of the wind turbine to convert wind energy into mechanical energy. It depends on two variables, the tip speed ratio (TSR) and the pitch angle. The TSR (λ) refers to a ratio of the turbine angular speed over the wind speed. The pitch angle (β) refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis. The value of TSR is obtained from Eq. (6).

$$\text{TSR} (\lambda) = \frac{R\omega}{V} \quad (6)$$

Where, R is the radius of the rotor of the wind turbine (m), and ω is the rotational shaft speed of the wind turbine (rad/s).

3.4. Fuel Cell

Fuel cells are electrochemical devices that process H_2 and oxygen to generate electric power, having water vapor as their only by-product [16]. There are several kinds of fuel cell. In particular, proton exchange membrane fuel cell has reached a high development status. In the last decade, a great number of researcher's has been conducted to improve the performance of the proton exchange membrane fuel cell, so that it can reach a significant market penetration.

Proton exchange membrane fuel cell primarily consists of three components: a negatively charged electrode (cathode), a positively charged electrode (anode) and a solid polymer electrolyte membrane. Hydrated hydrogen gas is supplied at the anode and air is supplied at the cathode. At the anode, hydrogen gas in the presence of the platinum catalyst is ionized into positively charged hydrogen ions and negatively charged electrons. The reaction at the anode is given by Eq. (7):



There are three voltage losses involved in fuel cell output voltage when the current flowing through the external circuit. Those are activation polarization, ohmic polarization and concentration polarization. The output voltage of a single cell can be defined by the following Eq. (8):

$$V_{FC} = E_{\text{Nernst}} - V_{\text{act}} - V_{\text{ohmic}} - V_{\text{conc}} \quad (8)$$

Where, V_{FC} is the output voltage of a single cell, E_{Nernst} is the electrochemical thermodynamic potential of the cell and it represents its reversible voltage, which is an ideal output voltage. V_{act} is the voltage drop due to the activation of the anode and cathode. V_{ohmic} is a measure of ohmic voltage drop associated with the conduction of the protons through the solid electrolyte and electrons through the internal electronic resistances and V_{conc} represents the voltage drop resulting from the concentration or mass transportation of the reacting gases.

3.5. Specification of Renewable Energy Sources

The specification of the renewable energy sources such as photovoltaic array, wind turbine and fuel cell as listed in Table I are used and implemented in the proposed scheme. The table shows characteristics of solar panel model SM100, wind turbine model 100S and fuel cell model H-100PEM.

Table 1. Specification of Renewable Energy Sources

Solar Panel Model SM100	
Peak power output	100W
Maximum power voltage	17.5V
Maximum power current	5.72A
Short circuit current	6.30A
Open circuit voltage	21.5V
No. and type of cell	36 & 72 Mono cells
Working temperature	-40°C ~ 90°C
Wind Turbine Model 100S	
Rated power	100W
Maximum power	130W
Nominal voltage	12/24V
Start-up wind speed	2.0m/s
Rated wind speed	10m/s
Survival wind speed	55m/s
Generator	Permanent Magnet Synchronous
Working temperature	-40°C ~ 80°C
Fuel Cell Model H-100PEM	
Type of fuel cell	Proton Exchange Membrane
Number of cells	20
Rated power	100W
Performance	12V@8.3A
Reactants	Hydrogen and Air
Max stack temperature	65°C
H2 pressure	0.45-0.55bar
Efficiency of stack	40%@12V

4. MULTI-INPUT DC-AC INVERTER CIRCUIT TOPOLOGY

The schematic diagram of the proposed multi-input DC-AC inverter is shown in Figure 3. It consists of a combined three input flyback DC-DC converter topology and a single phase full bridge dc-ac inverter. By applying the PWM control scheme and driver circuit to the DC-DC converter, the power can be delivered from the source individually and simultaneously. Meanwhile, the converter output voltage will be regulated by the dc-ac inverter with the SPWM control scheme to get the constant input-output power balance.

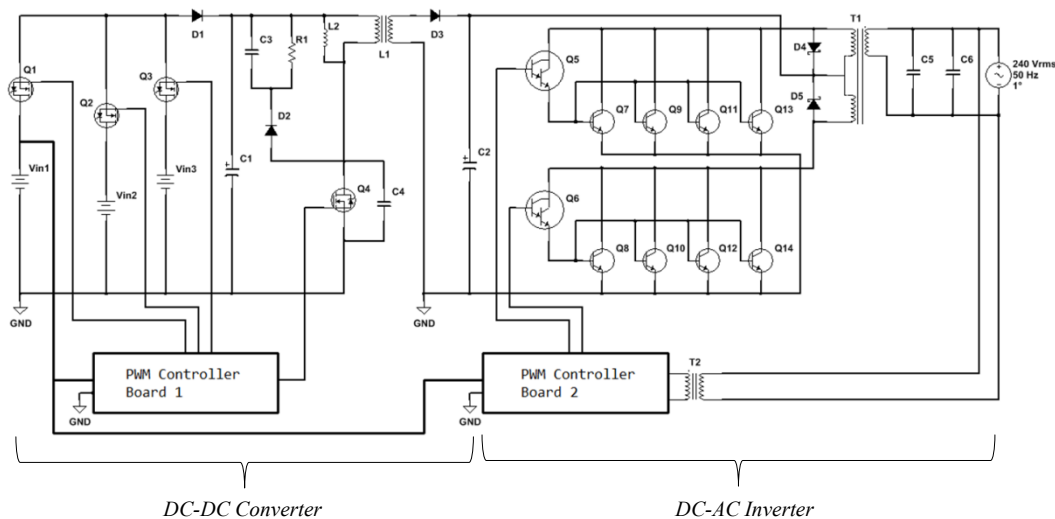


Figure 3. Schematic diagram of proposed multi-input inverter

4.1. Three Input Flyback DC-DC Converter

Multiple-input DC-DC converters are used to combine several input power sources where voltage levels and/or power capacity are different for regulated output voltage [17]. The proposed isolated three input flyback DC-DC converter has a simple isolated topology and thus incurring the lowest cost, least number of power components, easily understood and easy to implement, it is well suited for hybrid renewable energy application with more than two input sources. A flyback is a coupled inductor and is not a true based transformer converter. The proposed converter can accept up to three input sources by other competitors with

the same voltage level. It only has one primary coupled inductor winding, which can transfer the power to the load individually or simultaneously with lower voltage stresses on the power switches. The converter uses the principle of magnetic coupling to combine more input sources which are connected in parallel. The advantages of proposed converter are the galvanic isolation is a desired feature so that faults on one side do not affect the other side of the converter [18], and the leakage inductor energy of the coupled inductor can be recycled, thus increasing the efficiency and restraining the voltage stress across the active switch [19].

Table 2. 8-Modes operation of three input flyback DC-DC converter

Mode	Source	Q1	Q2	Q3	Q4	D1	D2	D3
1	V _{in1}	On	Off	Off	On	On	On	Off
2	V _{in2}	Off	On	Off	On	On	On	Off
3	V _{in3}	Off	Off	On	On	On	On	Off
4	V _{in1} +V _{in2}	On	On	Off	On	On	On	Off
5	V _{in2} +V _{in3}	Off	On	On	On	On	On	Off
6	V _{in1} +V _{in3}	On	Off	On	On	On	On	Off
7	V _{in1} +V _{in2} +V _{in3}	On	On	On	On	On	On	Off
8	V _{in1} +V _{in2} +V _{in3}	Off	Off	Off	Off	Off	Off	On

To achieve a successful design of the proposed converter, the Metal Oxide Semiconductor Field Effect (MOSFET) had been chosen. In this paper, the converter adopts three input sources such as photovoltaic array, wind turbine and fuel cell. Output from this converter is connected to full bridge DC-AC inverter before delivering the power to the ac loads. In this section, the analysis of three input flyback DC-DC converter topology is explained. Table 2 shows the HREGS under different operation modes by PWM controller of three input flyback converter. This table shows the equivalent circuits condition for mode 1 until mode 8, respectively. These operating modes are employed to feed the load by optimizing the energy obtained from the renewable energy sources.

From the Table 2, Mode 1 shows the switches Q1 and Q4 are conducting while Q2 and Q3 are turned off. D1 and D2 are conducting, D3 are blocked. The photovoltaic voltage source V_{in1} is applied to the primary winding of the couple inductor and current of the primary winding increases linearly. The inductor of the couple inductor accumulates energy, and the load current is provided by the filter capacitor, C2. During this mode, Q2 and Q3 sustain the voltages of V_{in2} and V_{in3} while D3 sustain the secondary winding voltage of couple inductor, V_{sec} respectively. In mode 2, Q2 and Q4 are conducting and Q1 and Q3 are off. D1 and D2 are on while D3 are blocked. The wind turbine voltage source V_{in2} is applied to the primary winding of the couple inductor and current of the primary winding increases linearly. During this mode, Q1 and Q3 sustain the voltages of V_{in1} and V_{in3} while D3 sustain the secondary winding voltage of couple inductor, V_{sec} respectively. In the third mode, Q3 and Q4 are conducting and Q1 and Q2 are off. D1 and D2 are on while D3 are blocked. The fuel-cell voltage source V_{in3} is applied to the primary winding of the couple inductor and current of the primary winding increases linearly. During this mode, Q1 and Q2 sustain the voltages of V_{in1} and V_{in2} while D3 sustain the secondary winding voltage of couple inductor, V_{sec} respectively. In the mode 4 condition, Q1, Q2 and Q4 are conducting and Q3 are off. D1 and D2 are on while D3 are blocked. The photovoltaic voltage source V_{in1} and wind turbine voltage source V_{in2} is applied to the primary winding of the couple inductor and current of the primary winding increases linearly. During this mode, Q3 sustain the voltage of V_{in3} while D3 sustain the secondary winding voltage of couple inductor, V_{sec} respectively.

In the equivalent circuit for mode 5, Q2, Q3 and Q4 are conducting and Q1 are off. D1 and D2 are on while D3 are blocked. The wind turbine voltage source V_{in2} and fuel cell voltage source V_{in3} is applied to the primary winding of the couple inductor and current of the primary winding increases linearly. During this mode, Q1 sustain the voltage of V_{in1} while D3 sustain the secondary winding voltage of couple inductor, V_{sec} respectively. In the mode 6, Q1, Q3 and Q4 are conducting and Q2 are off. D1 and D2 are on while D3 are blocked. The photovoltaic voltage source V_{in1} and fuel cell voltage source V_{in3} is applied to the primary winding of the couple inductor and current of the primary winding increases linearly. During this mode, Q2 sustain the voltage of V_{in2} while D3 sustain the secondary winding voltage of couple inductor, V_{sec} respectively. Mode 7 shows all the power switches Q1, Q2, Q3 and Q4 are conducting, and D1 and D2 are conducting and D3 are all reversely blocked. The three input power sources V_{in1}, V_{in2} and V_{in3} are connected in parallel, applying on the primary winding of the couple inductor. The current of the primary winding increases linearly. During this mode, only D3 sustain the secondary winding voltages of couple inductor, V_{sec} respectively.

For the mode 8, Q1, Q2, Q3 and Q4 are all turned off, D1 and D2 are reversely blocked and D3 is on. The energy stored in the inductor of the couple inductor is released to the load through the secondary winding, and the current of the secondary winding decreases linearly. Q1, Q2, Q3, D1 and D2 sustain the voltages of V_{in1} , V_{in2} and V_{in3} , respectively. Lastly, Q1, Q2 and Q3 are all turned off and the energy stored in the couple inductor has been released completely and the load current is provided by C2. It's should be noted that this mode only exists under discontinuous current mode. From the above analysis, we can see that as long as when one of Q1, Q2 and Q3 is turned on, and Q4 must be turned on, and Q4 must be turned off at the same time when Q1, Q2 and Q3 are turned off. Practically, in Mode 1 through Mode 3, the input sources can power the load individually or separately, Mode 4 through Mode 6 the power deliver from two input sources simultaneously, and Mode 7 is combine all input sources to power the load simultaneously.

The converter is under continuous current mode, in which the power provided by photovoltaic arrayas a V_{in1} , wind turbineas a V_{in2} and fuel cell as a V_{in3} can be controlled by the duty cycles δ_1 , δ_2 and δ_3 of the power switches Q1, Q2 and Q3. In simulation, the assumption are that δ_1 the duty cycle of Q1 is equal to δ_2 the duty cycle of Q2, and δ_2 the duty cycle of Q2 is equal to δ_3 the duty cycle of Q3. In modes 1 until 8, the increase in the coupled inductor magnetic flux is governed by Eq. (9) to Eq. (16) respectively.

$$\Delta\phi_{+1_1} = \frac{V_{in1}}{N_p} \delta_1 T_s \quad (9)$$

$$\Delta\phi_{+1_2} = \frac{V_{in2}}{N_p} \delta_2 T_s \quad (10)$$

$$\Delta\phi_{+1_3} = \frac{V_{in3}}{N_p} \delta_3 T_s \quad (11)$$

$$\Delta\phi_{+2_1} = \frac{(V_{in1}\delta_1 + V_{in2}\delta_2)}{2N_p} T_s \quad (12)$$

$$\Delta\phi_{+2_2} = \frac{(V_{in2}\delta_2 + V_{in3}\delta_3)}{2N_p} T_s \quad (13)$$

$$\Delta\phi_{+2_3} = \frac{(V_{in1}\delta_1 + V_{in3}\delta_3)}{2N_p} T_s \quad (14)$$

$$\Delta\phi_{+3} = \frac{(V_{in1}\delta_1 + V_{in2}\delta_2 + V_{in3}\delta_3)}{3N_p} T_s \quad (15)$$

Where, T_s is a switching period.

The decrease in the coupled inductor magnetic flux is;

$$\Delta\phi_- = \frac{V_o}{N_p} (1 - \delta_1) T_s \quad (16)$$

In a switching period, the coupled inductor magnetic flux is conservative, namely given by Eq. (17).

$$\Delta\phi_{+1} + \Delta\phi_{+2} + \Delta\phi_{+3} = \Delta\phi_- \quad (17)$$

From Eq. (9) to Eq. (17), the output voltage equation V_o is derived as Eq. (18).

$$V_o = \frac{1}{n} \frac{(V_{in1}\delta_1 + V_{in2}\delta_2 + V_{in3}\delta_3)}{3(1 - \delta_1)} \quad (18)$$

The input currents of three input sources can be obtained as stated in Eq. (19), Eq. (20) and Eq. (21) respectively.

$$I_{in1} = \frac{I_o \delta_1}{n(1 - \delta_1)} + \frac{(V_{in2} \delta_2 + V_{in3} \delta_3)/2}{2L_p} T_s \quad (19)$$

$$I_{in2} = \frac{I_o \delta_2}{n(1 - \delta_1)} - \frac{(V_{in1} \delta_1 + V_{in3} \delta_3)/2}{2L_p} T_s \quad (20)$$

$$I_{in3} = \frac{I_o \delta_3}{n(1 - \delta_1)} - \frac{(V_{in1} \delta_1 + V_{in2} \delta_2)/2}{2L_p} T_s \quad (21)$$

The average output current I_o , Eq. (22) is found to be

$$I_o = \frac{1}{2} (I_{smin} + I_{smax}) (1 - \delta_1) \quad (22)$$

Where, I_{smax} and I_{smin} are the maximum and minimum value of the secondary winding current of the coupled inductor, respectively.

For the control strategies, the isolated three input flyback DC-DC converter should achieve the following two functions: (i) output voltage regulation, and (ii) realize the power generation of the three input renewable energy sources. The regulating pulse width modulation is commonly used in the circuit to control the power switching device on and off by providing the pulse signal according to the duty cycle and switching frequency. Furthermore, the value of output is inadequate to conduct the gate terminal of the switch. So, the control circuit will function that can amplify control signal which is voltage output of PWM to level required to drive these power switches. When the controller turns on (t_{on}) the mosfet, the couple inductor current, I_{Lp} will increase linearly from zero to I_{pk} . During the turn-on period the energy is stored in the couple inductor. When the mosfet turns off (t_{off}), the energy stored in couple inductor will deliver to the output of the power converter through the output rectifier.

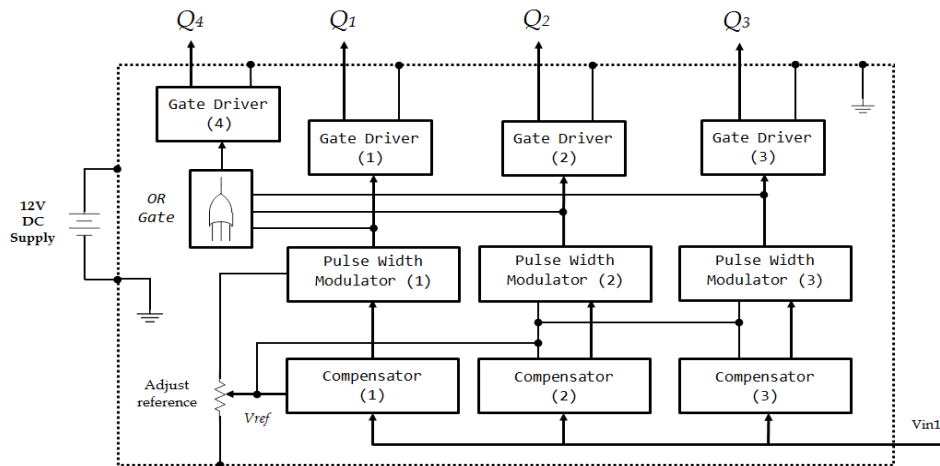


Figure 4. Block diagram of the control system for DC-DC converter

Figure 4 shows the corresponding control system block diagram for proposed converter, including the 12V dc supply, Compensator, Pulse Width Modulator (PWM) circuit, Gate Driver (GD) and OR gate. The PWM 1 through PWM 3 will generate desired gate signals for power switches Q_1 through Q_3 while OR gate will generate output signal for power switches Q_4 . The output signals of the Compensator 1, Compensator 2 and Compensator 3 are the drive signal of PWM Circuit 1, PWM Circuit 2 and PWM Circuit 3. The output signals of the PWM Circuit 1, PWM Circuit 2 and PWM Circuit 3 are the drive signal of GD Circuit 1, GD Circuit 2 and GD Circuit 3. The output signals of the GD Circuit 1, GD Circuit 2 and GD Circuit 3 are drive signal of switching devices Q_1 , Q_2 and Q_3 separately. The output signals from all PWM circuit is an input signals for the OR gate circuit. The output signal of OR gate is the driven at switching

device Q4. The pulse signal of the Q1, Q2 and Q3 can be controlled by adjusted the duty ratio (d) and switching frequency (f) in the PWM circuits. The design implementation of the control circuit is realized by using the auxiliary analog circuits design. Implementation of control of power converter had been dominated with analogue control technique due to its simplicity and low cost.

4.2. DC-AC Power Inverter and Controller

For providing electric power to ac, the dc output of isolated three input flyback DC-DCconverter is regulated or inverted in a single phase full bridge dc-ac inverter. The inverter power is provided by the dc source and will inject a sinusoidal current into the ac mains. Usually a PWM controller is used to perform the tasks. This system is used to simplify the operation complexity and reduce the cost. The equivalent circuit of a typical single phase full bridge DC-AC inverter with the PWM controller for hybrid renewable energy generation system is shown in Figure 5. Transistors Q5 through Q10 are used as power switching devices. In voltage source inverter, switches are represented by Darlington transistors. The output voltage (V_{out}) from inverter will be delivered to the PWM controller and sense by compensator as a feedback controlled. The output signal of compensator is an input signal for PWM circuit and can adjusted the voltage (V_{ref}) as a reference for the PWM circuit. The output signal of the gate drive circuit is a drive signal to the switches Q5 through Q10 for producing sinusoidal AC current. In order to control the proposed DC-AC inverter properly, the central control unit need to sense the output voltage continuously. The design implementation of the control unit is realized by using the auxiliary analog control circuit.

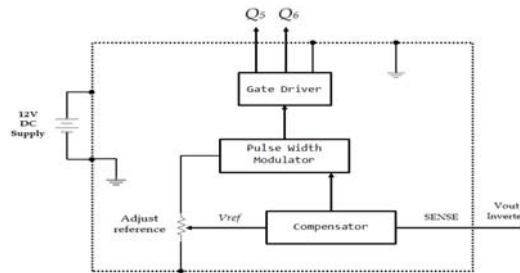


Figure 5. Block diagram of the control system for DC-AC inverter

4.3. Performance Comparison

The previous multi-input inverter consists of a buck/buck-boost fused multi-input DC-DC converter and a full-bridge DC-AC inverter [6], [7]. These power inverters are non-isolated circuit topology and regulated power by two input renewable energy sources to the load individually or simultaneously. These topologies are very complex configurations and will increase the number of power switches and components. To improve the power inverter design, the new multi-input inverter is proposed. It consists of a multi-input flyback DC-DC converter and a single phase full-bridge DC-AC inverter. The proposed converter is an electrical isolation between the input and output, has a simple structure and suitable for hybrid renewable energy power system for input sources more than two. The parameters of the previous and proposed multi-input inverter are shown in Table 3.

Table 3. Comparison of input and output parameters

Previous work [6]		Previous work [7]		Proposed work	
Solar voltage, V _{pv}	230V DC	250~450V DC	Solar voltage, V _{pv}	12 ~ 17.5V DC	
Wind turbine voltage, V _{wind}	80 ~ 200V DC	80~200V DC	Wind turbine voltage, V _{wind}	12V DC	
DC bus voltage, V _{dc}	230V DC	230V DC	Fuel cell voltage, V _{fc}	12V DC	
Output voltage, V _{ac}	110V AC, 60Hz	110V AC, 60Hz	DC bus voltage, V _{dc}	±12V DC	
Output power, P _{max}	1kW	1kW	Output voltage, V _{ac}	240V AC, 50Hz	
Converter topology	Buck/buck-boost fused converter	Buck/buck-boost fused converter	Output power, P _{max}	250W	
Input sources	2 input, 1 battery	2 input, 1 battery	Converter topology	Flyback converter	
			Input sources	3 input	

Table 3 shows the concept of previous multi-input inverter. It is a complicated structure to combine two input power sources with the different high voltage levels in high voltage ranges and difficult to get regulated constant output voltage for the load from them. The proposed inverter accept up to three input sources by other competitors with the same voltage level in low voltage ranges to produce constant output voltage for the load. The output power is always in constant wether the input sources deliver power to the load individually or simultaneously.

5. SIMULATION RESULTS

The proposed system is implemented and simulated using NI Multisim 12.0 software. The output voltage and current are shown in Figure 6 to Figure 12. In order to verify the operation principle of the new multi-input inverter, a 250W system was designed to supply a constant DC bus voltage of 12V DC from a three input sources with the voltage range 12~17.5V DC and produce load voltage of 240V AC, 50Hz. The switching frequency of 100 kHz is used for driving all the switching devices, Q1~Q4 of converter.

From the simulation results, Figure 6 shows the output voltage and current waveforms of the three input flyback DC-DC converter when the power is delivered to the DC-AC inverter by one input source individually ($V_{in1}/V_{in2}/V_{in3}$). Figure 7 shows the output voltage and current waveforms of the converter when the power is delivered to the inverter from two input sources simultaneously ($V_{in1}+V_{in2}$), ($V_{in2}+V_{in3}$) and ($V_{in1}+V_{in3}$). The last condition, Figure 8 shows the output waveforms of converter when power delivered by all three input sources simultaneously ($V_{in1}+V_{in2}+V_{in3}$). Figure 9 shows the sinusoidal output regulated voltage and current waveforms of the DC-AC inverter when the power from multi-input converter is delivered to the load by one input source individually ($V_{in1}/V_{in2}/V_{in3}$). Figure 10 shows the output regulated voltage and current waveforms of the inverter when the power is delivered to the load from two input sources simultaneously ($V_{in1}+V_{in2}$), ($V_{in2}+V_{in3}$) and ($V_{in1}+V_{in3}$). The last condition, Figure 11 shows the output regulated waveforms when power delivered by all three input sources simultaneously ($V_{in1}+V_{in2}+V_{in3}$). Figure 12 shows the output voltage and output current in pure sinusoidal waveforms of single phase full-bridge DC-AC inverter.

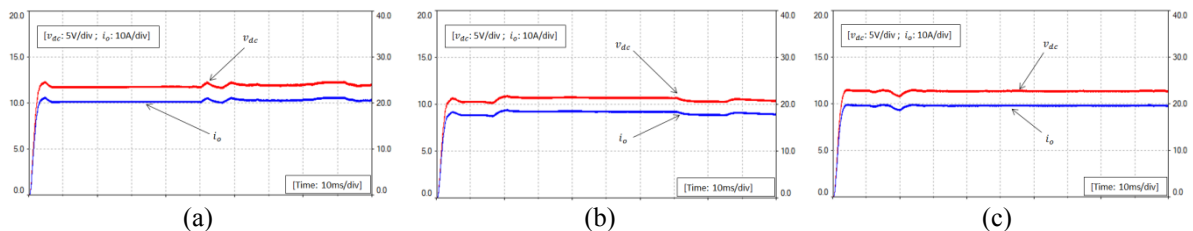


Figure 6. Output voltage and current of three input flyback DC-DC converter (a) V_{in1} work individually, (b) V_{in2} work individually and (c) V_{in3} work individually

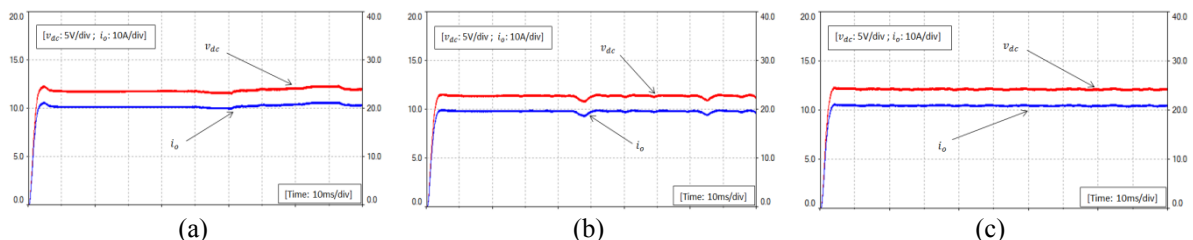


Figure 7. Output voltage and current of three input flyback DC-DC converter (a) V_{in1} and V_{in2} works simultaneously, (b) V_{in2} and V_{in3} works simultaneously and (c) V_{in1} and V_{in3} works simultaneously

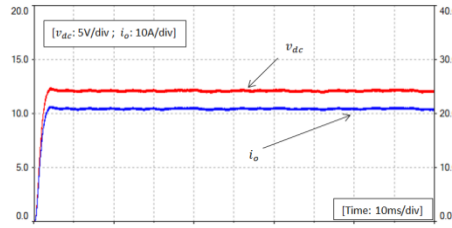


Figure 8. Output voltage and current of three input flyback DC-DC converter for three sources, Vin1, Vin2 and Vin3 works simultaneously

From the Figure 6 to Figure 8, we can see that voltage output and current output waveforms obtained in DC-DC mode operation of the proposed multi-input flyback DC-DC converters are produced in same level of 12V DC and ±21A. When $Q1$, $Q2$, $Q3$ and $Q4$ connected in parallel and opened condition, the voltage waveforms of them are in coincidence. That's mean the output voltage deliver to the DC-AC inverter are always constant either run in individually or simultaneously. The dc bus voltage of the converter is designed to be regulated on $V_{dc} = 12V$ and power output with $P_{max} = 250W$.

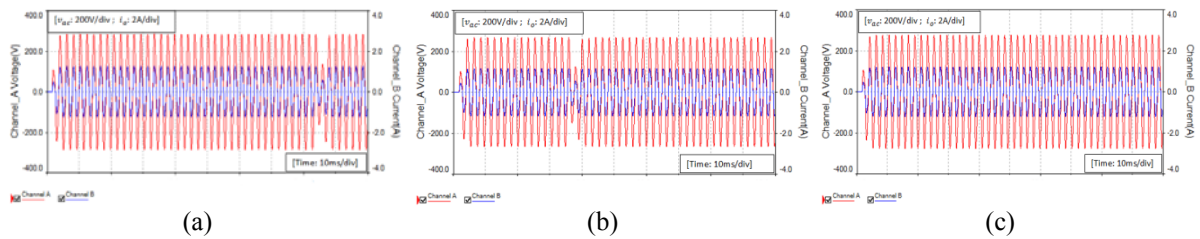


Figure 9. Output voltage and current of DC-AC inverter (a) Vin1 work individually, (b) Vin2 work individually and (c) Vin3 work individually

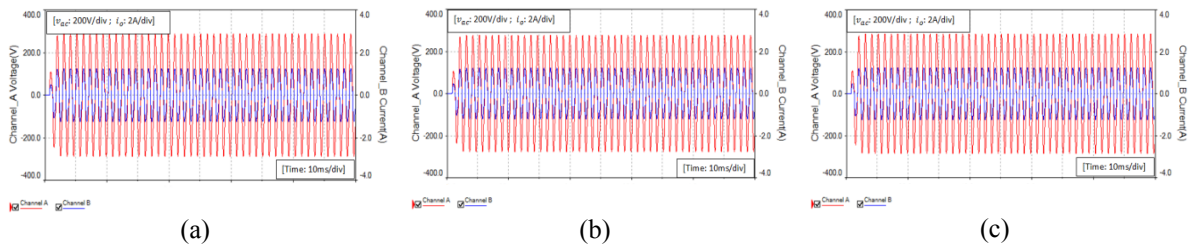


Figure 10. Output voltage and current of DC-AC inverter (a) Vin1 and Vin2 works simultaneously, (b) Vin2 and Vin3 works simultaneously and (c) Vin1 and Vin3 works simultaneously

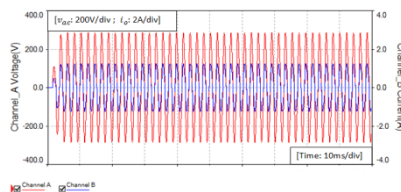


Figure 11. Output voltage and current of DC-AC inverter for three sources, Vin1, Vin2 and Vin3 works simultaneously

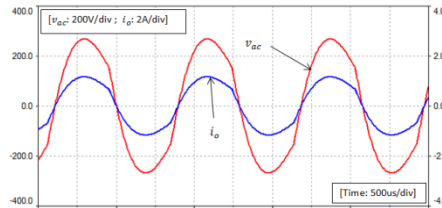


Figure 12. Pure sine wave inverter output voltage and current

Figure 9 to Figure 12 shows the output voltage and current waveforms obtained in DC-AC mode operation of the proposed single phase full-bridge dc-ac inverter topology. The output power of the inverter is designed to be regulated on $V_{ac} = 240V$ and power output with $P_{max} = 250W$. From the results it is clear that perfect constant sinusoidal output when power deliver from multi-input flyback converter in individually or simultaneously. The results are obtained with using a harmonic filter.

6. CONCLUSION

A multi-input inverter design consists of a three input flyback DC-DC converter and a full-bridge DC-AC inverter is explained. Lesser number of power switches and active components are used in this topology. This multi-input dc-ac inverter is capable of being operated in five conditions and the power from the three input sources can be delivered to ac load individually or simultaneously. Simulation results under different operating conditions are shown here to verify the performance of the proposed multi-input inverter system with the desired features. The control circuit is implemented by using an auxiliary analog circuit design to accomplish the desired control functions and circuit protection. From the simulation results, it is confirmed that with a well-designed system including a proper inverter and controller, and selecting of an efficient and proven algorithm is simple and can be easily constructed to achieve an acceptable efficiency to produce a constant output voltage from the different energy sources. In comparison with the previous topologies of hybridizing, three input sources with the proposed inverter can economize the number of power components, simple structure, high extendibility and flexibility, making it well suited for hybrid renewable energy application for three input power sources with same voltage input level.

A successful outcome, through design and development of efficient hybrid energy integration scheme would improve performance and usage of renewable generation, consequently improving electricity supply efficiency and availability, thereby promoting economic usage of renewable generation, resulting in reduced greenhouse gas emissions and consequently contributing to the achievement of global climate change. The future enhancement of this work is to realize a model or prototype of the multi-input inverter for hybrid renewable energy power system.

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BIOGRAPHIES OF AUTHORS



Mohd Azman Rosli was born in Kuala Lumpur, Malaysia, on October 3, 1978. He received the B.Tech. and M.E. degrees from Malaysia University of Technology, Skudai, Johor, Malaysia, in 2001 and 2010, respectively, both in electrical engineering. In 2001, he joined the Goodyear (M) Berhad, Shah Alam, Selangor, Malaysia, in an Engineering Department. He has 9 years of teaching experience as lecturer in electrical technology, Community College, Sabak Bernam, Selangor, Malaysia. Currently he is doing research in the field of power converter for renewable energy hybrid power system.



Nor Zaihar Yahaya was born in Lumut, Malaysia. He went to the University of Missouri-Kansas City, USA to study electronics and graduated with BSc in Electrical Engineering in 1996. After that he served 5 years in the industry in Malaysia. In 2002, he was awarded the MSc in Microelectronics from the University of Newcastle Upon Tyne, UK and later in 2011, he was granted with PhD in Electrical Engineering from Universiti Teknologi PETRONAS, Malaysia. Since then, he has published more than 40 papers in proceedings, cited journals and book chapter as well as secured several national and internal grants. His main teaching and research areas are the study of Power Electronics, Renewable Energy, Li-Fi technology, high powered PCB and device lithography.



Zuhairi Baharudin was born in Malaysia. He went to the Universiti Teknologi MARA, Malaysia to study electrical and graduated with BEng (Honours) in Electrical Engineering. After He was awarded the MEng and PhD in Electrical Power from the University of South, Australia. Since then, he has published more papers in proceedings, cited journals and book chapter as well as secured several national and internal grants. His main specializations are the study of Forecasting, Power System Planning, Time Series Application and Artificial Intelligence. Currently he is doing research in the field of Time Series Application in Load Forecasting.