Journal of Scientific Research and Development 3 (5): 12-17, 2016
Available online at www.jsrad.org
ISSN 1115-7569

Multi-input DC-AC inverter for low voltage hybrid PV/wind/hydrogen fuel cell power system

N. Z. Yahaya *, Z. Baharudin, M. A. Rosli

Department of Electrical and Electronics, Universiti Teknologi PETRONAS, Perak, Malaysia

Abstract: This paper looks into multi-input renewable energy sources for DC-AC inverter (MII) design. The proposed MII consists of a DC-DC boost converter and a single phase full bridge DC-AC inverter. The structure of MII is simpler compared to several single-input inverters used for each source. The input sources applied in this work comprise of photovoltaic (PV), wind turbine (WT) and hydrogen fuel cell (HFC). As the power from PV and WT are intermittent, a charge controller is required to provide uninterrupted supply to the MII. This MII is capable to operate in three different operating modes and power delivered to the load can be either individually or simultaneously. The proposed inverter was simulated using NI Multisim 12.0 circuit simulator and the results are discussed in details.

Key words: Renewable energy sources; Charge controller; DC-AC inverter; Hybrid power system

1. Introduction

The development of Renewable Energy (RE) sources such as Photovoltaic (PV), Wind Turbine (WT) and Hydrogen Fuel Cell (HFC) has continuously increased recently. The fossil resources which make up crude oil and gas are almost exhausted. The environmental concern on the other hand such as global warming has become increasingly serious and required significant attention. Therefore, RE sources are the answer to these since they are available, sustainable and have no or small impact on the environment. Interestingly, the cost of the PV, WT and HFC are expected to decrease in future with the development of RE technologies.

A hybrid renewable energy power system (HREPS) normally contains more than one RE source. The main advantage in implementing this system is the enhancement of reliability and also reduction in battery size. Nowadays, these systems are expected to be better than conventional ones. In order to accommodate different RE sources, the concept of multi-input inverter (MII) was proposed. Some literatures have given much attention in HREPS recently. Most of the multi-input converters are based on multi-input DC-DC boost (Jose et al., 2015; Sathya and Vinoth, 2014; Kamalakkannan and Tina, 2013; Ramya and Manokaran, 2012; Hosseini,et al., 2010) and the multi-input inverters are constructed from combination of buck/buck-boost fused multi-input DC-DC converter and a full-bridge DC-AC inverter (Sivakumar and Sumathi, 2013; Chen et al., 2007). The main disadvantage of these topologies is that they are not giving the operation at wide variable input voltage from different RE sources to produce a constant output voltage at the load. In addition, the inverter uses several stages in power conversion which increases the number of power switches resulting in a complicated control system. It also increases the cost; size and weight of the hybrid system which makes the control become difficult.

The objective of this study is to develop a MII for hybrid PV, WT and HFC power system which consist of a multi-input DC-DC boost converter and a single phase full-bridge DC-AC inverter. As the power from PV and WT sources is intermittent, a charge controller is required to provide uninterrupted supply to the MII with constant HFC power source. It is expected that the design will provide simpler configuration, high extendibility and flexibility, increase the efficiency and reliability of the inverter with a lower cost and small in size and lastly be suitable for hybrid RE application having more than two inputs.

2. Operating principle of MII

The use of individual input inverters in HREGS leads to relatively complex configuration, high cost and low integration. Alternatively, multi-input inverter is used instead (Salazar and Urra, 2011). Fig. 1 shows the block diagram of multi-input DC-AC inverter in HREPS. The Maximum Power Point Tracking (MPPT) is dedicated to extract the maximum power point from PV and WT by using perturbation and observation technique. The optimum fuel cell operation range is set by Proton Exchange Membrane Fuel Cell (PEMFC) and the

* Corresponding Author.

charging or discharging of battery is governed by the charge controller.

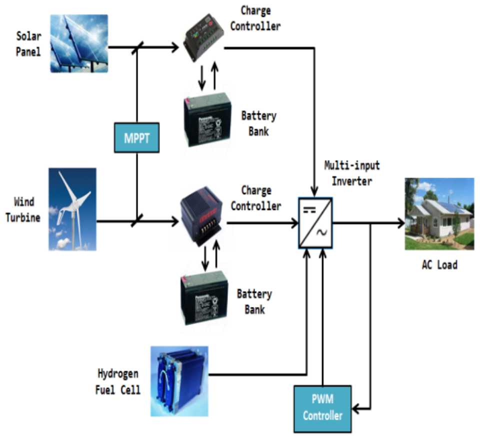

Fig. 1: Block diagram of MII

The constant output voltage from both PV and WT and HFC will be regulated by the multi-input DC-DC boost converter utilizing Pulse Width Modulation (PWM) control scheme. Then, the DC output power from the converter will be stabilized within the single phase full bridge DC-AC inverter employing Sinusoidal Pulse Width Modulation (SPWM) control to achieve the input output power flow balance. The expected output from the inverter is 240 V AC, 50 Hz and 300 W.

3. Multi-input DC-DC converter

3.1. DC-DC boost converter

A converter that produces an output voltage higher than that of the input voltage is called Boost converter (Wai et al., 2011) or step-up converter. The fundamental of a boost converter consists of an inductor, diode, capacitor and switch. The input to a boost converter can be from any kind of sources as well as batteries. The DC input voltage is in series with a large inductor acting as a current source. A switch connected in parallel with the current source and the output is turned off periodically, providing energy from the inductor and source to raise the output voltage. The circuit diagram of DC-DC boost converter is shown in Fig. 2.

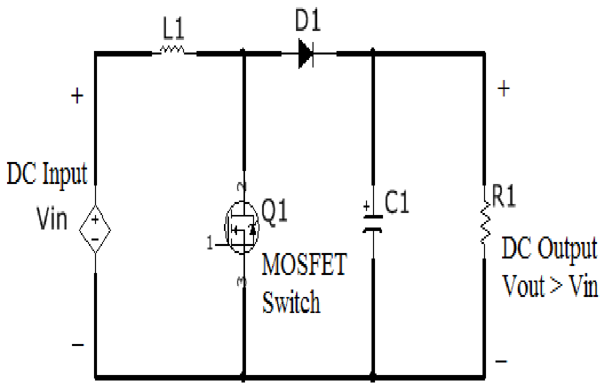

Fig. 2: Circuit diagram of DC-DC boost converter

From Fig. 2, the average output voltage can be calculated using Eq. (1) where V_O is the output voltage, V_{IN} is the input voltage and D is the duty cycle of the switching Metal Oxide Semiconductor Field Effect (MOSFET).

$$V_O = \frac{V_{IN}}{1-D} \tag{1}$$

3.2 Multi-input DC-DC converter

Multi-input DC-DC converters are used to combine several RE input sources which carry different voltage levels. In this application, all these sources will be connected together, generating power at the load.

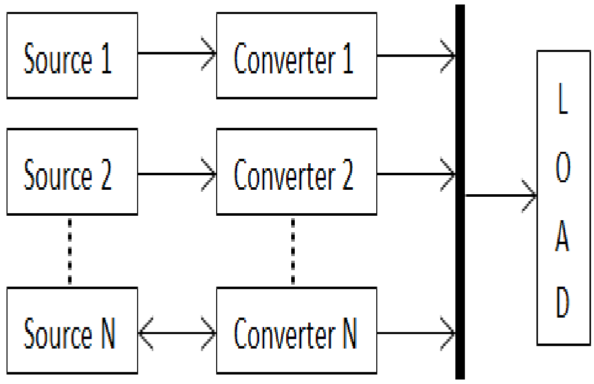

Fig. 3: Individual single input converters

Unlike in Fig. 3, the individual single input converters are used for different sources. Source 1 to Source N-1 can be of the RE energy sources such as PV, WT, HFC, micro turbines and/or electric grid whereas Source N is the storage unit such as battery, ultra-capacitor, flywheel or superconducting magnetic energy storage system. All RE sources are unidirectional except the storage element, is bidirectional which can perform both charging and discharging operations.

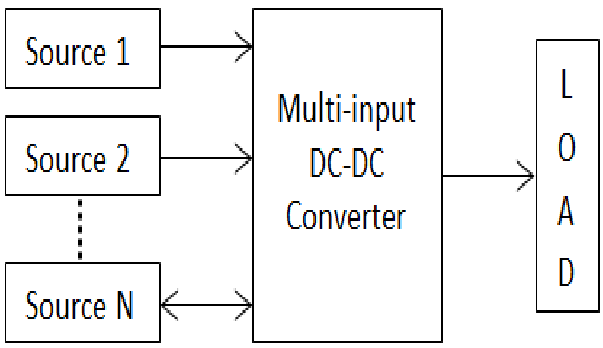

Fig. 4: Multi-input DC-DC converter

In a study, a single multi-input DC-DC converter (Liu and Chen, 2009; Matsuo et al., 2004) has been developed to replace several number of parallel connected single converters as shown in Fig. 4. They were used to connect several different RE sources to effectively regulate the load voltage (Yang et al., 2014). However, this converter has complicated structure hence led significant increase in switching loss.

Fig. 5 shows the configuration of the multi-input DC-DC boost converter. The converter produces a constant output voltage at the load from Vin1, Vin2 and Vin3. It uses only a single inductor which reduces the number of components with better control algorithm.

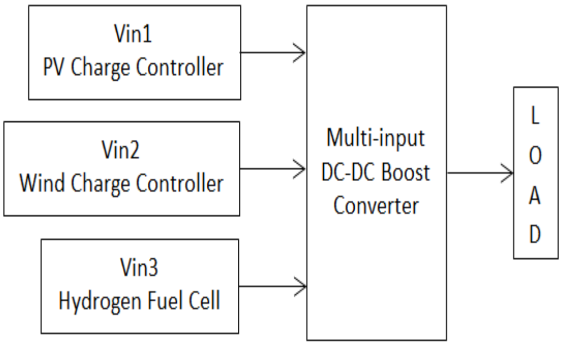

Fig. 5: Multi-input DC-DC boost converter

4. New multi-input DC-AC inverter

The schematic diagram of the multi-input DC-AC inverter is shown in Fig. 6. It consists of three RE inputs operating in DC-DC boost converter and a single phase full bridge DC-AC inverter. By applying the PWM control scheme and driver circuit to the converter, the power can be delivered from the source individually or simultaneously. At the same time, the DC output voltage from converter will be regulated by the DC-AC inverter to produce constant input-output power balance.

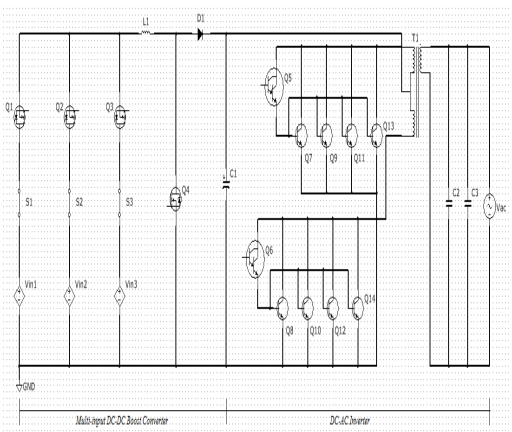

Fig. 6: Schematic diagram of MII

4.1. Multi-input DC-DC boost converter

As shown in Fig. 6, Vin1, Vin2 and Vin3 are three independent RE sources where MOSFET has been chosen as switch. Table 1 shows the HREPS under different operating modes, namely mode 1, mode 2 and mode 3, configured by PWM controller of the converter. These modes explain the current feed from source to optimize the energy at the load.

Table 1: Operation modes of multi-input converter

Mode	Source	Q1	Q2	Q3	Q4
1	Vin1	On	Off	Off	On
	Vin2	Off	On	Off	On
	Vin3	Off	Off	On	On
2	Vin1+Vin2	On	On	Off	On
	Vin2+Vin3	Off	On	On	On
	Vin1+Vin3	On	Off	On	On
3	Vin1+Vin2+Vin3	On	On	On	On

4.1.1. Mode 1

From Table 1, a single RE source is used individually. When Vin1 is applied, Q1/Q4 is ON while Q2/Q3 is OFF. Here, inductor L1 is charged with voltage across Vin1. As for Vin2, Q2/Q4 is ON while Q1/Q3 is OFF with inductor L1 is charged with voltage across Vin2. The same applies for Vin3 for Q3/Q4 is ON and Q1/Q2 is OFF.

4.1.2. Mode 2

In mode 2, two RE inputs are supplying the energy simultaneously. When Vin1/Vin2 is applied, Q1/Q2/Q4 is ON while Q3 is OFF. The voltage across L1 will be the summation of Vin1 and Vin2. When Vin2/Vin3 is used, Q2/Q3/Q4 is ON and Q1 is OFF. Here L1 voltage will take in Vin2 and Vin3 values. In the last combination where Vin1/Vin3 is used, Q1/Q3/Q4 is switched ON and Q2 is turned OFF.

4.1.3. Mode 3

This is the mode where all RE sources are applied. Here, all switches are conducting with voltage across L1 will be the total energy supplied by sources. The cycle repeats if there is any combination of supplying energy from sources takes place.

As for the control strategies, the three input DC-DC boost converter should achieve the following two functions: (i) output voltage regulation, and (ii) realization of power generation of the three input RE sources. The PWM is used to control the power switching device ON and OFF by providing the pulse signal according to the duty cycle and switching frequency. It has the function to amplify the signal to a level required to drive these power switches.

Table 2: Simulation parameters

Parameters	Ratings
Input voltages (Vin1, Vin2 & Vin3)	12V DC
DC bus voltage (Vdc)	11~14.5V DC
Inductor (L1)	0.8uH
Capacitor (C1)	4700uF
Switching frequency (fs)	35kHz
Output voltage (Vac)	240V AC, 50Hz
Output power (Po, max)	250W
Capacitor (C2)	0.1uF
Capacitor (C3)	2.2uF
Transformer (T1)	Centre Tapped Transformer, 12V/240V, 250VA, [P:12V "9-0-9" / S:240V]

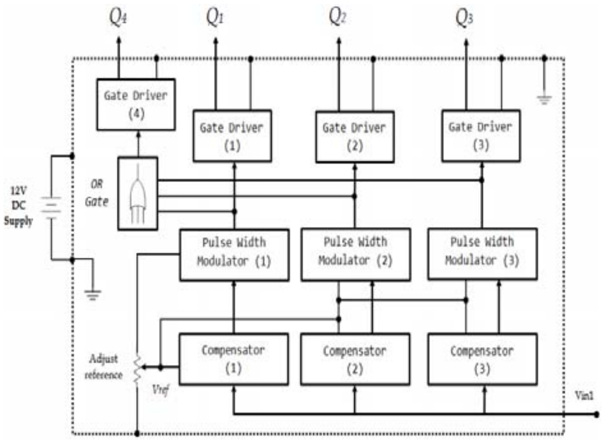

Fig. 7: Control system for DC-DC converter

Fig. 7 shows the control system block diagram for the converter. It includes the 12 V DC supply, compensator, PWM circuit, Gate Driver (GD) and OR gate. The PWMs will generate desired gate signals for power switches, Qs while OR gate will generate output signal for Q4. PWM circuits will modulate the signals used for the compensators. This can be clearly seen from the line diagram in the Fig. 7.

In addition, the output of the GD circuits will drive switching devices Qs separately. The outputs from all PWM circuits will feed to the OR gate circuit and then drive Q4. The pulse signal of the Q1, Q2 and Q3 can be controlled by adjusting the duty ratio (*D*) and switching frequency (f_s). Table 2 lists the values used for all components in the simulation stage.

4.2. DC-AC inverter

The DC output of multi-input DC-DC boost converter is regulated or inverted in a single phase full bridge DC-AC inverter to produce sinusoidal current into the AC mains using SPWM controller. The block diagram of the control system for the voltage source DC-AC inverter is shown in Fig. 8 where Q7 and Q14 (referred to Fig. 6) are the Darlington switches.

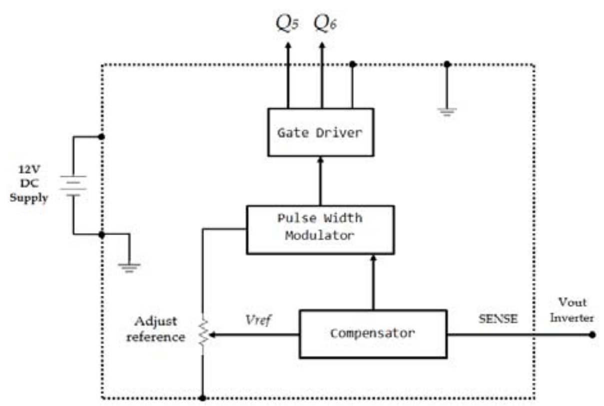

Fig. 8: Control system for DC-AC inverter

The output voltage, (Vout) from inverter will be fed to the SPWM controller and sensed by compensator as a feedback controlled. The reference voltage, (Vref) is used to trigger correct signal pulses for SPWM circuit before driving switches Q5 and Q6 via gate drivers.

5. Simulation results

The system is constructed and simulated using NI Multisim 12.0 software. In order to verify the operating principle of the new multi-input inverter, a 300 W system was set as the benchmark. The parameters of MII with three input RE sources are listed in Table 2 where all values are selected and calculated using formulas.

Fig. 9 shows the waveforms of the DC output current and voltage from the converter to the DC-AC inverter using a single RE input, Vin1 for example. It also shows the switching transistors used to trigger the load voltage and current. The DC power generated is found to be 300.29 W. Fig. 10 shows the waveforms when two RE sources are used, namely Vin1 and Vin2. The DC load power is measured to be 324.72 W. Lastly when all three RE inputs are used as shown in Fig. 11, the power increases further to 355.15 W and eventually the regulated high power factored AC sine load current and voltage waveforms are shown in Fig. 12. The enhanced version of these signals is indicated in Fig. 13.

The output power of the inverter is found to successfully regulated at V_{AC} = 240 V with load power output of P_{max} = 300 W. Using harmonic filter, the load has be successfully received a consistent power regardless the number of operating RE inputs used.

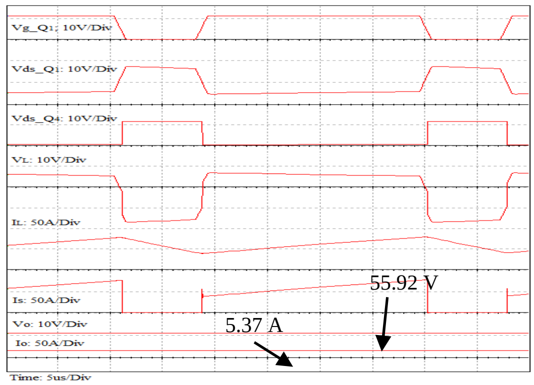

Fig. 9: DC load waveforms of converter using single RE source, Vin1

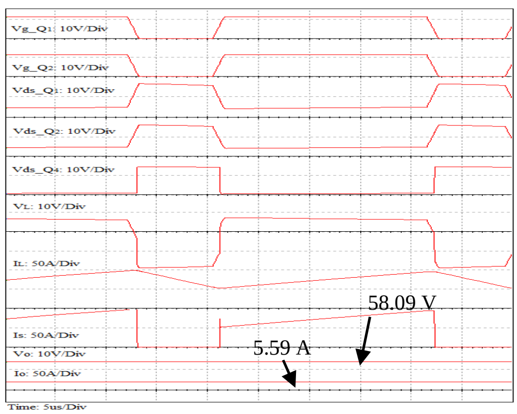

Fig. 10: DC load waveforms of converter using two RE sources, Vin1 and Vin2

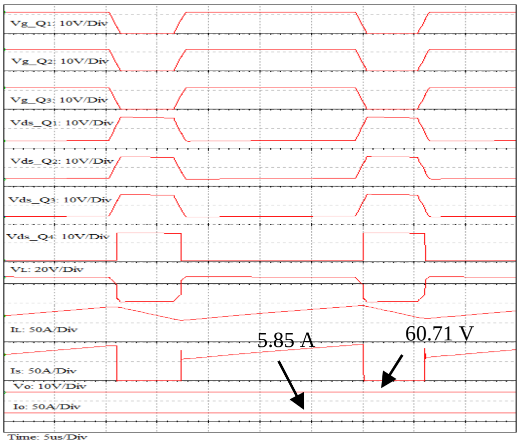

Fig. 11: DC load waveforms of converter using three RE sources, Vin1, Vin2 and Vin3

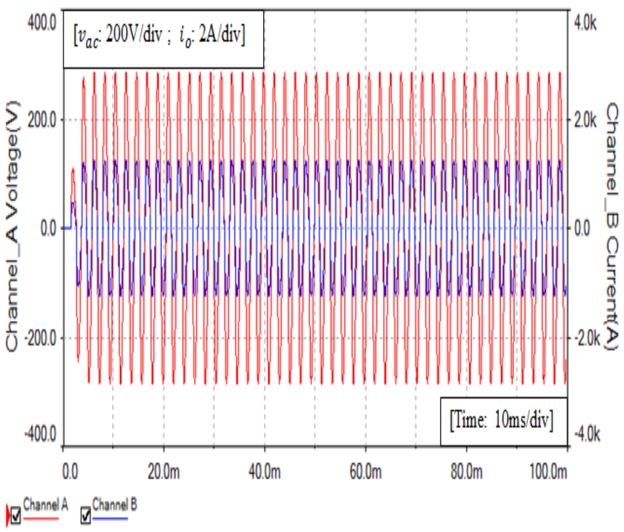

Fig. 12: Output voltage and current of DC-AC inverter using three RE sources

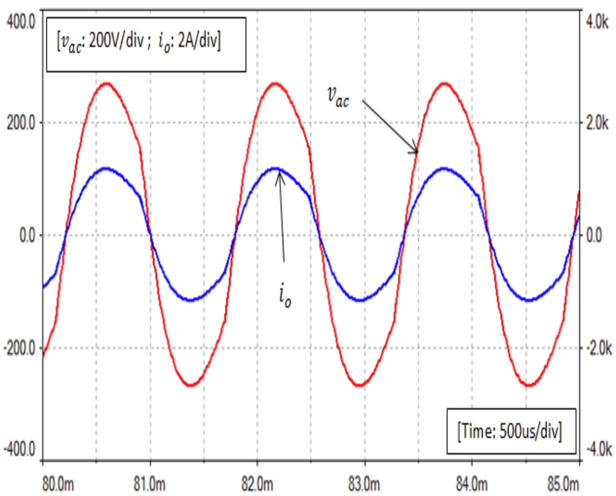

Fig. 13: Enhanced sine AC Inverter output voltage and current using three RE sources

6. Conclusions

A MII consists of a multi-input DC-DC boost converter and a single phase full-bridge DC-AC inverter. Using a less number of power switches and active components in this topology, it has shown its capability to operate in either single, two or three inputs for a constant AC load power of 300 W. Under different operating conditions, the simulation results have verified the performance of the MII.

Using a simple PWM control circuit and protection schemes, the final design has been achieved with an efficient algorithm. In addition, when comparing with existing hybrid technology, the design explained in this paper has utilized less number of components leading to simpler circuit configuration, high extendibility and flexibility. Hence, it will be well suited for any applications in remote areas, vessels and platforms especially in oil and gas operations.

Acknowledgment

The authors wish to thank the Universiti Teknologi PETRONAS (UTP) and MyRA grant for providing financial support to publish this work.

References

H. Matsuo, W. Lin, F. Kurokawa, T. Shigemizu, and N. Watanabe. (2004). Characteristics of The Multiple-input DC-DC Converter. IEEE Trans. Ind. Electron., 51(3), 625-631.

J. Jose, B. Sreenath, and B. Midhu Das. (2015). Multi-input DC-DC/AC Boost Converter. International Journal of Advanced Computing and Electronics Technology, vol. 2, 44-49.

L. Salazar, and J. Urra. (2011). A Novel Two Input Single Switch DC-DC Converter for Hybrid Electricity Generators. Canadian Journal on Electrical and Electronics Engineering, 2(11), 536-541.

N. Sivakumar, and A. Sumathi. (2013). Control of Hybrid System Using Multi-input Inverter and Maximum Power Point Tracking. International Journal of Engineering Research and Applications, 3(4), 77-81.

R. J. Wai, Ch. Y. Lin, J. J. Liaw, and Y. R. Chang. (2011). Newly Designed ZVS Multi-input Converter. IEEE Trans. Ind. Electron., 58(2), 555-566.

S. H. Hosseini, S. Danyali, F. Nejabatkhah, and S. A. K. Mozafari Niapour. (2010). Multi-input DC Boost Converter for Grid Connected Hybrid PV/FC/Battery Power System. Proc. IEEE Elect. Power Energy Conf., 1-6.

S. Kamalakkannan, and T. Tina Devi. (2013). Simulation of Multi-input DC-DC Boost Converter for Hybrid PV/FC/Super Capacitor Power Systems. International Journal of Power Control and Computation, 5(2), 47-52.

S. Ramya, and T. Manokaran. (2012). Analysis and Design of Multi-input DC-DC Converter for Integrated Wind PV Cell Renewable Energy

Generated System. International Journal of Recent Technology and Engineering, 1(5), 14-19.

S. Sathya, and B. Vinoth kumar. (2014). Modeling and Control of Hybrid Systems-Solar/Wind/Battery Using Three Inputs DC-DC Boost Converter. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 3(2), 7320-7326.

Y. Ch. Liu, and Y. M. Chen. (2009). A Systematic Approach to Synthesizing Multiinput DC-DC Converters. IEEE Trans. Power Electronic. 24(1), 116-127.

Y. M. Chen, Y. C. Liu, S. C. Hung, and C. S. Cheng. (2007). Multi-Input Inverter for Grid-Connected Hybrid PV/Wind Power System. IEEE Transactions on Power Electronics, 22(3), 1070-1077.

Y. Yang, X. He, R. Shao, S. Xu, and L. Chang. (2014). Multi-input Single-Phase Grid-Connected Inverter for Hybrid PV/Wind Power System. International Journal of Renewable and Sustainable Energy, 3(2), 35-42.