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Implementation and control of Multi – Input Power Converter for Grid Connected Hybrid Renewable Energy Generation System

Yuvaraj V, Roger Rozario, S.N. Deepa
yuvatheking@skygroups.org; roger.rozario@gmail.com; deepapsg@gmail.com
Department of EEE, Anna University of Technology
Coimbatore, India

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Abstract—**The objective of this paper is to propose a novel multi-input power converter for the grid-connected hybrid renewable energy system in order to simplify the power system and reduce the cost. The proposed multi-input power converter consists of a Cuk fused multi-input dc–dc converter and a fullbridge dc–ac inverter. The incremental conductance (IncCond) method is mainly used to accomplish the maximum power point tracking (MPPT) algorithm for input sources. The operational principle of the proposed multi-input power converter is explained. A multi-input power converter (MIPC) which operates in four modes: first an operation type wherein power is delivered to dc Bus from hybrid renewable energy sources; second a single type wherein only one renewable energy source supplies power to the dc Bus; third an inverter type wherein power is delivered to dc Bus from ac grid via inverter module, and fourth a battery type wherein power is delivered to dc Bus from batteries without renewable energy source. The integration of the dc Bus and a hybrid renewable power supply system is implemented and simulated using MATLAB/SIMULINK. A hybrid renewable power energy which integrates the solar energy, wind-power.**

Keywords— **Inverter, Photo Voltaic(PV), Wind Energy, MIPC, CUK, IncCond, Renewable Energy System, DC bus.**

I. INTRODUCTION

Based on conventional sources 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) abundant; 2) pollution free; 3) distributed throughout the earth; and 4) recyclable. The main drawbacks are that the initial installation cost is considerably high and the energy conversion efficiency is relatively low. To overcome these problems, the following two essential ways can be used: 1) increase the efficiency of conversion and 2) maximize the output power. With the development of technology, the cost of the solar arrays and wind turbines is expected to decrease continuously in the future, making them attractive for residential and industrial applications.

Various methods of maximum power tracking have been considered in photovoltaic power applications [1]–[8]. Of these, the incremental conductance (IncCond), which moves the operating point toward the maximum power point by periodically increasing or decreasing the array voltage, is often used in many photovoltaic systems [3]–[6]. The incremental conductance method (IncCond) is also now often used in photovoltaic systems [7], [8]. The IncCond method quickly tracks the maximum power points by comparing the incremental and instantaneous conductance's of the solar array. The incremental conductance is estimated by measuring small changes occur in array voltage and current. These small changes may be induced by deliberate control action. Methods which improve the IncCond method and can identify the incremental conductance of the array are now more rapidly has been proposed [9]. However, the harmonic components of the array voltage and current need to be measured and it is used to adjust the array reference voltage. The objective of this paper is to propose a novel multi-input power converter for grid-connected hybrid renewable system. The proposed multi-input power converter system has three advantages: i) power from the PV and the wind turbine can be delivered to the utility grid individually or simultaneously, ii) maximum power point tracking feature is realized for both solar and wind energy, and iii) a wide range of input voltage variation is caused by different insolation and wind speed is acceptable.

II. PRINCIPLE OF THE PROPOSED MULTI-INPUT POWER CONVERTER

The circuit diagram of the proposed multi-input power converter is shown in Fig. 2. It consists of a cuk fused multi-input dc–dc converter and a full-bridge dc/ac inverter. The input dc voltage sources, V_{pv} and V_{wind}, are obtained from the PV array and the rectified wind turbine output voltage. By applying the pulse-with-modulation (PWM) control scheme with appropriate MPPT algorithm to the power switches $M_1$and M_2, the multi-input dc–dc converter can draw maximum power from both the PV array and the wind turbine individually or simultaneously. The dc bus voltage V_{DC}, will be regulated by the dc/ac inverter with sinusoidal PWM (SPWM) control to achieve the input output power-flow balance. Details of the operation principle for the proposed multi-input inverter are introduced as follows.

A. PV Array

The PV array is constructed by many series or parallel connected solar cells [10]. Each solar cell is form by a P–N junction semiconductor, which can produce currents by the photovoltaic effect. It can be seen that a maximum power point exists on each output power characteristic curve. Therefore, to utilize the maximum output power from the PV array, an appropriate control algorithm must be adopted.

B. MPPT Algorithm

Different MPPT techniques have been developed. Among these techniques, the incremental conductance (IncCond) method with the merit of simplicity is used in this paper. The perturbation of the output power is achieved by periodically changing (either increasing or decreasing) the controlled output current. The objective of the IncCond method is to determine the changing direction of the load current. Fig. 1 shows the flow chart of the MPPT algorithm with IncCond method for the proposed multi-input inverter. Since there are two individual input sources, each one of them needs an independent controller. However, both of the controllers can be implemented by using one integrated controller. At the beginning of the control scheme, the output voltage and output current of the source (either the PV array or the wind turbine) are measured, then the output power can be calculated. On comparing the recent values of power, current and voltage with previous method, the IncCond method shown in the flow chart can determine the value of reference current to adjust the output power toward the maximum point.[11]

C. Wind Energy Generating System

The induction generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable loads, and has natural protection against short circuit. The available power of wind energy system is presented as under in Eq.1.

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

Where ρ (kg/m) is the air density and A (m) is the area swept out by turbine blade, V_{wind} is the wind speed in mtr/s.

It is not possible to extract all the kinetic energy of wind, but it extract a fraction of power in wind, which we call power coefficient C_p of the wind turbine, and is given in Eq.2.

$$P_{mech} = C_p P_{wind} \quad (2)$$

Where Cp is the power coefficient, depends on operating condition of wind turbine. This coefficient can be express as a function of tip speed ratio λ and pitch angle θ . The mechanical power produce by wind turbine is given in Eq. 3.

$$P_{mech} = \frac{1}{2}\rho \Pi R^2 V_{wind}^3 C_p \quad (3)$$

Where R is the radius of the wind blade (m).

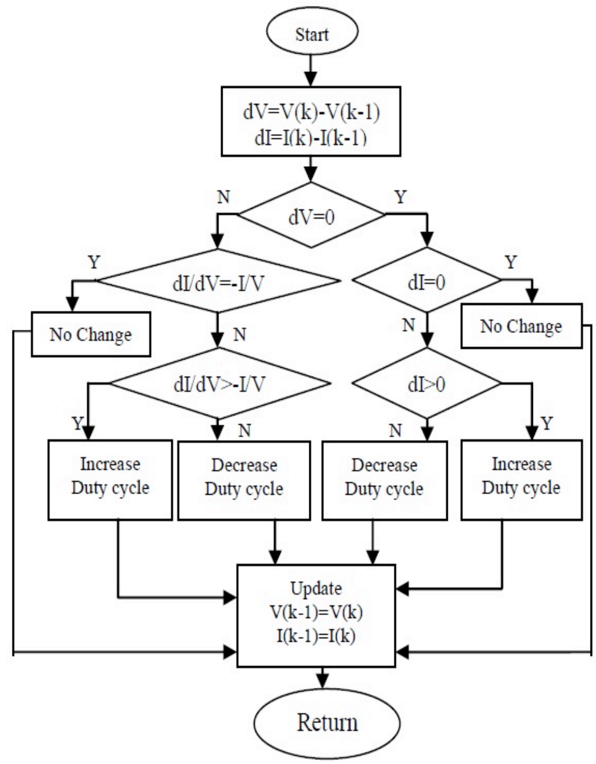

Fig.1 Flowchart of IncCond method with direct control

D. Multi-Input DC–DC Converter

The proposed multi-input dc–dc converter is the fusion of the Cuk converter [12]. Syntheses of the multi input dc–dc converter are done by inserting the pulsating voltage source of the buck-boost converter

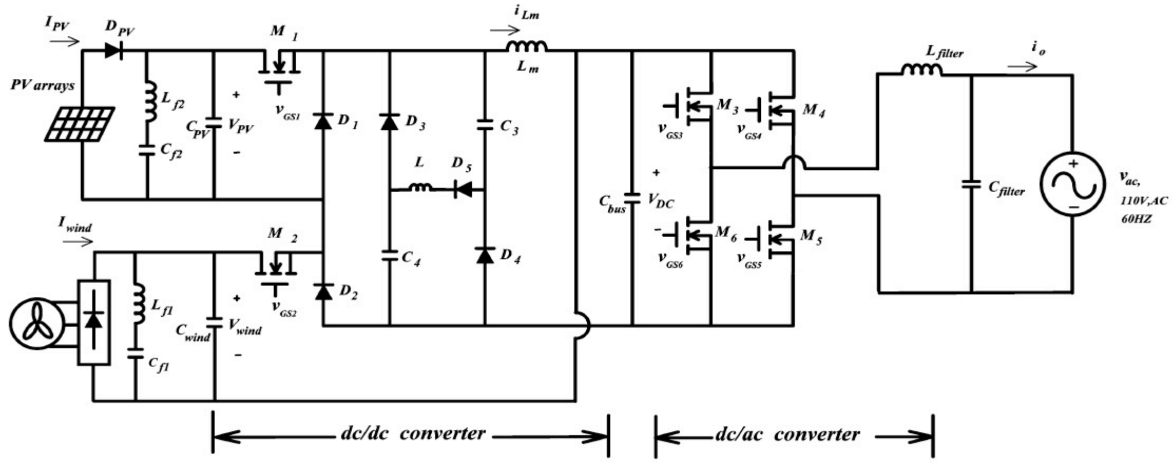

Fig.2. Schematic diagram of the proposed multi-input inverter.

into the Cuk converter. In order not to hamper the normal operation of the buck-boost converter and to utilize the inductor for the Cuk converter, the pulsating voltage source of the Cuk converter must be series-connected with the output inductor. Fig. 3 presents the configuration of the proposed hybrid renewable energy generation with multi-input power converter for dc bus [13]. The generation subsystems comprise a wind turbine (WT) generator, a PV, two HCPVs including active sun tracker, and a battery bank (BT). The multi-input power converter comprises WT modules, PV modules, HCPV modules, hydraulic generator module [14] in expectation, an inverter (IT) module, a control module, and a BT module, in which the dc power was charged for storing energy.

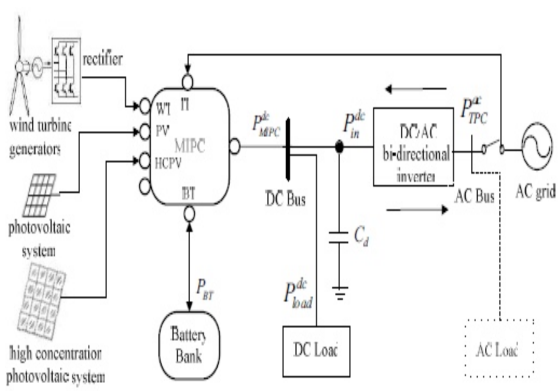

Fig. 3. Configuration of the hybrid power generation with multi-input power converter.

III. MODES OF PROPOSED MULTI-INPUT POWER CONVERTER

According to renewable energy sources provide power for the dc bus or the storage batter and where the battery bank absorbs the power to supplies dc Bus, operation states of proposed four-type multi-input power converter can be classified into eight possible modes which are listed in Table I. For the WT PV, and HCPV, supplying power for the dc bus via the MIPC is denoted by the "1", otherwise by the "0". For the storage battery bank, the "1" indicates a charge from MIPC, otherwise by the "0". Moreover, for the power factor correction (PFC) mode of the inverter module connecting to the multi-power converter for supplying power is expressed by the "1", else by the "0". Therefore, we can use the bit-coding method to command or change the mode for the data patterns of typical digital signal processor (DSP) applications on data buses by MIPC. For example, consider the operation state from [11110] to [00011] that is the full mode of the operation type switching to the PFC mode of the inverter type in MIPC. Fig.4 shows the simplified sketch maps of the hybrid renewable energy distributed generation system under different operation modes by MIPC controller. Note that operation in each mode can be maintained as long as the battery bank energy is sufficient to satisfy the load requirements. If the high voltage dc Bus is under voltage low limit or over voltage high-limit, and then the output stage of MIPC is disconnected from the dc bus and avoids damages. At 3 this point in time, the hybrid renewable energy only export energy through the storage stage i.e. the power sources just charge up the storage battery. By following the above analytic approach, other operation modes also can be educed.

TABLE I
8- MODES OF FOUR-TYPE MULTI-INPUT POWER CONVERTER

Type	Mode	WT	PV	HCPV	Inverter

Operation type	Full mode	1	1	1	0
Operation type	WT+PV	1	1	0	0
Operation type	PV+HCPV	0	1	1	0
Single type	WT	1	0	0	0
Single type	PV	0	1	0	0
Single type	HCPV	0	0	1	0

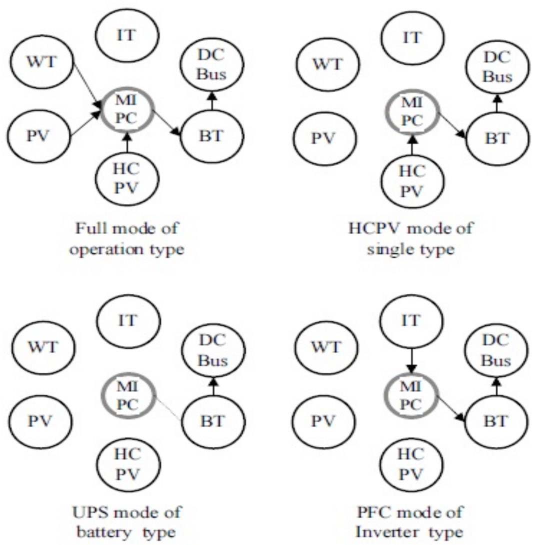

Fig. 4. The simplified sketch maps of the hybrid renewable energy distributed generation system under different operation modes by MIPC controller.

IV. CONTROL SCHEME

A. Direct Control Method

Conventional MPPT systems have two independent control loops to control MPPT. The first control loop contains the MPPT algorithm and the second one is usually a (proportional) P or (proportional and integral) PI controller. IncCond method makes use of instantaneous and incremental conductance to generate an error signal which is zero at MPP; however it is not zero at most of the operating points. The main purpose of the second control loop is to make the error from the MPPs near to zero [8]. Simplicity of operation, ease of design, inexpensive maintenance and low cost made PI controllers very popular in most linear systems. However, MPPT system of standalone photovoltaic (PV) and wind is a nonlinear control problem due to the nonlinearity nature of PV and unpredictable environmental conditions and hence PI controllers do not generally work well [15]. In this paper, the incremental conductance method with direct control is selected. The PI control loop is eliminated and duty cycle is adjusted directly in the algorithm. The control loop is simplified and the computational time for tuning controller gains is eliminated. To compensate the lack of PI controller in the proposed system a small marginal error of 0.002 was allowed. The objective of this work is to eliminate the second control loop and to show that sophisticated MPPT methods do not necessarily obtain the best results but employing them in simple manner for complicated electronic subjects is considered necessary. Feasibility of the proposed system is investigated with a DC-DC converter configured as the MPPT. In [16] it was mentioned that power extracted from PV modules with an analog circuitry can only operate at the MPP in a predefined illumination level.

V. SIMULATION RESULTS

The proposed system is implemented and simulated using Matlab/Simulink that includes the PV module electrical circuit, Cuk converter and the MPPT algorithm. The PV module is modeled using electrical characteristics to provide output current and voltage of the PV module and wind turbine. The provided current and voltage are fed to the converter and the controller simultaneously.

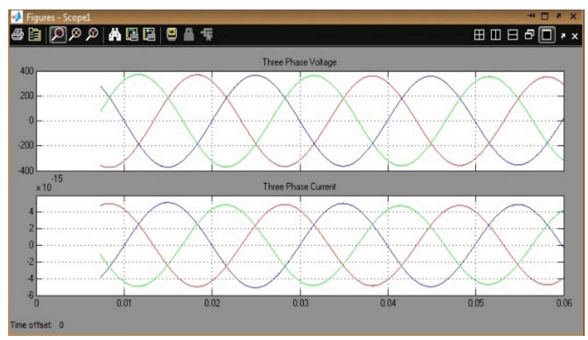

Fig.5. Wind Turbine Output Voltage and Current

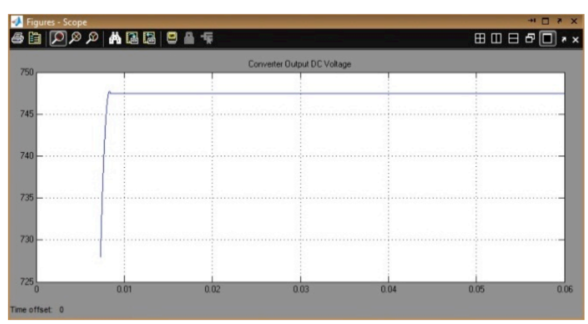

Fig.6. Converter Output Voltage

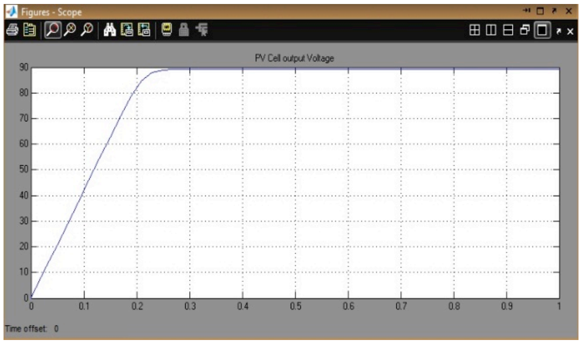

Fig.7. PV Output Voltage

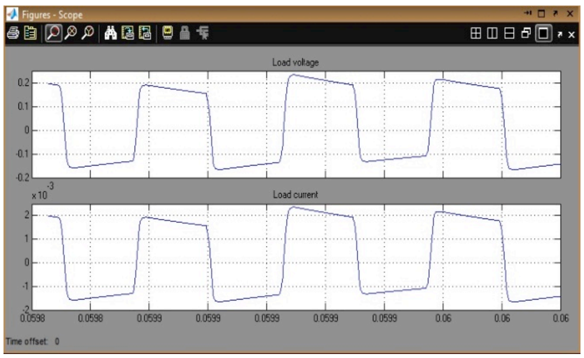

Fig.8. Load Voltage and Current

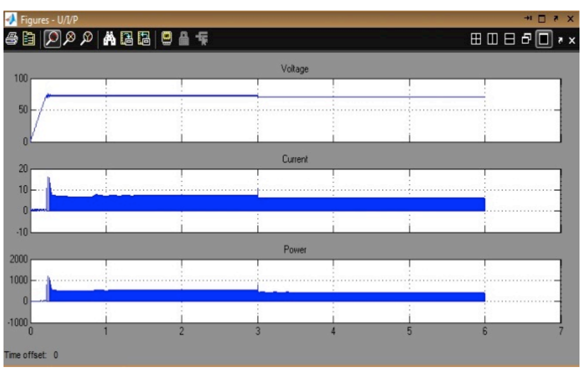

Fig.9. Output before Cuk converter

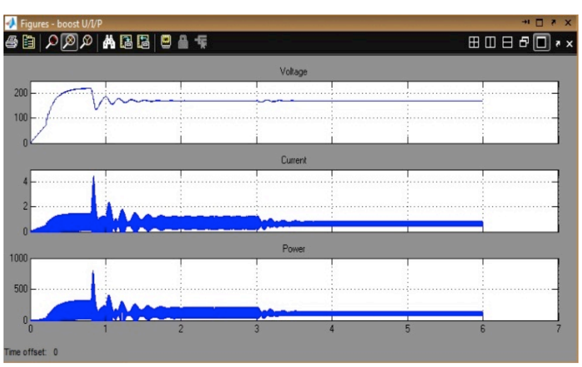

Fig.10. Output after Cuk converter

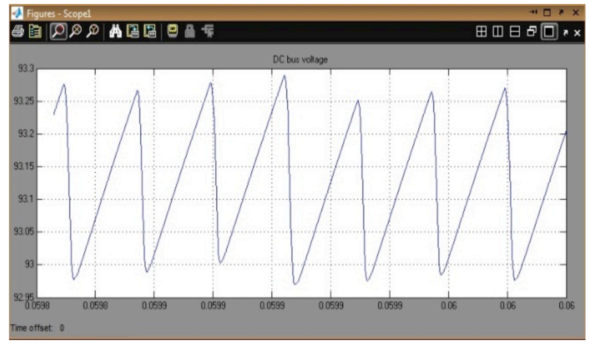

Fig.11. DC bus voltage

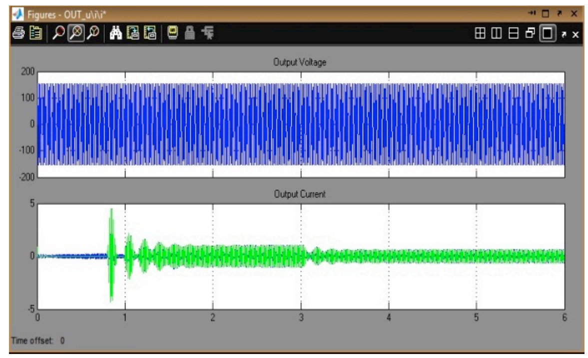

Fig.12. Output voltage and current with MPPT controller

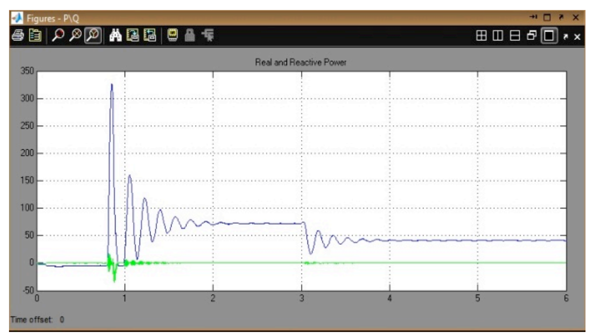

Fig.13. Output power

VI. CONCLUSION

A novel multi-input power converter for the grid-connected hybrid renewable energy system is proposed. It has the following advantages: 1) power from the PV array or/and the wind turbine can be delivered to the utility grid individually or simultaneously, 2) MPPT feature is realized for both PV and wind energy, and 3) a large range of input voltage variation caused by different insolation and wind speed is made acceptable. In this paper, the operation principle of the proposed multi-input power converter has been introduced. Incremental conductance method is adopted to realize the MPPT algorithm for the PV array and the wind turbine. The control circuit is implemented and simulated by using MATLAB/SIMULINK. Simulation results at different operating conditions are shown here to verify the performance of the proposed multi-input power converter system with the desired features. From the results acquired during the simulation, it was confirmed that with a well-designed system including a proper converter and selecting an efficient proven algorithm, implementation of MPPT is simple and can be easily constructed to achieve an acceptable efficiency level of the PV modules and wind turbine.

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