Control of Hybrid System Using Multi-Input Inverter and Maximum Power Point Tracking

N.Sivakumar, Dr.A.Sumathi

(Dept., of Electrical and Electronics Engg, Jayalakshmi Institute of Technology, Thoppur-636352, India)
(Dept., of Electronics and Communication Engg, Adhiyamaan College of Engineering, Hosur-635109, India)

ABSTRACT

The objective of this paper is to control the Wind/PV hybrid system using Multi-input inverter to get constant output power for different operating conditions. The MPPT also used in this system to get the maximum peak power to the load. The perturbation observation (P&O) method is used to accomplish the maximum power point tracking algorithm for input sources. The operating principle of the open loop and closed loop circuit of multi-input inverter is discussed.

Keywords -Inverter, photovoltaic (PV), MPPT,wind energy.

I. Introduction

The photovoltaic (PV) power and wind energy applications have been increased significantly due to the rapid growth of power electronics techniques [1]–[3]. Generally, PV power and wind power are complementary since sunny days are usually calm and strong winds are often occurred at cloudy days or at night time. Hence, the hybrid PV/wind power system has higher reliability to deliver continuous power than individual source [4], [5].But the size and components are made the system to complex and high cost.

Usually, two separate inverters for the PV array and the wind turbine are used for the hybrid PV/wind power system [7]. But here the multi-input inverter is combining with renewable energy sources in the dc end instead of the ac end. It can simplify the hybrid PV/wind power system to reduce the cost. This system is used to get maximum constant power from hybrid system.

The multi-input inverter has the following advantages:
1) Power from the PV array or the wind turbine can be delivered to the utility grid individually or simultaneously. 2) Maximum power point tracking (MPPT) feature can be realized for both solar and wind energy and 3) a large range of input voltage variation caused by different insolation and wind speed is acceptable.

II. Multi-Input Inverter

The schematic diagram of the proposed multi-input inverter is shown in Fig. 1. It consists of a buck/buck-boost 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.

2.1. Hybrid system

In this project the wind/PV hybrid system is used to deliver continuous power to the load. The control of this hybrid system is obtained by Multi-input inverter and control circuits. MPPT algorithm (P&O method) also used to get maximum peak power to the load. The operations of PV/Wind is connected with multi-input inverter are used to get the power characteristic analysis of hybrid system.
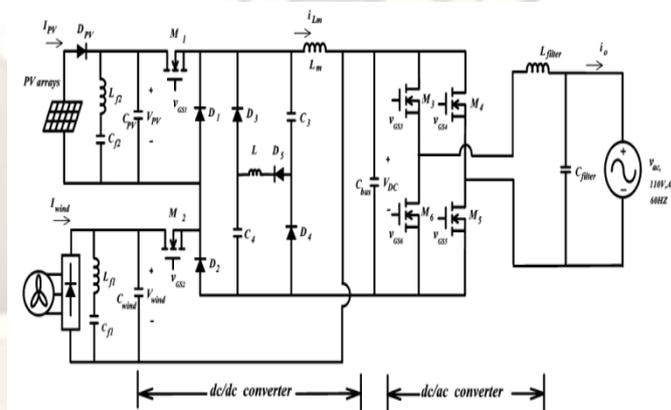
Fig 1: Schematic diagram of Multi-input inverter.

2.2. PV Array

The PV array is constructed by many series or parallel connected solar cells [8]. Each solar cell is formed by a junction semiconductor, which can produce currents by the photovoltaic effect. Typical output power characteristic curves for the PV array under different insolation are shown in Fig. 2. 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.
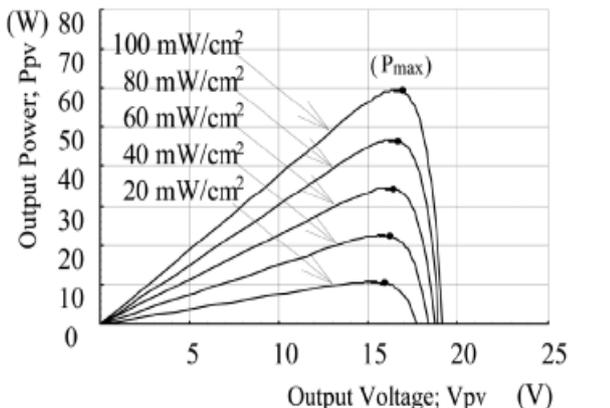
Fig.2. Typical output power characteristic curves of the PV array

2.2.1. Parameters of PV system
DC bus voltage (Vdc) = 230 V DC.
Switching Frequency (fs) = 50 kHz, Switch (M1).
Power Factor = 0.99.
Total Harmonic distortion is less than 3%.

Only the PV array is connected to the proposed multi-input inverter. At the beginning, the controller will send out the PWM gate signal with MPPT feature to switch when the utility line voltage is detected. Once the dc bus voltage reaches its pre-set range, the dc/ac inverter will begin to inject ac output current into the utility line.

(20 V/div, 5 A/div, 5 µs/div)
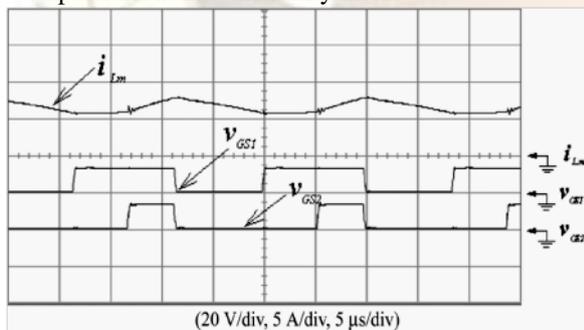
Fig 3: Gate signals Vgs1 & Vgs2 for M1 & M2 switches.

Fig. 3 shows the measured waveforms of gate driving signals, (Vgs1) of (M1) and (Vgs2) of (M2) , and inductor current . Because switches M1and M2 have different duty ratios, the inductor current has two different charging slopes. The multi-input dc–dc converter can deliver power from both of the two energy sources to the dc bus simultaneously. The measured waveforms of voltage, current, and power for the PV array and the wind turbine are shown in Fig. 4.

(V_{pv}: 250 V/div; I_{PV}: 2 A/div; P_{pv}: 500 W/div; V_{wind}: 120V/div.; I_{wind}: 5 A/div; 10 sec./div)
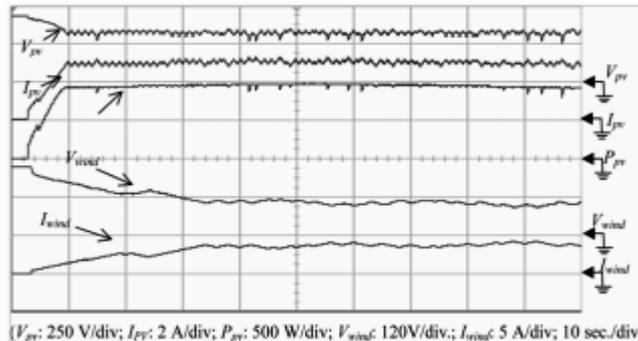
Fig 4. Measured waveforms of voltage, current, and power for the PV array and the wind turbine.

2.3. Wind Turbine
Among various types of wind turbines, the permanent magnet synchronous wind turbine, which has higher reliability and efficiency, is preferred [13]–[16]. The power (P_{wind}) of the wind can be derived as

$$Pwind = \frac{1}{2}\rho AV_{wind}^3 \qquad \dots\dots\dots(1)$$

Where p is the air density (kg/m), A is the area (m) swept by wind blades, and V_{wind} is the wind speed (m/s). It has been proved that the energy conversion efficiency, Cp, of the wind turbine is a function of the tip speed ratio .The tip speed ratio is

$$\lambda_{tip} = \frac{wr}{V_{wind}} \qquad \dots\dots\dots(2)$$

Where w is the rotational speed (rad/sec) of wind turbine blades, r is the radius of the area swept by wind turbine blades.

When the output power of the wind turbine is small, the dc motor will request small power from the dc source to drive the wind turbine. When the output current of the wind turbine is increased, the output voltage and the rotational speed will be decreased. Also, the dc motor needs to provide a larger torque to the wind turbine. Since the dc motor has limited maximum input power predetermined by the control box, it can only provide limited maximum torque to the wind turbine which can only generate a limited maximum power to the load.
Fig. 6 shows typical output power characteristic curves of the wind turbine under different driving power from the controllable dc motor. These curves have same characteristics with those driven by the natural air-stream.
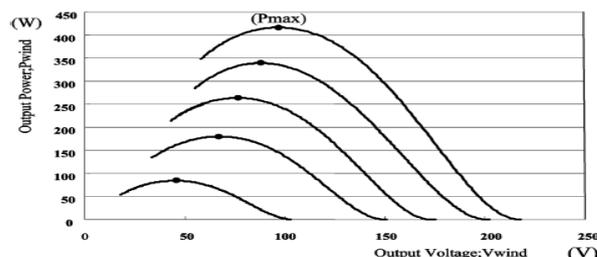
Fig.5: Output power characteristic curves of the wind turbine for different wind speed

Each curve represents a constant driving power from the dc motor. The output power of the wind turbine is drawn by an electronic load. The load current is gradually increased, and then the output power can be measured. Output power characteristic curves are shown in Fig.5. The P&O method is adopted as the MPPT algorithm for the wind turbine. Therefore, a power electronic converter with appropriate controller is needed to process the wind energy which varies considerably according to the meteorological conditions such as wind speed.

2.3.1. Wind parameters
Vwind =80 ~200 V DC.
Switching frequency =
50 kHz (M2), 20 kHz (M3, M6).
Power factor = 0.99.
THD =below 3.5%

III.   Multi-input DC-DC Converter

The proposed multi-input dc–dc converter is the fusion of the buck-boost and the buck converter [17]. Syntheses of the multi-input dc–dc converter are done by inserting the pulsating voltage source of the buck converter into the buck-boost converter. In order to hamper the normal operation of the buck-boost converter and to utilize the inductor for the buck converter, the pulsating voltage source of the buck converter must be series-connected with the output inductor. Base on the conduction status of the switches and the multi-input dc–dc converter has four operation modes. Fig. 8(a) to (d) shows the equivalent circuits for Mode I through Mode IV, respectively. When switches on or turned off, the diodes which will provide a free-wheeling path for the inductor current. If one of the voltage source is failed, the other source can still provide the electric energy, normally. Therefore, it is very suitable for renewable energy applications.
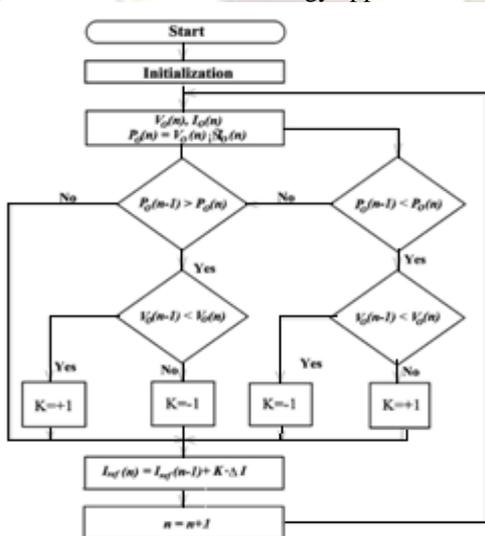
Fig.6: Flow chart of Maximum Power Point Tracking.

The input-output voltage relationship can be derived from the steady state volt-second balance analysis of the inductor has longer conduction time for one switching cycle and follows the sequence of Mode I, Mode III, and Mode IV. On the other hand, if it has longer conduction time then the sequence becomes Mode II, Mode III, and Mode IV.
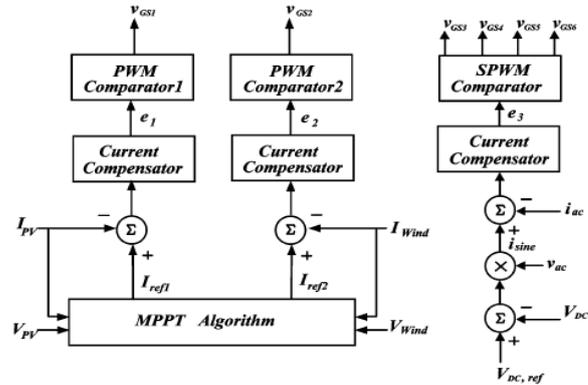
Fig.7.Control block diagram of the multi-input inverter.

In either case, the output voltage can be expressed as

$$V_{dc} = \frac{d_1}{1-d_2} V_{PV} + \frac{d_2}{1-d_2} V_{wind} \quad ..(3)$$

Where d1 and are d2 are the duty ratio of switches M1 and M2, respectively. Similarly, the average input and output current can be obtained as

$$I_{PV} = \frac{d_1}{1-d_2} I_0 \qquad ..(4)$$

$$I_{wind} = \frac{d_2}{1-d_2} I_0 \qquad ..(5)$$

From the above derived steady-state voltage and current equations, different power distribution demands of the multi-input dc–dc converter can be achieved.

3.1. Output Parameters
Output Voltage (Vac) = 110V,60Hz.
Output Power (Pmax) = 1kW.

IV.   Control Scheme

The conceptual control block diagram of the proposed multi-input inverter is shown in Fig.7. The hardware implementation of the control circuit is realized by using a central control unit, digital signal processor (DSP) TMS320F240, and auxiliary analog circuits. The sensed voltage and current values for the PV array and the wind turbine are sent to the DSP where the MPPT algorithm will determine the reference current (Iref$_1$ and Iref$_2$) for the PV array and the wind turbine. The PWM Comparator1 and Comparator2 will generate desired

gate signals for power switches M1 and M2 according to the current error signals e1 and e2 respectively.

The dc/ac inverter will inject a sinusoidal current into the ac mains. The SPWM gate signals of switches M3 through M6 for producing sinusoidal ac current is generated by the DSP and the amplitude of the ac current is determined by the error signal of the measured dc bus voltage Vdc and Vdcref. If the measured dc bus voltage is lesser than the reference value, then the amplitude of the ac output current will be decreased in order to increase the dc bus voltage. On the other hand, if the dc bus voltage is higher than the reference one, then the amplitude of the ac output current will be decreased and at the same time, the dc bus voltage is regulated by the dc–ac inverter and the input-output power balance can be achieved.
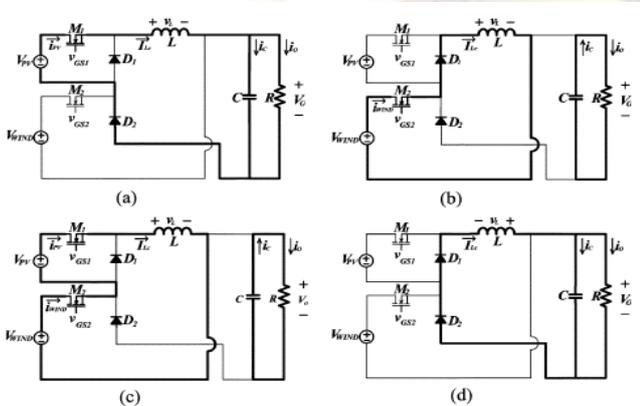
Fig.8.Equivalent circuits for the multi-input dc–dc converter.
(a)Mode-I (b) Mode-II(c) Mode-III (d) Mode-IV

4.1. Open loop of Multi-input inverter

The open loop control of multi input inverter is shown in fig 9. This system consist of one multi input DC-DC converter and DC-AC inverter. This converter is used to obtain maximum power from WIND/PV hybrid system. Inverter is used to regulate the dc bus voltage. This system is used to simplify the operation complexity and reduce the cost. The Output regulated voltage and current waveform of multi-input inverter is shown in fig 10.

4.1.1. Simulation Diagram - Open Loop
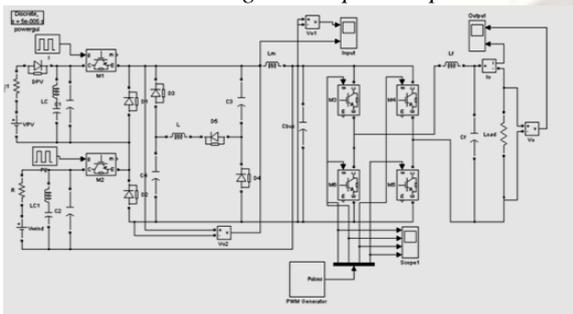
Fig.9. Open loop circuit of multi-input inverter
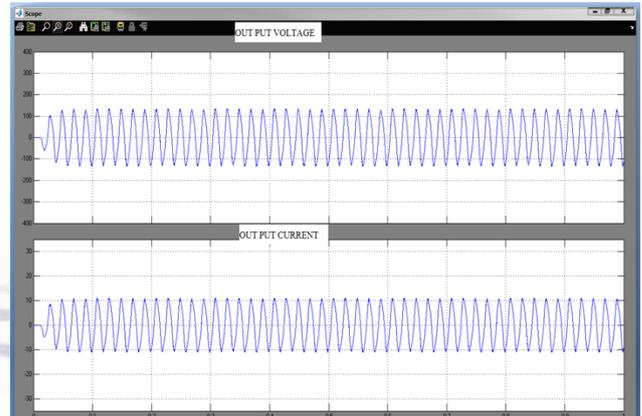
Fig.10.Output voltage and current waveform of multi- input inverter.

4.2. Closed loop of Multi-input inverter

Fig.11 shows the maximum constant output power from the wind/PV hybrid system using Multi-input inverter and MPPT (P&O) method. This output current and voltages are for the particular predefined input values of voltages (Vin) and gate signals (Vgs).

4.2.1. Simulation Diagram - Closed Loop
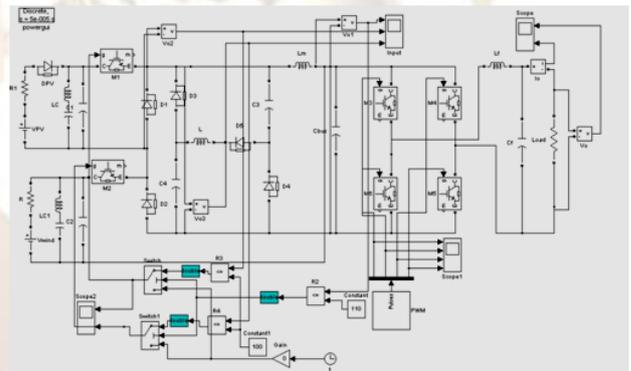
Fig.11 Closed loop operation of Multi-input inverter.
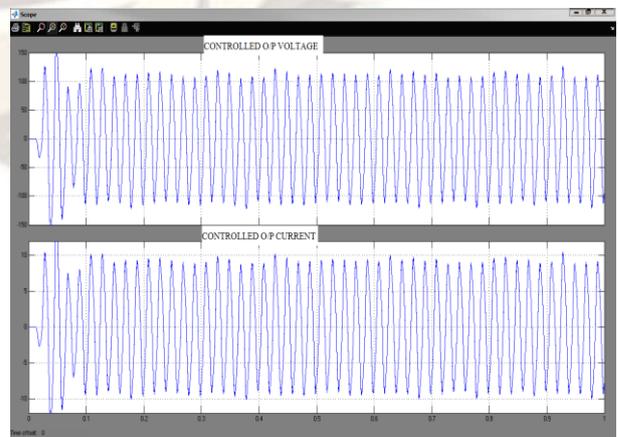
Fig.12 Output voltage and current waveform of multi-input inverter.

But in the closed loop of Multi-input inverter operation the maximum constant output power obtained for the different variable input conditions. This input and output balance controlled by using central control unit and DSP. So here no need of additional sensors.

V.   CONCLUSION

A multi-input inverter for the hybrid PV/wind power system is explained. Power from the PV array or the wind turbine can be delivered to the utility grid individually or simultaneously. MPPT feature can be realized for both PV and wind energy. A large range of input voltage variation caused by different insulation and wind speed is acceptable. The perturbation and observation method is adopted to realize the MPPT algorithm for the PV array and the wind turbine. Simulation results for open loop operation shown in fig.10 to verify the performance of the multi-input inverter. The efficient control of Wind/PV system with closed loop operation of multi input inverter and simulation results for closed loop is shown in fig12.Thus the performance of the multi-input inverter and the maximum constant output power is obtained for the different variable input conditions.

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