Hybrid Renewable Energy System: Optimum Design, Control and Maximum Utilization with SIBB Converter using DSP Controller

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Abstract—**Global warming and the shortage of fossil fuels increase the usage of renewable energy resources to satisfy the future energy demand of our depleting planet. This paper presents an innovative Switching logic for hybrid Distributed Energy Generators (DEG) by using a Single Input Buck-Boost (SIBB) converter and DSP controller based on their availability. With this proposed logic maximum amount of energy is extracted from the renewable energy resources depend on their availability. The combination of suggested switching logic and circuit configuration allows the two renewable energy resources, to supply the load individually or simultaneously based on the availability. The fast operation and reliability of DSP controller is utilized to increase the efficiency of the proposed system at the most. At any given instant to achieve extreme system efficiency three different modes of operations are projected. To analyze the real time feasibility of this logic the system is simulated by using MATLAB/Simulink 2010a; and the obtained results are studied and presented in the past. In laboratory a hardware model of the system is developed along with integrating the switching logic proposed for the learning of system in contradiction of the real world conditions. The results attained are discussed and presented in this paper.**

Keywords-DEG; DSP controller; Single Input Buck-Boost converter (SIBB)

I. INTRODUCTION

Rapid development of industries and the uncontrolled growth of population dramatically increase the energy utilization of our biosphere. Renewable energy resources are the best alternatives to satisfy our future energy demand. But the highly unpredictable nature restricts us to use them in our desired fashion. By considering this unavoidable and unpleasant task, this new switching logic is developed and proposed in this paper to utilize the renewable energy resources in optimum manner, depends on their availability with the help of a DSP controller.

Because of holding more advantages on production, maintenance, etc., wind and solar are considered as predominant resources when compared with others. Still in this field many studies are carrying on to improve the system efficiency of the systems using wind and solar as power feeders. Since the presence of these resources is highly irregular in nature due to the natural elements such as trees, buildings, clouds, etc. The growth of power electronics techniques and digital control methods helps us to develop some circuit models to improve the efficiency of hybrid system [1] – [16].

MPPT algorithm is one powerful suggestion for stand-alone Solar systems to improve the efficiency. Photovoltaic systems with MPPT technique was developed [1] – [3] to achieve high performance in actual field. In the similar way wind energy schemes are also developed [4] – [5] with some control algorithms. To get optimum efficiency under unpredictable nature also some systems are developed by combining wind and solar and they are globally called as Hybrid systems [6] – [8]. Some studies are carried out for the better understanding of the characteristic features of solar cell and hybrid systems under different working scenarios [9] – [11]. By understanding the intermittent nature of resources, the energy is stored in battery-banks, when it is available. A new digitally controlled battery storage system was developed in [13] and a better battery charge control technique along with its control algorithm is discussed in [12]. Some circuit models using multi-input converters for hybrid systems along with their benefits are listed [14] – [15].

In this paper, a switching logic using DSP controller along with a single input buck-boost converter is proposed, which can deal with photovoltaic power and wind energy resources individually or simultaneously based on their availability at that given instant. The authors have already projected the idea and simulation in [16] and the implementation of the same is carried out in this paper.Based on the idea proposed in the past, the system is designed to extract energy to the maximum level from the renewable sources. At the maximum availability of both sources, system will supply the load directly from the wind and the remaining energy from solar is stored in battery for future use. To effectively increase the maximum efficiency of the system a dsPIC30F4011 is used as controller for the whole system control. This controller is comparatively of less size than the conventional controller, hence the converter volume is reduced, but the system reliability is improved considerably.

978-1-4799-3421-8/14/$31.00 ©2014 IEEE

II. System Architecture

The proposed switching logic is integrated with a SIBB converter model for the maximum extraction of energy from hybrid renewable energy resources. Fig. 1 illustrates block diagram of the hybrid renewable energy system. The major circuit elements are of a PV array, a wind energy generator, a single input buck-boost converter, DSP controller and a battery with charger. The controller generates the control signal depends on the availability of resources by doing all required power calculations, to achieve optimum efficiency. The resource available with required power level is connected to the active system to supply the load and the mode of operation preferred will be selected by the controller.

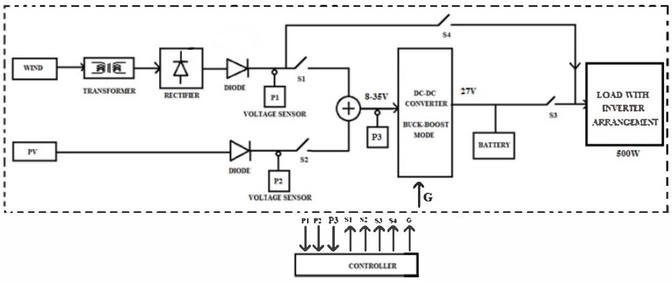


Fig 1. Block diagram of the proposed system

III. Principle Operation of the Proposed System

A pictorial representation of a single input buck-boost converter used for the proposed system is given in Fig. 2. To achieve optimum performance with improved efficiency, the system is intended to operate under three different modes of operation. The control signal generation, for the selection of available energy resource and the regulation of output voltage of the dc-dc converter is controlled by the dsPIC30F4011 DSP controller. The three different possible modes of operations [16]discussed above are described in the followings.

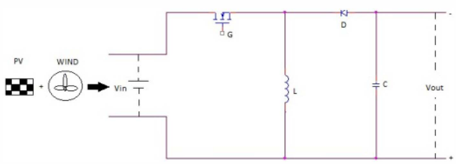


Fig 2. Single input Buck-Boost converter of the proposed hybrid system

Mode1: Stand alone mode

The sensor inputs are instantly monitored by the controller to check the availability of resources. To avoid overloading, when any one of the sources is not available, i.e. less than the minimum rated input of the converter (8V), the controller is programmed to disconnect that particular resource from the active system. On the other hand available resource (wind or solar) will be connected to the active system to meet the load demand.

Mode 2: Hybrid mode

When both the sources are available (>8V) at any instant, but less than the maximum rated input voltage of the buck-boost converter (35V), then the control signal generated by the controller connect both the resources to the active system and they together supply the power to the load. In parallel battery will store energy for the future demand (Power shut-down period).

Mode 3: Direct On-Line mode

At any point of time, both sources are available with their maximum power level, then the controller is programmed to generate control signal to connect the wind energy alone to supply the load directly, and the photovoltaic power is used to charge the battery bank to satisfy the energy demand in the power off period. Because of this innovative idea the utilization and efficiency of the hybrid system can be improve to a substantial level. The power flow control of this proposed system is described in Table 1.

TABLE I. Flow of Power Control

	Low (< 8V)	**Medium (8<V<35)**	**Maximum (=35V)**
Wind	Not Connected	Connected	Connected (Power directly fed to the Load)
Solar	Not Connected	Connected	Connected
Battery	Discharging	Charging	Charging by using Solar Power

IV. Design of SIBB DC-DC Converter

The design of SIBB circuit parameters for real time system operations are discussed in this section. The circuit model this proposed hybrid renewable energy system is designed to operate in a voltage range of 8-35V. Some of the important circuit parameters are listed as follows:

PV panel voltage	: 20V
Wind turbine voltage	: 15V
Battery	: 24V (as a load)
Switching frequency	: 21.5 kHz

Regulated output obtained from the dc-dc converter is used to charge the battery and supply the load connected. The duty cycle range of dc-dc converter is calculated based on the relation given in equation (1).

$$d = \frac{V_o}{V_d} = \frac{d}{1-d} \tag{1}$$

The duty cycle (d) range of the proposed SIBB converter is 0.44 - 0.77 obtained from (1). Along with this the design specifications considered are 10% of maximum output current (I_{max}) as ripple current through the inductor and 10% of output voltage (V_o)as ripple voltage across the capacitor.

$$L = \frac{V_o(1-d)}{\Delta I_l * f_s} \tag{2}$$

$$C = \frac{I_o * d}{\Delta V_o * f_s} \tag{3}$$

Equations (2) and (3), are used to compute the values of inductor and capacitor of the dc-dc converter respectively, and their values are expressed below

Output inductance (L)	: 7mH
Output capacitance (C)	: 72µF.

V. Flowchart

Fig. 3 demonstrates the flowchart of the projected hybrid system. To increase the system efficiency, the DSP controller is programmed to generate the appropriate control signals to the switches and for the SIBB converter to extract maximum energy from the renewable resources and for regulating the output voltage, thus increasing the system efficiency by better utilization of resources. The flowchart describes the switching logic behind the proposed idea and concept behind the selection of available renewable energy resources to the active system, as well as the possible modes of operations desired for this configuration.

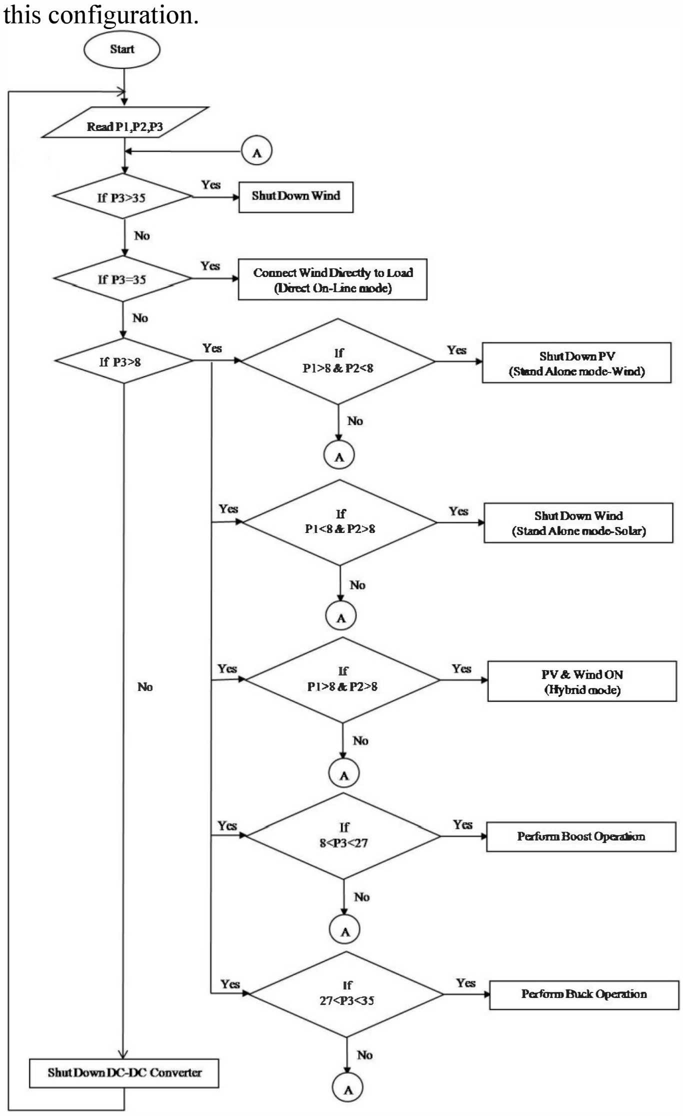


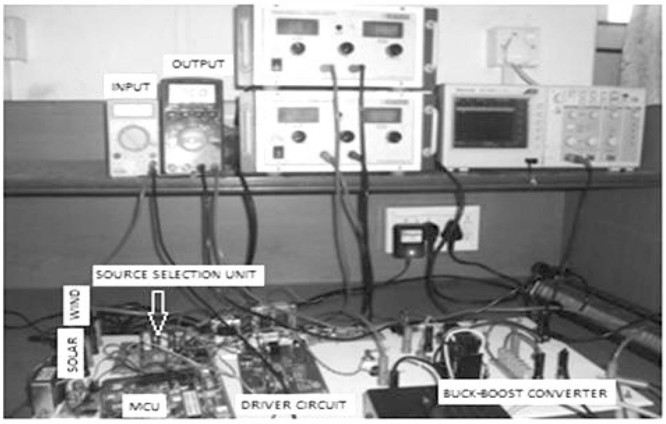
Fig. 3. Flowchart of the proposed hybrid system

VI. SIMULATION RESULTS

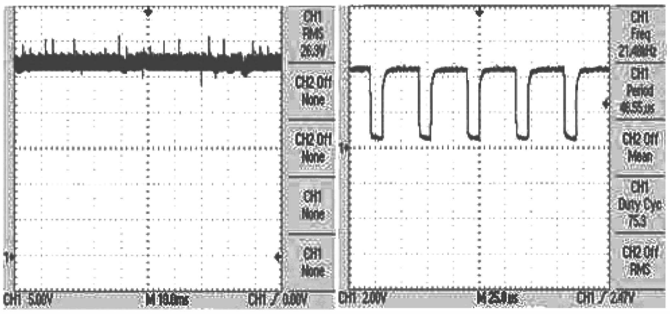
The adaptability of this hybrid system proposed is studied by simulating the circuit model against the different possible real world situations using MATLAB/Simulink 2010a. The open loop simulation study of hybrid, stand-alone system was carried out by the authors and the results obtained are analyzed in [16].

VII. HARDWARE IMPLEMENTATION AND ANALYSIS

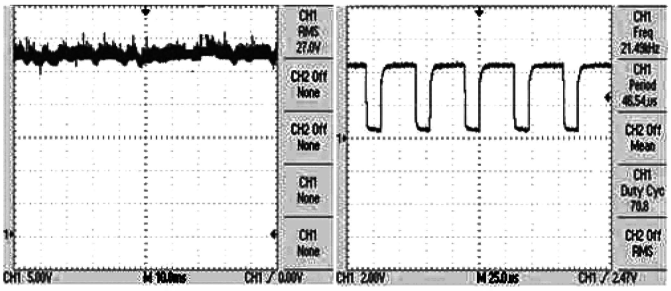
For better analysis of the proposed system under field conditions, a hardware arrangement of whole system is developed with AC and DC input sources as equivalent for wind and solar energies. The control signal generation for source selection, operation of dc-dc converter under buck and boost modes and the regulation of output voltage of the converter are analyzed and tested against real world conditions. Fig. 4(a) shows the hardware circuit configuration and the output waveforms of the system. The results obtained in different real world conditions such as, only with wind, only with solar and hybrid sources under different power levels of the sources are specified in Fig.4 (b) –(d). Both the sources are tested for medium and maximum power levels individually, simultaneously and the respective switching logic also checked for the described power levels.



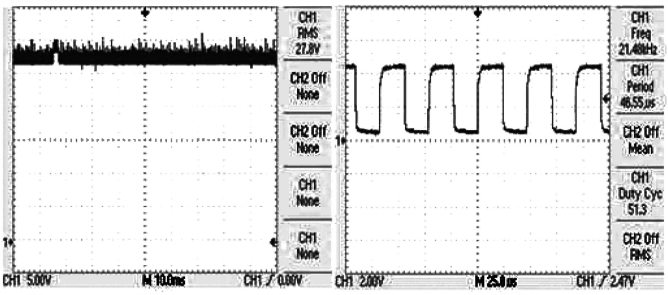
(a) Hardware Model-SIBB Hybrid System



(b) Output voltage, switching pulse waveforms of Standalone system with only Wind (Input = 14V)



(c) Output voltage, switching pulse waveforms of Standalone system with only Solar (Input = 18V)



(d) Output voltage, switching pulse waveforms of Hybrid system with Wind and Solar (Input = 34V)

Fig. 4. Hardware arrangement and Output waveforms of the whole system

VIII. ANALYSIS

System efficiency always has a special attention, while applying any new approach in practical. Based on this factor a detailed study is carried out on the proposed system and the efficiency of the converter as well as the system is calculated under all modes explained above with different source availability. Figure 5 shows the whole system efficiency and converter efficiency of the model developed in the laboratory. The proposed model is suitable for household lighting applications as well as all small power applications integrated with renewable sources. The system efficiency is 72% and is high when compared with 68% and 58% efficiency of the system with solar energy and wind energy alone available. In productive level the efficiency can be increase to 5-7% also.

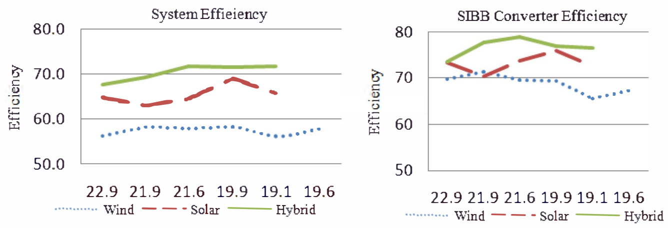


Fig. 5. Efficiency graph of the whole system

IX. CONCLUSION

This paper presented an idea on Hybrid renewable system with SIBB converter controlled by dsPIC30F4011 controller to extract maximum energy from renewable energy resources based on their availability. Laboratory hardware model of the proposed system is developed and the results obtained under different field conditions are discussed and presented in this paper.Also a study on efficiency of the system is done and the consequences on efficiency are plotted for better analysis of the hybrid system. The efficiency graph is an evident proof to justify the validation and real time feasibility of the proposed new model. The system modeldeveloped in laboratory has taken due care on all real time non-linearity's and hence can deals with PV power and wind energy individually or simultaneouslyat various atmospheric conditions. The system proposed in this paper increases the reliability of the system to a greater extent. The hybrid system is 10% more efficient than wind energy fed systems and 4% more efficient than a solar fed system.

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