Simulation and Hardware Implementation of FPGA Based Controller for Hybrid Power System

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Abstract—Fossil fuels leave behind harmful by-products upon combustion, thereby it causes a lot of pollution. Renewable energy is gaining more importance these days. But the problem with the renewable energy systems is its intermittent availability. Hybrid power system which combines various renewable sources is the next available option. This paper discusses the scheme of Solar-Wind Hybrid power system using multi-input power converter topology. Simulations are carried out using MATLAB/SIMULNK. Charge controllers are implemented with MPPT algorithm. The hardware implementation of the controller is done using FPGA controllers. The experimental details are given and the results are discussed.

Index Terms—hybrid power system, PV, solar, wind, MPPT, controller, FPGA

I. INTRODUCTION

Fossil fuels leave behind harmful by-products upon combustion, thereby it cause a lot of pollution. While burning, it produces carbon dioxide which is a major cause of global warming and it is running out and new energy sources need to be used such as solar and wind energy. [1] There is a huge potential for utilizing renewable energy sources, for example solar energy, wind energy, or micro hydropower to provide a quality power supply to remote areas. The abundant energy available in nature can be harnessed and converted to electricity in a sustainable way to supply the necessary power to elevate the living standards of the people without access to the electricity grid. The advantages of using renewable energy sources for generating power in remote areas are obvious such as the cost of transported fuel are often prohibitive fossil fuel and that there is increasing concern on the issues of climate change and global warming. The disadvantage of standalone power systems using renewable energy is that the availability of renewable energy sources has daily and seasonal patterns which results in difficulties in regulating the output power to cope with the load demand. Combining more than one form of the renewable energy generation and also conventional diesel power generation will enable the power generated from a renewable energy sources to be more reliable and affordable. This kind of electric power generation system, which consists of renewable energy and fossil fuel generators together with an energy storage system and power conditioning system, is known as a hybrid power system. [2] This paper elaborates on the analysis of small capacity hybrid power system for supplying electricity and clean water demand in rural and remote areas by using mini-grid hybrid power system consisting of renewable energy (Solar Photovoltaic cells & Windmill) and battery with a reverse osmosis desalination plant as a primary/deferrable load. Renewable energy is becoming more important nowadays. It will find out the alternative method for power demand in the world. Solar and wind energy is the most important energy resource since it is clean, pollution free and inexhaustible.

This paper presents a FPGA based real time control using designed for hybrid power system to achieve the maximum power without affecting the efficiency of the system.

II. OPERATION OF THE PROPOSED SYSTEM

A. Solar Energy

The solar panels consist of solar cells. When the sun energy is illuminated to solar cell the source of current due to the separation of excited electrons and holes take place. This is due to the built in electric field of the p-n junction present at the depletion region. It will produce current by the photovoltaic effect. The output of the current source is directly proportional to the light falling on the cell. During darkness, the cell is not active, it work as a diode (i.e.,) a p-n junction. Thus the diode determines the I-V characteristic of the cell. Fig. 1 gives the equivalent circuit of PV cell. The output current I and the output voltage of a solar cell is given by,

\[ I = I_{pht} - I_{do} \left( \exp \left( \frac{qV_{do}}{n \cdot k \cdot T} \right) - 1 \right) \left( \frac{V_{do}}{R_{sh}} \right) \]  

(1)
here $I_{ph}$ is the photo current, $I_o$ is a reverse saturation, $I_{do}$ is the average current through the diode, $n$ is the diode factor, $Q$ is the electron charge ($q=1.6\times10^{-19}$), $K$ is Boltmann’s constant ($k=1.38\times10^{-23}$), $T$ is the solar array panel temperature, $R_s$ is the intrinsic series resistance of the solar cell, $R_{sh}$ is the equivalent shunt resistance of the solar array.

If the circuit is shorted the output voltage $V=0$, the average current through the diode is generally neglected, the $I_{sc}$ is expressed as,

$$I_{sc} = I = \frac{I_{ph}}{1 + \frac{R_s}{R_{sh}}}$$  \hspace{1cm} (3)

Finally the output power $P$ is expressed by,

$$P = VI = \left(I_{ph} - I_{do} - \frac{V_{do}}{R_{sh}}\right)V$$  \hspace{1cm} (4)

**MPPT algorithm**

MPPT algorithm is implemented to maximize the power output from the PV cells with varying radiations. We chose Perturb & Observe (P&O) algorithm for its simplicity in implementation. In this algorithm, we measure the PV array voltage and current. The cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less. Since there are two individual input sources, each one of them needs a real time controller. By using the MPPT algorithm shown in Fig. 2, the controller is designed to obtain the maximum power. [3]-[6]

![Flow chart of the MPPT algorithm with P&O method for solar cell.](image)

Initially we sense the, the output voltage $V_{dc}$ and output current $I_d$ of the solar energy. From this the output power $P_0$ can be calculated is shown in Fig. 3. At each point of output power the maximum power is measured by using the P&O method shown in the flow chart Fig. 2. We can determine the value of reference current to adjust the output power toward the maximum point. [7]-[13]

**B. Wind Energy**

The first important factor is to obtain the reference power curve for MPPT. The second factor is whether the generator speed and output power will converge to the points along this reference power curve regardless of the wind variations. [14]
The optimal reference power curve $P_e(w_m)$ is obtained by finding the optimal power ($P_{opt}$) and optimal generator speed ($w_{mopt}$) for any given wind speed ($V_m$). For a given $V_w$, the generator speed $w_m$ is swept, and the output power $P$ is observed. The $w_m$ and $P$ that would give the $dp/dw_m=0$ are selected as $w_{mopt}$ and $P_{opt}$ for the specific $V_m$. By repeating the same procedure for different $V_m$, a fitting curve can be obtained by connection all optimal operating points ($w_{mopt}$, $P_{opt}$). The fitting curve is then used as reference power curve $P_e(w_m)$. The procedure for preparing the $P_e(w_m)$ curve is summarized in where $k$ and $I$ are the indices of operating point and wind speed is shown in Fig. 4. Since this is an offline procedure, the measurement and calculation will not affect the online system operation speed. [15]

MPPT algorithm

The performance of wind turbine under reference power curve MPPT power control is showed in Fig. 5. The MPPT process is based on monitoring the WG output power using measurements of the WG output voltage and current and directly adjusting the power converter duty cycle according to the result of comparison between successive wind output power values. In this proposed system the reference electrical power $P_e$ is dependent on $w_m$ according to the polynomial,

$$P_e = b_1 w_m^3 + b_2 w_m^2 + b_3 w_m + b_4$$

(5)

where the coefficients $b_1$ to $b_4$ are determined by the fitting curve of optimal operation point connection. The mechanical model that connects the wind turbine shaft and generator rotor can be written as:

$$J \frac{d w_m}{dt} = T_m - T_e - B_w$$

(6)

where $J$ denote the inertia of the combined system, $B$ is the damping coefficient, $w_m$ is the generator rotor speed, and $T_m$ and $T_e$ represent the turbine and generator torques, respectively.

The MPPT algorithm using P&O method for wind energy flow chart is shown in Fig. 6.
The turbine performance coefficient \( C_p(w_m, V_m) \) and is expressed as follows,
\[
C_p(w_m, V_m) = c_1 \left( \frac{c_2}{\lambda_p} - c_3 \beta - c_4 \right) e^{-c_5 \lambda_i} + c_6 \lambda
\]  
(7)
where \( \lambda = (w_m R/V) \), \( \beta \) is the pitch angle, and \( c_1-c_6 \) are the coefficients determined by individual turbine characteristics.

III. PROPOSED HYBRID POWER CONVERTER AND CONTROL SYSTEM

The basic block diagram is shown in Fig. 7. The input for solar energy is irradiance \( (I) \), temperature \( (T) \) for wind energy input is \( (W) \). In this proposed system the FPGA send the control signal for each block. From the MPPT algorithm the controller will take the input signal to extract the maximum power and sent it to load. At every variation in the solar and wind energy, the controller will get the information without losing any power and store the energy in battery. The charging and discharging of the battery is also noted, under certain condition there will not be maximum power in the output power characteristic. [16], [17] Therefore, the battery will transfer the energy to load. For power converter circuit, the controller will generate a PWM signal. Most real time control systems, particularly power electronics and ac motor drive application require fast processing the FPGA can achieve higher performance with faster control and more advanced control is implemented. FPGA avoid high initial cost, lengthy development cycle and inherent flexibility of conventional ASIC control schemes proves less costly and hence they are economically suitable for small designs. It also increases the overall efficiency and machinery lifetime.

The maximum power is extracted by a real time supervisory control using FPGA. It is a reconfigurable device, which can be reprogrammed in actual application field. FPGA offers the most preferred way of designing ADPID controller for temperature control application. They are basically interconnection between different logic blocks, When design is implemented on FPGA they are designed in such a way that they can be easily modified if any need arise in future. We have to just change the interconnection between these logic blocks. This feature of Reprogramming capability of FPGA makes it suitable to make your design using FPGA. Also using FPGA we can implement design within a short time. The FPGA tools are powerful for building system with the flexibility of digital and the speed of analog.

![Figure 7. Basic block diagram for proposed system](image)

![Figure 8. Schematic diagram of the converter system](image)
The schematic diagram of the proposed converter topology that takes both the Solar PV and Wind inputs is shown in Fig. 8. The topology consists of a buck/buck-boost converters that are fused together to receive two inputs simultaneously. [18] The input dc voltage sources are obtained from the PV array and the rectified wind turbine generator output voltage. By applying the PWM control with MPPT algorithm the power switches S1 and S2, the double input dc-d converter can draw maximum power from both the sources. The uniqueness of this topology is that the power can be drawn individually or simultaneously.

IV. SIMULATION AND HARDWARE IMPLEMENTATION OF PROPOSED SYSTEM

The proposed two input converter has been simulated using the MATLAB/SIMULINK. The simulation is shown in Fig. 9.

A dc supply is given as the input, with different voltage source. A resistive load is connected to the output. The two MOSFET switches S1&S2 are connected to pulse generator are used to control the conduction period and hence control the frequency. The capacitance current will compensate the unfiltered output current then a stable DC load current can be obtained. The simulation model using MPPT is shown in the Fig. 10.

The output waveform is obtained from both of two voltage sources to the load simultaneously. The output waveform for voltage and current is simulated and given in Fig. 11a and Fig. 11b.

Simulation parameters:

- Supply voltage:
  - DC source1 = 20V
  - DC source2 = 60V
- Pulse generator:
  - Switching Frequency = 50KHz

Figure 9. Simulation model for converter system under study

Figure 10. Simulation model for converter system under study
Pulse width = 50 seconds

- Output voltages = 36V

Figure 11a. Output voltage waveform

Figure 11b. Output current waveform

The control signal using FPGA is shown in Fig. 12. It has to control the power converter circuit and deliver the power to load. Interfacing hardware with FPGA is a challenging work using renewable energy as input source. The every module of circuit is controlled by the control signal the maximum power is extracted from the solar and wind energy.

Figure 12. Controller output signal

V. EXPERIMENTAL RESULTS

To verify the performance of the power converter circuit, a prototype circuit with the following specifications is implemented. Various input conditions were tested to study the performance of the circuit.

Case 1: Input dc voltage: \( V_1 = 15V \), \( V_2 = 30V \). Output dc voltage: \( V_0 = 22V \). Input current: \( I_i = 1A \). Output current, \( I_o = 2.5A \). Switching frequency, \( F = 50KHz \). Fig. 13a shows the measured waveforms of output voltage and current. It reveals that the power converter can deliver power from both of the two voltage sources to the load simultaneously.

Figure 13a. Case 1 - Experimental result of DC voltage and current waveform

Figure 13b. Case 2 - Experimental DC voltage and current waveform
The power quality of a system is increased when compared with the single input sources. It can be reduced significantly at turn-off transition simultaneously.

It reveals that the power converter can deliver power from both of the two voltage sources to the load simultaneously.

It can be seen that the switching loss of each power switch can be reduced significantly at turn-off transition with the passive lossless soft-switching cell. The power converter with multi input renewable source has more efficient, when compared with the single input sources. The power quality of a system is increased, it can deliver the power to load by utilizing both or single sources.

REFERENCES


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