Modeling and Simulation of SEPIC Converter for Hybrid Energy System

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Abstract. Industrialization & urbanization of India leads to increase in the demand for electricity. Due to abundant availability in nature renewable energy sources are considered to be an better option over conventional energy sources. Solar-Wind energy systems combines two of the renewable energy technologies. Because of this the inherent nature of wind and solar power production can be levelled out all throughout the day. This system is used to generate and maximize power from solar and wind energy with MPPT using incremental conductance algorithm and it is given to the DC Motor and also battery is used for storage purpose. Simulation was carried out using MATLAB/Simulink and a prototype model of hardware setup is developed with PIC16F877A controller.

Keywords – Hybrid system, MPPT Algorithm (Incremental conductance), SEPIC converter, DC-DC converter, Battery.

1. Introduction

Due to increased availability of light energy from the sun during day time and kinetic energy from the wind during night time these two energy sources are considered as a Renewable energy which is an alternative source to non-renewable energy sources[1]. The power produced from the wind energy varies from year to year and it is also not constant even for short time period. The disadvantages associated with the wind and solar energy systems like instability of operation when connected to the grid, intermittency a new hybrid method of renewable energy system with storage unit is proposed in this project. During day time maximum solar energy is available compared to wind energy, similarly at a night time maximum wind energy is available with minimal solar energy, so this helps to overcome the intermittency of solar and wind energy[2]. Combination of solar, wind and storage batteries are found to be an effective one to overcome the above difficulties and it is applicable for remote areas. By using storage batteries the intermittency of solar and wind energy can be eliminated. Nowadays many power converters like Z - source converter, CUK converters are available to interface the two renewable energies along with the batteries. Even though Z - source converters are best suited but, it has the problem of leakage current[3,9,10]. Hence for this project SEPIC converter is used. In this project the sources are not connected to the grid but it is connected to the DC motor which is acting as a load and also battery is used as a storage device. Depending upon the maximum power availability the PIC16F877A controller selects the type of the source to which the load is to be
connected. The battery will be charged or discharged based on the level of dc bus voltage. Thus the charging and discharging of the battery is done based on the level of dc bus voltage. This is done using the PIC16F877A type controller. The bus voltage is determined by the voltage level in the battery. Hence PIC micro controller is used to control both the sources and also it is used to satisfy the load requirement periodically. It is also used to manage the state of charging of the battery.

2. SEPIC Converter

The single-ended primary-inductor converter (SEPIC) shown in figure 1 is a DC – DC converter which can operate either as a buck or as a boost converter depending upon the duty cycle.

![Figure 1 SEPIC Converter](image)

The output voltage of the SEPIC converter is increased or decreased by changing the value of the duty cycle (D) of MOSFET. It is useful in applications such as battery voltage can be below or above the regulators intended output. SEPIC exchanges energy between the inductors and capacitors in order to convert from one voltage to another voltage. The amount of energy exchanged is controlled by switch S1, which is typically a transistor[4].

This SEPIC converter has two modes of operation.

(i) When the switch is ON

![Figure 2 When the Switch S1 is closed](image)

In this mode, the switch S1 is switched ON, current in inductor L1 i.e. I_{L1} increases and current in inductor L2 i.e. I_{L2} goes more negative. The current I_{L1} comes from input source. Hence when S1 is closed, instantaneous voltage V_{L1} is approximately equal to V_{IN} and voltage V_{L2} is approximately equal to V_{C1}. Then, capacitor C1 and D1 is opened due to which the energy stored in L2 and magnitude
of current in I_{L2} is increased. I_L is supplied by C_2. Consider the bias voltage of circuit in a D.C. state, then close S_1.

ii) When the switch is OFF

![diagram](image-url)

Figure. 3 When the Switch S_1 is Open

In this mode the switch S_1 is switched OFF, the current I_{C1} is equal to current I_{L1}. The current I_{L2} will continue in flow in negative direction. The negative I_{L2} will add to the current I_{L1} to increase the current delivered to load. According to this, power is delivered to load from both L_1 and L_2 while S_1 is OFF. During the OFF cycle C_1, is being charged by L_1 and will turn recharge L_2 during the cycle[5,11].

2.1. Design of open loop SEPIC converter:

Inductor Selection:

The ripple current value in inductor L_1 and L_2 is given by

$$\Delta I = I_{in} \times 25\% = \frac{I_{out} \times V_{in}}{V_{in}} \times 25\%$$

The inductor value calculated by

$$L = \frac{V_{in}}{\Delta I} \times L \times D_{min}$$

The peak current in inductor is given by

$$I_{L1(peak)} = I_{out} \times \frac{V_{out} + V_D}{V_{in(min)}} \times \left(1 + \frac{25\%}{2}\right)$$

$$I_{L2(peak)} = I_{out} \times \left(1 + \frac{25\%}{2}\right)$$

Here maximum input current = 1.25 A

$$L_1 = L_2 = \frac{12}{25} * 0.464 = 0.866mH$$

$$I_{L1(peak)} = 1 * \frac{14 + 4}{12} \times \left(1 + \frac{25\%}{2}\right) = 1.35A$$

$$I_{L2(peak)} = 1 * \left(1 + \frac{25\%}{2}\right) = 1.125A$$

Coupling Capacitor Selection:

The selection of coupling capacitor C_s depends on the RMS current and is given by
The peak to peak ripple voltage on $C_s$ is

$$\Delta V_{ss} = \frac{I_{out} \cdot D_{max}}{C_s \cdot F_{TV}}$$

Output Capacitor Selection:
The output capacitor should be capable of handling high value of rms current given by

$$I_{out(rms)} = I_{out} \cdot \sqrt{\frac{V_{out} + V_d}{V_{in(min)}}}$$

Input Capacitor Selection:
The rms value of current in the input capacitor is given by

$$I_{cin(rms)} = \frac{I_{cin}}{\sqrt{2}} = 0.072A$$

Input capacitor value is 10 micro farad

| S. No. | Parameters | Value       |
|--------|------------|-------------|
| 1      | Input voltage, | 350V        |
| 2      | Output voltage, | 300V        |
| 3      | Output current, | 60A         |
| 4      | Frequency, $f$ | 50 kHz      |
| 5      | Duty cycle, $D$ | 0.46        |
| 6      | Inductance, $L_1$ | 0.28H   |
| 7      | Inductance, $L_2$ | 0.28H   |
| 8      | Capacitance, $C_1$ | 0.059mF |
| 9      | Capacitance, $C_2$ | 1mF      |
| 10     | Resistance, $R$ | 5Ω         |

3. Solar and Wind Energy

The Solar PV cell converts the heat energy from the sun into an electric energy through Photovoltaic effect. Photovoltaic effect means that generation of voltage form the heat energy emitted from the sun. The solar cells are made of semiconductor materials if it is connected in series and in parallel combination and when exposed to sunlight it generates voltage due to that current flow across the load[6,7].

The V-I equations of solar cell is

$$I = I_L - I_D$$  \hspace{1cm} (1)

$$I = I_L - I_S \left( e^{\frac{V}{E_T}} - 1 \right)$$  \hspace{1cm} (2)

The wind energy system is shown in figure 4. The kinetic energy of the wind and wind turbine is the main source of wind energy. The equation of wind turbine is
The wind turbine provides the mechanical power which is converted to electrical power through permanent magnet generator.

To convert the kinetic energy into mechanical, the wind turbine is used. Where the value of wind turbine power $P_m$ is

$$P_m = \frac{1}{2} \rho AV^3$$  \[3\]

Here, $\rho$ air density, $A=\pi R^2$ turbine’s blade swept, Where $V$ speed of the wind, $C_p(\lambda,\beta)$ Power coefficient $\lambda$ tip speed ratio and $\beta$ pitch angle[6,8].

The parameters of autonomous control PMSG wind turbine.

Table: II Design Specifications for Permanent Magnet Generator

| S. No. | Parameters                  | Assigned Values |
|--------|-----------------------------|-----------------|
| 1      | Rated voltage of stator     | 5KV             |
| 2      | Rated frequency of stator   | 50Hz            |
| 3      | Rated rotor torque          | 450N·m          |
| 4      | Stator phase resistance     | 0.01Ω           |
| 5      | Armature inductance         | 0.03H           |
| 6      | $d$-axis inductance         | 5.5 mH          |
| 7      | $q$-axis inductance         | 3.75 mH         |
| 8      | Number of poles             | 56              |

4. MPPT for Solar and Wind System

The disadvantage of perturb and observe algorithm is that it is difficult to obtain the peak power during high variation in the atmospheric temperature or irradiance. This disadvantage is overcome by IC algorithm. In the IC algorithm initially the Maximum power point is obtained from the $V_p$ and
I_p after that no tracking is done. If this condition is not met, then the direction in which the operating point must be perturbed is calculated using the relationship between \(\frac{dI}{dV}\) and \(-\frac{I}{V}\). If the value of \(\frac{dP}{dV}\) is negative then the MPP is shifted to right or if the \(\frac{dP}{dV}\) is positive then the MPP is shifted to the left. The characteristic of IC algorithm is shown in figure 5. The flow chart of the IC algorithm is shown in figure 6.

![Figure 5 V-I Characteristics of IC Algorithm](image)

![Figure 6 Incremental conductance algorithm](image)

5. Simulation Results
The design specification for the solar cell is given shown in table II. The DC output voltage obtained from the solar module is 350 V. This voltage is given to the SEPIC converter and the output obtained by the boost converter is 300 V.
### Table: III Design Specifications of Solar Cell

| S. No. | Parameters | Values |
|-------|------------|--------|
| 1     | $V_{OC}$: Open Circuit Voltage | 21.1V  |
| 2     | $I_{ph}$: Photocurrent function of irradiation and junction temperature | 5 A    |
| 3     | $I_s$: Reverse Saturation Current of Diode | $2 \times 10^{-4}$ A |
| 4     | $I_{sc}$: Short Circuit Current | 3.8 A  |
| 5     | $T_{REF}$: Reference Operating Temperature of Cell | 25 °C  |
| 6     | $R_{sh}$: Shunt Resistance of Cell | 360.002 Ω |
| 7     | $R_s$: Series Resistance of Cell | 0.18Ω  |
| 8     | $E_g$: Energy Band Gap | 1.12 eV |
| 9     | $k_B$: Boltzmann constant | $1.38 \times 10^{-23}$ J/K |
| 10    | $k_i$: Current Proportionality constant | $2.2 \times 10^{-3}$ |
| 11    | $k_v$: Voltage Proportionality constant | $73 \times 10^{-23}$ |
| 12    | $q$: Electron charge | $1.602 \times 10^{-19}$ C |
| 13    | $G$: Irradiance | 100W/m² |
| 14    | $C$: No. of cells in Module | 36     |

Figure 7 Equivalent circuit of solar cell in MATLAB/SIMULINK
The specifications for wind are given in table II. Permanent Magnet Synchronous generator is used to obtain the electrical output from the wind. The three phase 440 V is rectified using Universal bridge rectifier and it is given to the SEPIC converter. Thus the combined output of the both the converter is 300 V and it given to the Battery and also to drive the DC motor.
Figure 10: $V_{dc}$ graphs of solar and wind models.

Figure 11: State of Charging the Battery
The speed of rotation of the dc motor is around 2000 rpm and the electromagnetic torque 5 N-m. The armature current consumed by the motor is 17 A. The voltage level of the battery is around 120 V as shown in figure 10. In this paper the result obtained was not compared with the other converters. Also the THD, % of efficiency of the converter are not discussed for this basic level.

6. Prototype Hardware Setup

When the sunlight falls on the solar panel, it generates voltage and current in a specific range and then it is given to a boost converter. The output of boost converter is given to a load (DC Motor) and also it is stored in a battery for later use. The controller used to control the output of both the converter is PIC16F877A. The duty cycle set for the converter is 0.45.
Thus this paper focuses mainly on the configuration of wind turbine and solar energy along with MPPT controller. The converter used to achieve the 300 V output is SEPIC converter. The simulation is carried out using Matlab/Simulink module. The output obtained from both the energy sources are combined and fed to the battery. Simulation results shows that the voltage around the battery is 120 V which is feasible. Prototype hardware setup was implemented using PIC16F877A microcontroller.

8. References

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