Design and Performance Analysis of SEPIC Converter With Different MPPT Control Algorithms For Hybrid Solar-Wind System

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Abstract
In this paper, the simulation model of a Single Input Primary Inductor Converter(SEPIC) with various Maximum Power Point Tracking(MPPT) control algorithms for a hybrid solar-wind system is presented and the performance of the SEPIC converter is studied with those MPPT control algorithms for a DC load(R-Load). The output voltage of a hybrid solar-wind system is weather dependent and intermittent, which is an inherent disadvantage. This problem can be solved by using an MPPT control algorithm-based SEPIC converter which provides interfacing between a hybrid solar-wind system and DC-load. Regardless of variations in weather, it a steady voltage at the output. Separate SEPIC converters have been designed for solar and wind power systems. To get the most power ouof the hybrid solar-wind system, MPPT control algorithms are used. The perturb and observe(P&O) control method and the neural network-based MPPT control algorithm are the MPPT control techniques applied to extract maximum power from the system. Different MPPT control algorithms based on SEPIC converters are simulated with MATLAB using SIMULINK for DC load(R- load).

Keywords: Hybrid Solar-Wind System, SEPIC Converter, MPPT Control techniques, Perturb and Observe Control Algorithm, Neural Network-Based MPPT Control Algorithm

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1 Introduction

The wider applications of non conventional(or) renewable energy technologies for energy production have significantly helped in reducing the need for fossil fuels. Integration of solar energy and wind energy system helped in increasing the reliability of the power generating system, and better use of the capital resource[1], [2]. The primary drawbacks of renewable sources are that they are irregular, and electrical energy production depends on weather conditions. The power output developed from non conventional sources such as solar power and wind power systems are unreliable, reducing conversion efficiency. But an improvement in technology in the field of power electronic converters helps in increasing power conversion efficiency. SEPIC, Buck, Boost, Bi-directional, and CUK converters are commonly used DC-DC converters to increase the system conversion efficiency by maintaining the constant voltage at the DC bus[3]. The most commonly used DC-to-DC converter for a hybrid solar-wind system is SEPIC converter. It overcomes the disadvantages of conventional Buck-Boost converters like reversed output voltage, pulsating input Current, and high electric stress on the components. The output voltage of the SEPIC converter can be varied by controlling the duty ratio(D) of the control switch. The MPPT controller is used to draw the max amount of power possible from the two natural sources. Based on the reference signal derived by the MPPT control algorithm, pulse width modulated(PWM) controller generates a duty cycle for the switch of the SEPIC converter[4][5][6][7][8].

The different MPPT control techniques include, the perturb and observe(P&O) control method, the incremental conductance control method, the neural network-based MPPT control algorithm, and the fuzzy logic control method[9][10].

In this project, the perturb & observe control method and the neural network-based MPPT control algorithm used for generating reference signals for the control of the SEPIC converter are analyzed and the performance of the SEPIC converter is studied through design and simulation[11][12].

Section II presents the system configuration, mathematical formulation, and control algorithms used for the simulation model. The simulation model, results, and discussions are presented in section III. Finally, in section IV, conclusions are provided.

2 SYSTEM CONFIGURATION

Figure 1 describes the overview of the proposed hybrid solar- wind system to be simulated.

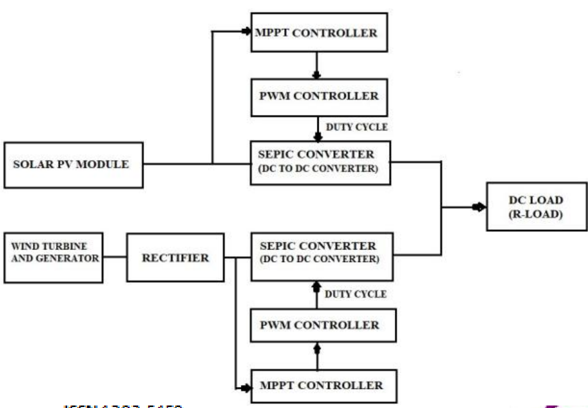


Figure 1 : Hybrid Solar-Wind System with DC load.

The proposed system consists of a solar PV module, wind turbine, permanent magnet synchronous generator(PMSG), three-phase uncontrolled rectifier, SEPIC converter1, SEPIC converter2, and a DC load(R-Load)[13].

2.1 *Design of SEPIC converter*

Figure 2 shows the schematic arrangement of components of the proposed converter. The converter rating is decided by the values of inductors and capacitors present in the circuit[14][15].

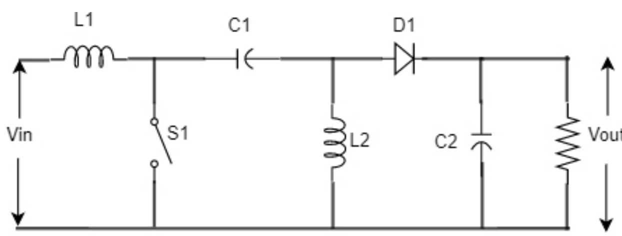


Figure 2 : SEPIC Converter

1. Calculation of Duty Cycle

The equation for the maximum duty cycle for a SEPIC converter is given by

$$D_{max} = \frac{V_{out}+V_D}{V_{out}+V_D+V_{in}} \quad (1)$$

Where V_{in}= Input Voltage

V_{out}= Output Voltage

V_D= Voltage across the diode

2. Calculation of Inductances(L_1&L_2)

The peak-to-peak ripple current flowing in the inductors L_1 and L_2 is given by

$$\Delta I_L = \frac{V_{out}*I_{out}}{V_{in}} \times 40\% \quad (2)$$

Where I_{out}= output current

The equations for inductors(L_1&L_2) are given by

$$L_1 = L_2 = \frac{V_{in}}{\Delta I_L * f_s} \times D_{max} \qquad (3)$$

3. Calculation of Capacitance(C_1)

Capacitor C_1 is called input capacitor(or)coupling capacitor and is given by the equation

$$D_{max} = \frac{I_{out}}{\Delta V_{cs} * f_s} \times D_{max} \qquad (4)$$

Where V_{cs}= The peak-to-peak ripple voltage on capacitor(C_1)

f_s= Switching frequency of the switch

4. Calculation of Capacitance(C_2)

The selection of output capacitance of SEPIC converter depends on ripple voltage(V_{ripple}) and switching frequency(f_s), and it can be calculated by

$$C_2 = \frac{I_{out} * D_{max}}{V_{ripple} * f_s} \qquad (5)$$

Where V_{ripple} is ripple voltage in capacitor C_2 and is approximately equal to 6% of input voltage of the converter

3 MPPT CONTROL ALGORITHMS

The proposed control algorithms for achieving the greatest power from the integrated solar-wind system are described in this section[16].

3.1 *Perturb and Observe Control Algorithm*

Because of its simple form and ease of implementation, this control method is likely the most extensively used. It works by perturbing the dc output power of the SEPIC converter by increasing or reducing the duty cycle(D) and then observing the effect on the output of solar and wind energy systems.The flowchart for this technique is shown in figure 3[17][18].

Figure 5 : Neural network control algorithm for wind power system

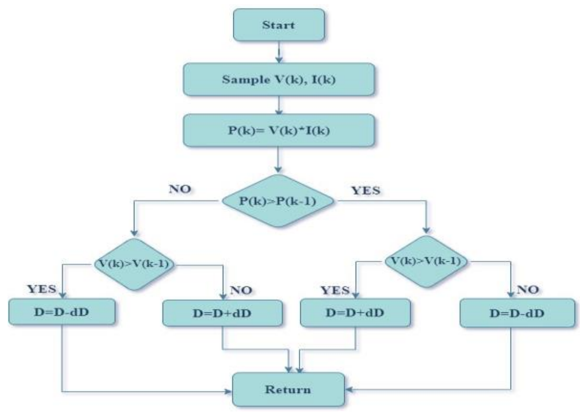
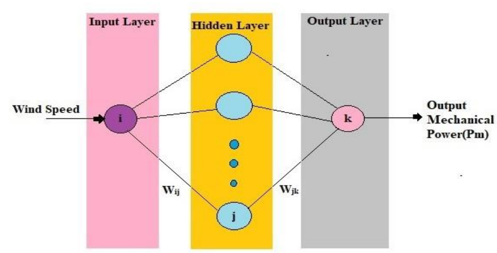


Figure 3 : Flow chart of the Perturb and Observe Control algorithm

3.2 *Neural Network Control Algorithm*

This control method is presented in figures 4 and 5 for solar and wind energy systems, respectively. An input layer, many hidden layers, and an output layer comprise a neural network. The neural network function depends on the connections between the neural network layers. These connections are called 'Weights' of the layers. By properly selecting the weights of layers, the network determines the values



of the required quantity under different input conditions[19][20][21][22].

4 SIMULATION OF HYBRID SOLAR-WIND SYSTEM

The designing parameters are listed in table.1 . A Wind turbine, PMSG, a solar PV module, a three-phase uncontrolled rectifier, SEPIC converter1, SEPIC converter2, MPPT controller, PWM generator, and DC load (R-load) make up the basic simulation model depicted in figure 6. This SEPIC converter is simulated for the above described control algorithms[23][24].

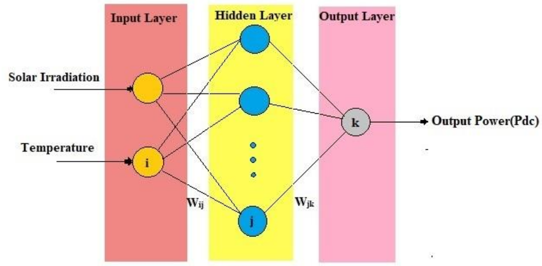


Figure 4 : Neural network control algorithm for solar power system

4.1 *Without SEPIC Converter*

The simulation is carried out without connecting the SEPIC converter to R-load system. Figure 7 shows

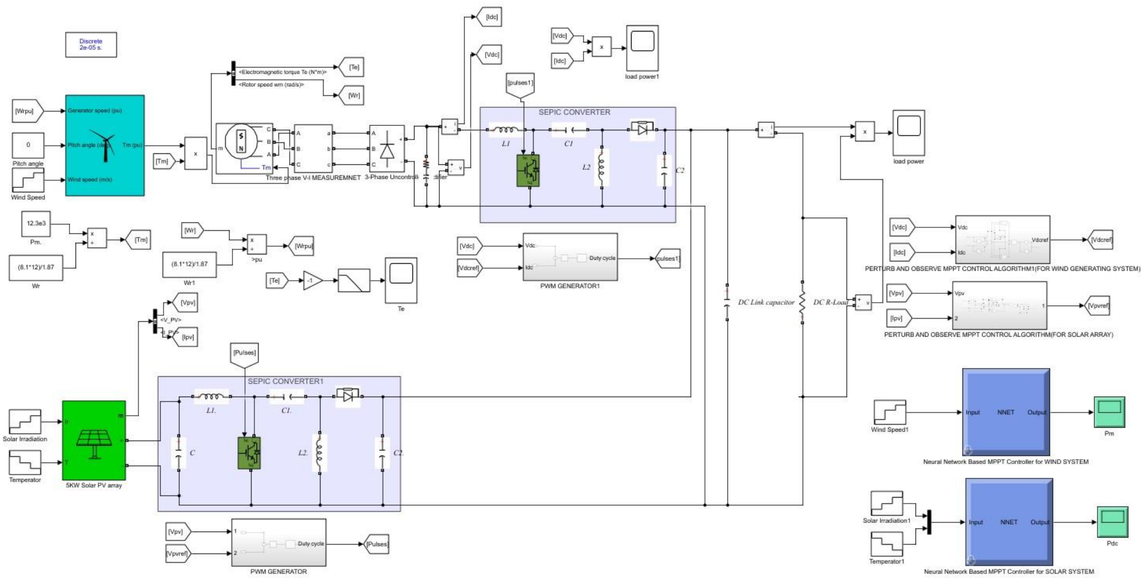


Figure 6 : Simulation model of Hybrid Solar-Wind System

the output power of solar array for various solar irradiations and temperature levels and it can be observed from the curves, at standard test conditions i.e irradiation 1000W/m^2 and temperature 25°C, solar array generates maximum power and for other irradiations and temperature values, the output power of Solar array decreases.

Figure 8 shows the wind system's output power at various wind speeds. The curve shows that when the wind velocity decreases, the generated power of the wind power system reduces.

4.2 *With SEPIC Converter*

The output of the solar array and three-phase uncontrolled rectifier are connected to SEPIC converter1 and SEPIC converter2 respectively. Here, I have used the perturb and observe control algorithm and the neural network control algorithm to generate required reference signals for the control of SEPIC converters.

4.2.1 *Simulation of the Perturb and Observe MPPT Control Technique*

Figure 9 presents the simulation diargram of this control algorithm for SEPIC converters 1 and 2.

DC voltages V_{dc}, V_{dc1} and DC currents I_{dc}, I_{dc1} were sensed and applied to MPPT controllers. Based on the sensed signals provided,

Table 1 : Simulation Parameters

Parameters	**Values**
Solar PV array	
Rated Power(Pmax in Watts)	6000 Watts
Volt at Max. power(Vmp in Volts)	160 Volts
Open circuit voltage(Voc in Volts)	197.1 Volts
Current at Max. Power(Imp in Amps)	37.84 Amps
Short circuit current(Isc in Amps)	40.2 Amps
Standard Test condition	Irradiance:1000W/m², Temp: 25°C
Wind Turbine	
Rated mechanical output power	12.3k Watts
Rated Wind Speed	12m/sec²
Pitch angle	0 degree
Permanent Magnet Synchronous Generator	
Rated power	12.3k Watts
Rotor type	Salient-pole
Inertia constant(J)	0.0027 kg/m²
Pole pairs	2
SEPIC Converter1&2	
Rated Capacity	6000 Watts
Inducatances(L1&L2)	0.041 mHenry
Capacitance(C1)	2.85 mFarad
Capacitance(C2)	0.8 mFarad
Switching frequency of the switch	20k Hz
DC load	
R-Load	**4.67** Ohms

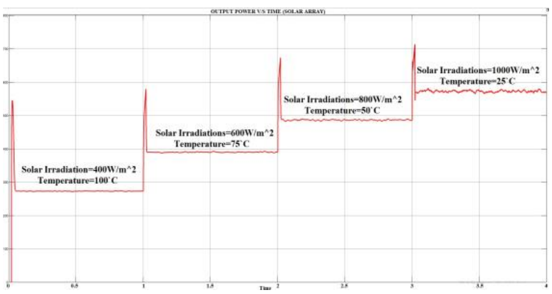
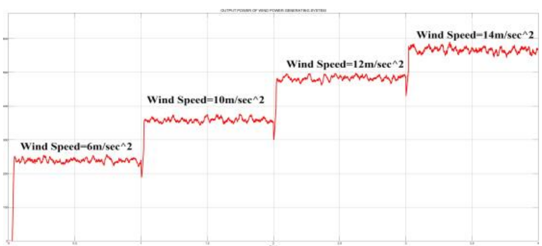


Figure 7 : Output power of solar PV system(without SEPIC converter)



MPPT controllers generate reference voltage signals V_{dcref} and V_{dcref1}. The reference voltage signals V_{dcref} and V_{dcref1} generated by the perturb and observe control algorithm blocks are compared with DC voltages V_{dc} and V_{dc1} and voltage errors are amplified through PI

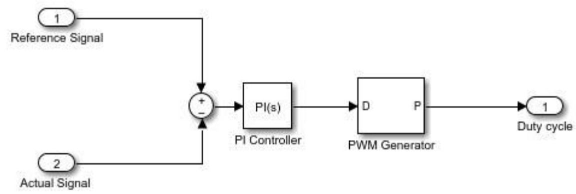


Figure 10 : PWM controller

regulators, their outputs are fed to a pulse width modulator(PWM) controller as shown in figure 10, to generate gating pulses for the switches S_1 and S_2. Based on the gating pulses generated by PWM controllers, SEPIC converters have drawn the maximum power from energy sources and fulfilled the load demand. Figures 11 and 12 depict the power generated by the hybrid system, under various input conditions. The amount of power obtained from the hybrid solar-wind system is given in the Table. II.

4.2.2 *Simulation of the Neural Network-Based MPPT ControlTechnique*

Figures 13 & 14 show the simulink models of the neural network-based controller for SEPIC converters 1 and 2. Different sun irradiations and temperatures for a solar energy system and different wind speeds for a wind power

Figure 8 : Output power of wind power system(without SEPIC converter)

system are regarded as inputs, while the output powers from the solar and wind systems are considered as desirable outputs when constructing neural network controllers. The data from the inputs and outputs is loaded into the network for training. Figures 15 and 16 illustrate the training results of proposed neural network-based MPPT controllers for solar and wind power systems. Gating pulses for the switches S1 and S2 are produced by PWM controllers. Based on the gating pulses generated by PWM controllers, SEPIC converters have extracted

Figure 9 : Simulation model of Perturb and Observe control algorithm

extracted from the hybrid solar-wind system is mentioned in the Table. II.

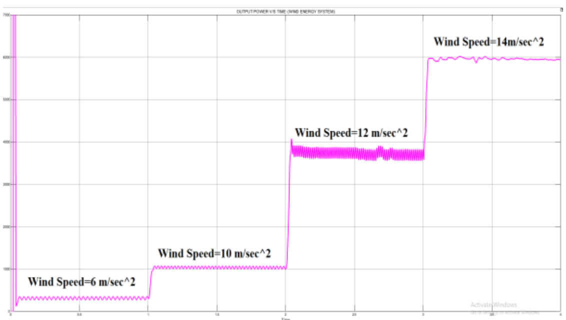


Figure 11 : Output power of solar power system(P&O control algorithm)

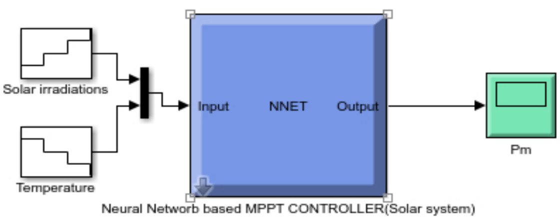


Figure 12 : Output power of wind power system(P&O control algorithm)

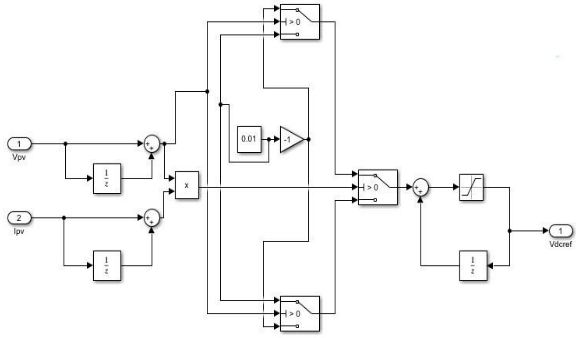


Figure 13 : Neural network-based MPPT controller(for solar system)

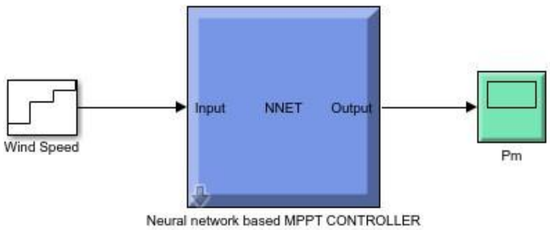


Figure 14 : Neural network-based MPPT controller(for wind system)

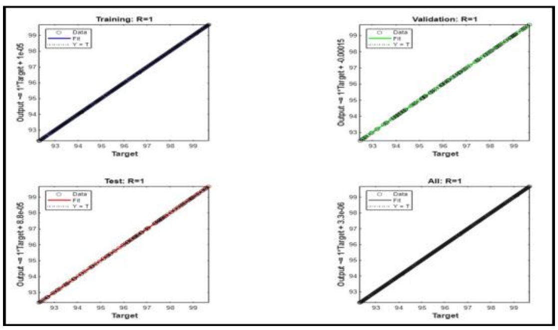


Figure 15 : Training and Response graph of the Neural network controller for given test data(for Solar system)

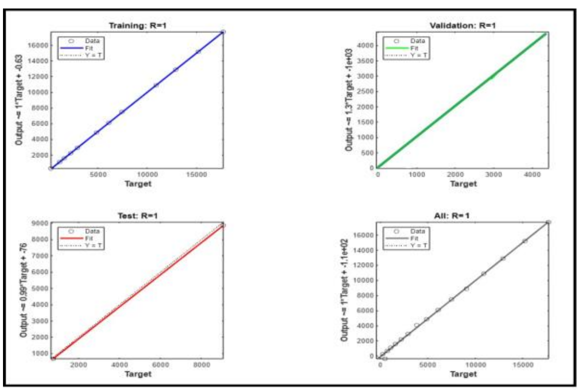


Figure 16 : Training and Response graph of the Neural network controller for given test data(for Wind system)

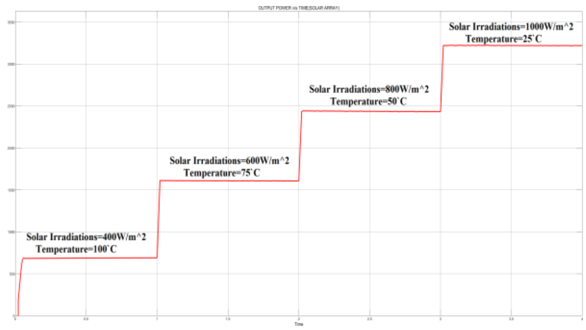


Figure 17 : Output power of solar PV system(Neural network-based control algorithm)

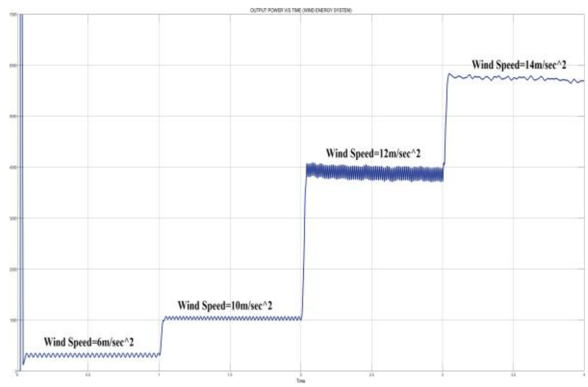


Figure 18 : Output power of wind power generating system(Neural network-based control algorithm)

5 CONCLUSION

The performance of the SEPIC converter is studied in this article using various maximum power point tracking(MPPT) control methods. The perturb and observe control algorithm and the neural network based MPPT Control algorithm are the two control algorithms.

Table 2 : Performance of SEPIC Converter

S.No	Hybrid Solar-Wind System	Input Conditions	Output Power of Hybrid Solar -Wind System Without SEPIC Converter	Power Extracted by MPPT Controllers (Watts)	
				Perturb & Observe MPPT Controler	Neural Network-Based MPPT Controller
1	Solar Power System	Solar irradiations 400W/m^2 Temperature 100`C	290 Watts	650 Watts	720 Watts
		Solar irradiations 600W/m^2 Temperature 75°C	395 Watts	1610 Watts	1700 Watts
		Solar irradiations 800W/m^2 Temperature 50°C	489 Watts	2450 Watts	2520 Watts
		Solar irradiations 1000W/m^2 Temperature 25°C	580 Watts	3350 Watts	3425 Watts
2	Wind Power System	Wind Speed 6m/sec^2	295 Watts	425 Watts	500 Watts
		Wind Speed 10m/sec^2	410 Watts	1000 Watts	1100 Watts
		Wind Speed 12m/sec^2	580 Watts	3876 Watts	3985 Watts
		Wind Speed 14m/sec^2	690 Watts	5968 Watts	6059 Watts

The load considered is DC load(R-Load). Simulation results are used to describe the SEPIC converter using these two control techniques. The output power drawn from the solar system and the wind power generating system is used as a comparison parameter. The simulation results show that SEPIC converter provides better performance with the neural network-based MPPT Control algorithm compared to the perturb and observe control method.

Future work on this project can be carried out by using different DC-DC converters. And also the experimental analysis can be done in a laboratory by developing a hardware model of SEPIC converter with these two methods.

Conflicts of Interest

The authors declare no conflict of interest.

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