ANFIS Based SEPIC Converter For Maximum Power Point Tracking Of Photovoltaic Modules

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Abstract— The use of solar energy has expanded dramatically in recent years. The photovoltaic (PV) system requires a adequate maximum power point tracking (MPPT) technique to maximize the PV output power. This paper presents the intelligent controllers based maximum power point tracking of PV system implemented with the Single Ended Primary Inductance converter (SEPIC) . The selection of the converter plays an important role for MPPT. The SEPIC converters have better efficiency as compared to other converters. SEPIC converters give step up and step down voltages depending up on the duty cycle, for duty cycle above 0.5 it will step up and below 0.5, it will step down the voltage to required value and it also gives non inverted output as compared to buck-boost and cuk converter.

The algorithm used for MPPT is the Perturb and Observe (P&O) method. In this method the controller adjusts the voltage by a small amount from the array and measures power. if the power increases, further adjustments in that direction are tried until power no longer increases. The P&O algorithm has a simple structure and requires few parameters that is why it is extensively used.

The maximum power point tracking of PV system using SEPIC is controlled by intelligent controllers, here the Adaptive Neuro Fuzzy Inference System (ANFIS) for MPPT of PV module using SEPIC is considered. The performance of the controller for MPPT is tested in simulation. Beside this, a scaled laboratory hardware prototype is developed.

Keywords- *SEPIC converters, Adaptive Neuro Fuzzy Inference System (ANFIS), Photo Voltaic(PV) cell, Maximum Power Point Tracking(MPPT), P&O algorithm.*

I. INTRODUCTION

The world's energy sources are derived from conventional sources such as coil, oil natural gases. These are also called non-renewable energy sources. Although the available quantity of these fuels are extremely large, they are nevertheless, finite and so will in principle 'run out' at some time in the future. The renewable energy sources continuously replenished by natural processes. The Solar energy, Hydro energy, Geo thermal energy, Wave and tidal energy are some of the example of renewable energy sources.

Solar energy is the most readily available and free source of energy since prehistoric times. It is estimated that solar energy equivalent to over 15,000 times worlds annual commercial energy consumption reaches the earth every year. Solar energy can be utilized through two different routes as solar thermal route and solar electric (solar photovoltaic) routes. Solar thermal route to produce hot water or air, cook food, drying materials etc. Solar photovoltaic uses the sun's heat to produce electricity for lighting home, and building running motors, pumps, electric appliances, and lighting. The solar cells also called photovoltaic cells convert sunlight(photons) directly in to electricity(voltage).

PV modules output voltage has a low dc amplitude value which will be the input voltage of the ac module. For lower input voltage, it is difficult for the ac module to reach high efficiency. However, employing a high step-up dc–dc converter in the front of the inverter improves power-conversion efficiency and provides a stable dc link to the inverter.The solar cell operate at very low efficiency and thus a better control mechanism is required to increase the efficiency of the solar cell. In this field researchers have developed what are now called the Maximum Power Point Tracking (MPPT) algorithm. In addition to the excellent geographical conditions, it is very important to have an effective and appropriate MPPT algorithm for the photovoltaic system. If there is a good irradiance condition, the photovoltaic system can generate maximum power efficiently while an MPPT algorithm used with the system. There are many factors that can be considered for proposing the dc–dc converters, such as input/output energy flow, cost, flexibility, and PV array effect. Unlike a buck–boost converter, the SEPIC has a noninverted output, and it uses a series capacitor to isolate input from output [1]. The buck and buck–boost converters have discontinuous input current, which causes more power loss due to input switching. The boost converter usually has higher efficiency than the SEPIC; however, its output voltage is always larger than the input, which causes inflexibility in maximum power extraction. Both the SEPIC and the Cuk converter provide the choice to have either higher or lower output voltage compared to the input voltage. Furthermore, they have contentious input current and better efficiency compared to buck–boost and fly-back converters [2]. There is no general agreement in the literature on which one of the two converters is better, i.e., the SEPIC or the Cuk [3]–[10]. This paper seeks to use the SEPIC converter because of the Cuk converter's inverted output. The MPPT algorithm represents optimal load for PV array, producing opportune voltage for the load. The PV panel yields exponential curves for current and voltage, where the maximum power occurs at the curve's mutual knee [11], [12]. The applied MPPT uses a type of control and logic to look for the knee, which in turn allows the SEPIC converter to extract the maximum power from the PV array. The tracking method used, i.e., perturb and observe (P&O) [13], [14], provides a new reference signal for the controller and extracts the maximum power from the PV array.

The MPPT algorithms are integrated with a efficient controller to switching the converter to obtain maximum power point. The different controllers used are Proportional-Integral (PI) controllers, Optimized one-cycle control, Slide-mode control and gradient algorithm based intelligent controllers [15]-[26]. [15] applied optimization for MPPT using a PI controller for their converter. The limitations of the PI controller are well known because it is sensitive to parameter variations, weather conditions, and other uncertainties. The one-cycle controller (OCC) of a single-stage inverter for photovoltaic application is carried out in [16],[17]. The OCC is based on the integration of a switched variable (voltage or current) in order to force its average value to be equal to some control reference. This OCC technique is also have the limitation of can't handle the uncertainties. Therefore, there is need to apply a more efficient controller that can handle the uncertainties, such as unpredictable weather, for the PV system. In recent years, sliding mode control (SMC) has met a growing interest in many application. The sliding-mode controller is famous for its large signal stability, robustness to parameter uncertainty, insensitivity to load disturbances, fast dynamic response, and simple implementation [18],[19]. Effectively, the sliding-mode controller operates at infinite, varying, and self-oscillating switching frequency; hence, the control variables follow a specific reference path to accomplish the wanted steady-state process. On the other hand, the direct implementation of standard SMC law may exhibit high-frequency of both controller output and state variables known as chattering. This phenomenon may cause various undesirable effects such as current harmonic, torque pulsation, and acoustic noise.

However, the advantage of an intelligent controller is that its design does not require an accurate system mathematical model, and it can handle the nonlinearity of arbitrary complexity. Among different intelligent controllers, fuzzy logic is the simplest to integrate with the system. Recently, the fuzzy logic controller (FLC) has received an increasing attention to researchers for converter control, motor drives, and other process control because it provides better responses than other conventional controllers [21]–[26]. The imprecision of the weather variations that can be reflected by PV arrays can be addressed accurately using a fuzzy controller. In order to take the advantages of the fuzzy logic algorithm, the MPPT algorithm is integrated with the FLC so that the overall control system can always provide maximum power transfer from the PV array to the inverter side, in spite of the unpredictable weather conditions [1]. When the fuzzy inference system is implemented in the framework of adaptive network the performance of the controller become better which is called as Adaptive Neuro Fuzzy Inference System (ANFIS).

II. ANFIS BASED SEPIC CONVERTER FOR MPPT

PV system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be gathered to form modules or arrays. More sophisticated applications require DC-DC converters to process the electricity from the PV device. These converters may be used to either increase or decrease the PV system voltage at the load. The important requirement of any DC–DC converter used in the MPPT scheme is that it should have a low input-current ripple. Buck converters will produce ripples on the PV module side currents and thus require a larger value of input capacitance on the module side.

On the other hand, boost converters will present low ripple on the PV module side, but the load current exhibits more ripple and gives a voltage higher than the array voltage to the loads. The buck–boost converters can be used where the requirement of load voltage, either low or higher than the array voltage. However, with this converter the input and load currents are pulsating in nature. Furthermore, the load voltage will be inverted with buck–boost or CUK converters. Under these conditions, the SEPIC converter, provide the buck–boost conversion function without polarity reversal, in addition to the low ripple current on the source and load sides

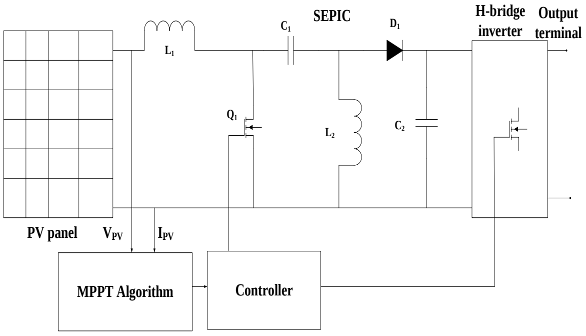

Fig. 1 Circuit diagram of the ANFIS based SEPIC converter for MPPT

The SEPIC (Single Ended Primary Inductor converter) topology together with MPPT and controller is shown in fig1 and it is proposed the converter is operated in Continuous Current Mode (CCM).This converter has two inductors and two capacitors. The capacitor C1 provides the isolation between input and output. The SEPIC converter exchanges energy between the capacitors and inductors in order to convert the voltage from one level to another. The amount of energy exchanged is controlled by switch, which is typically a transistor such as a MOSFET.

The controller changes the voltage level by changing the duty cycle of the pulse width-modulated (PWM) signal, which tracks the reference signal. A sinusoidal reference signal is compared with the output signal to produce a supposedly zero error signal. Another reference signal is used to compare the SEPIC's output, to achieve the maximum power. This reference signal is adaptive, changing its shape according to weather conditions. The SEPIC's output signal is, thus, compared with the adaptive reference signal, to feed the inverter with the most suitable power.

III. CONTROL STRATEGY

Adaptive Neuro Fuzzy Inference System (ANFIS)

The ANFIS controller has received an increasing attention to researchers for converter control. The MPPT is integrated with the ANFIS so that the overall control system can can always provide maximum power transfer from the PV array to the inverter side. Fig.2 shows the overall block diagram of ANFIS based SEPIC converter for MPPT. The design of the ANFIS controller was done using Takagi-Sugeno method for both the converter and the single-phase inverter. The selection of the membership functions will be discussed in the next section. The PWM changes its duty cycle according to the control signal, configuring a feedback from the output signal represented in voltage, current, and power to get the reference signal, which is unpredictable and adapts itself depending on the maximum power achieved by the duty cycle's changes. The maximum power point can be achieved in case of a grid-connected system, a full-load condition, or using battery charging in case of a standalone system.

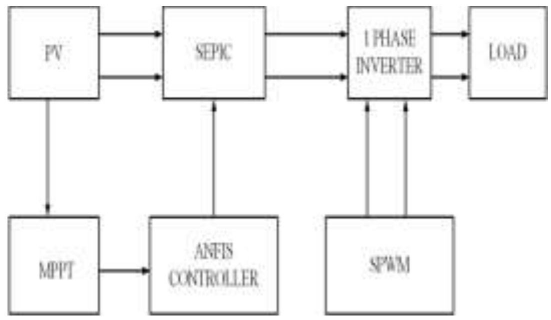

Fig. 2 Block diagram of ANFIS based SEPIC converter for MPPT

The specific structure of the FLC is shown in Fig.3. which is the fuzzy inference system.

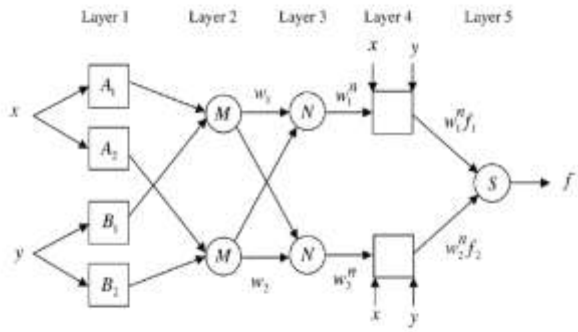

Fig. 3 Architecture of ANFIS.

Adaptive network based fuzzy inference system (ANFIS) is a neuro fuzzy technique where the fusion is made between the neural network and the fuzzy inference system. ANN has strong learning capabilities at the numerical level. Fuzzy logic has a good capability of interpretability and can also integrate expert's knowledge. The hybridization of both paradigms yields the capabilities of learning, good interpretation and incorporating prior knowledge. ANN can be used to learn the membership values for fuzzy systems, to construct IF-THEN rules, or to construct decision logic. The true scheme of the two paradigms is a hybrid neural/fuzzy system, which captures the merits of both the systems. Using this hybrid method, at first an initial fuzzy model along with its input variables are derived with the help of the rules extracted from the input output data of the system that is being modeled. Next the neural network is used to fine tune the rules of the initial fuzzy model to produce the final ANFIS model of the system

This concept is made use of in developing the ANFIS controller in this paper. A neuro-fuzzy system has a neural-network architecture constructed from fuzzy reasoning. Structured knowledge is codified as fuzzy rules, while the adapting and learning capabilities of neural networks are retained. Expert knowledge can increase learning speed and estimation accuracy. The ANFIS model is shown in Fig.3.14.

It has 5 layers described below:-

Layer 1: This layer consists of input variables (membership functions), viz., input 1 and input 2. Here, triangular or bell-shaped MF can be used. This layer supplies the input values to the next layer,

Layer 2: This layer (membership layer) checks the weights of each MF. It receives the input values *xi* from the *1st* layer and acts as MFs to represent the fuzzy sets of the respective input variables. Furthermore, it computes the membership values that specify the degree to which the input value xi belongs to the fuzzy set, which acts as the inputs to the next layer.

Layer 3: This layer performs the pre-condition matching of the fuzzy rules, i.e., they compute the activation level of each rule, the number of layers being equal to the number of fuzzy rules. Each node of these layers calculates the weights that are normalized.

Layer 4: This layer provides the output values *y*, resulting from the inference of rules. Connections between the layers *l3* and *l4* are weighted by the fuzzy singletons that represent another set of parameters for the neuro-fuzzy network. Each neuron in layer 4 performs the normalization, and the outputs are called normalized firing strengths.

Layer 5: This layer is called the output layer, which sums up all the inputs coming from layer 4 and transforms the fuzzy classification results into a crisp (binary). The outputs of layer 5 are summed up and the final output of the network can be re-written as . The ANFIS structure is tuned automatically by least-square-estimation and the back-propagation algorithm.

IV. SIMULATION RESULT

The SEPIC converter can be used for MPPT which is more efficiently controlled by ANFIS controller, which is confirmed by computer simulation carried out using MATLAB. The simulation circuit is shown in Fig. 4.Where the SEPIC converter output is fed to a H-bridge inverter. The parameters are shown in TABLE I.

The SEPIC converter act as a maximum power point tracker that optimizes the match between the solar array and the battery bank or utility grid. They convert a higher voltage DC from solar panel to the lower voltage needed to charge batteries. If the DC output from solar panel lower than the voltage needed to charge the battery then they convert lower voltage to higher voltage.Loads are assumed to be resistance simply which are set to make the output powers of the load side converters their rating value. The duty ratio of the controlled switch in the SEPIC converter is controlled by the ANFIS controller. The reference for the ANFIS is given by the P&O algorithm.

The photovoltaic system consist of solar panel and and balance of the components (BOC). The BOC components include the DC-DC converter and the DC-AC converter which convert the DC output to utility frequency alternating current of 230V.

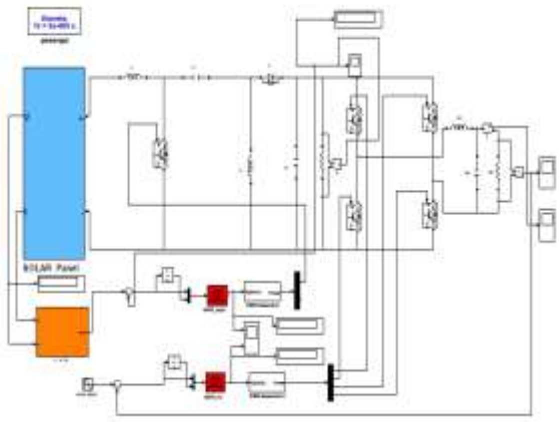

Fig. 4 Simulation circuit of ANFIS based SEPIC converter for MPPT

TABLE I

MAIN PARAMETERS OF THE SIMULATION

PARAMETERS	VALUE
Input Voltage (DC)	15V-17V
L_1, L_2	1.35e-3
C_1	10e-6
C_2	4700e-6
R_{dc}	50Ω
L_{ac}	100e-3
C_{ac}	100e-6
R_{ac}	100 Ω
Switching frequency	20kHz

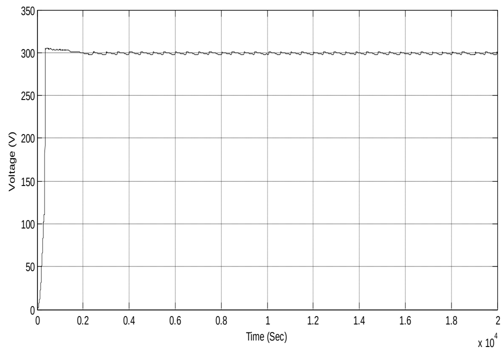

Fig. 5 DC output voltage of SEPIC

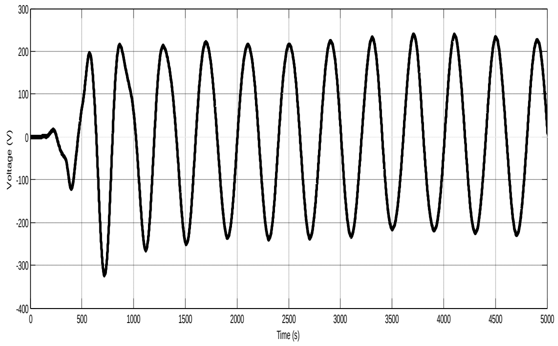

Fig. 6 AC output of H-bridge inverter.

Fig. 5 and Fig. 6 shows the DC output of the SEPIC converter and the 230V AC output of the H-bridge inverter.

V. HARDWARE IMPLEMENTATION

A prototype was built to investigate the performance of the ANFIS based MPPT scheme for the SEPIC converter and inverter for PV application. Fig.7. shows the hardware setup of the project. Instead of PV module variable DC source is used in the prototype. The controllers of the DC-DC power converter and the DC-AC inverter are implemented using the dsPIC30F2010. The pwer electronics switches used used in this paper are MOSFETS. The switching frequency is 20kHz. The output is analyzed with the help of DSO.

Fig. 7 Schematic of experimental setup.

The SEPIC converter's output voltage is shown in Fig.8. The SEPIC converter is designed with battery as the load. So the output of the SEPIC converter is 12V dc. Where the voltage signal shows that the output is varying, owing to irradiation variation. Fig 9.shows the experimental waveform of the inverter's voltage.

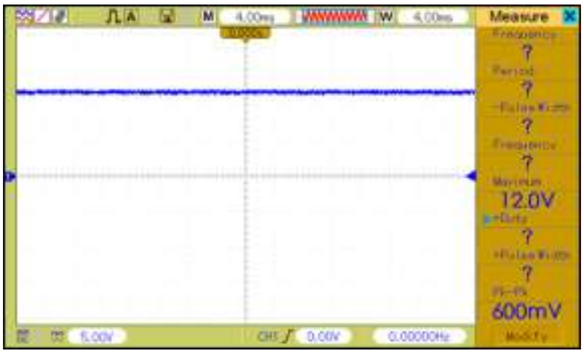

Fig. 8 AC output of H-bridge inverter.

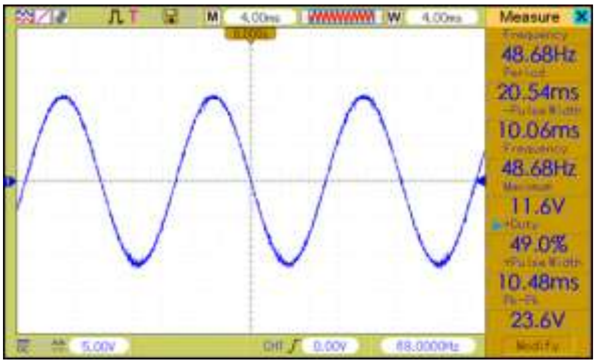

Fig 9. AC output of H-bridge inverter.

VI. CONCLUSION

The ANFIS based SEPIC converter for MPPT of PV module is presented in this paper. The SEPIC converter are more efficient converters for maximum power point tracking operation for photovoltaic system by considering the factors such as cost, efficiency, flexibility and energy flow. The SEPIC converter is capable of operating either step-up or step-down mode. In This paper Perturb & Observe algorithm is used to obtain the MPPT. Different controllers can be used for SEPIC converters for MPPT. The comparison of fuzzy logic controller based SEPIC for MPPT and the ANFIS based SEPIC for MPPT is carried out. The MPPT algorithm gives the input to the controller and which generate the PWM signal to control the SEPIC converter to track the maximum power point of the PV module. The ANFIS based controller base SEPIC is more efficient as compared to other controller based converters for MPPT. A prototype of ANFIS based SEPIC converter for MPPT of PV module has also been implemented in the laboratory.

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