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Feed-Forward Control Algorithm for Hybrid Energy Systems

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Abstract

The paper presents a comparative analysis of the control strategies that can be used for hybrid energy systems. In the system considered, solar energy and battery are the two input sources to the DC-DC converter. Due to the intermittent availability of solar energy, a control circuit needs to be designed for the voltage regulation of the hybrid energy system. A single input fuzzy logic controller can maintain the output voltage constant for variations in either Photovoltaic (PV) or battery voltage only. Hence a control strategy is proposed in this paper to accomplish output voltage regulation for variations in both PV and battery voltages. The comparison of the two control techniques is presented along with the simulation results.

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Keywords: Photovoltaic;Hybrid system; Control strategy; Fuzzy logic controller;Feed-Forward;Feed-Back

1. Introduction

Increased global warming emissions create an adverse impact on environment and climate. Conventional energy technologies constitute majorly to the environmental pollution and climate change. Compared to conventional technologies, renewable energy sources like sun and wind produce no waste products and hence have negligible environmental effects [1, 2]. The additional benefits of PV arrays and wind-based power generators are extended lifetime and reduced maintenance costs for both systems. PV array has been preferred over wind power systems due to its ease of deployment and noise free operation [3].

Renewable energy sources generate a fluctuating power output due to the changing weather conditions.This drawback impacts the continuous supply of power especially in standalone applications [4]. This varying weather conditions, emphasizes the necessity for a stable system in order to nullify the impact of fluctuations from renewable energy source. Maintaining the limit for batterydischarging and charging and battery bank efficiency maintenance are also of utmost importance. To overcome the unpredictability associated with renewable sources, a control strategy can be implemented to improve the overall performance of hybrid energy systems. It also improves the

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operating life of solar plants, thereby reducing the cost of energy generation. The load demand can be addressed economically and effectively by the hybrid energy system using appropriate control strategy. The power output from the PV array and battery must be coordinated to meet load demand [5]. In this paper, the control strategies that can be used for hybrid energy system, areanalysed. The hybrid system considered here, has a two-input port DC/DC converter with flyback inverter. The output voltage can be maintained constant by using single input fuzzy logic controller for variations in either PV or battery voltage. In order to maintain the output voltage constant for both PV and battery voltage variations, a control algorithm is proposed in this paper. The discharging and charging of battery can also be accomplished by means of control algorithm. The load demand will be addressed by either or both of the sources based on the availability.

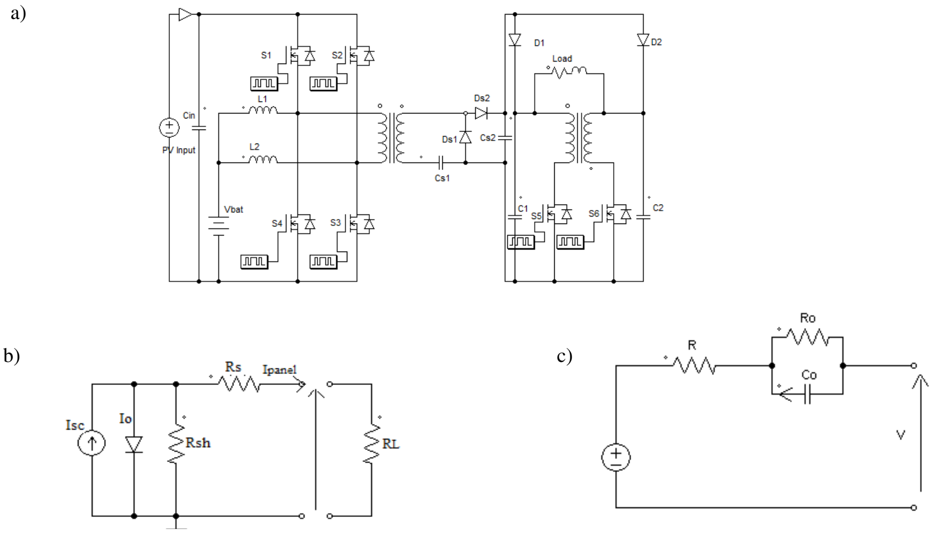

Fig. 1(a)Circuit Configurationof hybrid system (b) Equivalent circuit of PV cell (c) Thevenin state model of Lead Acid battery

2. Circuit Configuration,Modeling – PV and Battery model

Fig.1 (a) shows the circuit configuration of the hybrid system for analysing the control strategy. PV and battery form the two input ports of the hybrid energy system [6]. The low frequency output voltage is obtained at the output of flyback inverter [7]. The modes of operation for the DC-DC converter are explained in [8].Fig.1 (b) shows an equivalent circuit which can be used to represent the PV panel. Isc represents the short-circuit current which is directly related to the exposure to sunlight.The modeling of PV arrayis explained in detail in [9].The lead acid battery can be represented by the Thevenin model as shown in Fig.1 (c).The battery must always retain a small charge in order to achieve longer durability. The battery model is analyzed in [10].

3. Control Strategy

Renewable energy sources are unpredictable in nature. Hence,there exists a need to implement a control strategy to ensure a highly reliable system under varying atmospheric conditions. In this paper, a Single Input Fuzzy Logic Controller (SI-FLC) has been implemented in feed-forward and feed-back mode to track the variations in input PV voltage. Also, a control strategy has been proposed, to track the variations in both PV and battery voltages and to maintain a constant output voltage. The control strategies implemented for the PV-battery hybrid system are explained below.

Fuzzy controller is preferred over conventional controllers because of its reduced control complexity. It is closer to human thinking and is able to deal with non-linearity and uncertainties in the system [11]. A typical FLC comprises three main components, namely Fuzzification unit, which uses membership functions to convert real-time variable into a fuzzy variable, an Inference engine, which calculates the fuzzy output, based on the If-Then rules and

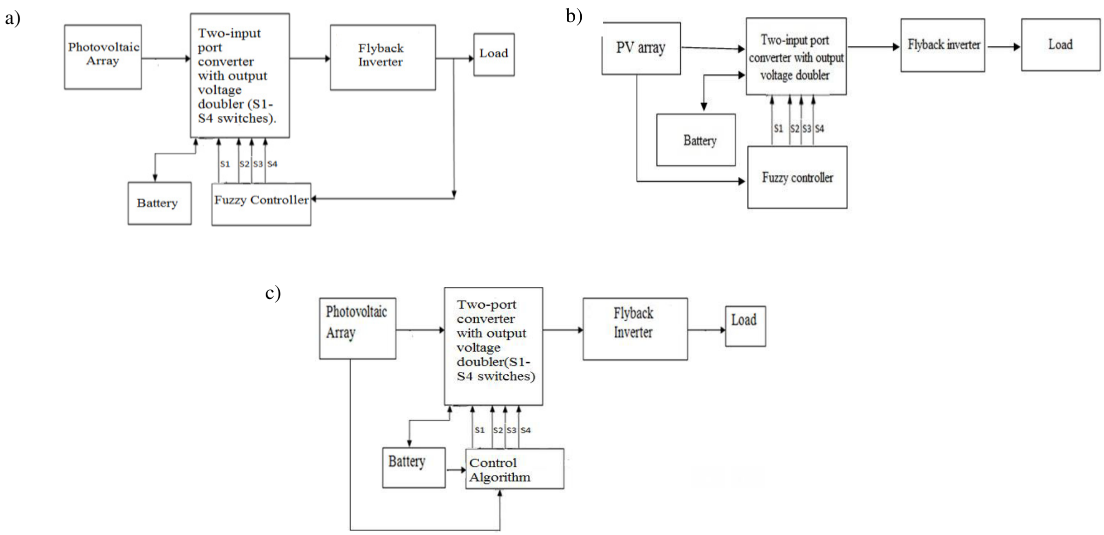

Fig..2: Block diagram of (a) FLC for tracking output voltage (b)FLC for tracking input voltage (c)Control Algorithm implementation.

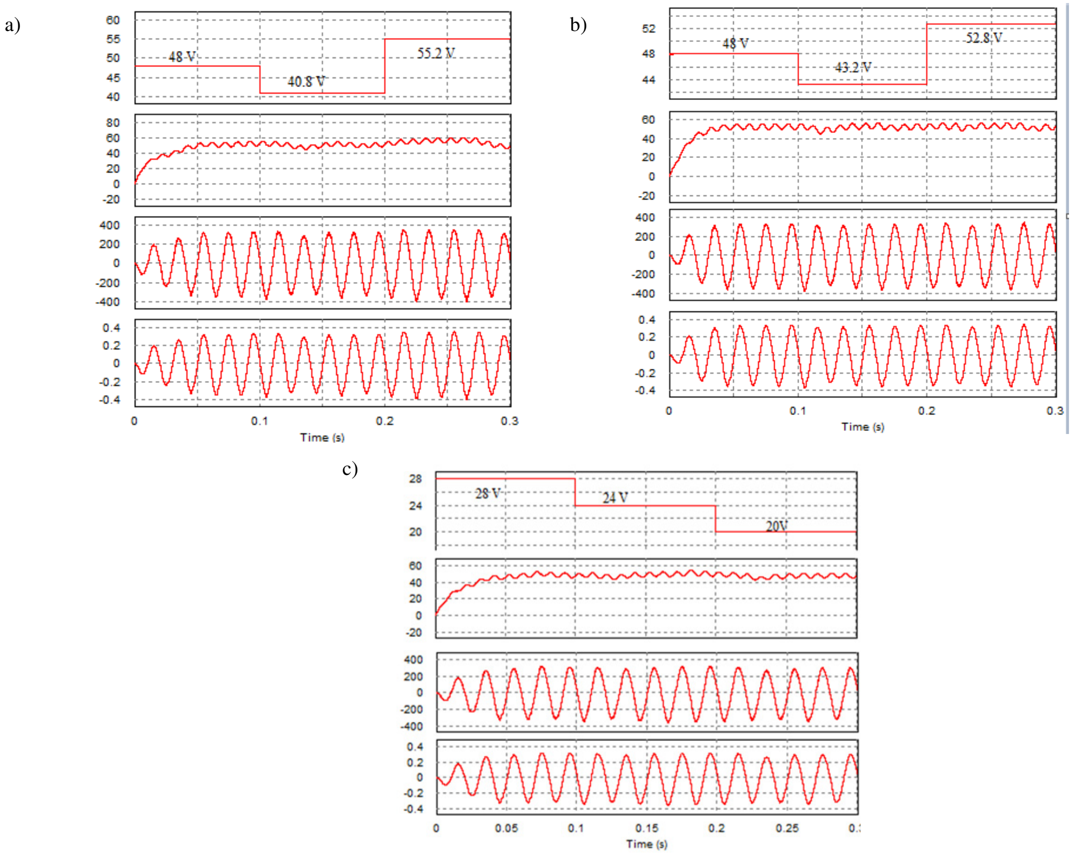

Fig. 3: PV supply, Voltage doubler Output, Output voltage and current for Fuzzy logic a)Feedback b)Feed forward c) Proposed Control algorithm.

the Defuzzification unit, which converts the fuzzy output to a crisp output [12]. The FLC can be implemented in the feed-back loop, by sensing the output voltage of the inverter. The FLC in feed-back loop is as depicted in Fig. 2 (a). For change in the input PV voltage, the output voltage is sensed and compared with the reference value of 325V (peak), 50 Hz. The error is calculated and fed as input to the FLC. The fuzzy controller controls the pulse width of the switches in the two-input port converter to achieve a regulated output voltage. The triangular membership functions are used for representing error (-60 60), change in error (-0.03 0.03) and output (-0.006 0.01).The regulated output voltages for input PV voltage variation are as shown in Fig. 3(a).The FLC is implemented for 15% increase as well as decrease in PV supply. The output of voltage doubler as well as output voltage and current are found to be constant irrespective of input voltage fluctuations.

FLC in feed forward loop is implemented to track the input voltage changes instantaneously and to achieve output voltage regulation.Compared to feedback loop, feed forward loop will be able to track the input changes faster since it is implemented at the supply side.The Fuzzy controller block shown in Fig.2 (b) is a combination of voltage measurement, error calculation, fuzzy rule base table, defuzzification stage and gate driver blocks. The triangular membership functions representing error (-4.8 4.8), change in error (-4.8 4.8) and output (-0.01 0.02) can be applied for FLC in feed-forward loop. The rule base applied is same for both FLC in feed-forward and feedback loop. The regulated output voltage and current for 10% variation in input PV voltage is shown in Fig. 3(b).

In FLC, only the change in PV voltage is taken into consideration. If the change in battery voltage also has to be monitored, two-input FLC is required, which is more complex. A simpler alternative will be to implement a control algorithm that monitors the instantaneous values of battery and PV voltages. A control algorithm Feed Forward Control algorithm for Hybrid energy system (F^2CAHES)is proposed, whose inputs are battery and PV voltages, and the error is calculated by comparing with the reference value. The block diagram of the F^2CAHES implementation is shown in Fig. 2(c).Table 1 shows the operational modes of the control algorithm. The flowchart depicting the control algorithm implementation is shown in Fig. 4. The discharging and charging of the battery can be achieved by means of control algorithm. When the battery voltage goes below a pre-set value, charging of battery takes place. For the effective functioning of the battery, at least 40% of the charge is to be retained so that it takes less time to charge than charging from 0%.Hence the battery is made to disconnect at the instant when its charge becomes 40%.40% of battery voltage corresponds to a value of 12V, which is equal to an error of 1.6. Fig.3(c) shows the output voltage waveforms for battery discharging. The main advantage of F^2CAHES is that it can be applied for wide variation of PV and battery voltages. The output voltage is found to be constant irrespective of the changes in both the supply voltages.

Table 1. Control & Comparisons

Mode	Energy flow
1	$P_{PV}+P_{Bat}=P_{Load}$
2	$P_{PV} = P_{Bat} + P_{Load}$
3	$P_{PV} = P_{Load}$
4	$P_{Bat} = P_{Load}$

Criteria	Feed-Forward FLC	Control Algorithm
ISE	3.6e-3	1.22e-3
IAE	8.4e-5	4.9e-5
ITAE	1.6e-10	4.05e-11
Settling Time	0.04s	0.08s
THD	4.6%	5.97%

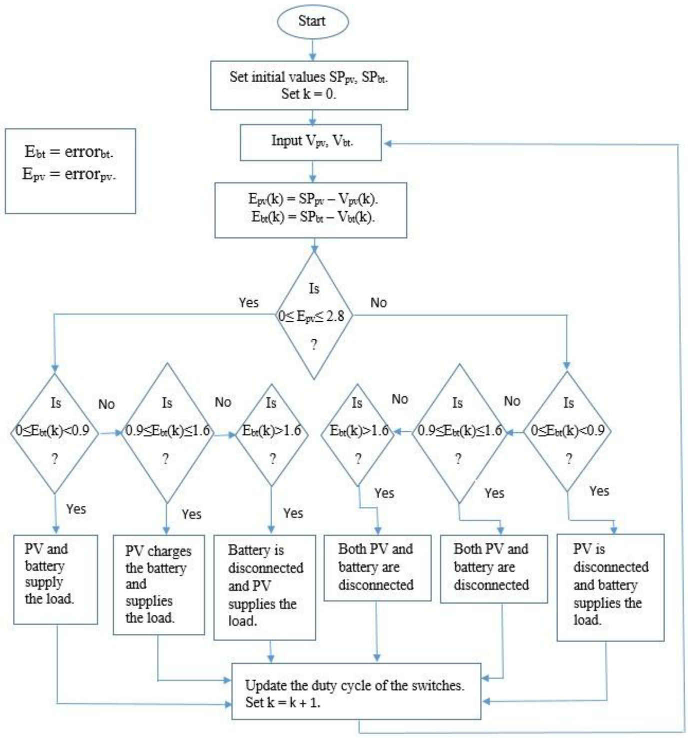

Fig 4: Flowchart for proposed control algorithm implementation

4. Analysis

Since FLC in feed-forward loop is more effective than FLC in feed-back loop, the below analysis has been presented as a comparison between FLC in feed-forward loop and control algorithm only.System performance can be measured using the performance indices (1) – (3).For the hybrid system under consideration, the performance indices are as shown in Table 1.The control algorithm has smaller values for ISE,IAE and ITAE compared to the FLC in feed-forward loop, indicating that the control algorithm responds faster to load changes. But the settling time and THD is slightly more for control algorithm. This is because the FLC in feed-forward loop, takes care of changes in PV voltage only, keeping the battery voltage constant, whereas the control algorithm takes care of both PV and battery voltage variations. Another alternative to track the PV and battery voltage variations using fuzzy logic controllers, is to use a multiple input Fuzzy logic controller (MI-FLC).The parameters of PV panel and converter are Open circuit voltage - 21 V, Short circuit current - 0.61 A, Maximum Power - 10 W, Battery voltage -28 V, Inductor – 1mH, Capacitor - 1μF.

Integral of Squared Error(ISE) Index: $ISE = \int_0^\infty e^2(t)dt$ (1)

Integral of Absolute magnitude of Error(IAE) Index: $IAE = \int_0^\infty |e(t)|dt$ (2)

Integral of Time multiplied by Absolute Error (ITAE) Index: $ITAE = \int_0^\infty t|e(t)|dt$ (3)

5. Conclusion

This paper analyzes the control strategies that can be used for PV-battery hybrid system. Single Input Fuzzy Logic Controller is implemented in feedback and feed forward loops to track variations in output voltage for input PV changes only. A control algorithm is proposed in this paper to achieve output voltage regulation for both

PV and battery voltage changes. Based on availability, PV and battery can supply the load either independently or concurrently. Battery can be replaced by supercapacitor with slight modifications in design. Supercapacitors have fast charging and discharging and hence the time taken for battery charging and discharging can be avoided. Multiple input Fuzzy logic controllers can also be a suitable strategy for hybrid energy systems.

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