Implementation of High Step-Up DC-DC Converter With Fuzzy Logic Controller based Solar Power Optimizer

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Abstract—Solar Power Optimizer for DC Distribution System is composed of a high step-up solar power optimizer (SPO), efficiently harvests maximum energy from a photovoltaic (PV) panel outputs energy to a dc-micro grid. Its structure integrates coupled inductor and switched capacitor technologies to realize high step-up voltage gain. The leakage inductance energy of the coupled inductor can be recycled to reduce voltage stress and power losses. A low voltage rating and low-conduction resistance switch improves system efficiency by employing the incremental conductance method for the maximum power point tracking (MPPT) algorithm. Because of its high tracking accuracy, the method is widely used in the energy harvesting of PV systems. The power reduction caused by the shadow effect on PV panels is an inevitable problem in a centralized PV system. This paper proposes an artificial intelligence-based fuzzy logic control scheme for the MPP tracking of a solar photovoltaic system under variable temperature and insolation conditions. The method uses a fuzzy logic controller (FLC) applied to a dc–dc converter device. The different steps of the design of this controller are presented together with its simulation. Simulation results are compared with those obtained by the perturbation and observation controller. The results show that the FLC exhibits a much better behavior.

Index Terms—High step-up voltage gain, maximum power point tracking (MPPT), Solar Energy, Photovoltaic system, Fuzzy Logic Control.

I. INTRODUCTION

The Solar Power Optimizer for DC Distribution System, a development of photovoltaic (PV) power generation system, which uses a renewable resource, has been extensively used in emergency facilities and in generating electricity for mass use[1]. A conventional PV generation system is either a single- or a multi string PV array that is connected to one or several central PV inverters. Numerous series-connected PV modules are connected in the PV array to achieve the DC link voltage that is high enough to be connected to electricity through the DCAC inverter[2]. Though, reduction in power caused by the shadow effect is an unavoidable nature in a centralized PV system. The use of a micro inverter or ac module has recently been proposed for individual PV panels. Although this discrete PV power generation solution may partially eliminate the shadow problem, a micro inverter structure constrains the system energy’s harvesting efficiency and entails high costs [3]. The SPO attempts to improve the use of distributed renewable resources and lower system cost. It may also potentially improve the efficiency of PV systems, has an anti-shadow effect, and can monitor the status of PV modules. Moreover, the dc-grid voltage is regulated by bidirectional inverter and battery tank. [4-5] In case of low-loading condition, the redundant energy will store into battery or through bidirectional inverter to ac grid. A solar power optimizer (SPO) was developed as an alternative to maximize energy harvest from each individual PV module.

The presented tracking algorithm shows better steady state and dynamical performance than traditional P&O. The implementation of fuzzy logic controller based on the change of power and change of power with respect to change of voltage is studied in [6], fuzzy determines the size of the perturbed voltage. The performance of fuzzy logic with various membership functions (MFs) is tested to optimize the MPPT. Fuzzy logic can facilitate the tracking of maximum power faster and minimize the voltage variation. A novel intelligent fuzzy logic controller for MPPT in grid-connected photovoltaic systems based on boost converter and single phase grid-connected inverter is introduced in [7]. This is simple to be implemented on MCU chip and needs no memory space to save fuzzy rules, and that optimizing factor in the fuzzy inference equation can adjust fuzzy rules on-line.
automatically to improve system control effect, which provides the system with an intelligent characteristic. An intelligent control method for MPPT of a photovoltaic system under variable temperature and insolation conditions which uses a fuzzy logic controller applied to a DC-DC converter device is proposed in [8-9]. Results of this simulation are compared to those obtained by the perturbation and observation controller. A fuzzy logic control (FLC) is proposed in [10] to control MPPT for a photovoltaic (PV) system; this technique uses the fuzzy logic control to specify the size of incremental current in the current command of MPPT. This paper presents a Maximum Power Point Tracker (MPPT) using Fuzzy Logic for a PV system. The work focused on the well known Perturb and Observe (P&O) algorithm and compared to a designed Fuzzy Logic Controller (FLC). A simulation work dealing with MPPT controller, a DC/DC Ćuk converter feeding a load is achieved. The results will show the validity of the proposed fuzzy logic MPPT in the PV system [11-13].

The proposed SPO is shown in Fig. 1; its configuration is based on a high step-up dc–dc converter with an MPPT control circuit. The converter includes a floating active switch S and a coupled inductor T1 with primary winding N1, which is similar to the input inductor of a conventional boost converter capacitor C1, and diode D1 recycle leakage inductance energy from N1. Secondary winding N2 is connected to another pair of capacitors, C2 and C3, and to diodes D2 and D3. Rectifier diode D4 connects to output capacitor Co and load R. The duty ratio is modulated by the MPPT algorithm, which uses the perturb and observer method that is employed in the proposed SPO. It detects PV module voltage Vpv and currentIpv to determine the increase and decrease in the duty cycle of the dc converter. Therefore, the MPP can be obtained by comparing instantaneous conductance I/V and incremental conductance dI/dV.

The proposed converter has the following features:
1) its voltage conversion ratio is efficiently increased by using the switched capacitor and coupled inductor techniques;
2) The leakage inductance energy of the coupled inductor can be recycled to increase efficiency, and the voltage spike on the active switch is restrained;
3) The floating active switch isolates the PV panel’s energy during non-operating conditions, thereby preventing any potential electric hazard to humans or facilities. The MPPT control algorithm exhibits high-tracking efficiency;

II. OPERATING PRINCIPLES

The operating principles for continuous conduction mode (CCM) and discontinuous conduction mode (DCM) are presented in detail. Fig. 2 illustrates a typical waveform of several major components in CCM operation during one switching period. To simplify the circuit analysis of the proposed converter, the following assumptions are made:1) all components are ideal, except for the leakage inductance of coupled inductor T1, which is taken into account. On-state resistance Rs(on) and all the parasitic capacitances of main switch S are disregarded, as are the forward voltage drops of diodes D1 to D4; 2) Capacitors C1 to C3 and Co are sufficiently large that the voltages across them are considered constant; 3) The equivalent series resistance (ESR) of capacitors C1 to C3 and Co, as well as the parasitic resistance of coupled inductor T1, is neglected; 4) Turns ratio n of coupled inductor T1 windings is equal to N2/N1. The CCM operating modes are described as follows.
A. CCM OPERATION
The CCM operating modes are described as follows.

**Mode I** \( [t_0, t_1] \): During this interval, switch \( S \) and diodes \( D_2 \) and \( D_3 \) are conducted; diodes \( D_1 \) and \( D_4 \) are turned OFF. The current flow path is shown in Fig.3(a). Magnetizing inductor \( L_m \) continues to release energy to capacitors \( C_2 \) and \( C_3 \) through secondary winding \( N_2 \) of coupled inductor \( T_1 \). Leakage inductance \( L_k \) denotes the stored energy from source energy \( V_{in} \). The energy that is stored in capacitor \( C_0 \) is constantly discharged to load \( R \). This mode ends when increasing \( i_{L_k} \) is equal to decreasing \( i_{L_m} \) at \( t = t_1 \).

**Mode II** \( [t_1, t_2] \): During this interval, switch \( S \) and diode \( D_4 \) are conducted. Source energy \( V_{in} \) is serially connected to \( C_1, C_2 \), and \( C_3 \), and secondary winding \( N_2 \); \( L_k \) discharges the energy that is stored in charge output capacitor \( C_0 \) and loads \( R \). Meanwhile, magnetizing inductor \( L_m \) also receives energy from \( V_{in} \). The current flow path is shown in Fig.3(b). This mode ends when switch \( S \) is turned OFF at \( t = t_2 \).

**Mode III** \( [t_2, t_3] \): During this transition interval, switch \( S \) and diodes \( D_2 \) and \( D_3 \) are turned OFF, and diodes \( D_1 \) and \( D_4 \) are conducted. The current flow path is shown in Fig.3(c). The energy stored in leakage inductance \( L_k \) instantly flows through the diode \( D_1 \) to charge capacitor \( C_1 \). The energy is released to magnetizing inductor \( L_m \) through coupled inductor \( T_1 \), which is serially connected to \( C_1, C_2 \), and \( C_3 \), and secondary winding \( N_2 \); \( L_k \) discharges the energy that is stored in charge output capacitor \( C_0 \) and loads \( R \). This mode ends when decreasing \( i_{L_k} \) is equal to increasing \( i_{L_m} \) at \( t = t_3 \).

**Mode IV** \( [t_3, t_4] \): During this interval, switch \( S \) and diode \( D_4 \) are turned OFF, and diodes \( D_1, D_2 \), and \( D_3 \) are conducted. The current flow path is shown in Fig.3(d). Leakage inductance \( L_k \) continues to release energy to charge capacitor \( C_1 \) through diode \( D_1 \). Magnetizing inductor \( L_m \) through coupled inductor \( T_1 \) transfers energy to capacitors \( C_2 \) and \( C_3 \). The energy that is stored in capacitor \( C_0 \) is constantly discharged to load \( R \). This mode ends when decreasing \( i_{L_k} \) is zero at \( t = t_4 \).

**Mode V** \( [t_4, t_5] \): During this interval, diodes \( D_2 \) and \( D_3 \) are conducted. The current flow path is shown in Fig.3(e). Magnetizing inductor \( L_m \) constantly transfers energy to secondary winding \( N_2 \), and charges capacitors \( C_2 \) and \( C_3 \). The energy that is stored in capacitor \( C_0 \) is constantly discharged to load \( R \). This mode ends when switch \( S \) is turned ON at the beginning of the next switching period.

B. DCM OPERATION

**Mode I** \( [t_0, t_1] \): During this interval, switch \( S \) and diode \( D_4 \) are turned OFF, and diodes \( D_1, D_2 \), and \( D_3 \) are conducted. The current flow path is shown in Fig.5(a). Magnetizing inductor \( L_m \) with leakage

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inductance \( L_k \) stores energy from source energy \( V_{in} \). Meanwhile, source energy \( V_{in} \) is also serially connected to capacitors \( C_1, C_2, \) and \( C_3 \), and secondary winding \( N_2 \) to charge capacitor \( C_0 \) and load \( R \). This mode ends when switch \( S \) is turned OFF at \( t = t_1 \).

### Mode II \([t_1, t_2]\):

During this transition interval, switch \( S \) and diodes \( D_1 \) and \( D_2 \) are turned OFF, and diodes \( D_3 \) and \( D_4 \) are conducted. The current flow path is shown in Fig. 5(b). The energy stored in leakage inductance \( L_k \) 1 instantly flows through the diode\( D_1 \) to charge capacitor \( C_1 \); this energy is also released to magnetizing inductor \( L_m \) through the coupled inductor \( T_1 \) series that is connected to \( C_1, C_2, \) and \( C_3 \), secondary winding \( N_2 \), and \( L_k 2 \) to charge output capacitor \( C_0 \) and load \( R \). This mode ends when decreasing \( iD_4 \) is zero at \( t = t_2 \).

### Mode III \([t_2, t_3]\):

During this transition interval, switch \( S \) and diode \( D_4 \) are turned OFF, and diodes \( D_1, D_2 \), and \( D_3 \) are conducted. The current flow path is shown in Fig. 5(c). Leakage inductance \( L_k \) 1 continues to release energy to charge capacitor \( C_1 \) through diode \( D_1 \). Magnetizing inductor \( L_m \) transfers energy to capacitors \( C_2 \) and \( C_3 \) through coupled inductor \( T_1 \). The energy stored in capacitor \( C_0 \) is constantly discharged to load \( R \). This mode ends when decreasing \( iL_k \) is zero at \( t = t_3 \).

### Mode IV \([t_3, t_4]\):

During this interval, switch \( S \), diodes \( D_1 \) and \( D_4 \) are turned OFF, and diodes \( D_2 \) and \( D_3 \) are conducted. The current flow path is shown in Fig. 5(d). Magnetizing inductor \( L_m \) constantly transfers energy to secondary winding \( N_2 \) and charges capacitors \( C_2 \) and \( C_3 \). The energy that is stored in capacitor \( C_0 \) is constantly discharged to load \( R \). This mode ends when decreasing \( iL_m \) is zero at \( t = t_4 \).

### Mode V \([t_4, t_5]\):

During this interval, the switch and all the diodes are turned OFF. The current flow path is shown in Fig. 5(e). The energy that is stored in capacitor \( C_0 \) is constantly discharged to load \( R \). This mode ends when switch \( S \) is turned ON at the beginning of the next switching period.
Fuzzy Logic Control

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometimes even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some applications such as power systems [5]. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of the converter. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at the same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been shown to improve the robustness of compensator.

The basic scheme of a fuzzy logic controller is shown in Fig 8 and consists of four principal components such as: a fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infers the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].
Fig. 9. Membership functions for change in error.

Fig. 10. Membership functions for Output.

Fuzzy rules for error and change of error.

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IV. MATLAB/SIMULATION RESULTS

Fig. 11. Matlab/Simulink model of proposed SPO with open loop system.

Fig. 12. Photovoltaic voltage.

Fig. 13. Output current of the proposed converter with open loop system.

Fig. 14. Output voltage of the proposed converter with open loop system.

Fig. 15. Output power of the proposed converter with open loop system.

Fig. 16. Matlab/Simulink model of proposed SPO with closed loop system and fuzzy logic controller.
V. CONCLUSION

The high step-up SPO uses the coupled inductor with an appropriate turn’s ratio design and switched-capacitor technology to achieve a high-voltage gain that is 20 times higher than the input voltage. The inputs of Photovoltaic (PV) panel are solar temperature and solar irradiance which converts the solar power into PV voltage and PV current which is fetch as input to MPPT. The MPPT control techniques are done with both PI and FUZZY and is designed in SIMULINK. The voltage gain and efficiency is then measured using display and then calculated theoretically. Both the results are then compared and the control technique enhancing maximum efficiency is implemented.

REFERENCES