CASCADED BOOST CONVERTER USING FUZZY AND SLIDING MODE CONTROL TO IMPROVE THE CAPABILITY OF GRID INTERACTED PV SYSTEMS

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Abstract

Switching dc to dc converters are mainly used to connect the distribution system with the output of renewable energy sources. The cascaded boost converters are controlled by the sliding mode control. This will not maintain the constant efficiency throughout the operation. This is because of errors which occur while doing the complex calculations in sliding mode control. The aim of this paper is to maintain the constant efficiency by replacing the sliding mode control by fuzzy controller, and also to compare the output of the system by controlling the cascaded converter by using "sliding mode and fuzzy control".

Index terms: cascaded boost converter, photovoltaic (PV) system, sliding mode control (SMC), fuzzy logic control (FLC).

I. INTRODUCTION

In the present scenario India is facing more demands regarding power crisis due to increase in population. According to Jan 2016 statistics India has generating 1,106,000 GWh. In total generation, 72% of power is generated by non-renewable energy resources and only 28% of power is generated by renewable energy resources [1]. To improve the power generation we need to utilize the renewable energy resources a lot. Among all renewable energy resources solar is one of the abundant resources to generate power.

The output of solar panel is mainly depends on the solar insolation i.e intensity of solar radiation and also the ambient temperature [9]. We cannot connect the load directly to the output of solar panel. Shadowing effect in the panel will reduces the efficiency of the panel. If partial shadowing occurs in panel it leads to degrade of the panel due to increased temperature in that particular area [13]. But in case of complete shadowing of a panel, by the use of bypass diode the power will be transferred to the next panel and to the load. By pass diode will be each and every cell in solar panel.

The output voltage of the photovoltaic system is determined by the cascaded DC-DC boost converter. Cascaded boost converter has two switches hence we can get high voltage and low current from one converter and low voltage and high current [3] from other converter so it increase the efficiency. In case of parallel boost converter the current sharing will not be same and it has low fault tolerance [4]. The output of the solar panel is variable and that variable voltage is given as the input to the boost converter. The output of first boost converter is given as a input to the second converter. The overall output of the cascaded boost converter is given to the grid [6]. The high manufacturing cost of PV panel and low conversion efficiency are the main drawback of photovoltaic system.

Maximum power from the solar panel is obtained by determining the maximum power point (MPP) [5] and this can be done by MPPT. Maximum power point can be achieved by using the algorithms like paturb and observe method, Incremental conductance method, and constant voltage method [11], current sweep method. According to the sun’s rays it tracks the panel to get maximum power. The converter switches are controlled by the instantaneous value of the state variables when the system trajectories stay on a suitable selected surface on the phase space is called the sliding surface. The motion of the system along trajectories on which the structure of the system changes is called sliding mode. To fix a sliding mode surface we need to determine the gain values, thus it produces the output with less accuracy due to errors in calculating gain value. That's why we are moving to fuzzy logic control [12].

II. PHOTOVOLTAIC PANEL

We are receiving solar energy in two forms: light and heat. The solar thermal system and solar PV system are the two main types of solar power system. solar PV system consist of more number of solar cells which are connected in series to form a module. More modules are connected in parallel to form a array. Each cell can produce 0.5V and 7A.
Mathematical Model of Solar Cell

Diode is connected with the current source as shown in fig.1 and output current is obtained by the equation,

\[ I = I_{ph} - I_d - I_p \]  \hspace{1cm} (1)

\( I_d \) – diode current, \( I_{ph} \) – photocurrent which is proportional to saturation current. \( I_p \) is the leakage current in parallel resistor. It is given by the equation

\[ I_d = I_{ph} - I_0 \exp \left( \frac{V}{A} \right) \left( \frac{1}{n} \right) \left( \frac{V + \frac{dI}{dr}}{V_T} \right) \]  \hspace{1cm} (2)

\( I_0 \) is the reverse saturation current. \( V \) is the imposed voltage on diode.

\[ I_{ph} = \frac{G}{G_{ref}} (I_{ph, ref} + \mu \Delta T) \]  \hspace{1cm} (3)

\( G \) – irradiance (W/m\(^2\)), \( G_{ref} \) – irradiance at STC = 1000(W/m\(^2\)), \( \Delta T = T_c - T_{c,ref} \), \( T_{c,ref} \) : Cell temperature at STC = 25 + 273 = 298 K, \( lSC \) : Coefficient temperature of short circuit current (A/K), provided by the manufacturer

\[ I_0 = DT_c^3 \exp \left( \frac{E_{c}}{kT_c} \right) \]  \hspace{1cm} (4)

Maximum Power Point Tracking

The main aim of the MPPT circuit is to ensure that the PV module is operating at its MPP regardless of the temperature, intensity by insolation, and load variation. Different types of tracking algorithms have been used for different types of dc-dc converter topologies [11]. ESC is one of the commonly used types of MPPT algorithms which can force the PV system to approach the MPP by increasing or decreasing a suitable control variable.

III. CASCADDED BOOST CONVERTER

The output of PV panel is variable voltage and this variable voltage is converted into constant output voltage across the output capacitor and the load is connected to it. The state of the art has revealed numerous advantages of cascaded DC/DC converters between PV modules and the load [6]. The main function of the converter is to charge and discharge the super capacitor (A storage device like a battery).
IV. PROPOSED SYSTEM

In the proposed system, fuzzy logic control is used to achieve the maximum power point and to control the converter switches. It has two implementation strategies such as combination of sliding mode control and fuzzy control (fig. 3), fuzzy alone (fig.4). Fuzzy reduces the high overshoots and errors [15]. In FLC we can choose the more input range.

![Fig. 3: Block diagram of converter with sliding mode control](image)

In fig. 4, the system can achieve high conversion ratio and maintains the efficiency up to 95% [17]. Also two cascaded dc-dc boost converter under FLC and sliding mode control is employed to the PV system, to improve the output voltage.

![Fig. 4: Block diagram of converter with fuzzy logic control](image)

Sliding Mode Control

Function of switching control law is to maintain the systems state trajectory for subsequent time and to drive a nonlinear system to pre-specified surface. This surface is known as sliding surface. Feedback path has gain as one when plant trajectory is above the surface and has different gain when plant trajectory is below the surface. By the proper design of sliding surface tracking, regulation, stabilization can be obtained.

Let $X$ be the voltage error, $Y$ be rate of change of voltage error and $Z$ be integral of voltage error. Under continuous conduction mode

$$X = (V_{ref} - \beta V_o)$$

$$Y = \frac{V_o}{C} - \int \frac{1}{R_L} (V_{ref} - V_o) dt$$

$$Z = \int X dt$$

$$X_{boost} = \left[ \frac{V_o}{C} \frac{V_{ref} - \beta V_o}{R_L} \frac{1}{R_L} \int V_{ref} - \beta V_o dt \right]$$

$$X_{boost} = AX_{boost} + BU$$

Where

$$A = \begin{bmatrix} 0 & \cdots & 1 & 0 \\ 0 & \cdots & 1/R1c & 0 \\ 1 & \cdots & 0 & 0 \end{bmatrix}$$
\[ B = \begin{bmatrix} \frac{B_V}{LC} & 0 \\ 0 & \frac{B_V}{LC} \end{bmatrix} \]

General SM control law that adopts a switching functions such as,
\[ u = 1 \] when \( S > 0 \),
\[ = 0 \] when \( S < 0 \),
\[ \frac{1}{A(1+\text{sign } S)} \] \[ \text{---------} \] (6)

Where, \( S \rightarrow \) instantaneous state variable's trajectory and is described as,
\[ S = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 = J^T X \]

With, \( J = [\alpha_1 \alpha_2 \alpha_3] \)
where, \( \alpha_1, \alpha_2, \alpha_3 \) are sliding coefficients

A sliding surface can be obtained by enforcing, \( S = 0 \). Equivalent control function onto the duty ratio control \( d \), where
\[ 0 < d = \frac{V_c}{V_{ramp}} < 1 \] \[ \text{---------} \] (7)
gives the following relationship for the control signal \( V_C \) and ramp signal \( V_{ramp} \), where
\[ V_C = U_{equ} = \frac{-B_V L}{\alpha_1 + \alpha_2} + \frac{V_r e f - \beta V_o}{\alpha_3} \]
\[ V_{ramp} = \beta (V_o - V_i) \]

Maximum Power point tracking using Fuzzy Logic Control

In fuzzification process, using the seven fuzzy subsets and membership functions are designed are to linguistic variables. Seven fuzzy subsets are negative very big(NVB), negative big(NB), negative small(NS), zero(ZE), positive small(PS), positive big(PB), positive very big(PVB)[14]. The value of change in error (ce) and value of input error (e) are normalized by an input scaling factor. The input scaling factor has been designed with the input values are between \(-1\) and \(1\).

The input error (e) for the FLC can be calculated from MPP is as follows
\[ E(K) = \frac{\Delta I}{\Delta V} = \frac{I(k) - I(k-1)}{V(k) - V(k-1)} \]

where \( I \) is the output current from PV array, \( \Delta I \) is the change of output current, \( I(k)K(k-1) \), \( V \) is output voltage from PV array, \( \Delta V \) is change of output voltage, \( V(k)K(k-1) \)

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Several composition methods such as Max–Min and Max-Dot have been used to generate the control output. Max–Min method is commonly used in this paper. The Min (minimum) operator and Max (maximum) operator is given as the output membership function of each rule[15].
Defuzzification stage is needed by the plant as it requires a nonfuzzy value of control [16]. In defuzzification height method is used because it is simple and fast. The system of $m$ rules given by

$$du = \left( \frac{\sum_{k=1}^{m} c(k)w_k}{\sum_{k=1}^{m} w_k} \right)$$

where, $c(k)$ is the peak value of each output, $du$ is the change of control output and $w_k$ is height of rule $k$. The output of fuzzy logic control is used to modify the output to be controlled one.

V. SIMULATION RESULTS

Fuzzy logic controllers have been used in the MPPT tracking of the photovoltaic system. Advantage of fuzzy logic control is to be robust and relatively simple to design. It uses the two input variables light intensity ($I$) and voltage ($V$). The equivalent model of solar panel consists of two diodes, one is to give the input voltage to the panel and the other is bypass diode. To avoid the shadowing effect bypass diode is used. The measured voltage and intensity is given as input to the fuzzy logic controller.

![Simulation diagram of solar panel](image1)

**Fig 5:** Simulation diagram of solar panel

![Simulation diagram of fuzzy logic control to generate PWM signal](image2)

**Fig 6:** Simulation diagram of fuzzy logic control to generate PWM signal

Fuzzy analyse the range of intensity and its voltage, based on that it will give voltage reference to the PWM converter [17]. The PWM is used to generate the corresponding pulses. One output of PWM is given to the first converter and the other is given to the second converter. NOT gate is connected to the output from the second converter in order to turn on both the converter at the same time. Both the converters are controlled by the pulse generated from PWM using fuzzy controller.
Output voltage of both the converter and overall output current of the converter is given as the input to this sliding mode control circuit. The output signal from the relay and pulse generated from PWM generator is combined by using AND logical operator.

While using the sliding mode control the output voltage of the photovoltaic system is about 250V and the output power is 800W. Due to the occurrence of error during the tedious calculations in sliding mode control which acts as a barrier for the constant maximum efficiency.
X Axis – Time; Y Axis – voltage and Current
Fig.9. Output current and voltage (converter) using fuzzy and sliding mode control

X Axis – Time; Y Axis – Power
Fig.10. Output power from converter using fuzzy and sliding mode control

VII. CONCLUSION

High voltage conversion ratio can be obtained by using cascaded boost converters. These converters are used to step up the low voltage obtained from the PV panel and send it to grid. This cascaded boost converter is robustly controlled by the fuzzy control and sliding mode control. In feature work, to obtain the constant cascaded boost converters are controlled by fuzzy controllers while comparing with sliding mode control, since the sliding mode uses the complex mathematical calculations. These calculations will lead to the error and cannot be used to obtain constant efficiency.

REFERENCES

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