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Prevention of Hotspot Effects in a Solar Photovoltaic Cell using Fuzzy Logic MPPT

G. Sivabakya
PG Student,
Dept. of ECE,
Velalar College of Engg. & Tech.
Thindal, Erode

K. Kavitha
Assistant Professor (Sr. Gr.)
Dept. of ECE,
Velalar College of Engg. & Tech.,
Thindal, Erode

G. Boopathi Raja
Assistant Professor,
Dept. of ECE,
Velalar College of Engg. & Tech.,
Thindal, Erode

***Abstract* – Today solar photovoltaic (PV) system plays an important role in electrical power applications. The major characteristic of solar panel is that the available maximum power is provided only in a single operating point given by a localized voltage and current known, called Maximum Power Point (MPP). But the position of this point is not fixed. It moves according to the irradiance level, the temperature and the load. The mechanism for the tracking of the MPP called maximum power point tracking (MPPT) is required. So that the maximum power is generated permanently. The incremental conductance and incremental resistance are the existing conventional MPPT methods. To overcome the limitations in the existing methods such as low convergence speed and low efficiency a fuzzy logic based MPPT model is proposed. This model can track the maximum power point accurately and improves the energy efficiency. It also avoids the permanent damage of the cells under hotspot condition and their drawbacks on the power efficiency. Then it is simulated using MATLAB software and implemented using ATmega8 controller and boost converter.**

Index Terms — Shading, maximum power point, irradiance level, hotspot.

1. INTRODUCTION

Solar panel and maximum power point

Nowadays, the solar photovoltaic (PV) systems are increasingly adopting in the urban areas, for the source of green energy. In such an environment, (partial) shading in the PV array is very frequent. In that case, the temperature of PV cells increases, which cause consequent reduction in the produced power. It can lead to a phenomenon called as hotspot. To prevent that the concept of Maximum Power Point Tracking (MPPT) is used. Solar energy is the renewable energy which can be produced from natural resource sunlight. Therefore, for all practical purposes, this resource can be considered to be inexhaustible. This renewable energy sources are much cleaner and produce energy without any harmful effects to the environment. Solar energy can be utilized in two major ways. One way is space heating in which the captured heat can be used as solar thermal energy. Another way is the conversion of incident solar radiation to electrical energy using solar photovoltaic cells or with concentrating solar power plants, which is the most usable form of energy.

Different MPPT techniques

There are different MPPT techniques such as Perturb and Observe (also called as hill climbing method), Incremental resistance (IR), Incremental conductance (IC), Fractional Short Circuit Current (FSCC), Fractional Open Circuit Voltage (FOCV), Fuzzy Logic (FL), Neural Network (NN) Control etc. Among all these methods Perturb and observe (P&O), Incremental resistance and Incremental conductance are most commonly used. Because their implementation is simple, takes lesser time to track the MPP and several other economic reasons. Instead of higher efficiency the complexity of the algorithm is very high when comparing to the previous one but the cost of implementation increases. So we have to mitigate with a tradeoff between complexity and efficiency. It is also seen that the efficiency of the system also depends upon the converter. The choice of the algorithm depends on the time and implementation complexity that the algorithm takes to track the MPP, implementation cost. Under the rapidly changing irradiance level (weather condition) as MPP changes continuously, P&O takes it as a change in MPP due to perturbation rather than that of irradiance and sometimes ends up in calculating wrong MPP. However this problem is avoided in Incremental resistance and Incremental Conductance method because the algorithm takes two samples of voltage and current to calculate MPP.

2. METHODOLOGY

Maximum power point tracking

Typically a solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. A maximum power point tracking technique based on Maximum Power Transfer theorem is used to improve the efficiency of the solar panel. According to this theorem, the power output of a circuit is maximum when the source impedance of the circuit matches with the load impedance. Hence our problem of tracking the maximum power point reduces to an impedance matching problem. In the source side the boost

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convertor connected to a solar panel to enhance the output voltage. So that it can be used for different applications for example motor load. The source impedance is matched with that of the load impedance duty cycle of the boost converter is changed by changing the duty cycle of the boost converter appropriately.

PV module and modeling

A photovoltaic cell is a semiconductor device in which light energy is converted into electrical energy by using photovoltaic effect. If the energy of photon of light is greater than the band gap then the electron is emitted and the flow of electrons creates current. A photovoltaic cell is different from a photodiode. In a photodiode light falls on n channel of the semiconductor junction and gets converted into current or voltage signal but a PV cell is always forward biased. PV modules of different sizes are commercially available (generally sized from 60W to 170W). For example, a typical small scale desalination plant requires a few thousand watts of power. A PV array consists of several PV cells in series and parallel connections. In which series connections are responsible for increasing the voltage of the module whereas the parallel connections are responsible for increasing the current in the array. A typical solar cell can be modeled by a current source and an inverted diode connected in parallel. It has its own series and parallel resistance. Here we consider a current source along with a diode and series resistance. The shunt resistance in parallel is very high, has a negligible effect. So that can be neglected. To model the solar panel accurately, we can use two diode model. But in our project our scope of study is limited to the single diode model.

Boost converter

The maximum power point tracking is basically a load matching problem. A DC to DC converter is required to change the input resistance of the panel to match the load resistance (by varying the duty cycle). It has been observed that the efficiency of the DC to DC converter is maximum for a buck converter, than for a buck-boost converter and minimum for a boost converter. But as we intend to use our system either for tying to a grid or for a water pumping system which requires 230 V at the output end, so we use a boost converter.

Pulse width modulation

Pulse width modulation (PWM) is a commonly used technique for controlling power to the electrical devices. The average value of voltage and current fed to the load is controlled by turning the switch on and off between supply and load. The longer the switch is on compared to the off periods, the higher the power supplied to the load. The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time. A low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off, there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current is close to zero in both cases. PWM also works well with digital controls, because of their on/off nature, which can easily set the needed duty cycle.

Fuzzy Logic

Fuzzy logic is the popular technique for MPPT which is used in microcontrollers over last decade. Fuzzy logic controllers have the merits of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity. Conventional methods for tracking the optimal point of operation have shown their limits to sudden changes of weather condition and the load connected to the panel. Several methods have emerged to try to overcome these shortcomings and improve the operation of these generators. The approach of Artificial Intelligence in the case of fuzzy logic is developed to improve control performance and the tracking of maximum power point by simulation and modeling of a controller based on fuzzy logic. The advent of microcontrollers has enabled the spread of fuzzy control in the pursuit of optimal point. The performance of the fuzzy logic controllers (FLC) is tested using stand-alone PV system for various operational conditions, such as changing solar irradiance, temperature and load. The three functional blocks in fuzzy controller are fuzzification, comparison and defuzzification. Fuzzification of input variables uses the trapezoidal and triangular functions. Then these variables in fuzzification inference are compared with pre-defined packages to determine the appropriate response. And finally, the defuzzification is proceeded to convert the subset fuzzification in values using the centroid defuzzification. NB (Negative Big), NS (Negative Small), ZE (Zero Approximately), PS (Positive Small), PB (Positive Big) are the five linguistic variables used in fuzzy logic. The linguistics variables are also called as membership functions.

Fuzzy rules

In this case, only one particular correspondence between two-valued and multivalued logical operations for AND, OR, and NOT is defined. In general, it is defined that what are known as the fuzzy intersection or conjunction (AND), fuzzy union or disjunction (OR), and fuzzy complement (NOT). AND = min, OR = max, and NOT = additive complement are the classical operators used for these functions. Mostly a typical fuzzy logic applications make use of these operators. However, these functions are arbitrary to a surprising degree. Fuzzy Logic Toolbox software uses the classical operator for the fuzzy complement. But also enables you to customize the AND and OR operators. Fuzzy logic is based on a single fuzzy if-then rule and assumes the form ***if x is A then y is B.***

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3. PROPOSED METHOD

Block diagram

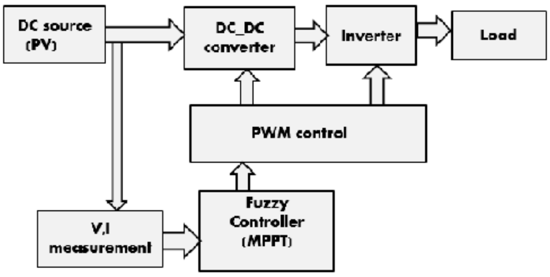

Fig. 1. Basic block diagram of the project

Hardware description

7805 regulator is used to provide the supply voltage to the controller. Solar panel provides input to the regulator. ATmega8 controller is a High - performance, Low-power AVR® 8-bit microcontroller with advanced RISC architecture is used here. It has the features such as three PWM Channels 8-channel ADC. Converter circuit used here is boost converter to get the output DC voltage greater than its input DC voltage. Inverter circuit is used to convert the DC voltage into AC voltage then given to the load. Transformer is used to isolates the output circuitry from the ac input, and steps down (or up) the voltage to the required operating level.

Circuit elements

Converter circuit uses two IRF840 MOSFET switches, inductors and capacitors. Inverter circuit uses four IRF840 MOSFET switches. This N-Channel enhancement mode silicon gate power field effect transistor switch is an advanced power MOSFET designed, tested, and guaranteed to withstand a specified level of energy in the breakdown avalanche mode of operation. All of these power MOSFETs are designed for applications such as switching regulators, switching converters, motor drivers, relay drivers, and drivers for high power bipolar switching transistors requiring high speed and low gate drive power. These types can be operated directly from integrated circuits. 1N4007 rectifier is used prevent the reverse bias current from the regulator to the solar panel.

Software description

Code vision AVR is used to write the code. Coding language used is embedded C. MATLAB is used to simulate the output voltage characteristics of both the existing and proposed methods.

4. SIMULATION RESULTS

The existing and the proposed methods are simulated using MATLAB software. MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourth-generation programming language. A proprietary programming language developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages. Here MATLAB 7.12(R2011a) is used to simulate MPPT models.

Incremental conductance (IC) MPPT

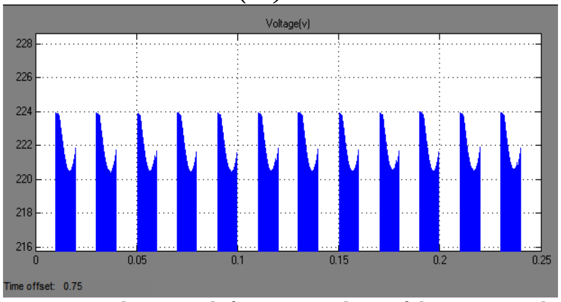

Fig. 2. Simulation result for Output voltage of the Incremental conductance MPPT model

Incremental resistance (IR) MPPT

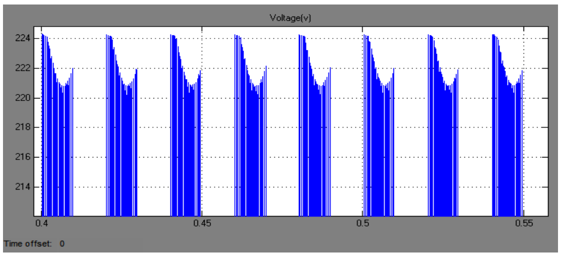

Fig. 3. Simulation result for Output voltage of the Incremental conductance MPPT model

Fuzzy logic (FL) MPPT

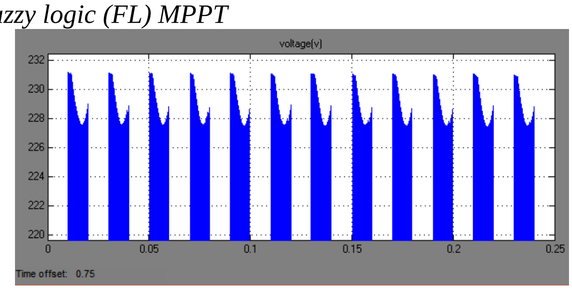

Fig. 4. Simulation result for Output voltage of the Fuzzy logic MPPT model

Tab. 1. Comparison of output voltage values

MPPT Method	Output voltage(v)
IC MPPT	223v (approx)
IR MPPT	225v (approx)
FL MPPT	231v (approx)

5. CONCLUSION

The above shown simulation results and the tabulated values shows that the efficiency of the incremental conductance MPPT model is lower when compared with the incremental resistance MPPT model. So it is clear that the efficiency, implementation complexity and convergence speed varies for different MPPT techniques. This project gives the better efficiency than the existing models with satisfaction at the sharp variations in voltage and a fast response time which is less when compared with the conventional algorithms. It also eliminates the fluctuations in the voltage and the resulting output will be more accurate.

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