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A Fuzzy Model Based MPPT Control for PV Systems

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ABSTRACT

This project introduces a polynomial fuzzy model based Maximum Power Point Tracking (MPPT) control approach to increase the performance and efficiency of the solar photovoltaic (PV) electricity generation. The proposed method relies on a polynomial fuzzy modeling, a polynomial Parallel Distributed Compensation (PDC) and a Sum-of-Squares (SOS)

decomposition. The proposed method is a generalization of the standard Takagi-Sugeno (T-S) fuzzy models and Linear Matrix Inequality (LMI) which showed its effectiveness in decreasing the tracking time and increasing the efficiency of the PV systems. In this study, a Direct Maximum Power (DMP)-based control structure is considered for MPPT. Using the polynomial fuzzy model representation, the DMP-based control structure is formulated in terms of SOS conditions. Unlike the conventional approaches, the proposed approach does not require exploring the maximum power operational point. Finally, the extensive studies and hardware-in-the-loop (HiL) simulations are presented to show the effectiveness of the proposed method.

CHAPTER-1

1.1. INTRODUCTION

In recent years, the use of photovoltaic (PV) energy has experienced significant progress as an alternative to solve energy problems in places with high solar density, which is due to pollution caused by fossil fuels and the constant decrease of prices of the PV modules. Unfortunately, the energy conversion efficiency of the PV modules is low, which reduces the cost-benefit ratio of PV systems. The maximum power that a PV module can supply is determined by the product of the current and the voltage at the maximum power point, which depends on the operating temperature and the solar irradiance.

The short-circuit current of a PV module is directly proportional to the solar irradiance, decreasing considerably as the irradiation decreases, while the open circuit voltage

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varies moderately due to changes in irradiation. In contrast, the voltage decreases considerably when the temperature increases, while the short circuit current increases moderately In summary, increases in solar irradiation produce increases in the short-circuit current, while increases in temperature decrease the open circuit voltage, which affects the output power of the PV module. This variability of the output power means that in the absence of a coupling device between the PV module and the load, the system does not operate at the maximum power point (MPP).

According to the previous context, the use of maximum power point (MPPT) controllers is currently increasing [1]. These devices are responsible for regulating the charge of the batteries, controlling the point at which the PV modules produces the greatest amount of energy possible, regardless of variations in climatic conditions. The use of MPPT controllers in PV systems has the following advantages: 1. They yield more power, depending on weather and temperature; 2. They allow the connection of PV modules in series to increase the voltage of the system, which reduces the wiring gauge and adds flexibility; 3. They offer a cost savings in the transmission wire needed for the installation of the PV system.

In contrast to MPPT controllers, traditional controllers make a direct connection of the PV modules to the batteries, which requires that the modules operate in a voltage range that is below to the voltage in maximum power point. For example, in the case of a 12 V system, the battery voltage can vary between 11 V and 15 V, but the voltage at the maximum power point is a typical value between 16 V and 17 V.

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Due to this situation, with the traditional controllers the energy that the PV modules can deliver is not maximized. Taking into account the above, different researches have been carried out using traditional algorithms for the modeling and implementation of MPPT controllers [2], of which the following are highlighted: perturb and observe (P&O) [3,4], modified P&O [5,6], fractional short circuit current [7], fractional open circuit voltage [8], sliding mode control [9,10] and incremental conductance [11]. The P&O algorithm has been used traditionally, but it has been shown that this method has problems for tracking the MPP when there are sudden changes in solar irradiance [12].

Also, algorithms based on artificial intelligence techniques such as fuzzy logic [13–19] and neural networks [20–22] have been used, as well as the implementation of optimization algorithms such as glowworm swarm [23], ant colony [24,25] and bee colony [26–28]. These algorithms are part of soft computing techniques and have the advantage of being easily implemented using embedded systems.

Additionally, MPPT controllers are widely used in hybrid power systems, in which different control techniques based on neural networks, fuzzy logic and particle swarm optimization have been evaluated. In [29–31], the effectiveness of these control techniques was demonstrated in order to achieve a fast and stable response for real power control and power system applications. The implementation of new control and optimization techniques that are detailed in [32–35] for electrical power and energy systems can be studied in the modeling and implementation of MPPT controllers.

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This paper presents the design and modeling of a fuzzy controller to track the maximum power point of a PV module, using the characteristics of fuzzy logic to represent a problem through linguistic expressions [36]. This paper presents as a novelty the use of the mathematical model proposed in [37,38] for modeling the PV module, which, unlike diode based models, only needs to calculate the curve fitting parameter. The results were compared with the P&O controller, which demonstrated that the proposed approach presents less energy losses and ensures MPP in all cases evaluated in simulation. It is worth mentioning that this work is part of a set of intelligent control techniques being evaluated in the research group Magma Ingeniería of the Universidad del Magdalena in order to implement a MPPT controller of low cost and high efficiency.

1.2 OBJECTIVE OF PROJECT

Battery storage is usually employed in Photovoltaic (PV) system to mitigate the power fluctuations due to the characteristics of PV panels and solar irradiance. Control schemes for PV-battery systems must be able to stabilize the bus voltages as well as to control the power flows flexibly. Finally for Grid-Connected and Islanded Modes.

1.3 ORGANISATION OF PROJECT

The main objective of this work is the design, modeling and simulation of a fuzzy logic controller and a dc-dc converter for an off-grid PV system. In a second stage, the fuzzy logic controller will be implemented using the low-cost Arduino platform [38], taking as a reference the input variables, output, fuzzification, inference system and defuzzification evaluated during the modeling stage. The dc-dc converter will also be implemented according to the design conditions evaluated in the simulations.

1.4 EXISTING SYSTEM

The idea of MPPT is not new, many MPPT methods have been proposed by researchers to improve the tracking efficiency. These techniques differ in sensor required, complexity, cost, and convergence speed.In fractional open circuit voltage method is implemented that based on the fact that the ratio of the maximum power voltage (VMP) and the open circuit voltage (VOC) are approximately linearly proportional under varying weather conditions.

The yielded power from PV panel definitely is less than the real power at MPP because of the obvious reason that this method is based on the approximation. Following the same pattern fractional short circuit current method is shown in which uses the fact that the ratio of maximum power current (IMP) and short circuit current (ISC) are linearly proportional. This method has the same drawbacks and weakness as that of fractional open circuit voltage method. Perturb and Observe (P&O) method and Hill climbing method [9] are most popular because of their simplicity and low cost. Both the methods work on the same principle of perturbing the PV system and observing its effect on the PV panel power output.

1.5 PROPOSED SYSTEM

The fuzzy-logic controller (FLC) based MPPT has been proposed in to overcome the shortcoming of the conventional algorithms. In this paper scaling factor and membership

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functions of FLC MPPT are investigated to improve the tracking speed and steady state fluctuations. Increasing the scaling factor (range) of output variable will improve the tracking speed but add large oscillations in the steady state which cause considerable power loss. To tackle this problem new memberships functions are introduced which control the operating point closer to the MPP and reduce the fluctuation. DC-DC converter, maximum power point tracker (MPPT) and load. After that the proposed Fuzzy based MPPT controller is discussed in section 3. It is followed by results and discussion in section 4 and conclusion is made in the end.

CHAPTER-2

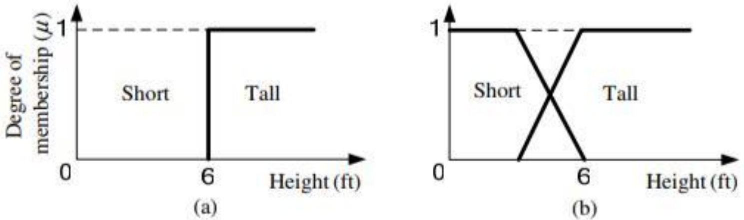
FUNDAMENTALS OF FUZZY LOGIC CONTROLLERS

2.1 FUZZY LOGIC

Fuzzy Logic is a branch of Artificial Intelligence. It owes its origin to LoftiZadeh, a professor at the University of California, Berkley, who developed fuzzy set theory in 1965 [15]. The basic concept underlying fuzzy logic is that of a linguistic variable, that is, a variable whose values are words rather than numbers (such as small and large). Fuzzy logic uses fuzzy sets to relate classes of objects with unclearly defined boundaries in which membership is a matter of degree. 1.5.2 Fuzzy Sets and Membership Functions A fuzzy set is an extension of a crisp set where an element can only belong to a set (full membership) or not belong at all (no membership). Fuzzy sets allow partial membership which means that an element may partially belong to more than one set. A fuzzy set A is characterized by a membership function μ A that assigns to each object in a given class a grade of membership to the set. The grade of membership ranges from 0 (no membership) to 1 (full membership) written as, :

$$\mu \ A \ U \rightarrow [0,1](1\text{-}1)$$

This means that the fuzzy set A belongs to the universal set U (called the universe of discourse) defined in a specific problem. A membership function defines how each point in the input space is mapped to a degree of membership. For example, consider the set of membership functions for a set of tall people shown in Figure 1-1. If the set is given the crisp boundary of a classical set, it can be considered that all people taller than six feet are considered tall, while those less than six feet are short. But, such a distinction is not fully realistic. If one would however consider a smooth curve from “short” to “tall”, then the transition would make more sense. A person may be both tall and short to some degree. The output axis would be a number between 0 and 1, known as the degree of membership in a fuzzy set of height.



(a) (b)

Figure 1-1 Illustration of membership functions for a set of tall people (a) crisp set (b) fuzzy set 1.5.3 Fuzzy Rules and Inferencing The use of fuzzy sets allows the characterization of the

R_i : IF x is *small* THEN y is *large* system behaviour through fuzzy rules between linguistic variables. A fuzzy rule is a conditional statement Ri based on expert knowledge expressed in the form:

Where x and y are fuzzy variables and small and large are labels of the fuzzy sets. If there are n rules, the rule set is represented by the union of these rules i.e.,

$$R = R_1 \text{ else } R_2 \text{ else } \ldots\ldots R_n .$$

A fuzzy controller is based on a collection R, of control rules. The execution of these rules is governed by the compositional rule of inference [17] [18]. 1.5.4 Fuzzy Controller Structure The general structure of a fuzzy logic controller is presented in Figure 1-2 and comprises of four principal components:

- Fuzzification interface: - It converts input data into suitable linguistic values using a membership function.
- Knowledge base: - Consists of a database with the necessary linguistic definitions and the control rule set.
- Inference engine: - It simulates a human decision making process in order to infer the fuzzy control action from the knowledge of the control rules and the linguistic variable definitions.
- Defuzzification interface: - Converts an inferred fuzzy controller output into a non-fuzzy control action.

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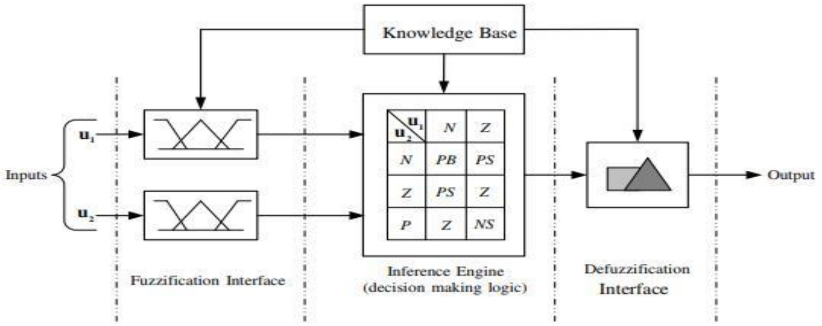

Figure 1-2 Basic configuration of a fuzzy logic controller

2.2 APPLICATION OF FUZZY LOGIC IN MPPT CONTROL

Dc-dc converter systems are becoming strong candidates for modern fuzzy control techniques due to their complex, nonlinear behavior, particularly for large load and line variations [16]. The highly nonlinear behavior of these power circuits is caused by the presence of a switch, which can be any electronic switch such as a transistor, a thyristor, or any other switching device. Depending on the state of the switch (ON/OFF) the plant structure exhibits very different functioning modes, resulting in a severe nonlinearity. PV modules also have nonlinear current-voltage (I-V) characteristics that are dependent on solar radiation, temperature, and degradation due to environmental effects.

Therefore, their operating point that corresponds to the maximum output power varies with the environmental and load conditions. MPPT control is therefore an intriguing subject from the control point of view, due to the intrinsic nonlinearity of dc-dc converters and PV

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modules. This is because an accurate model of the plant and the controller is necessary while formulating the control algorithm.

There are two possible ways of overcoming this. One method is to develop more accurate nonlinear models for controllers, but the discouraging fact about taking this route is that complex mathematical derivations are involved. Even when developed, the complicated control algorithms may not be suitable for practical implementations. The other method is to employ heuristic reasoning based on human experience of the plant. Such experience is usually collected in the form of linguistic statements and rules.

In this case, no modeling is required, and the whole business of controller design reduces to the "conversion" of a set of linguistic rules into an automatic control algorithm. Here, fuzzy logic comes into play as it provides the essential machinery for performing the said conversion. Such a completely different approach is offered by fuzzy logic, which does not require a precise mathematical modeling of the system nor complex computations [17], [18]. This control technique relies on the human capability to understand the system's behavior and is based on qualitative control rules.

Thus, controller design is simple, since it is only based on linguistic rules of the type: “IF the change in output power is positive AND the change in duty cycle is negative THEN reduce slightly the duty cycle" and so on. Fuzzy logic control relies on basic physical properties of the system, and it is potentially able to extend control capability even to those

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operating conditions where linear control techniques fail, i.e., large signal dynamics and large parameter variations.

As fuzzy logic control is based on heuristic rules, application of nonlinear control laws to overcome the nonlinear nature of dc-dc converters is easy. Fuzzy logic offers several unique features that make it a particularly good choice for these types of control problems because: • It is inherently robust as it does not require precise, noise-free inputs. The output control is a smooth control function despite a wide range of input variations.

- It can be easily modified to improve system performance by generating appropriate governing rules.
- Any sensor data that provides some indication of a system's actions and reactions is sufficient. This allows the sensors to be inexpensive and imprecise thus keeping the overall system cost and complexity low.
- Its rule-based operation enables any reasonable number of inputs to be processed and numerous outputs generated. The control system can be broken into smaller units that use several smaller fuzzy logic controllers distributed on the system, each with more limited responsibilities.

2.3 MODELING OF A PHOTOVOLTAIC MODULE

The modeling framework for a photovoltaic module. A model is developed and validated using manufacturer supplied data for a specific module. The model is used to study PV module operation characteristics with the view of formulating a suitable control strategy

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for extraction of maximum power. The model theory in this chapter is adapted from the Hybrid2 theory manual [19]. Hybrid2 is a computer simulation model for hybrid power systems developed by the University of Massachusetts. The model in Hybrid2 can calculate the expected cost savings when maximum power point trackers are included in photovoltaic systems but has no provision for formulating or testing control strategies.

3.4 MODEL THEORY

A PV module is composed of individual solar cells connected in series and parallel and mounted on a single panel. The goal is to calculate the power output from a PV module based on an analytical model that defines the current-voltage relationships based on the electrical characteristics of the module. As described in the following theory section, a one diode model forms the basic circuit model used to establish the current-voltage curve specific to a PV module. The theory is used to formulate a PV module model using Simulink software. This model is able to include the effects of solar radiation level and cell temperature on the output power. The performance of PV arrays that consist of several modules connected in series or parallel is also discussed.

3.4.1 Model Inputs

The primary inputs that affect the PV module output are the parameters that define the basic module current-voltage (I-V) relationship. These parameters are determined from information supplied by the manufacturer and include the open circuit voltage and short

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circuit current of the module. The model inputs during simulation are the solar radiation and ambient temperature.

2.4.2 Model Outputs

The model outputs at the beginning of the simulation are 1) the light generated current, 2) the diode (or cell) reverse saturation current, 3) the series resistance, and 4) a curve fitting parameter. The output of the model at each time step is the generated module current and voltage.

2.4.3 Modifying Parameters

These parameters affect the calculations performed in the PV module model. They relate to the module behavior under various ambient and load conditions. Modules are rated at various standard conditions. Ratings or specifications at other conditions are considered using the modifying parameters. These parameters include the number of cells in series (Ns), solar radiation (Ga) and cell temperature (Tc) at normal operating conditions (NOCT).

2.4.4 Solar Cell Model

Solar cells are solid-state semiconductor devices that convert incident sunlight energy into an electrical current. Currently, Silicon and Gallium Arsenide are the most commonly used materials in the manufacture of solar cells. The equivalent circuit of a solar cell is based on the well-known single- diode representation as shown in Figure 2-1 [19]. The model contains a current source G , one diode T , a shunt resistance Rsh , and a series resistance Rs .

Rsh models the surface leakage along the edges of the cell or the crystal defects along the junction depletion region, while Rs models the resistance of the diffused layer that is in series

with the junction as well as the resistance of the ohmic contacts [20]. The net current I is the difference between the light-generated current G I ,

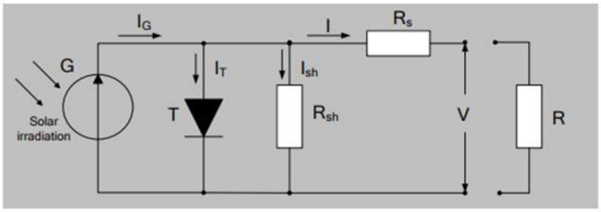

Figure 2-1 Equivalent Circuit of a Solar Cell

2.5 MODELING OF THE PV MODULE

2.5.1 PV Module Structure

A PV module consists of Np parallel branches, each with Ns solar cells in series as shown in Figure 2-2 [21]. A model for the PV module is obtained by replacing each cell in Figure 2-2 by its individual solar cell model. For clarity, the following notation is used: the parameters with subscript “m” refer to the PV module, while the parameters with subscript “c” refer to the solar cell.

2.5.2 Determination of Model Parameters

Reference values for the three parameters in this model, namely, the light generated current GI, reverse saturation current I , and absolute cell temperature Tc , can be obtained

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indirectly using measurements of the current and voltage characteristics of a solar module at reference conditions.

Measurements of current and voltage at these or other known reference conditions are often available at open circuit conditions, short circuit conditions, and maximum power conditions from manufacturer’s data sheets. All quantities with the subscript ‘ref’ are obtained from measurements taken at reference conditions. Traditionally, measurements of PV electrical characteristics are made at reference incident radiation of 2 1 / kW m and an ambient temperature of 25^{o}C . These are the standard conditions used by manufacturers to test PV modules.

CHAPTER -3

RESULTS

3.1.OVERALL CIRCUIT DESIGN

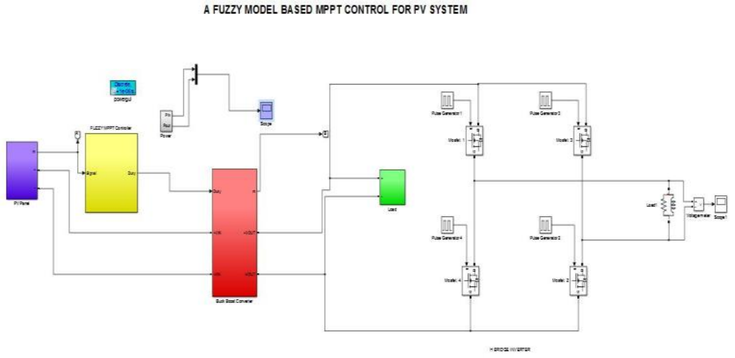

Fig 3.1.A FUZZY MODEL BASED MPPT CONTROL FOR PV SYSTEM

3.2.FUZZY MPPT CONTROLLER

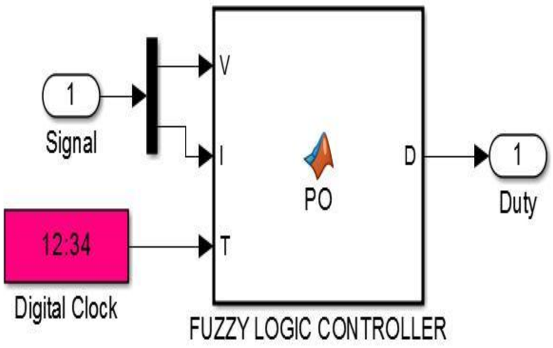

Fig 3.2.Fuzzy mppt controller

3.3.PV PANEL

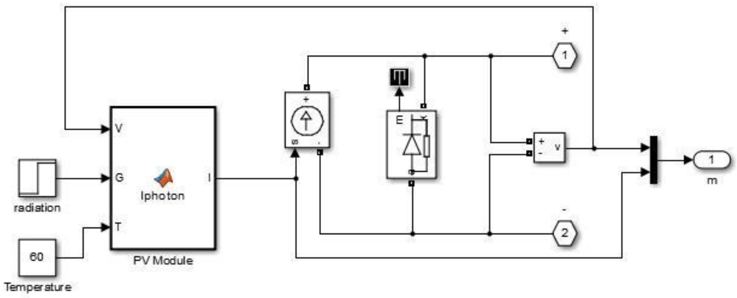

Fig 3.3.Pv panel

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3.4.BUCK BOOST CONVERTER

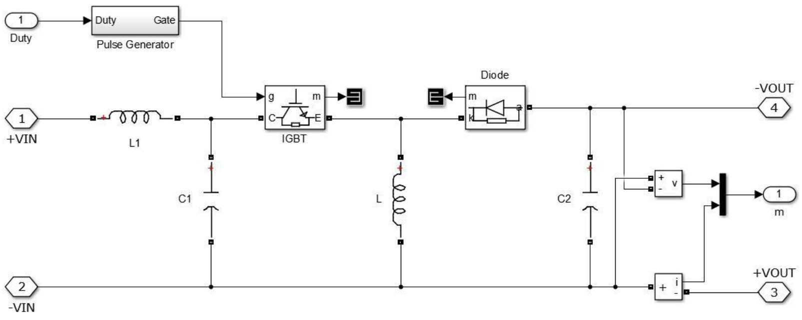


Fig 3.4.Buck boost converter

3.5.H BRIDGE INVERTER

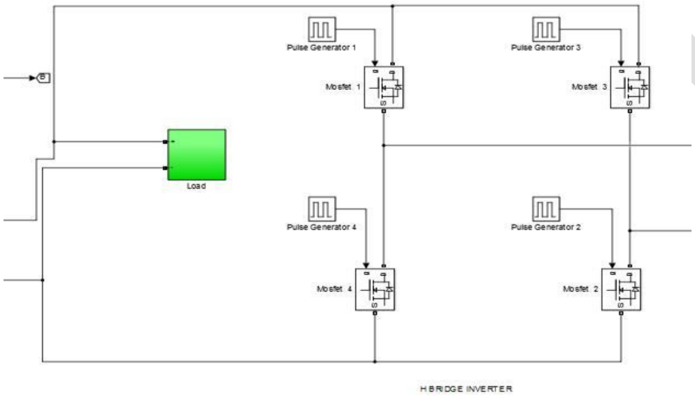
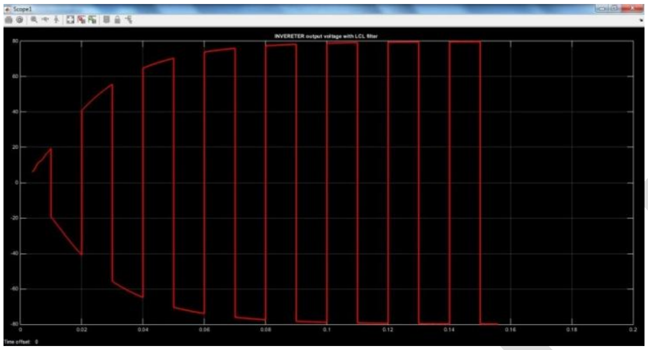


Fig.3.5.H bridge inverter

3.6.INVERTER OUTPUT VOLTAGE



3.6.Inverter output voltage with LEL filter

3.7.OUTPUT POWER

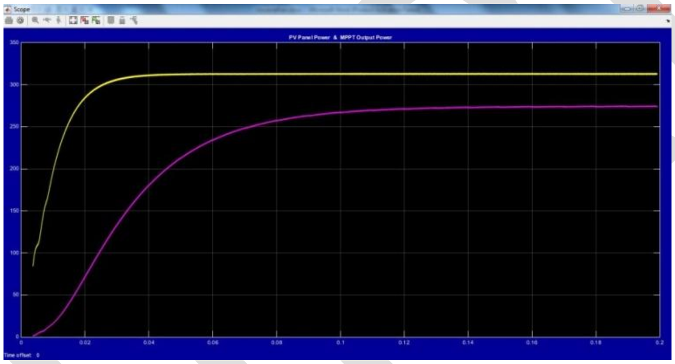


Fig 3.7.Pv panel power and mppt output power

CHAPTER -4

CONCLUSION & FUTURE SCOPE

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The main objective of this study was to introduce a polynomial fuzzy MPPT control approach for solar power generation systems. Using the polynomial fuzzy model, the fuzzy DMP-based control method is proposed. A new Fuzzy Logic based Maximum power point tracker (MPPT) controller has been proposed in this paper. MPPT is used to extract maximum power from the PV array under varying environment conditions. Performance of the proposed controller is assessed using the PV array model developed in MATALB/Simulink software. Results show that the proposed FLC MPPT has faster converging speed, less fluctuation in the steady state and may not fail under rapidly changing irradiation conditions. The robustness of the proposed FLC MPPT has been tested under rapidly changing irradiation condition and compared with the existed MPPT methods.

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