

CONTROL OF DELTA POWER FOR MULTI STRING PV INVERTERS BY FUZZY BASED MPPT AND CPG MODE

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Abstract -With a still increasing penetration level of grid connected photovoltaic (PV) systems, more advanced active power control functionalities have been introduced in certain grid regulations. A delta power control, where active power from the PV panels is injected into grid at unity power factor. In this paper Multistring PV inverter configuration is adopted to realize delta power control (DPC) for grid-connected PV systems. This control strategy is a combination of maximum power point tracking (MPPT) and constant power generation (CPG) modes. This paper proposes intelligent fuzzy logic control (FLC) method for maximum power point tracking of photovoltaic systems. In this control scheme, one PV string operating in the MPPT mode estimates the available power, whereas the other PV strings regulates the total PV power by the CPG control strategy in such a way that the delta power control for the entire PV system is achieved. Simulations have been performed on a 3-kW single-phase grid connected PV system. The results have confirmed the effectiveness of the proposed DPC strategy, where the delta power control is achieved under several operating conditions.

Index Terms—Delta power control, maximum power point tracking (MPPT), fuzzy logic control ,photovoltaic (PV) system, constant power generation (CPG) control, grid-connected power converters.

I. INTRODUCTION

The increasing renewable energy penetration together with the price reduction of photovoltaic modules supported the development of large scale photovoltaic power plants connected to the medium and low voltage grid. As the portion of electricity that is produced by solar photovoltaic (PV) systems increases, it is important for PV systems to provide many of the grid support functions that are traditionally performed by conventional rotating machines. Many concerns are emerging about the electrical system stability when it is connected to renewable sources. Once, photovoltaic plants were thought to reach always the maximum power point and to extract the maximum power available [1]. Nowadays, there are new challenges that photovoltaic plants have to overcome for ensuring the production and control with a variable energy resource as solar

radiation. Photovoltaic generation components and control are being investigated according to new grid requirements proposed by Puerto Rico and South Africa [2]. The control of active power should match the variability of solar energy during the day and it is divided into absolute production, delta production and power gradient . In the requirements of PREPA it is established that in normal operating conditions the system should be able to provide a reduction of active power in the connection point with steps of 10% of the estimated power [2]. Besides, in grid codes of NERSA, the active power capability value shall not be less than 3% of the available power in order to guarantee a reserve for frequency stabilization [3] .

First of all the literal review starts with a focus into the PV generator topologies. Then, there is a description of the principal topologies of PV plants currently diffused. Each technique has its own advantages and basically there are three main topologies: central, string and multi-string. This section analyzes the main characteristics of different topologies with a particular focus on their principal advantages and disadvantages.

Central topology:

This topology interconnects several thousands of PV panels to one inverter. Each array has several strings connected in parallel, the strings are composed by PV panels connected in series and strings are connected with inverters. Generally, it is used for large PV systems with high power output [3]. The main characteristics of this topology are low MPPT efficiency and flexibility but high robustness.

String topology:

This technique connects one inverter per string. It generates more power than the central topology in non-uniform conditions but costs of installation are high due to greater number of inverters [3].

Multi-string topology:

The multi-string topology connects one PV string to a dc-dc converter for tracking the maximum power point and then several converters are connected to one inverter via a dc bus. This technique

is featured by higher efficiency because there is one dedicated MPPT per string [3].

In the case of PV active power control (APC), the solution proposed here avoids storage altogether and instead takes advantage of the components already present in a typical grid interactive PV system, with some added sensors, to provide bi-directional, fast, and reliable active power support to the electric power system. When looking into the prior artwork, there are mainly three approaches [4] to realize delta power control (DPC). Firstly, integrating energy storage system where surplus PV power can be stored but it is not feasible as it cost high and limited life time. Second solution is by dumping a load to dissipate surplus PV power which increases overall complexity of the system. The third approach is by modifying the MPPT algorithm offers a more cost-effective solution.

A typical PV plant has no rotational inertia and has negligible energy storage, it must operate below its maximum power point, creating a power reserve margin that can be automatically dispatched during frequency transients. Typical PV inverters attempt to constantly operate at the maximum power available from the PV array using one of many MPPT methods. The maximum power point of a PV array changes continuously over a wide range based on irradiance incident on the array and the temperature of the PV cells. Both conditions change during the day and are also different depending on the season of the year. Furthermore, irradiation can change rapidly due to changing atmospheric conditions such as clouds. Hence it is very important to track the MPP accurately under all environmental conditions so as to obtain maximum power available.

This paper thus uses fuzzy techniques to determine the maximum power capability of a PV module for variable solar irradiance and temperature conditions. The other maximum power point tracking (MPPT) algorithms such as perturb and observe, incremental conductance and their improvements suffer from drawbacks such as oscillations at the operating point and lack in fast dynamic response. The proposed technique of using Fuzzy-based MPPT offers highly precise and fast control with robust operation and is highly suitable for application in PV generation systems. fuzzy logic is appropriate for nonlinear control because it does not use complex mathematical equation.

The rest of this paper is arranged as follows: Section 2 explains control scheme for DPC strategy. Section 3 describes the fuzzy based MPPT control. Section 4 describes grid connected PV system. Simulation results obtained by matlab software are presented in Section 5.

II. CONTROL SCHEME FOR DPC STRATEGY

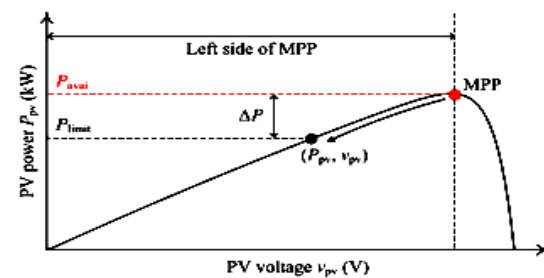


Fig.1 PV characteristics of pv panel

In this approach, the operating point of the PV system in the power–voltage (P–V) curve is regulated below the maximum power point (MPP) in order to limit the PV power P_{pv} [4] to a certain level P_{limit} . The paper is focussed on active power control of PV string, where the MPPT and the CPG operation are co-ordinately controlled.

$$P_{pv} = \begin{cases} P_{MPPT} & \text{When } P_{MPPT} \leq P_{limit} \\ P_{limit} & \text{When } P_{MPPT} \geq P_{limit} \end{cases}$$

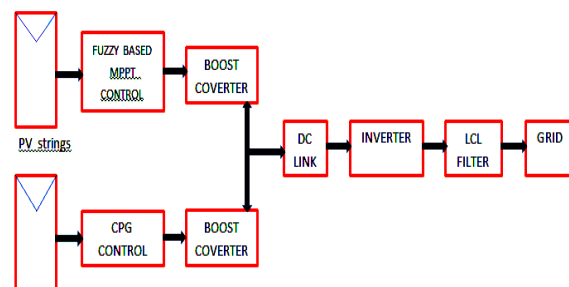


Fig.2 Block diagram for control scheme of DPC Strategy

III. FUZZY BASED MPPT

Rule-based fuzzy control, where the human knowledge is approximated by means of linguistic fuzzy rules in the form if then. Each rule describes the control action in a particular condition of the system. Control action that would be done by a human operator. Therefore, under a specified condition of the system (if condition1) can be specified an action (then action1).

A rule base can be defined throughout different conditions of a system in which each rule defines an action for a specified condition. In the same way, both condition and action are represented by linguistic terms such as (large, medium, small) for condition and (increase a few, increase a lot) for actions, those linguistic terms belong to fuzzy sets with overlapped boundaries. Therefore, by means of fuzzy sets it is possible to get smooth interpolation between different rules, in order to describe completely the behaviour of the system with few rules. Due to the nonlinear behaviour showed by the converter and supported in the advantages of fuzzy

control exposed before, nonlinear fuzzy controllers might be desirable to control the active power independently.

The input variables of MPPT are the PV module output voltage and current. In this paper the fuzzy logic based P&O MPPT algorithm is implemented. A fuzzy logic based MPPT control is implemented to generate the optimal voltage reference from the PV system by modulating the duty cycle applied to the boost converter. The output voltage and current of the PV panel are measured and fed to the fuzzy based control unit for MPP tracking. Based on the change of power with respect to change of voltage dp/dv and $\Delta dp/dv$, fuzzy determines the voltage reference and compared with the modulating signal which generate pulse and is applied to the gate of IGBT[10].

Fuzzy model of the system is designed based on prior expert knowledge of the system. The fuzzy logic controller is divided into four sections: Fuzzification, rulebase, inference and defuzzification. The inputs to the fuzzy logic controller are change in PV array power (ΔP_{pv}) and change in PV array voltage (ΔV_{pv}) and the output is the change in reference voltage (ΔV_{ref}) [11].

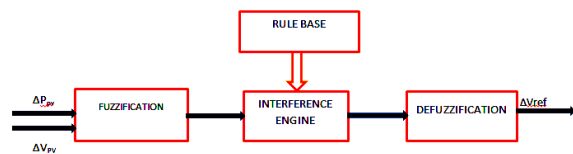


Fig.3 Block diagram of Fuzzy logic controller

A. Fuzzification

The process of converting a crisp input value into a fuzzy value is called “fuzzification”. The membership function values are assigned to the linguistic variables using seven fuzzy subset called as negative big (NB), negative small (NS), Zero (ZE), positive small (PS), Positive Big (PB).

B. Membership Function

The membership function is a curvature that describes each point of membership value in the input space. The number of membership functions are used depends on the required accuracy of the controller.

In fuzzy logic based MPPT technique, the error (E) and change in error (CE) are taken as input variables which are as below for Kth sample time [9].

$$E(k) = \frac{dp}{dv} \frac{P(k) - P(k-1)}{V(k) - V(k-1)}$$

$$CE(k) = P(k) - P(k-1)$$

Inference Method

Inference engine mainly consist of Fuzzy rule base and fuzzy implication sub blocks. The inputs are now fuzzified are fed to the inference engine and the rule base is then applied. The output fuzzy set are then identified using fuzzy implication method. The Inference method determines the output of the fuzzy controller. Mamdani's inference method is used in the considered system along with the max-min composition method. This is because this method is computationally more efficient and is usually popular for most control engineering applications.

The 25 control fuzzy rules are included in the table.1. These rules control the boost converter such that MPP of the PV generator is reached. As shown in table .2, the main aim of the rule is to bring operating point of MPP either by increasing or decreasing the duty cycle ratio. If the last change in the reference voltage (V_{ref}) has caused the power to increase then keep changing the reference voltage in the same direction; else it causes the power to drop and move it in the opposite direction.

E	CE				
	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

Table .1.Fuzzy rules

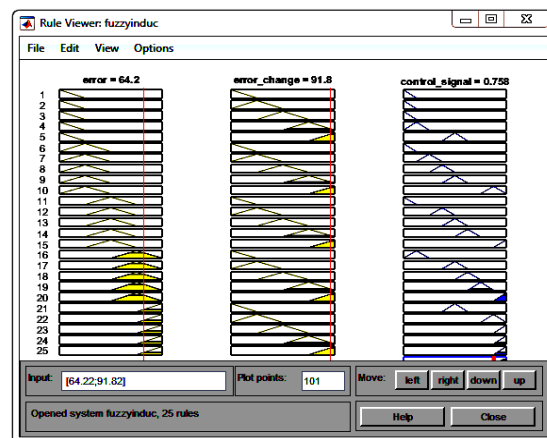


Table.2 Rule viewer

Defuzzification

The output of the fuzzy controller is a fuzzy set. However a crisp output value is required. Hence the output of the fuzzy controller should be defuzzified. The centroid method is one of the

commonly used defuzzification methods and is the one being employed for the proposed system.

Fuzzy logic controller outputs a larger incremental reference voltage to speed up the transient response but outputs almost zero incremental reference voltage near the peak power region to reduce oscillations about the MPP.

Estimation of available output power in MPPT mode

When solar irradiance is not measured, it is a challenging task to estimate available PV power. In commercial scale PV systems, PV systems are located close to each other. Most PV strings have same solar irradiance and temperature profiles, and therefore same power production profiles. If master PV string operate in MPPT mode, its P_{pv1} can be used to estimate available power of the rest PV strings [4]. Total available power of the PV plant P_{avai} can be simply estimated by

$$P_{avai} = N_{pv} P_{pv1}$$

Where N_{pv} is the ratio between the rated power of the total PV plant and master PV string. If the PV system consists of two PV string with the equal rated power, then power ratio can be determined as $N_{pv} = 2$. The rated power of master PV string is half of total PV system rated power.

Output power compensation by CPG mode

In CPG mode PV voltage can be regulated at the left side of the MPP by reducing the PV power to a certain set point [5]. When the PV power is below the set point (i.e., $P_{pv2} \leq P_{limit}$), the MPPT algorithm is employed in order to allow the PV power to reach the set point shown in Fig.1. However, once the PV power reaches and starts to exceed the set point (i.e., $P_{pv2} > P_{limit}$), the PV voltage is continuously perturbed toward the left side of the MPP until the PV output power is equal to the set point [6]. DPC method dynamically changes the value of the set point P_{limit} during the operation in order to achieve the delta power control.

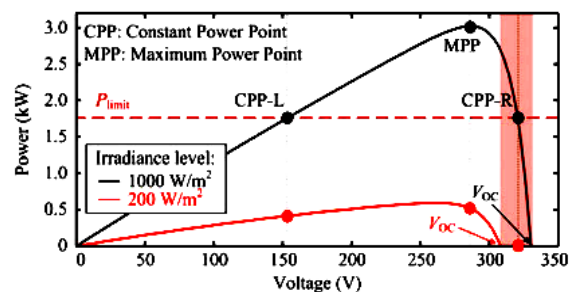


Fig.4 Operating points of PV system during CPG Operation.

The operating area of the CPG control is limited to be at the right side of the

maximum power point (MPP) of the PV arrays (CPP-R) in Fig.4, due to the single-stage configuration. Unfortunately, this decreases the robustness of the control algorithm when the PV systems experience a fast decrease in the irradiance. A two-stage grid connected PV is employed to extend the operating area of the P&O-CPG algorithm. By regulating the PV output power at the left side of the MPP (CPP-L), a stable CPG operation is always achieved, since the operating point will never “fall off the hill” during a fast decrease in the irradiance

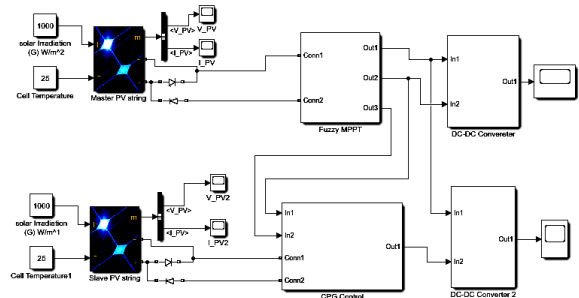


Fig.5 Proposed fuzzy based MPPT and CPG mode

IV .GRID CONNECTED SYSTEM

In grid-connected PV applications, a two-stage conversion system, consisting of a dc–dc and a dc–ac conversion stages, is usually referred to as a multistring inverter configuration. Each PV string, consisting of several PV panels connected in series and/or parallel, is equipped with a dc–dc boost converter to step up the PV voltage V_{pv} to match the required dc-link voltage V_{dc} [9].

The boost converter also performs the active power control for each PV string individually. This gives a possibility to coordinate the active power control of each PV string in order to achieve the delta power constraint. Dc–ac inverter is employed to inject the extracted PV power to the ac grid. This is normally achieved by regulating the dc-link voltage to be constant through the control of the grid current I_g . In order to produce a pure sine wave output with low harmonics, an LCL-filter is used. The inverter output voltage can be utilized for grid integration.

V. SIMULATION RESULTS

The solar Photovoltaic system is simulated in MATLAB /Simulink. The PV module has the variable temperature and the irradiance. For analysis purpose, irradiance level of $500W/m^2$, $750W/m^2$, $1000 W/m^2$ is considered. Fig.5 shows proposed fuzzy based MPPT and CPG mode. Fig.6 shows the fuzzy logic control output which is change in duty cycle to boost converter. Fig.7 shows

power variations with FLC control. Fig.8 shows boost voltage of the converter for different conditions.

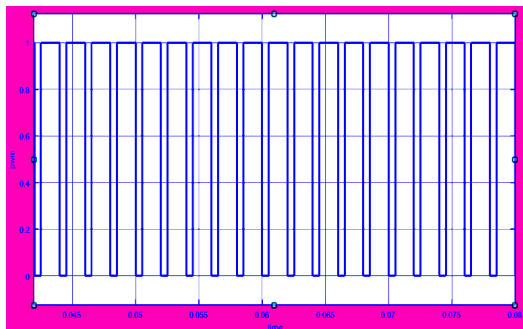


Fig.6 Proposed fuzzy logic control output

Irradiance W/m ²	Maximum power tracked by fuzzy logic controller in W
1000	3073
750	1728
500	767

Table .3 Maximum power for different irradiances

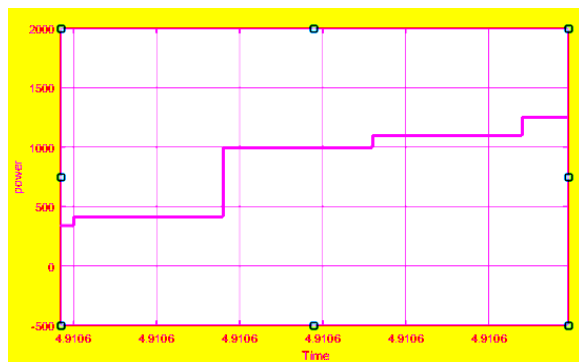


Fig. 7 Power variations with FLC control

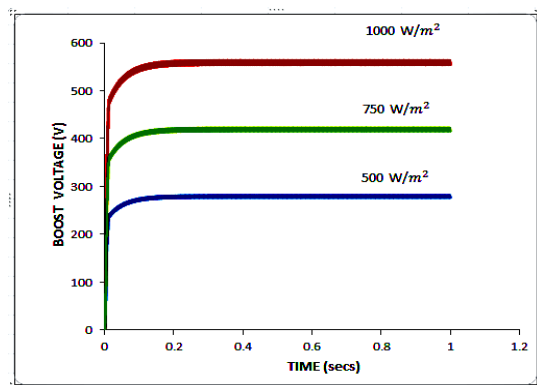


Fig .8 Boost voltage for different irradiances

When irradiance is 1000 W/m², boost voltage is 557V. When irradiance is 750 W/m², boost voltage is 415V.

When irradiance is 500 W/m², boost voltage is 276V. The maximum power is tracked for various irradiance levels in which the optimum Maximum Power Point voltage is obtained.

VI .CONCLUSION

The performance of DPC with fuzzy based MPPT and CPG mode is examined with temperature and solar irradiance through simulation. The total P_{pv} active power is injected in to grid when PV system operates at unity power factor. The frequency of output AC voltage can be controlled by controlling the frequency of gate pulses.

Fuzzy logic based MPPT controller is developed in Matlab/Simulink in this paper. Fuzzy logic toolbox of Simulink is used to achieve the FLC. The proposed FLC can track the MPPT very fast and accurately even if the environment changes abruptly. The simulation results show that the FLC-based MPPT method can quickly track the maximum power point (MPP) of the PV module at the transient state and shows better response with less power oscillation around the MPP at steady state.

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