To Elevate the Grid Stability of PV System by Using Fuzzy MPPT Control

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Abstract

The main objective of this paper is to evaluate the stability of a grid for a Non-Conventional energy generating system that is photovoltaic power plant that features a maximum power point tracking (MPPT) scheme based on fuzzy logic control. The step of modeling with MATLAB/Simulink of the photovoltaic system is shown respectively and simulation results are discussed. This fuzzy MPPT shows accurate and fast response, and is integrated in the inverter, so that a DC-DC converter is not needed. The inverter allows full control of reactive power and shows the good response.

Keywords – Photovoltaic, Inverter, MPPT, Fuzzy logic, Power electronics.

I. Introduction

Governments around the world are facing a steadily rising demand on global electric power. To face this challenge, they are striving to put in place regulatory guidelines to aid the adoption of best practices by utilities in terms of the Smart Grid and renewable energy applications. Smart Grid organization provides the consumers with the ability to monitor and control energy consumption. This is crucial because as the world population grows the electricity demand will also increase, but at the same time, we will need to reduce our electricity consumption to fight global warming.

By using the Smart Grid, energy consumers will have an incentive to create power on their own with the use of wind turbines or solar paneling, and subsequently sell any power that is generated in excess to electrical companies. Several researches are being made to improve the system and reduce its cost and size. As a result, the photovoltaic (PV) system is becoming much easier to install but the efficiency of solar module is still low (about 27%). Furthermore, it is desirable to operate the module at the peak power point.

This thesis will discuss about the photovoltaic system, the power electronics interface and the method to track the maximum power point (MPPT) of the solar panel. Before getting into detail, in this will describe the PV market and its future, the application of energy storage with photovoltaic system and the different standard requirement when having a grid connected PV system.

Photovoltaic systems are increasing in size as they become more affordable and supporting schemes start to include larger installations. In a near future, photovoltaic systems of 100kW peak power or more are going to be very common, and it is expected that they will contribute with a significant share to power generation. In such a scenario, the contribution to the grid stability of PV systems is likely to become relevant[2], as it has already happened with other renewable energies like wind power in some countries. In Spain, for instance, wind farm operators are encouraged to contribute to system stability by means of a remuneration for reactive power control. The requirements for robust operation under grid faults and perturbances have also increased. This could be applied to PV systems once they reach a certain amount of installed power in a given region. Proper integration of medium or large PV systems in the grid may therefore require additional functionality from the inverter, such as reactive power control. Furthermore, the increase of average PV system size may lead to new strategies like eliminating the DC-DC converter that is usually placed between the PV array and the inverter, and moving the MPPT to the inverter, resulting in increased simplicity, overall efficiency and a cost reduction. These two characteristics are present in the three-phase inverter that is presented here, with the addition of a fuzzy MPPT control that shows excellent performance.

II. Proposed System Description

The system that has been simulated consists of a photovoltaic array with a peak power of 100kW connected through a DC bus to a three-phase inverter that is connected to an ideal 400V grid through a simple filter, as shown in Fig. 2. The MPP tracker is integrated in the inverter control (Fig.3), as there is no DC-DC converter in the chosen configuration. The whole system was simulated in Matlab-Simulink.

A.PV Array Simulation

The PV array is simulated using a model of moderated complexity based on [1]. In this model, a PV cell is represented by a current source in parallel with a diode, and a series resistance as shown in Fig. 1. There is no need for a more complex model with a second diode and / or a shunt resistance. The photo current I depends on the irradiance *G* and the cell temperature T. The current I provided by the cell can be calculated as:

$$I^c = I_{ph} - I_D = I_{ph} - I_0\left(\exp\frac{e(V+IR_s)}{nkT^c} - 1\right) \qquad (1)$$

Where the saturation current I is temperature dependent, e is the charge of an electron, k is Boltzmann's gas constant and n is the idealising factor of the diode. The module is an association of solar cells in parallel and series. Extending the previous cell model to a module, a similar equation can be found. But it is more useful to express such an equation in terms of the open circuit voltage V and short circuit current I , as these can be estimated from the open circuit voltage and short circuit current in standard conditions that are usually provided by module manufacturers, and their linear dependence on Tcand G respectively.

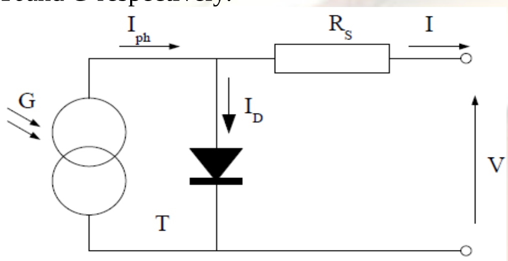

Fig1: Equivalent circuit of PV Cell

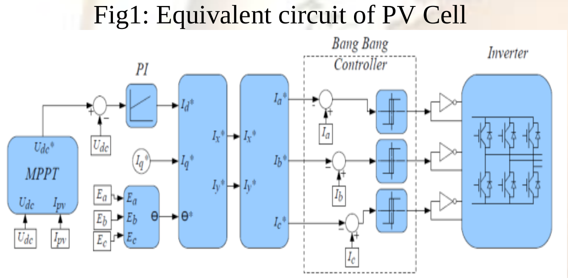

Fig2: Proposed control scheme

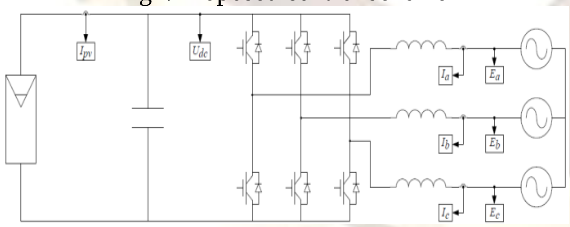

Fig3: Proposed Electrical Scheme

The cell temperature T^c is estimated considering its linear dependence on G and the cell temperature in normal operating conditions that is provided by the module manufacturer. The final model used to determine the relationship of a module current and voltage is shown in equation (2), where m designs module magnitudes.

$$I^m = I^m_{sc}\left(1 - \exp\frac{e(V^m - V^m_{oc} + I^m R^m_s)}{N_s \cdot nkT^c}\right) \qquad (2)$$

The PV array is made of 20 strings of 35 series connected modules each, connected in parallel. This gives a total peak power of around 100kW. All modules are considered to be identical, and to work in identical conditions of temperature and irradiance.

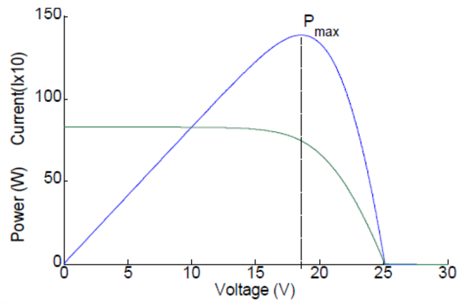

Fig4: Module power and current Vs voltage

B.Fuzzy MPPT

When a PV module is directly coupled to a load, the PV module's operating point will be at the intersection of its *I–V* curve and the load line which is the *I-V* relationship of load. In other words, the impedance of load dictates the operating condition of the PV module. In general, this operating point is seldom at the PV module's MPP, thus it is not producing the maximum power. A study shows that a direct-coupled system utilizes a mere 31% of the PV capacity. A PV array is usually oversized to compensate for a low power yield during winter months. This mismatching between a PV module and a load requires further over-sizing of the PV array and thus increases the overall system cost. To mitigate this problem, a maximum power point tracker (MPPT) can be used to maintain the PV module's operating point at the MPP. MPPTs can extract more than 97% of the PV power when properly optimized.

For a given set of operating conditions G and T our module model shows that the relationship between voltage, current and power are functions similar to the ones shown in Fig. 4. The voltage that corresponds to the module maximum power varies with temperature and irradiance variations, so a MPP tracking system is needed to ensure that we stay as close as possible to the optimum. Usual MPPT methods include Perturb and Observe (P&O) [3], incremental conductance [4], fuzzy logic [5] and other [6,7] methods.

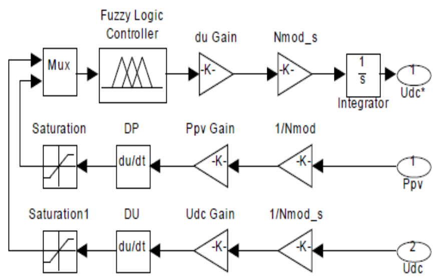

Fig5: Fuzzy MPPT diagram

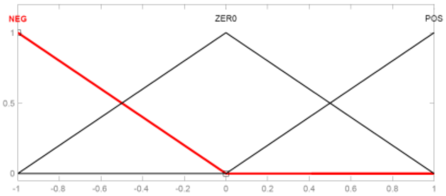

Fig 6: Fuzzy membership functions

Here a method based on a fuzzy controller is presented that differs from current ones, as it has been designed to be integrated in the inverter instead of a DC-DC converter, and uses a reduced set of membership functions (and therefore is simpler to fine-tune) without compromising performance.
Fuzzy logic controllers are suitable for nonlinear problems where the desired system behaviour in terms of input and output variables can be expressed as a set of semantic rules. They present a robust performance and good response in noisy environments. Usually the MPPT controls a DC-DC converter to maintain a constant DC voltage at the output of the generator. With an appropriate sizing of the PV array the DC-DC converter can be avoided due to the relatively small changes in the optimum voltage in operating conditions. This will save one stage in the system and therefore will increase efficiency. In the usual configuration with a DC-DC converter the MPPT system outputs a signal to change the duty cycle of the converter. In this case, the MPPT will output a DC voltage reference *Uto the inverter control*.As inputs, the MPPT will need the DC bus voltage U and the power delivered by the PV array P*pv*, which is obtained as the product of *Udc*and the PV array current. The increment of these variables *ΔUdc*and ΔP*pv*over a sample period are computed, which are going to be the inputs of the fuzzy logic controller. The output will be *ΔUdc** which is then integrated to obtain the desired reference *Udc**.A gain is applied to all variables in order to fine tune the controller response. These gains are separated in Fig. 5 in two groups: a first group that brings variable levels to a module level (so that the MPPT can be tuned for a single module, and remain tuned for different PV array configurations) and a second group that controls the MPPT dynamic response. These inputs and output were chosen as it is easy to express a set of semantic rules that lead to maximum power point tracking. The shape of the P-V curve (Fig. 4). makes suitable a hill-climbing approach to search the maximum. The chosen rules are shown in Table 1. Usually, a large number of membership functions are defined, such as negative-big, negative-medium,, negative-small, etc. This is not necessary, and it introduces an additional complexity to the controller tuning, as the boundaries between seven or more membership functions have to be defined, for each variable. In this case we have chosen a set of three membership functions: negative (NEG) positive (POS) and zero (ZERO). Their shapes for all input and output variables are the same as shown in Fig. 6. They are all normalised to [-1 1] and [0 1] so the characteristics are controlled by the input and output gains. This reduces tuning complexity.

C.Inverter

The inverter control is based on a decoupled control of the active and reactive power.The DC voltage is set by a PI controller that compares the actual DC bus voltage and the reference generated by the MPPT, and provides a active current reference in a synchronous reference frame attached at grid voltage vector. The other component of current vector represents the reactive current and it can be fixed at the desired level for power factor or voltage control. By applying the inverse Park transformation to d-q current vector components, the desired phase current references are obtained. These are passed to a bang bang controller, which outputs the pulses to drive the inverter switches. The output line voltage of the inverter is shown in Fig. 7.

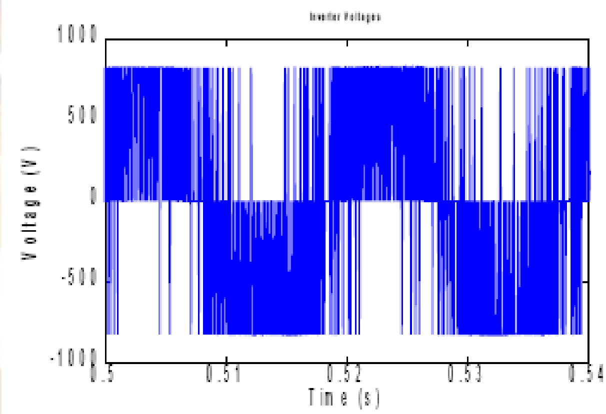

Fig 7: Inverter line voltages

As there is no DC/DC converter between the PV generator and the inverter, the PV array configuration has to be chosen so that the output voltage of the PV generator suits the inverter's requirements. In this case a 400V grid has been chosen, so the inverter will need at least 600V in the DC bus in order to be able to operate properly. The lowest DC voltage will occur with high ambient temperature and high irradiance (because the irradiance increases the cell temperature, and this effect predominates over the increase of optimal voltage caused by an increment of the irradiance at a constant cell temperature), so the minimum number of series connected modules should be determined by this worst case. As the PV array model estimates cell temperature as a function of irradiance and ambient temperature, for the worst case an ambient temperature of 50ºC and an irradiance of *G*=1000were chosen. The PV array was found to require 35 series connected modules per string.The optimal voltage for this configuration should stay around 700-800V most of the time, with some peaks that could reach a minimum of 600V and a maximum of 900V in very extreme situations. The only drawback of such a voltage is a slight increase of the inverter price as higher rated voltage of DC link capacitors and switches are required.

III. Simulink Models

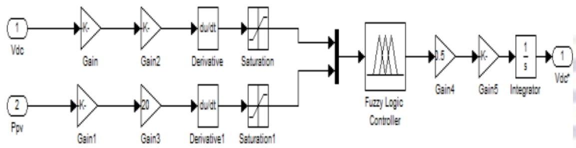

Fig 8: Fuzzy controller

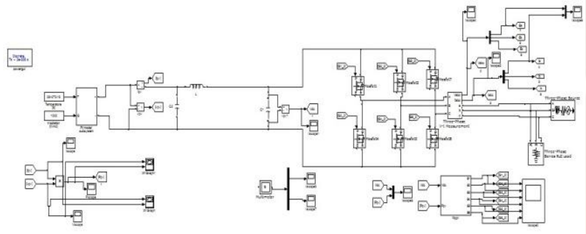

Fig 9: Simulink block diagram of photovoltaic system with MPPT controller

IV. Simulation Results

In Fig. 10 and Fig. 11 the system response to an irradiance step is shown. In t=0.2s the irradiance is changed from 150 to 1000 It can be seen that the system tracks the new operating point very quickly, faster than most MPPT strategies. It has to be said that this is an extreme change in irradiation levels that is unlikely to occur but shows the good performance of the MPPT. 2 / W m

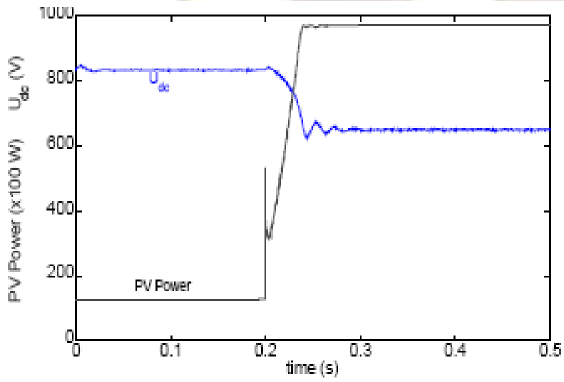

Fig 10: System response to an irradiance step t=0.2

The maximum power point is tracked with excellent accuracy as can be seen in Fig. 9, where the generated power is compared to the theoretical optimum calculated from the PV array model.

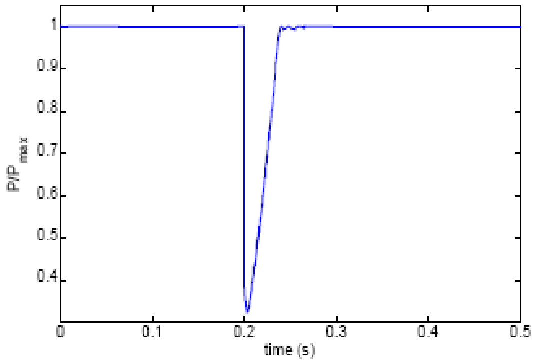

Fig11: System response to an irradiance step t=0.2 sec

In Fig. 12 is shown the system response to a step in the reactive current reference. Only one phase is shown in order to clearly see the reference step. Before t=0,35s voltage and current are in phase, until the step command is applied and current leads voltage afterwards. A great advantage of this inverter control scheme is the ability to control power factor instantaneously, and with good accuracy.

In Fig. 13 are represented the grid currents and voltages at unity power factor, showing good performance.

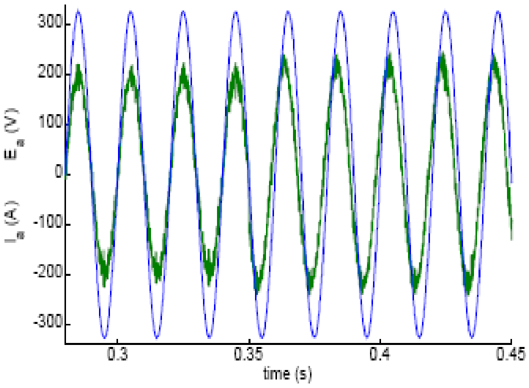

Fig. 12: Inverter response to a step in reactive power reference in t=0.35s.

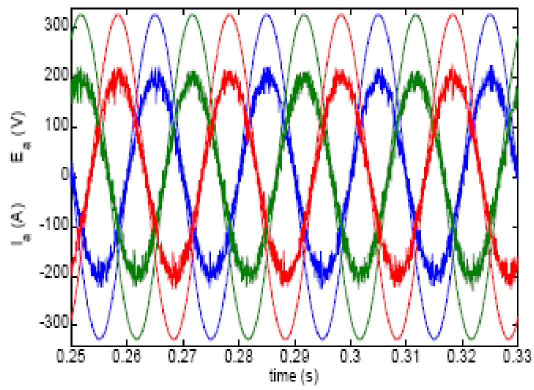

Fig. 13: Inverter behavior in operation at unity power factor

V. Conclusion

This system is for medium or large photovoltaic applications are presented. It is not require any DC/DC control scheme throughout the process. And it mainly control the both active and reactive powers simultaneously. as the optimum DC voltage is set by the inverter itself by means of a fuzzy MPPT. The simulation of the whole system has been done in Matlab- Simulink and it shows an excellent performance of both inverter and MPPT, with negligible fluctuation of the DC bus voltage, fast tracking of optimum operating point, and almost instantaneous tracking of power factor reference.

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BIOGRAPHIES

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