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Artificial Intelligence Based Control for Three-Phase Autonomous PV Residential Systems with Improved Power Quality

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Abstract:

This work presents an intelligent approach to the improvement and optimization of control performance of a PV system, the method further maximum power point tracking (MPPT) based on fuzzy logic. Our system consists of a photovoltaic panel (PV), a DC-DC buck-boost converter, considered a matching stage between the PV and the load. The strategy for the synthesis of control laws is based on modeling the behavior of the PV system, which allows us to integrate different control techniques to ensure a smooth continuation in the presence of modeling errors and external disturbances. Modeling and simulation system (photovoltaic panel, Buck-Boost DC-DC converter, the MPPT algorithm based on fuzzy logic and load) is achieved through the Matlab / Simulink software.

Keywords: Fuzzy Logic Controller(FLC/), inverters, photovoltaic (PV) systems, power quality.

1. INTRODUCTION:

The liberalization of electrical energy markets, the rising costs of electrical power, and the technological progress in the conversion of solar energy to electricity have significantly increased the installation of residential photovoltaic (PV) systems (either grid-tied or standalone), establishing them as a significant component of the electrical networks [1], [2]. Both financial and ecological criteria and incentives urge consumers to install PV systems.

These investments have been encouraged and subsidized, especially in remote areas where transmission and distribution systems are weak and difficult to be upgraded. The appropriate design of autonomous PV systems and their harmonization with national and international standards are critical issues. Among other benefits, this will guarantee the uninterrupted power supply, avoid compatibility problems, reduce the expected failure rate, and moderate the operational cost. The regulation of a series of power quality indices can warrant adherence to the above requirements. The power quality parameters must fulfill the demands of the national norms and standards, whereas at the same time, extreme equipment dimensioning and designs must be avoided.

Solar energy is free to use and the most abundant form of renewable form of energy available on our planet. Solar photovoltaic (PV) system uses photo-voltaic modules composed of several PV cells to convert solar radiant energy directly in to an electrical energy. Several solar cells are connected together in either series or parallel configuration (to form a solar PV module or PV panel) to increase output voltage or current respectively. Individual PV modules are connected in array called solar PV array to further enhance the output. The major components of solar PV system are PV array, power converter, battery, AC / DC load etc. (figure 1).

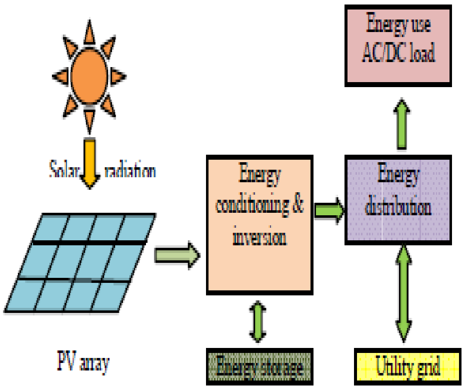

Fig. 1 Components of solar photo-voltaic system

In solar power system the power delivered to the load is highly dependent on solar radiation and PV array temperature. I-V and P-V curves of a solar cell with constant module temperature and solar radiation have been shown in figure 2. At the intersection of Imp and Vmp, array generates maximum electrical power [1].

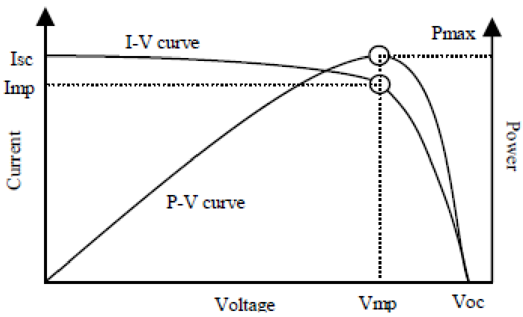

Fig. 2 Current-voltage and power-voltage characteristics of a solar cell

As per maximum power transfer theorem, the circuit delivers maximum power to the load when source impedance matches the load impedance. In case of stand-alone solar system dc-dc converter is connected in between PV array and the dc load. Maximum power point tracking (MPPT) system varies the duty cycle of the dc-dc converter in order to match source and load impedance and to deliver maximum power to the load. Various MPPT methods have been reported in the literature.

These methods can be classified as: i) methods based on load line adjustment of I-V curve and ii) method based on artificial intelligence (fuzzy logic or neural network based MPPT methods). The MPPT methods viz. perturb and observe (P & O), incremental conductance (INC), voltage feedback (VF) are based on load line adjustment of I-V curve. These methods have been found less suitable under uncertainties due to varying atmospheric and load conditions. The MPPT system based on artificial intelligence (fuzzy logic or neural network) has robust capabilities in regard to uncertainties [2, 3].

Real time simulation and comparative analysis of five mostly referred MPPT techniques viz. perturb and observe, incremental conductance, fuzzy logic, neural network and adaptive neuro-fuzzy inference system (ANFIS) based MPPT techniques have been presented in this paper. The paper is organized as follows. In section two a brief introduction of various MPPT techniques has been presented. Section three describes the modeling of solar PV system. Modeling and real time simulation of MPPT algorithms has been given in section four. In section five, comparative analysis of five MPPT techniques and experimentation results have been presented, followed by conclusions.

2. PV CELL MODELLING:

The photovoltaic generator is neither voltage nor current sources but can be approximated as current generator with dependent voltage source, where the I-V characteristic can be expressed by the equation 1[7],[8].

$$I_{PV} = I_{SC} - I_o \left[\exp\left(\frac{V_{PV} + R_S I_{PV}}{V_t}\right) - 1\right] \qquad (1)$$

The I-V curve is essentially influenced by the variation of two inputs which are the solar insolation and the array temperature. The adaption of the equation (1) to different levels of the solar insolation and temperature can be represented by the following equations [9]:

$$\Delta I = \beta\left(\frac{E}{E_r}\right)\Delta T + \left(\frac{E}{E_r} - 1\right)I_{SC} \qquad (2)$$

$$\Delta V = \gamma \Delta T - R_S\, \Delta I \qquad (3)$$

$$V = V_r + \Delta V \quad (4)$$

$$I = I_r + \Delta I \quad (5)$$

3. PV ARRAY CHARACTERISTICS

The use of single diode equivalent electric circuit makes it possible to model the characteristics of a PV cell. The mathematical model of a photovoltaic cell can be developed using MATLAB simulink toolbox. The basic equation from the theory of semiconductors that mathematically describes the I-V characteristic of the Ideal photovoltaic cell is given by

$$I = I_{pvcell} - I_d \quad (1)$$

Where,

$$I_d = I_{0cell}[\exp(qv/\alpha kT)-1] \quad (2)$$

Therefore

$$I = I_{pvcell} - I_{0cell}[\exp(qv/\alpha kT)-1] \quad (3)$$

Where, 'I_{PVCell}' is the current generated by the incident light (it is directly proportional to the Sun irradiation), I_d is the diode equation, Io, cell' is the reverse saturation or leakage current of the diode, 'q' is the electron charge [1.60217646* 10−19C], k is the Boltzmann constant [1.3806503 *10−23J/K], 'T' is the temperature of the p-n junction, and 'a' is the diode ideality constant. Fig.3 shows the equivalent circuit of ideal PV cell.

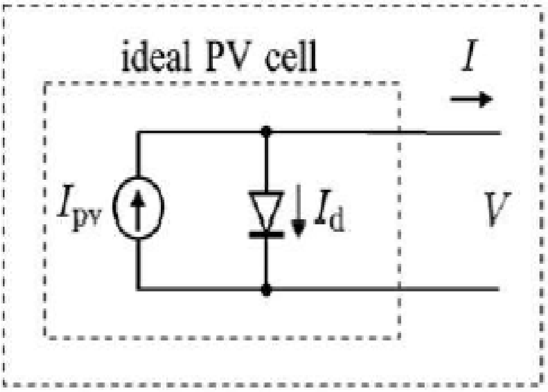

Fig.3 Equivalent circuit of ideal PV cell

Practical arrays are composed of several connected PV cells and the observation of the characteristics at the terminals of the PV array requires the inclusion of additional parameters (as shown in Fig.8) to the basic equation:

$$I = I_{pv} - I_o[\exp(V+IR_s/V_t\alpha)-1]-(V+IR_s/R_p) \quad (1)$$

Where Vt = NskT/q is the thermal voltage of the array with 'Ns' cells are connected in series. Cells connected in parallel increases the current and cells connected in series provide greater output voltages. V and I are the terminal voltage and current. The equivalent circuit of ideal PV cell with the series resistance (Rs) and parallel resistance (Rp) is shown in Fig.8.

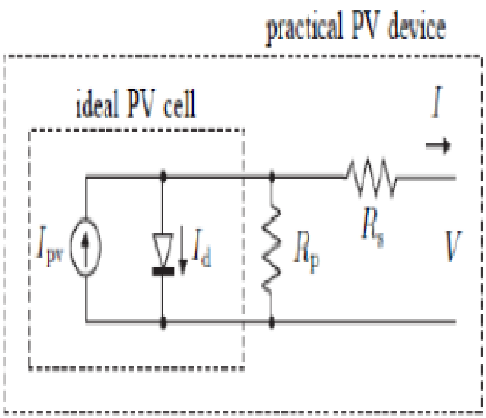

Fig. 4 Equivalent circuit of ideal PV cell with Rp and Rs.

For a good solar cell, the series resistance (Rs), should be very small and the shunt (parallel) resistance (Rp), should be very large. For commercial solar cells (Rp) is much greater than the forward resistance of a diode. The I-V curve is shown in Fig.5. The curve has three important parameters namely open circuit voltage (Voc), short circuit current (Isc) and maximum power point (MPP). In this model single diode equivalent circuit is considered. The I-V characteristic of the photovoltaic device depends on the internal characteristics of the device and on external influences such as irradiation level and the temperature.

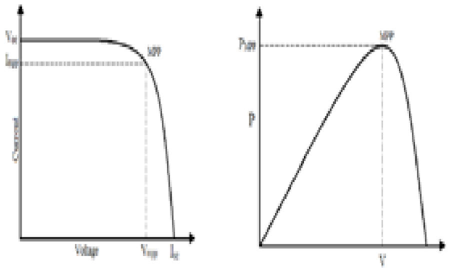

Fig. 5 I-V and P-V characteristics of PV cell

4. BOOST CONVERTER MODEL:

As mentioned above, a DC/DC boost converter is placed between the PV array and load stage to vary the output voltage of the PV array to the maximum power point which is calculated by the fuzzy logic or the neural network controller.From Fig. 6, by considering the steady state operation, the transfer function of the boost converter can be expressed as,

$$V_{out} = \alpha V_{PV}$$

Where, α is the duty cycle used by converter control, Vout is the output voltage and VPV is the PV array output voltage.

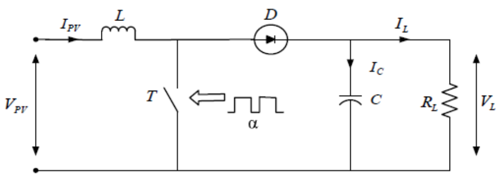

Fig. 6 Equivalent circuit of a boost converter.

The relation between the input and output of the boost converter can be expressed with the help of differential equations obtained by direct application of KCL and KVL to the circuit.

$$L\frac{dI_L}{dt} = V_{PV} - V_L$$
$$C\frac{dV_{PV}}{dt} = I_L - \frac{V_L}{R}$$

where, IL the is DC/DC output current.

5. FUZZY LOGIC BASED MPPT:

Recently, FLC are introduced for MPPT in the PV system. These controllers are robust and advantageous as in their design procedure exact model information is not required. [9]. The main parts of a fuzzy logic controller are fuzzification, inference, rule base and defuzzification, are shown in Fig. 7 as,

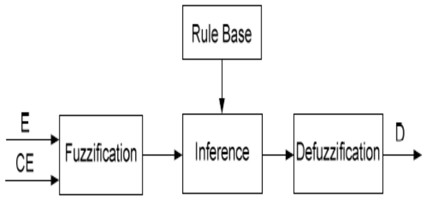

Fig. 7 Block diagram of Fuzzy Controller.

The two inputs i.e. change of error (CE) and error (E) are defined as,

$$E(k) = \frac{P_{PV}(k) - P_{PV}(k-1)}{V_{PV}(k) - V_{PV}(k-1)}$$
$$CE(k) = E(k) - E(k-1)$$

Where, PPV is the instantaneous power of PV array fuzzy inference is processed using Mamdani's method [10]. Defuzzification uses the center of gravity to process output which is the duty cycle [11].

$$D = \frac{\sum_{j=1}^{n} \mu(D_j) - D_j}{\sum_{j=1}^{n} \mu(D_j)}$$

The fuzzy rule base used in this paper [12], is given in Table I as,

TABLE I:FUZZY RULE BASE FOR FLC

E \ CE	NL	NM	NS	ZE	PS	PM	PL
NL	PL	PL	PL	PL	NM	ZE	ZE
NM	PL	PL	PL	PM	PS	ZE	ZE
NS	PL	PM	PS	PS	PS	ZE	ZE
ZE	PL	PM	PS	ZE	NS	NM	NL
PS	ZE	ZE	NM	NS	NS	NM	NL
PM	ZE	ZE	NS	NM	NL	NL	NL
PL	ZE	ZE	NM	NL	NL	NL	NL

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MPPT methods based on artificial intelligence have become prevalent in recent years as compared to conventional methods because of good and fast response under rapid variations in temperature and solar radiation. The fuzzy logic based MPPT method does not require the exact model of PV system for its design [5]. In most of the literature, fuzzy logic based MPPT has been proposed with two inputs and one output. The two input variables are error E(k) and change in error ΔE(k), given by:

$E(k) = \Delta I/\Delta V + I/V$ (3)

$\Delta E(k) = E(k) – E(k-1)$ (4)

Where, I is output current from PV array, ΔI is I(k)-I(k-1); V is output voltage from array, ΔV is V(k)-V(k-1).The fuzzy inference can be carried out by one of the various available methods (Mamdani's method has been mostly used) and the defuzzification can be done using centre of gravity method to compute the output (duty cycle). The scheme of such MPPT method has been shown in figure 8.

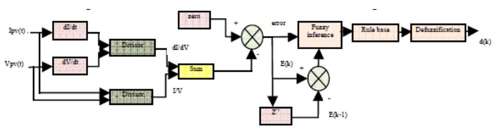


Fig. 8 Fuzzy logic based scheme for MPP tracking

6. SIMULATION RESULTS

The simulation circuit of proposed RSC circuit is shown in Fig.12. The simulation circuit of perturb and observe MPPT method is shown in Fig.13. The simulation circuit of Incremental Conductance MPPT method is shown in Fig.14.

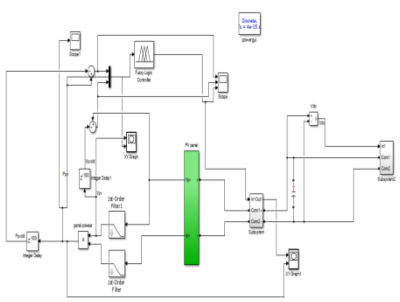
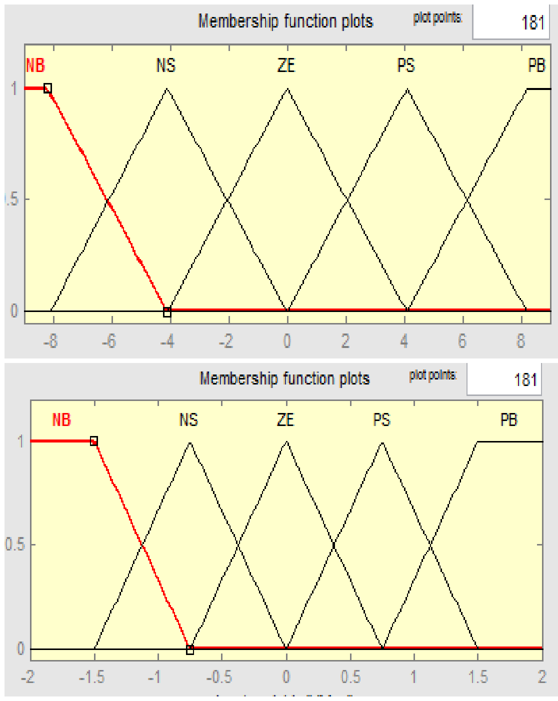
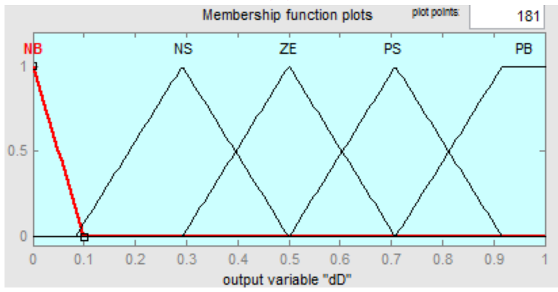


Fig.9 Simulation Circuit of Artificial Intelligence Based PV System



(a)



(b)

Fig.10 (a) FLC input MF's (b) FLC output MF's

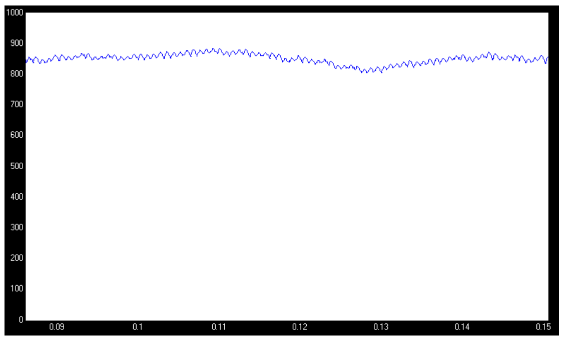


Fig. 11 Inverter Input DC Link Voltage

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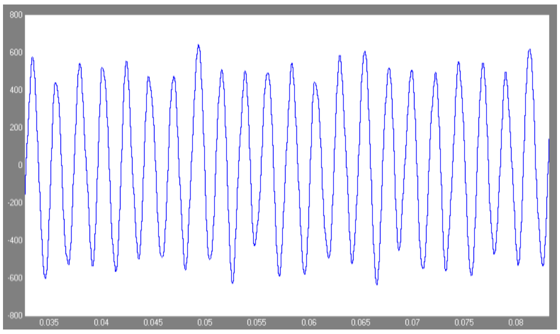

Fig.12 Load Voltage

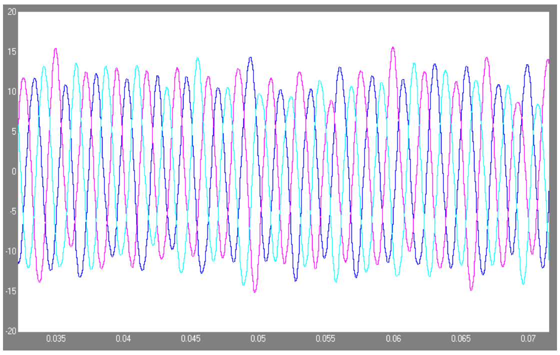

Fig.13 Load Currents

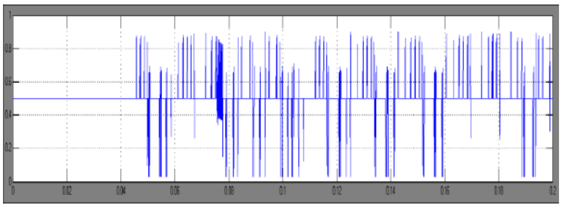

Fig.14 FLC Output Signal

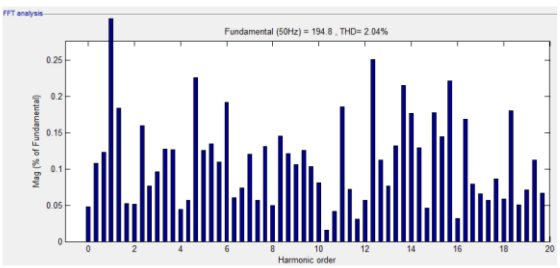

Fig. 15 THD spectrum of currents

7. CONCLUSION:

In this work, a real time implementation of a small scale photovoltaic system is presented. The control technique has been tested through simulation providing similar performances. The fuzzy logic based MPPT controller proved a notable efficiency, since it permits to track the optimum power very fast despite the atmosphere condition changing. The outcomes of the present paper verify the appropriateness of the proposed design methodology and prove that high power quality of supply in three-phase autonomous PV residential applications is a realistic target, depending on the initial design.

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