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ABSTRACT

Recently, photovoltaic panels have become one of the main Distributed Energy Resources (DERs) in the world of renewable power. Such a panel gives DC power which can be directly used in some DC power applications. In this paper, we deal with the modeling and control of a proposed PV panel system comprising an inverter and an induction motor based on photovoltaic system. At first, the modeling and control of a standalone photovoltaic pumping system with integrated maximum power point tracking (MPPT) to reach an optimum power transfer is addressed. Moreover, the system performance is measured in terms of the efficiency of the MPPT controller and flexibility in the solar photovoltaic operation. In the present work, we present a comparative study between two maximum power point tracking methods which are the perturb-and-observe PO method and incremental conductance method. The feature of the proposed algorithm is supported by theoretical analysis and a series of Matlab-Simulink simulation results.

Keywords: Component Water Pumping System, Renewable Energy Sources, Photovoltaic System.

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Introduction

Photovoltaic power is being employed universally around the whole world in recent years. It is used in many applications in islands and remote areas. Using photovoltaic as the power source for water pumping is also considered as one of the most promising areas of PV application. PV water pumping systems generally consist of PV array, controller, inverter, motor, pump and water storage tank. Photovoltaic water pumping systems are particularly suitable for water supply in remote areas where the electricity is not available. Water can be pumped during the day and stored in tanks, making water available also at night or when it is cloudy. The pumped water can be used in many applications such as domestic use, for irrigation and village water supplies. The advantages of using water pumps powered by photovoltaic systems include low maintenance, ease of installation, reliability and the matching between the powers generated and the water usage needs. In addition, water tanks can be used in photovoltaic pumping systems [1-2].

The electricity production via these sources is growing rapidly nowadays because it can be exploited in different ways. It offers a supply to the consumer in a safe manner and represents an unlimited energy source, in which solar energy is characterized as one of the solutions for covering the electricity in remote locations [3-5].

Nowadays, the distribution grid infrastructure is under pressure due to the increasing penetration of renewable energy sources [6-9]. Solar photovoltaic PV cells are a popular choice for residential installation since they require little maintenance, are noiseless, and can be mounted on unused space such as rooftops [10-12]. The sharp increase in the deployment of large capacity solar PV distributed generation plants and rooftop applications across the world have given a tremendous momentum to research in field of solar PV [13-14]. The proposed paper is divided into four sections. In the first section, we will give a bibliographic research on Solar photovoltaic PV panel. In the second section, we will give a detailed analysis of the modeling of the different elements constituting the proposed system ie, PV panel sources, modular three level inverter, induction machine model and the centrifugal pump. In the third section, we will describe the analysis and P&O MPPT algorithm control strategy which may be able to improve the dynamic and steady state performance of the PV system simultaneously. In the fourth section, we will present the simulation results with some comments as well as a detailed cost analysis and comparison with the existing systems.

Photovoltaic Pumping System

The power configuration of the studied photovoltaic pumping system is depicted in Figure 1.

Figure 1. *Bloc Diagram of Pumping System*

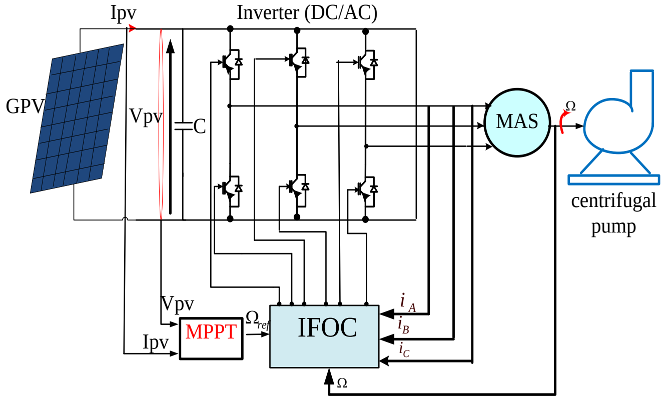
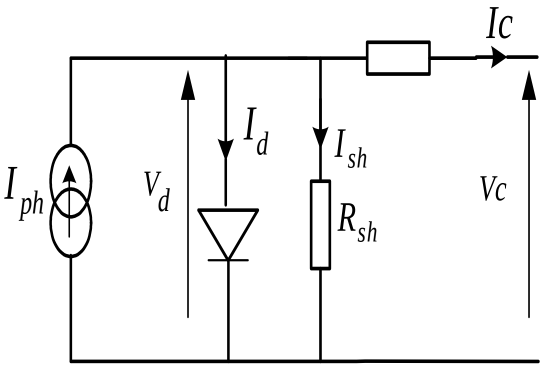


Figure 2. *Equivalent Circuit of a Solar Cell*



The Photovoltaic module used in this system is a 36 multi-crystalline solar cell in series able to provide 53.32W of maximum power. A mathematical model of a solar cell can be treated as a current source parallel with a diode, the model is completed by a parallel resistor and a series resistor as shown in Figure 2.

Thus, to achieve the desired current and voltage, an association of modules in series and in parallel connected modules gives rise to a generator, its output current voltage characteristic is given by equation (1) as explained in [11].

$$I_{pv} = N_p I_{ph} - N_p I_0 \left(\exp\left(\frac{\frac{V_{pv}}{N_s} + \frac{R_s I_{pv}}{N_p}}{a V_T} \right) - 1 \right) - \left(\frac{V_{pv} + \frac{N_s R_s I_{pv}}{N_p}}{\frac{R_{sh} N_s}{N_p}} \right) \qquad (1)$$

With:

$V_T = \frac{nKT}{q}$ & V_{pv} is the array voltage.

The electrical model of the induction machine in the d-q referential axis and the stator and rotor voltages are governed by the following differential equations:

$$\begin{cases} v_{sd} = R_s.i_{sd} + \dfrac{d\Phi_{sd}}{dt} - w_s.\Phi_{sq} \\ v_{sq} = R_s.i_{sq} + \dfrac{d\Phi_{sq}}{dt} + w_s.\Phi_{sd} \\ 0 = R_r.i_{rd} + \dfrac{d\Phi_{rd}}{dt} - w_r.\Phi_{rq} \\ 0 = R_r.i_{rq} + \dfrac{d\Phi_{rq}}{dt} + w_r.\Phi_{rd} \end{cases} \qquad (2)$$

The flux of the induction machine is given by:

$$\begin{cases} \Phi_{sd} = L_s.i_{sd} + M.i_{rd} \\ \Phi_{sq} = L_s.i_{sq} + M.i_{rq} \\ \Phi_{rd} = L_r.i_{rd} + M.i_{sd} \\ \Phi_{rq} = L_r.i_{rq} + M.i_{sq} \end{cases} \qquad (3)$$

The electromagnetic torque produced can be expressed by:

$$Cem = \frac{3}{2}\frac{pM}{L_r}(\phi_{rd}i_{sq} - \phi_{rq}i_{sd}) \qquad (4)$$

The water pump chosen is a centrifugal pump which applies a load torque proportional to the square of the rotor speed.

$$C_r = K\Omega^2$$

Photovoltaic Pumping System Modeling For Simulink

The photovoltaic array is regulated at the optimum power point so that best performance from the system can be obtained.

MPPT Control Algorithm

The aim of the maximum power point tracking is to extract the maximum output power. It is used in this paper in concordance with two different algorithms that are perturb and observe (P&O) algorithm and Incremental conductance algorithm (IC).

The basic equations for this method are as follows:

$$\begin{cases} \dfrac{dI_{pv}}{dV_{pv}} = -\dfrac{I_{pv}}{V_{pv}} & for\ V = V_{mp} \\ \dfrac{dI_{pv}}{dV_{pv}} > -\dfrac{I_{pv}}{V_{pv}} & for\ V < V_{mp} \\ \dfrac{dI_{pv}}{dV_{pv}} < -\dfrac{I_{pv}}{V_{pv}} & for\ V > V_{mp} \end{cases} \quad (5)$$

The disadvantage of the incremental conductance algorithm is its increased complexity compared to perturb and observe algorithm.

Control of the Induction Machine

The well-known IFOC control ensures the decoupling between the flux and the torque in order to control the rotor flux, the speed and the two stator currents. The electromagnetic torque becomes proportional to the stator quadrature current as in a DC machine. The field oriented control is obtained as in (7).

$$\begin{cases} \phi_{dr} = \phi_r \\ \phi_{qr} = 0 \end{cases} \quad (6)$$

Thus the equations (2) and (4) become:

$$\begin{cases} \dfrac{di_{ds}}{dt} = \dfrac{1}{\sigma L_s}\left[-R_s i_{ds} - w_s \sigma L_s i_{qs} + \dfrac{M}{L_r}\dfrac{d\phi_r}{dt} + V_{ds}\right] \\ \dfrac{di_{qs}}{dt} = \dfrac{1}{\sigma L_s}\left[-R_s i_{qs} - w_s \sigma L_s i_{ds} - \dfrac{M}{L_r} w_s \phi_r + V_{qs}\right] \\ \dfrac{d\phi_r}{dt} = \dfrac{M}{\tau_r} i_{ds} - \dfrac{1}{\tau_r}\varphi_r \\ w_s = \dfrac{M}{\tau_r}\dfrac{i_{qs}}{\phi_r} + p\Omega \\ Cem = \dfrac{3pM}{2L_r}\phi_r iqs \end{cases} \quad (7)$$

Results and Discussion

The simulation results obtained of the proposed control techniques applied to the photovoltaic pumping system using parameters given in the appendix are as follows. Figures 3 and 4 present the evolution of Power voltage and current voltage characteristics by P&O algorithm during a variation transient in solar radiation. The irradiation varies from 200W/m² to 1000w/m² assuming constant temperature 298K. It can be seen that the increase of the illumination explained by an increase of the maximum power available and the system track the new maximum power point tracking very quickly when the weather change suddenly but the operating point oscillates around the MPP, resulting in loss of power system. These oscillations would reduce the effectiveness of the photovoltaic power.

Pv Panel Simulation with P&O Controller

Figure 3. *Power-Voltage Characteristics*

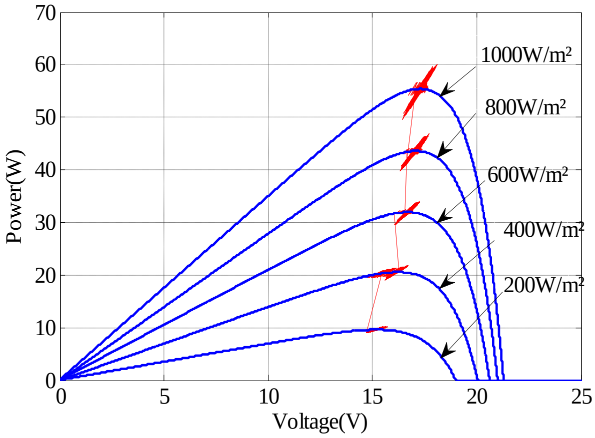
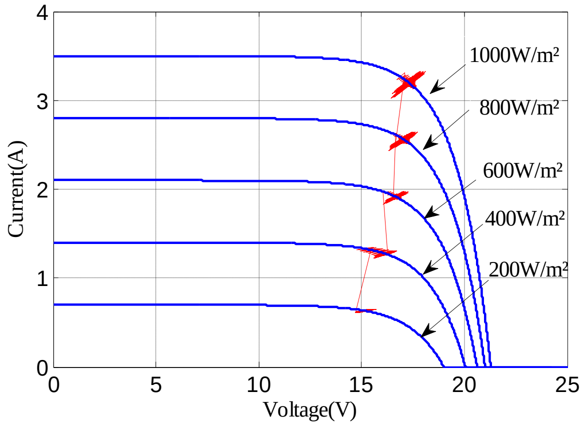


Figure 4. *Current-Voltage Characteristics*



Figures 5 and 6 show the IC algorithm efficiency in that the MPP has reached without perturbing the operating point from the start to the end of the simulation.

Pv Panel Simulation with IC Controller

Figure 5. *Power-Voltage Characteristics*

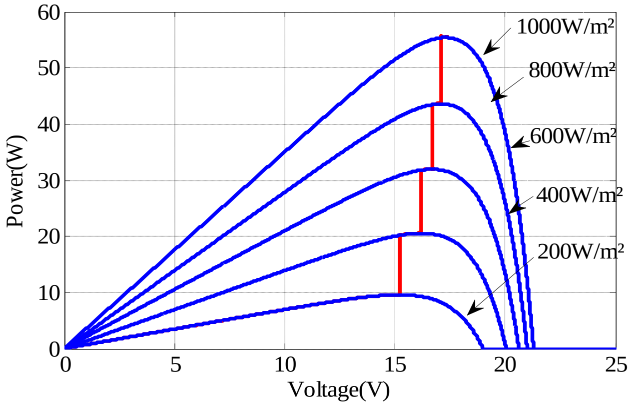
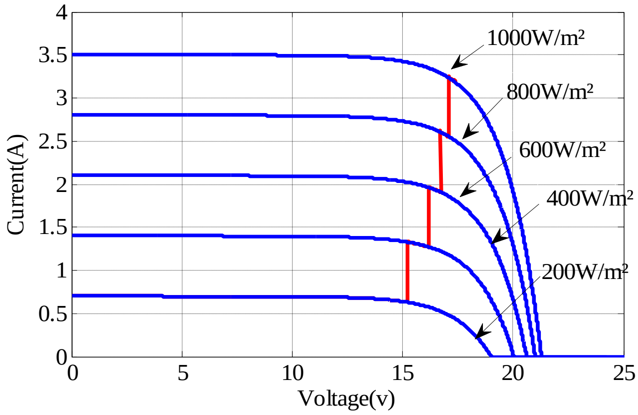


Figure 6. *Current-Voltage Characteristics*



Comparison of the given results in this system, we can conclude that the incremental conductance algorithm performs better. It improves the stability and offers higher energy utilization efficiencies compared to P&O algorithm. The MPPT without oscillations is desirable, for this reason we choose using the IC employed in our standalone P_v pumping system to further reduce the power loss.

Variation of the Temperature Value T

Initially, in Figure 7, we consider a fixed illumination E= 1000W / m² and a variable temperature to see its impact on the photovoltaic power generator. It shows a good convergence of the power generator P_v with its optimum value.

Figure 7. *Profile of Temperature & Power by* G_{pv}

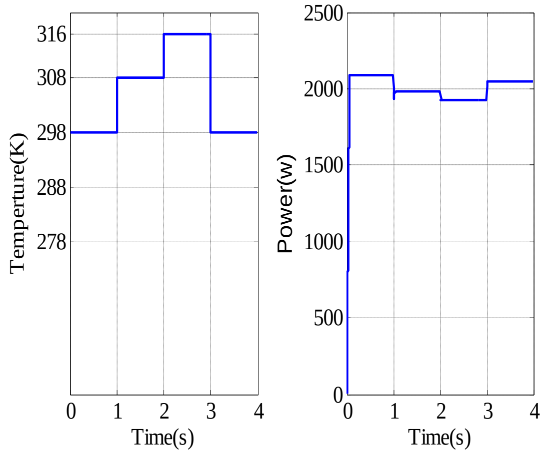
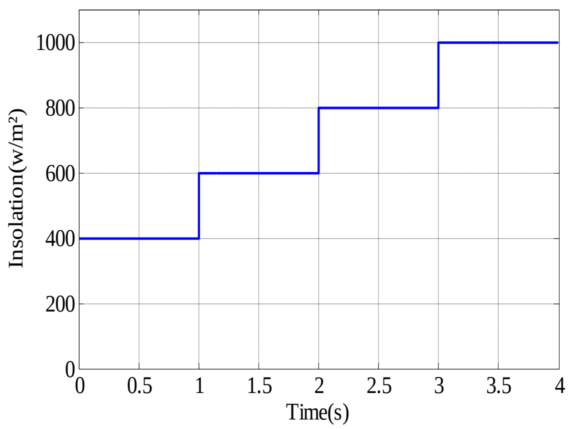


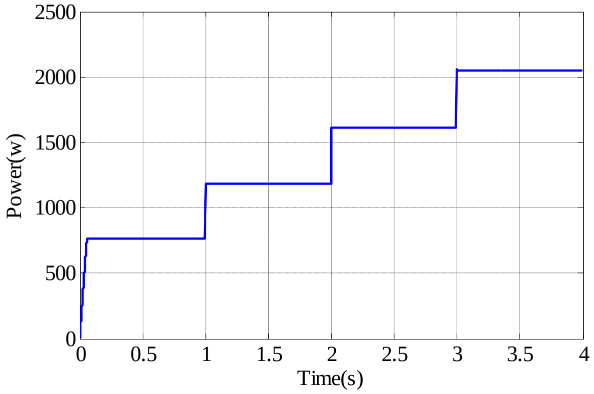
Figure 8. *Variation in Solar Radiation*



Variation of the Solar Illumination Value E

In order to test the continuation of the P_{max}, we choose to vary the solar illumination value of E as shown in Figure 8, and its impact on the performance of the photovoltaic pumping.

Figure 9. *P_V Array Power for Sudden Increase in Illumination*



The simulation results show the excellent performance of the Photovoltaic control in response to sudden change in temperature and solar intensity condition. The output power of the generator photovoltaic system is substantially changed with the weather condition.

Conclusions

In this paper, we have presented a SIMULINK model of a photovoltaic structure made up of a PV generator, MPPT converter supplying an asynchronous motor –pump. The main conclusion remarks are summarized as follows: A remote PV pumping system unit was designed. We have studied and applied new controls dedicated for this type of pumping system taking into account the elimination of storage battery. The use of MPPT algorithm that maximizes the energy transfer towards the whole system. The static and dynamic performances were presented by simulations.

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