Daily Constant PV Output Power Supplying AC Pumps using Batteries

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Abstract

This paper presents 200 KW three phase standalone photovoltaic systems supplying pumping station consist of four pumps 40 KW rating. The system utilizes a two stage energy conversion power conditioning unit topology composed of a DC-DC boost converter and three level-three phase voltage source inverter (VSI). The Boost converter in this paper is designed to operate in continuous mode and controlled for maximum power point tracking (MPPT). The fluctuating output power of the PV array system during the day is the commonly problem in the power system. The PV array system usually cannot give constant power for 24 hours day. Supplying a certain load from PV array system usually face this problem. Now and only now this problem is solved in this article. A nickel-Cadmium battery will be used to maintain the output power generated from the PV array supplying the pumps to be constant all the day. The system is modeled and studied using MATLAB/Simulink.

Keywords: PV array, AC pumps, batteries and constant output power

1. Introduction

The electricity demand in the world's developing countries is increasing rapidly and it is a great challenge to meet this demand, without affecting the climate and the environment. The main energy source for power production in the world today is the petroleum fuels. However, with threatening climate change the use of these must arguably decrease. The power generation is globally the largest source of green-house gases and, preferably, the generation should be shifted to more renewable sources. Solar power is often regarded as one of the most promising energy sources for the future, but it is today one of the most expensive sources, due to high investment costs. However the price has steadily decreased and in some countries, grid connected solar panels is today economically feasible. In places with a lot of solar radiation and a weak existing power grid, specifically for off-grid locations, solar power is regarded as a cost-effective solution [1].

The deregulation of electricity markets and requirement to reduce greenhouse gas emission from the conventional electric power generation make the distributed generation (DG) renewable energy systems gain a great opportunity as a new means of power generation that meet the accelerated demand for electric energy [2, 3].

Among all the various DG technologies, solar photovoltaic systems are rapidly growing in electricity markets due to the declining cost of PV modules [4, 5], increasing efficiency of PV cells, manufacturing- technology enhancements and economics of scale. However, the increasing penetration levels of PV systems into the grid have given rise to potential problems relating to power quality and PV performance [6-8].

One of the most important applications of photovoltaic (PV) standalone systems is for rural areas that have a considerable amount of solar radiation and no access to national grids [9].The performance of PV system is affected due to the amount of sun radiation and the environmental ambient temperature [10]. Many techniques of the VSI are implemented on the PV grid connected systems [11-13]. Some of the previous articles were using the batteries with PV array system as in [14-20] but none of them using the batteries as a restorer of the PV array source. The fluctuation of the PV output power during the day is one of the most commonly problems appeared in the power system and usually lead to make the renewable energy resources to be non-dependable power sources

In this article, the batteries are implemented online with the PV array all the time to maintain the PV output power and voltages to be constant all the day under different operating conditions

The simulation is implemented on 200 KW standalone PV system supplying pumping station consist of four 40 KW pumps. The system is tested during the different operating conditions using MATLAB SIMULINK to demonstrate the validation of the proposed technique.

2. The PV Model

In this paper, the assembly of PV model connected to the pumping station indicated in Figures 1 and 2 respectively. The total power required for the pumping station is about 175 KW. The pumping station is consist of four pumps driven by AC motor 40 KW rating and 15 KW other loads including lighting and air conditioning. Constant output power and voltage can be achieved by connecting batteries online with the PV array system as shown in Figure 3. The battery control system is described in details in Figures 4 and 5.
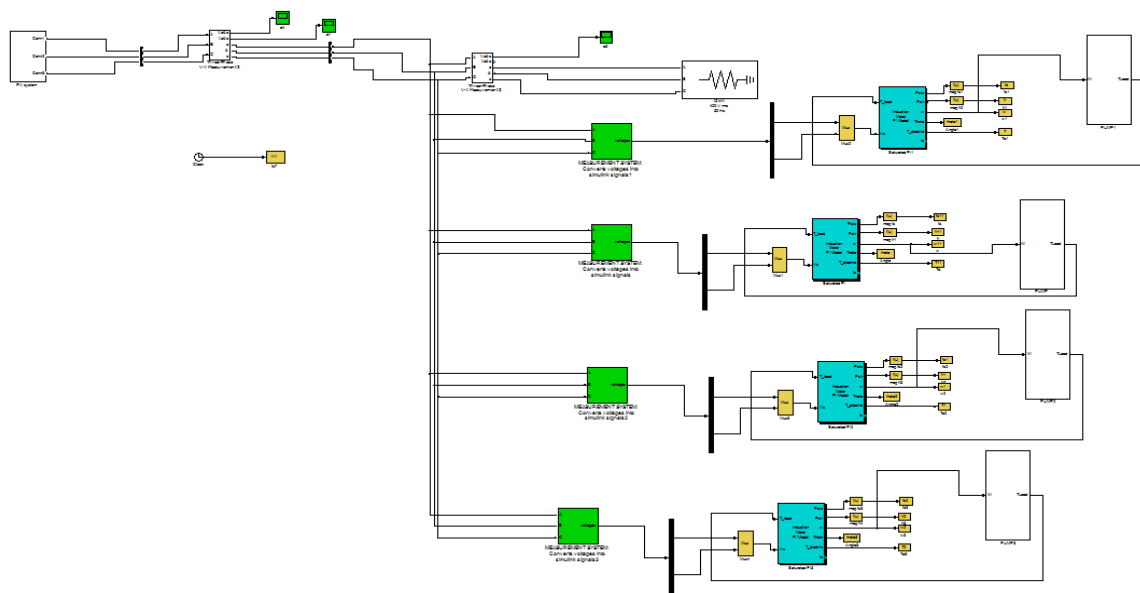

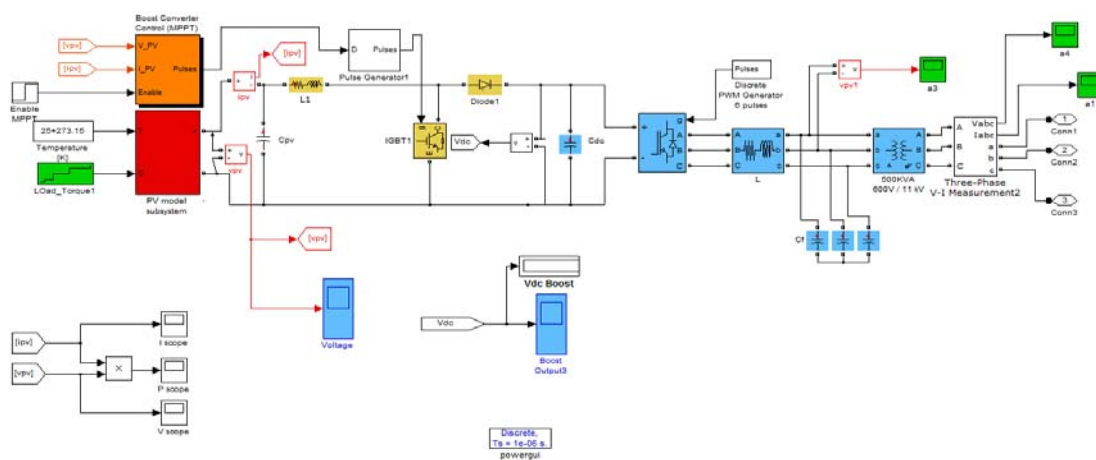Figure 1. PV supplying the pumping station
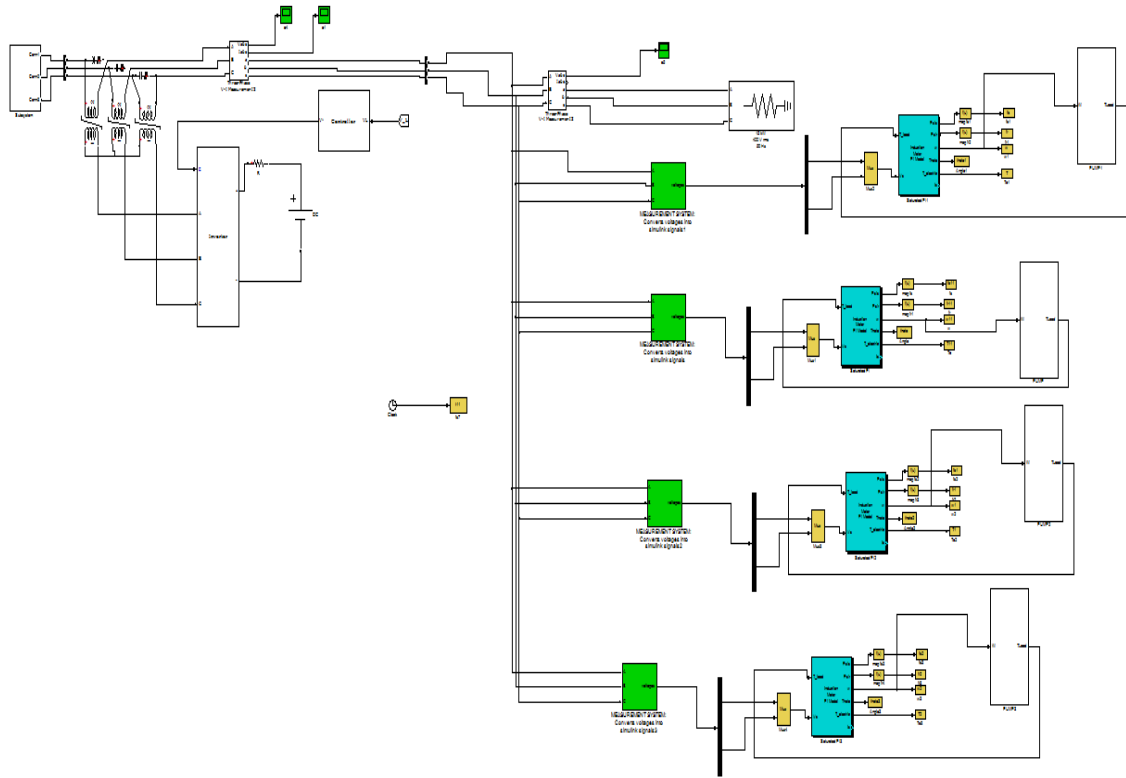

Figure 2. The PV array systems

Figure 3. Online PV and batteries supplying the pumping station for constant output power
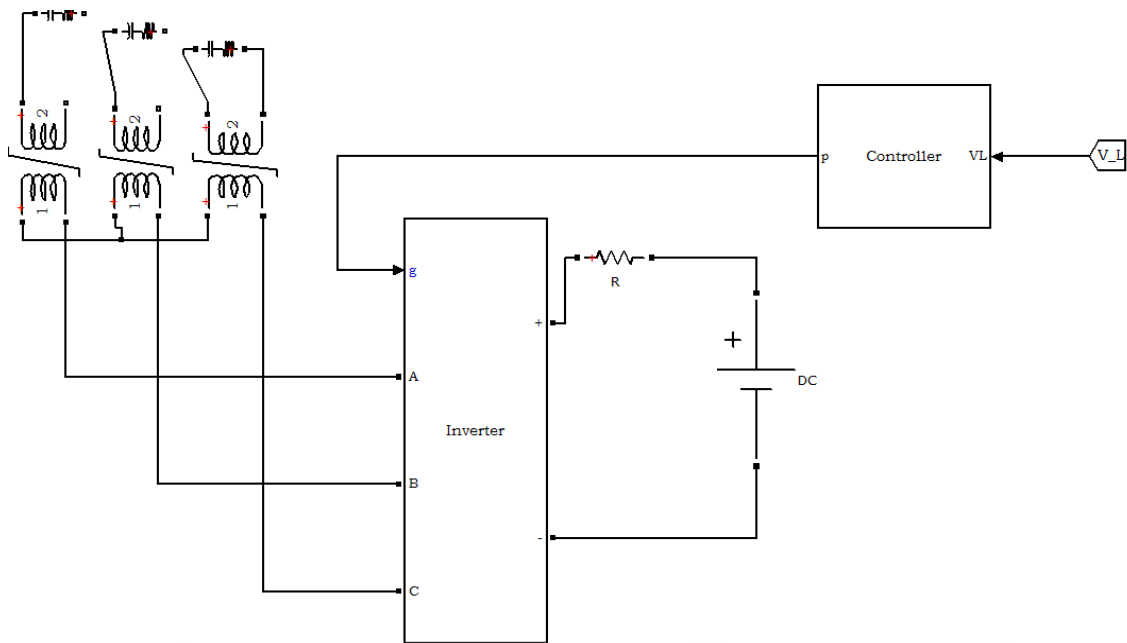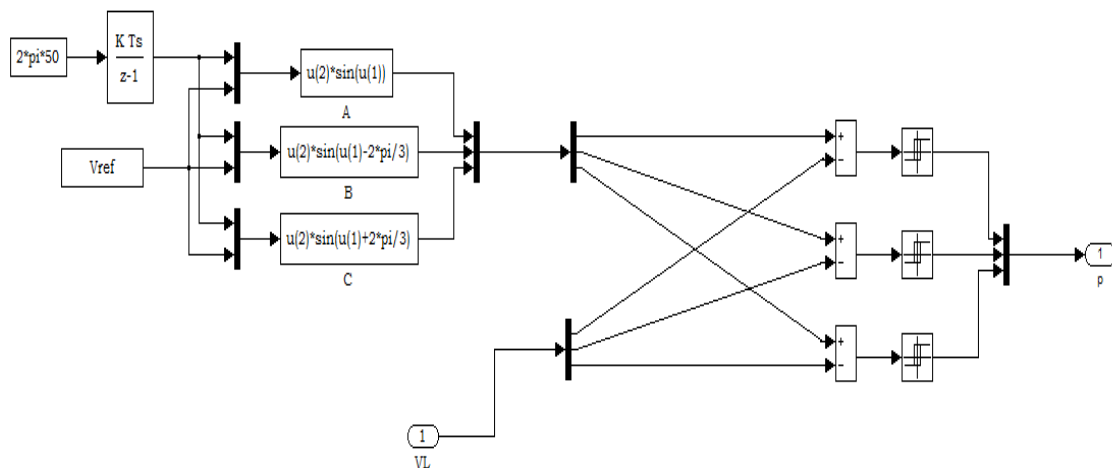

Figure 4. Battery control system

Figure 5. Details of the battery controller

3. Centrifugal Pump Model

In general, two types of pumps are commonly used for water-pumping applications [21]. One is positive displacement pump and another is centrifugal pump. In displacement pumps, the water output is directly proportional to the speed of the pump, but almost independent of head. Centrifugal pumps are used for low-head applications. Centrifugal pumps are designed for fixed-head applications, and the pressure difference generated increases in relation to the speed of the pump. Centrifugal pumps also have relatively high efficiency and are capable of pumping a high volume of water. The centrifugal pump is used in this article. Any pump is characterized by its absorptive power which is obviously a mechanical power on the shaft coupled to the pump, which is given by:

$$P = \frac{\rho g H Q}{\eta} \qquad (1)$$

Useful power: power consumed of the absorptive power is given by:

$$P_u = \rho g H Q \qquad (2)$$

where η, the total output; ρ, density (Kg/m3); G, acceleration of gravity (m2/S); H, height of rise (m); Q, flow(m3/S). The pumps are driven using AC induction motors.

4. Induction Motor Model

The motors used to drive the pumps in this article taking the magnetic saturation in consideration based on the π- model [22].

The π-model for the complete motor, at zero speed, is shown in Figure (4). The two phase electrical equations for an induction machine in an arbitrary frame rotating with speed (ω0) are given by:
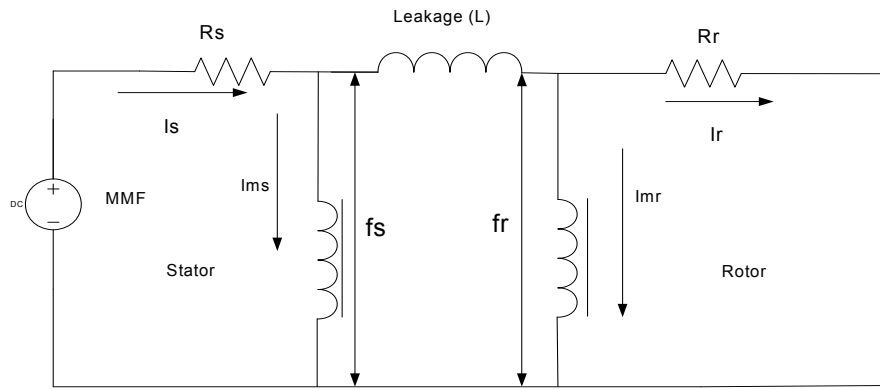
Figure 4. Induction Motor π- Model

$$V_s = R_s I_s + \frac{d\psi_s}{dt} + \omega_0 J_2 \psi_s$$

$$0 = R_r I_r + \frac{d\psi_r}{dt} + (\omega_0 - \omega_e) J_2 \psi_r \qquad (3)$$

Where;
Vs is the stator phase voltage vector,
Is is the stator phase current vector,
Ir   is the rotor phase current vector,
p is t he number of pole pair s,
ω is the rotor speed,
Rs is the stator phase resistance,
Rr is the rotor phase resistance,
Ψs and Ψr are the stator and rotor flux linkage vector s respectively.
     Equation (1) holds whether the induction motor magnetic circuit is considered linear or saturated and J2 is the 2 × 2 rotating matrix defined by;

$$J_2 = [0\ -1;\ 1\ 0] \qquad (4)$$

The mechanical equation can be expressed as:

$$J \frac{d\omega}{dt} + b\omega = T - T_L \qquad (5)$$

Where J is the motor inertia, b is the viscous damping, TL is the load torque and T is the generated torque.
     The relationship between the currents and the fluxes for the π model at d-q frame rotating with speed (ω0) are given by:

$$\begin{bmatrix} I_s \\ I_r \end{bmatrix} = \begin{bmatrix} G_s(\|\psi_s\|) \\ G_r(\|\psi_r\|) \end{bmatrix} + \begin{bmatrix} g_l I_2 & -g_l I_2 \\ -g_l I_2 & g_l I_2 \end{bmatrix} \begin{bmatrix} \psi_s \\ \psi_r \end{bmatrix} \qquad (6)$$

Where gl is defined as:

$$g_l = \frac{1}{L_l} \qquad\qquad (7)$$

Where G_s and G_r are the stator and rotor vector-valued nonlinear functions and defined as:

$$G_X(\psi_X) = G_X\left(\begin{bmatrix} \psi_{xd} \\ \psi_{xq} \end{bmatrix}\right) = \begin{bmatrix} I_{mxd} \\ I_{mxq} \end{bmatrix} = I_{mx} \qquad (8)$$

Where; Im and Ψm are the mutual current and flux vector, respectively, and subscript (x) can be (s) for stator and (r) for rotor. The relationship between the currents and the fluxes for the   π model can be compactly written as:

$$\begin{bmatrix} I_s \\ I_r \end{bmatrix} = \begin{bmatrix} (g_s(\|\psi_s\|) + g_l)I_2 & -g_lI_2 \\ -g_lI_2 & (g_r(\|\psi_s\|) + g_l)I_2 \end{bmatrix} \begin{bmatrix} \psi_s \\ \psi_r \end{bmatrix} \qquad (9)$$

Where; I_2 is the 2 × 2 identity matrix, g_l is defined as the reciprocal of the leakage inductance (L_l), g_s and g_r are the stator and rotor vector-valued nonlinear saturation functions. The scalar saturation functions g_s and g_r only affect the magnitude, while keeping the directions of the fluxes and currents the same. These functions are monotone increasing and are non-zero at the origin. The saturation functions $g_s(x)$ and $g_r(x)$ have to be identified experimentally for each motor as shown in the next section.
        Finally, the generated torque (T) and p is the poles number is given by;

$$T = P\, g_l\left(\psi_s\right)^T J_2(\psi_r) \qquad (10)$$

5. Simulation Results
        The simulation is performed using MATLAB Simulink by supplying a pumping station consist of four pumps 40 KW rating using 200 KW three phase standalone photovoltaic systems. The pumps are driven by an induction motor taking the saturation in consideration. The test is by varying the radiation while the environmental temperature is constant. The behaviors of the pumps are compared when supplied from the PV modules with and without the battery control system as shown in figures 5 to 9. Figure 5 show the sun radiation variation during simulation. Figure 6 indicate the load power consumption and figure 7 show the voltage applied on the motors of the pumps. Figures 8 and 9 show the motor load torque and motor speed respectively. The simulation show the successful improvement of the pumping station behavior when the battery control system is applied online with the PV system. By using the battery control system with PV array, the motor speed will become almost constant and not depending on the sun radiation. The power consumption and the voltage applied on the motor are also almost constant when the battery system is applied online with the PV array.
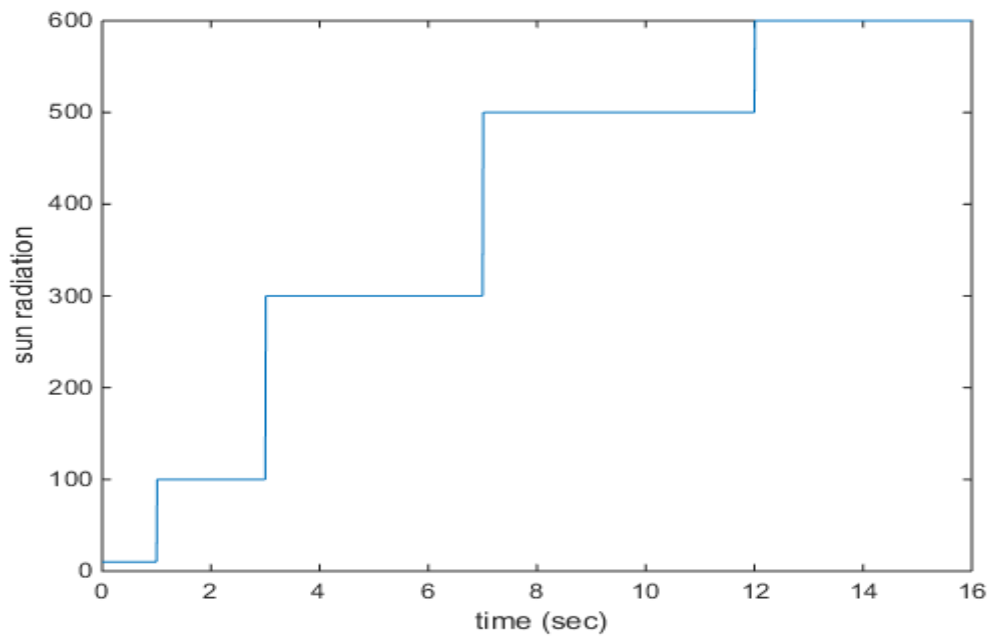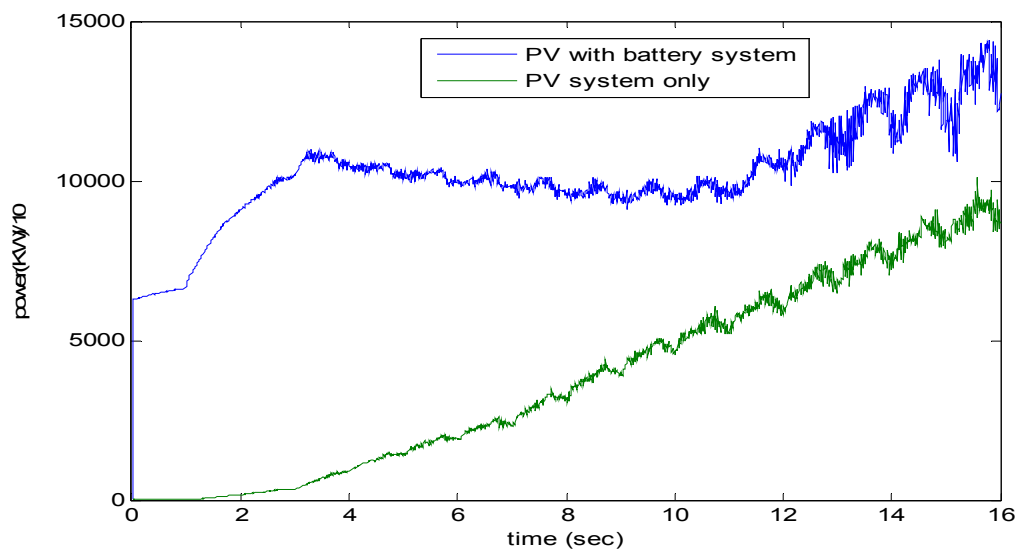
Figure 5. The variation in sun radiation
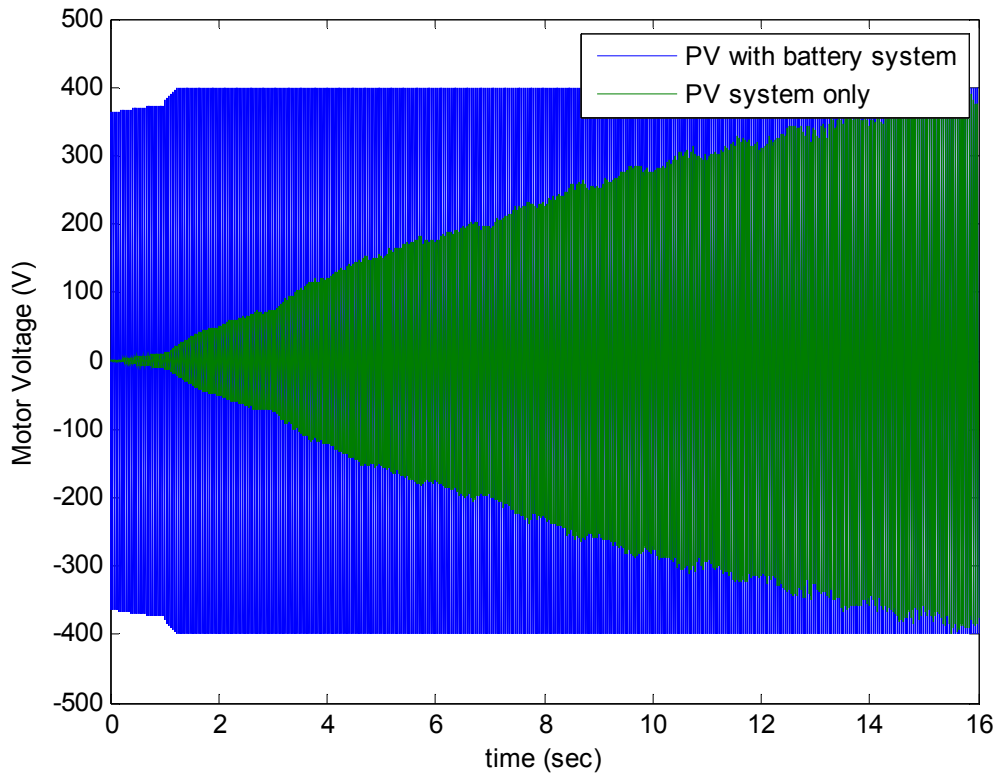

Figure 6. The load power consumption

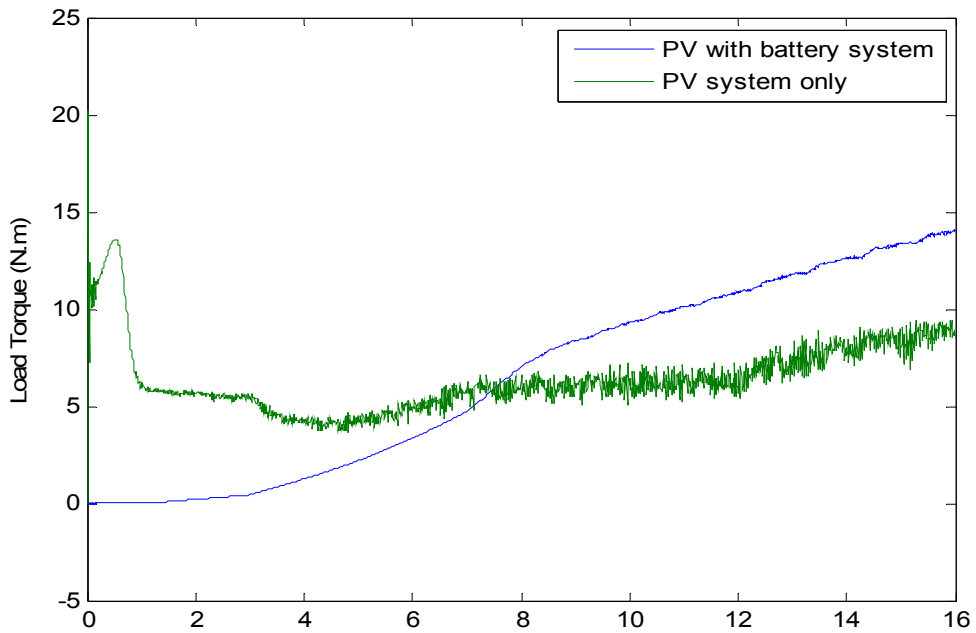Figure 7. The voltage applied on the motors
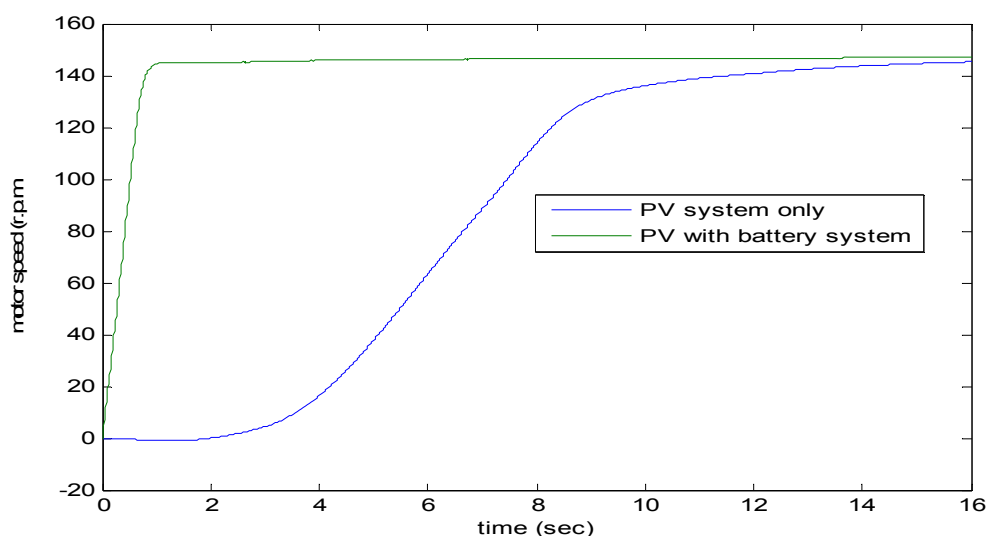

Figure 8. The motor load torque

Figure 9. The motor speed

6. Conclusion

This paper presents 200 KW three phase standalone photovoltaic systems supplying pumping station. A Nickel-Cadmium battery will be connected online with the PV array. A new technique is used in this article to maintain the PV output power and voltages to be constant all the day and under different operating conditions. The new technique is tested using MATLAB Simulink The simulation result show that the new technique is succeeded to achieve the target.

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