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FOPID Controller Based AC Pump Supplied from PV Standalone Source Tuned using Fuzzy Logic Type 2

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Abstract

This paper presents 500 KW three phase standalone photovoltaic systems supplying pumping station consist of four pumps 80 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). In this paper, the performance of the pumps is improved by adapting the controller of MPPT using different techniques. The system is modeled and studied using MATLAB/Simulink.

Keywords: *PV array, AC pumps and MPPT*

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 were used for MPPT with PV system [11-15]. The FOPID controller is firstly used with PV system as in [15] but none of the previous research used the fuzzy logic for adopting the parameters of the FOPID controller. The fuzzy logic technique is frequently used with PV system as in [16-20] but none of previous research implements the fuzzy logic for adaptation for FOPID controller. Fuzzy type 2 was implemented from 2013 in the research and some authors use this technique for MPPT of PV system as in [21] and [22] but none of them use this technique with FOPID controller. The system used in this paper is related to a real boost pumping station in ras ghareb city located in Egypt. The pumping

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station till now based on the diesel generators for 24-hour day operation and the plan is to be supplied from PV standalone system as well as the diesel generator to reduce the fuel cost.

In this article, the controller of MPPT is tuned using fuzzy logic technique and the performance of the pumps is improved by using FOPID instead of the conventional PID controller. The FOPID controller is tuned using the conventional fuzzy logic and fuzzy logic type 2.

The simulation is implemented on 500 KW standalone PV system supplying pumping station consist of four 80 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 Figure 1 and 2. The total power required for the pumping station is about 320 KW. The pumping station is consisting of four pumps driven by AC motor 80 KW rating and 40 KW other loads including lighting and air conditioning. Figure 3 show the block diagram of MPPT using conventional PID controller.

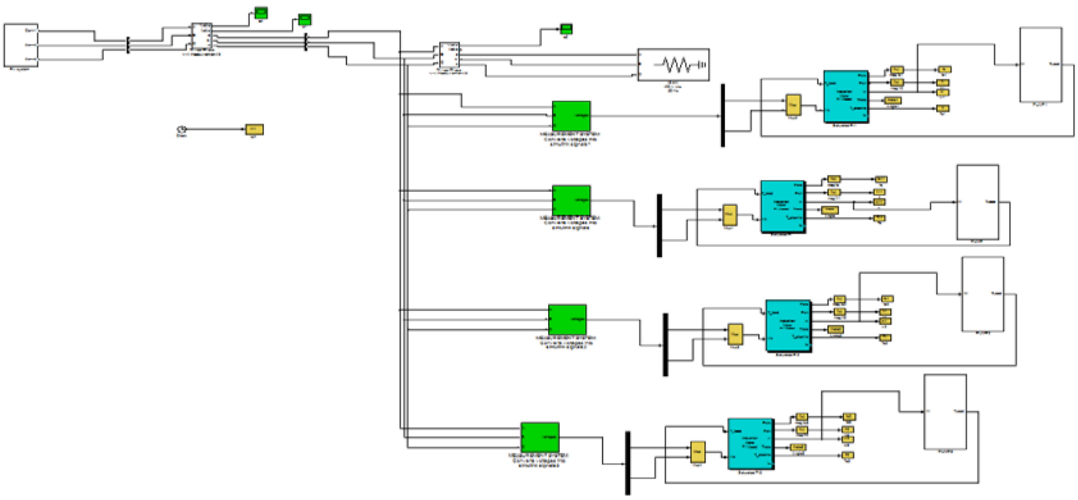

Figure 1. PV supplying the pumping station

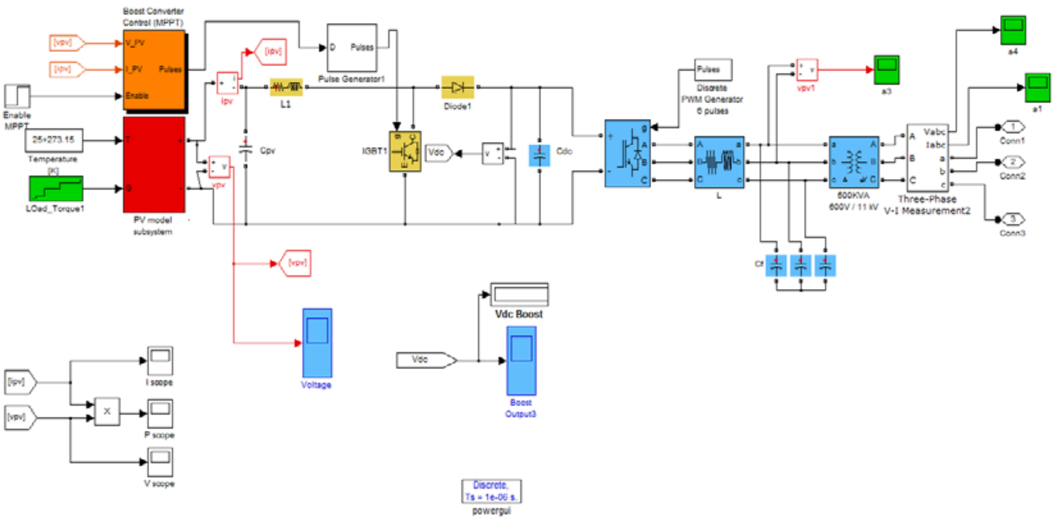

Figure 2. The PV array system

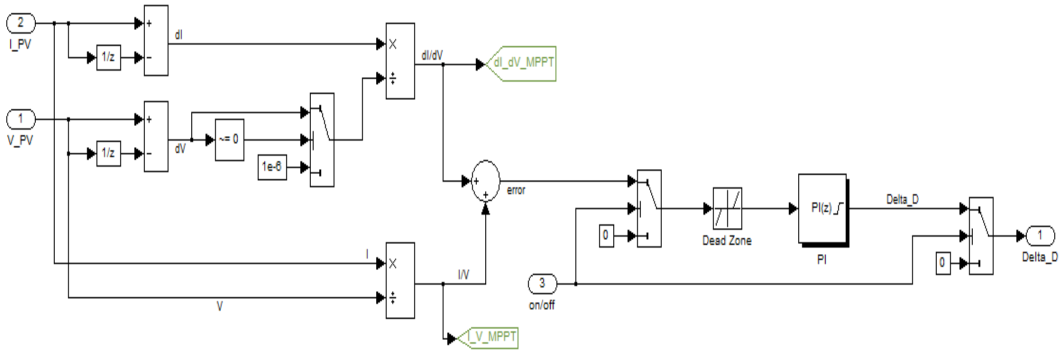

Figure 3. The block diagram of MPPT

3. Centrifugal Pump Model

In general, two types of pumps are commonly used for water-pumping applications [23]. 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:

$$P = \frac{\rho g H Q}{\eta} \tag{1}$$

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

$$P_u = \rho g H Q \tag{2}$$

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. The motors used to drive the pumps in this article taking the magnetic saturation in consideration based on the π- model [24].

4. FOPID Based Controller

Fractional-order calculus is an area of mathematics that deals with derivatives and integrals from non-integer orders. This concept was proposed by Podlubny in 1997, it deals with derivatives and integrals from non-integer orders In other words, it is a generalization of the traditional calculus that leads to similar concepts and tools, but with a much wider applicability. In the last two decades, fractional calculus has been rediscovered by scientists and engineers and applied in an increasing number of fields, namely in the area of control theory. The success of fractional-order controllers is unquestionable with a lot of success due to emerging of effective methods in differentiation and integration of non-integer order equations.

Fractional-order proportional-integral-derivative (FOPID) controllers have received a considerable attention in the last years both from academic and industrial point of view. In fact, in principle, they provide more flexibility in the controller design, with respect to the standard PID controllers, because they have five parameters to select (instead of three).

However, this also implies that the tuning of the controller can be much more complex. In order to address this problem, different methods for the design of a FOPID controller have been proposed. Further research activities are running in order to develop new tuning rules for fractional Controllers, studying previously the effects of the non-integer order of the derivative and Integral parts to design a more effective controller to be used in real-life models. Some of these techniques are based on an extension of the classical PID control theory. The extension of differentiation and integration order from integer to non-integer numbers provides a more flexible tuning strategy and therefore an easier achieving of control requirements with respect to classical controllers. The fraction order controller form is [25] and [26]:

$$G_c(s) = k_p + \frac{k_i}{s^{\lambda}} + k_d\, s^{\mu} \tag{3}$$

The interest of this kind of controller is justified by a better flexibility, since it exhibits fractional powers (λ and μ) of the integral and derivative parts, respectively. Thus, five parameters can be tuned in this structure (λ; μ; kp; ki and kd), that is, two more parameters than in the case of a conventional PID controller (λ = 1 and μ = 1). The fractional orders λ and μ can be used to fulfill additional specifications of design or other interesting requirements for the controlled system.

In this paper a simulation for a fractional-order system is done by using the frequency domain approximations, the fractional order equations of the system is first considered in the frequency domain and then Laplace form of the fractional integral operator is replaced by its integer order approximation then the approximated equations in frequency domain are transformed back into the time domain. The optimization work is done through using GA and Ninteger toolbox. Ninteger is a toolbox for MATLAB intended to help developing fractional-order controllers and assess their performance. This toolbox includes about thirty methods for implementing approximations of fractional-order and three identification methods. The Ninteger toolbox allows implementing, simulating and analyzing FOPID controllers easily via its functions.

The most common form of a fractional order PID controller is the $PI^{\lambda}D^{\mu}$ controller. Involving an integrator of order λ and a differentiator of order μ where λ and μ can be any real numbers.

The transfer function of such a controller has the form:

$$G_c = \frac{U(s)}{E(s)} = k_p + k_I \frac{1}{s^{\lambda}} + k_D s^{\mu}, (\lambda\,, \mu > 0) \tag{4}$$

Where Gc(s) is the transfer function of the controller, E(s) is an error, and U(s) is controller's output. The integrator term is 1/ sλ, that is to say, on a semi-logarithmic plane. The control signal u(t) can then be expressed in the time domain as:

$$u(t) = k_P e(t) + k_I D^{-\lambda} e(t) + k_D D^{\mu} e(t) \tag{5}$$

The block-diagram configuration of FOPID is presented in Figure 4. Clearly, selecting λ= 1 and μ = 1, a classical PID controller can be recovered. The selections of λ= 1, μ= 0, and λ= 0, μ= 1 respectively corresponds conventional PI & PD controllers. All these classical types of PID controllers are the special cases of the fractional $PI^{\lambda}D^{\mu}$ controller.

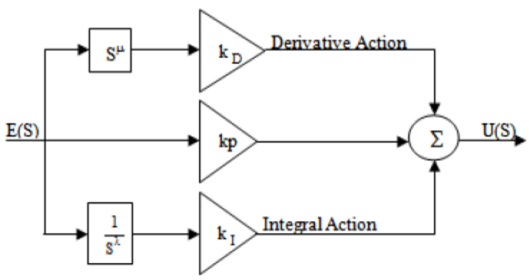

Figure 4. Block-diagram of FOPID

The analytic method, which lies behind the proposed tuning rules, is based on a specified desirable behavior of the controlled system; in this section the desirable dynamics described by the following criteria is only optimized through minimization the overall squared error, overshoot, rise time and settling time, which means that the response be as close as possible to the set point value along the time line till the steady state and leads to have a Zero steady-state error. The fitness function used for the GA will be square of error plus square of error differentiation

5. Fuzzy Logic Based PID Controller

The fuzzy logic programming has been become widely used in industry. Extensive number of researches were developed using fuzzy logic technique. This paper proposed two inputs-three outputs self-tuning of a PID controller. The controller design used the error and change of error as inputs to the self-tuning, and the gains (KP1, KI1, KD1) as outputs. The FLC is adding to the conventional PID controller to adjust the parameters of the PID controller on-line according to the change of the signals error and change of the error. The controller proposed also contain a scaling gains inputs (Ke, KΔe) as shown in Figure (5), to satisfy the operational ranges (the universe of discourse) making them more general.

Now the control action of the PID controller after self-tuning can be describing as:

$$U_{PID} = K_{P2} * e(t) + K_{I2} \int edt + K_{d2} \frac{de(t)}{dt} \tag{6}$$

Where KP2, KI2, and KD2 are the new gains of PID controller and are equals to:

KP2=KP1 * KP, KI2=KI1 * KI, and KD2=KD1 * KD (7)

Where KP1, KI1, and KD1 are the gains outputs of fuzzy control that are varying online with the output of the system under control. And KP, KI, and KD are the initial values of the conventional PID.

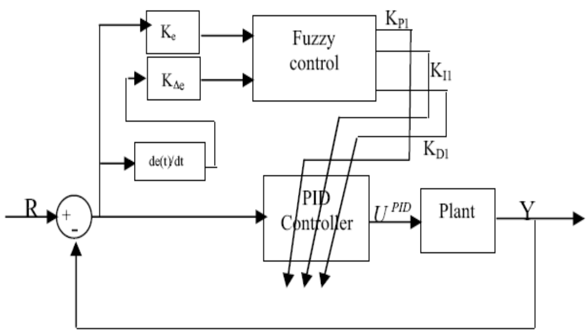

Figure 5. Proposed Fuzzy Self Tuning

As shown in Figure 5, there are two inputs to the controller: error and rate change of the error signals. The error is defined as e(t) = r(t) - y(t), Rate of error is defined as Δe(t)=de(t)/dt, where r (t) is the reference input, y (t) is the output, e(t) is the error signal, and Δe(t) is the rate of error. The seventh triangular input and output member ship functions of the fuzzy self-tuning are shown in the Figure 6, 7 and 8.

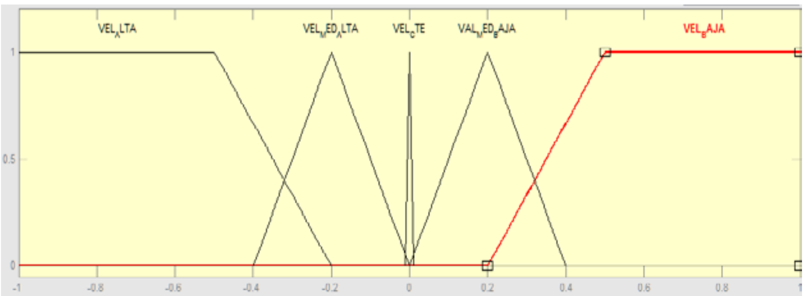

Figure 6. Memberships Function of Inputs (e)

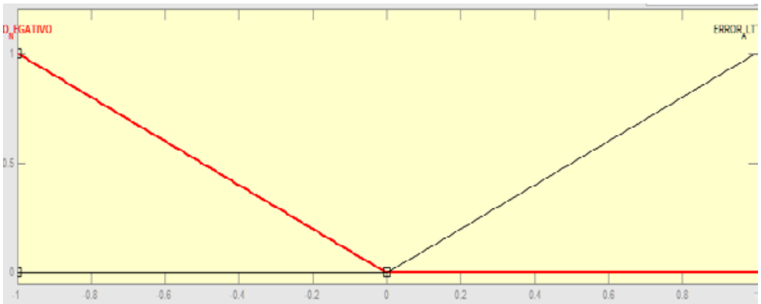

Figure 7. Memberships Function of Inputs (∆e)

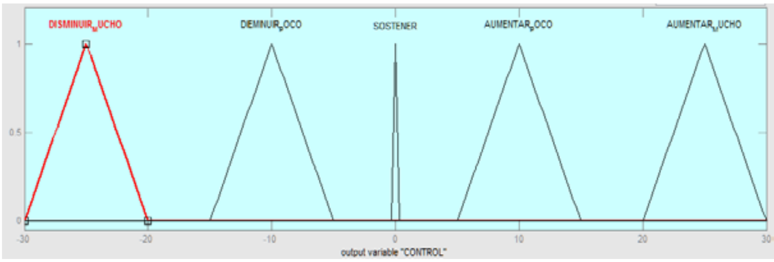

Figure 8. Memberships Functions of Outputs

The same controller is also implemented by using the fuzzy logic type 2. The main difference between the type 2 and the conventional fuzzy controller is the shape of the membership function. Figure 9, 10 and 11 are the input output membership functions used for fuzzy type 2 PID controller.

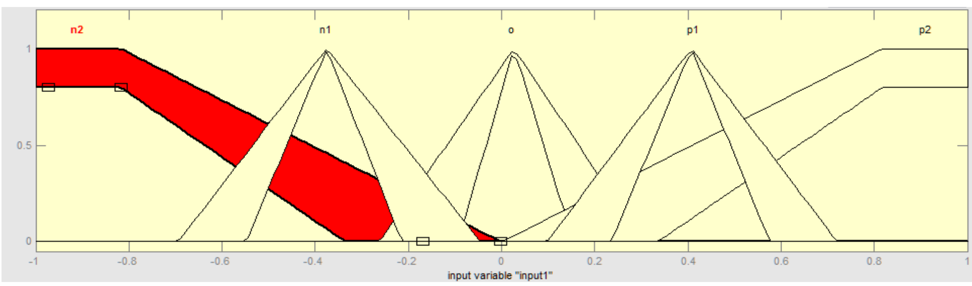

Figure 9. Memberships Function of Inputs (e)

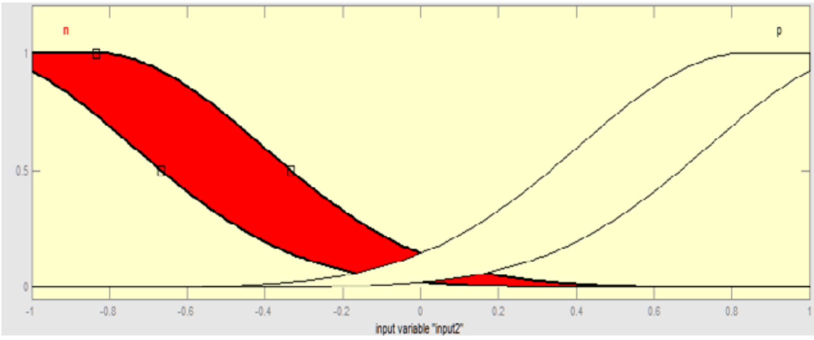

Figure 10. Memberships Function of Inputs (Δe)

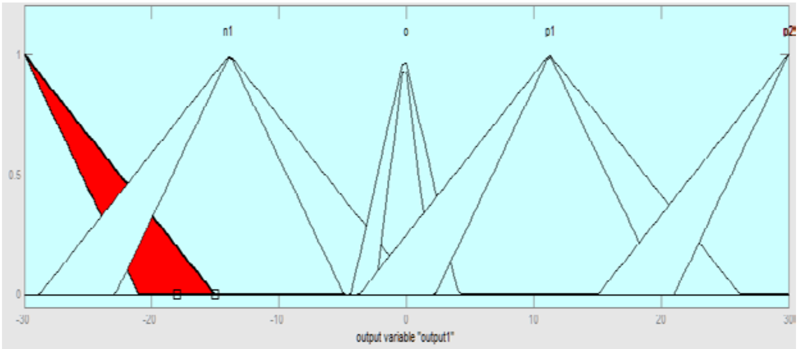

Figure 11. Memberships Functions of Outputs.

6. Fuzzy Logic FOPID Controller

The construction of fuzzy logic FOPID is shown in Figure 12.

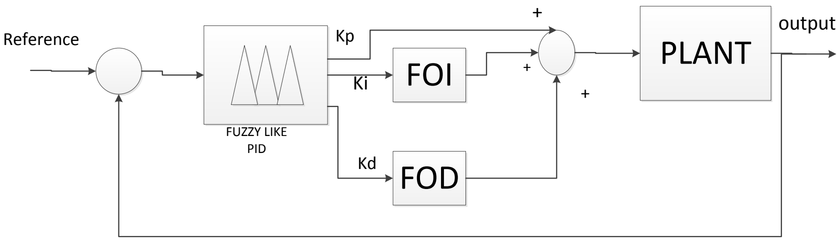

Figure 12. Fuzzy FOPID construction

For the fuzzy FOPID, we are using the same fuzzy logic like PID controller with multiplying the parameter of FOI with the term of Ki fuzzy output and FOD with the term of Kd fuzzy output.

The transfer function of FOI will be $G_c(s) = \frac{k_i}{s^{\lambda}}$, while the transfer function of FOD will be: $G_c(s) = k_d s^{\mu}$

The construction of fuzzy FOPID controller using MATLAB Simulink is indicated in Figure 13.

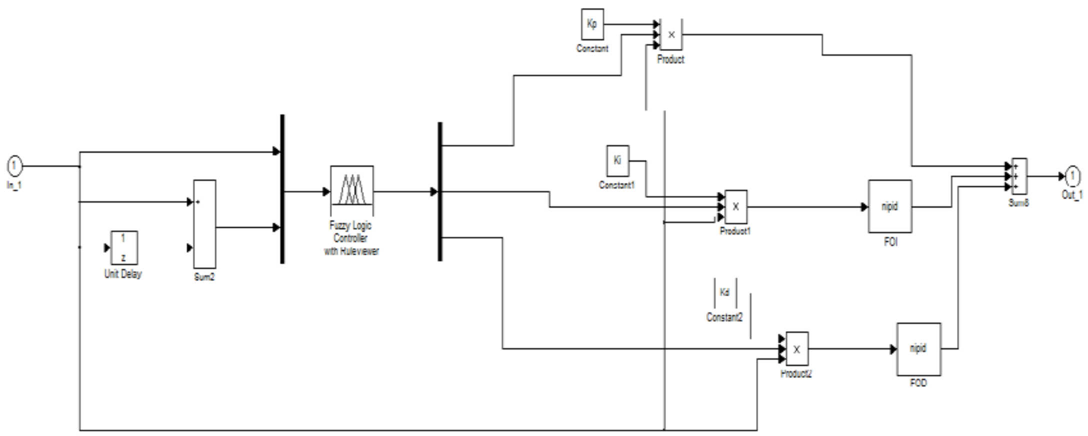

Figure 13. Fuzzy FOPID construction in MATLAB Simulink

7. Simulation Results

The simulation is performed using MATLAB Simulink by supplying a pumping station located in ras ghareb city in Egypt which consist of four pumps 80 KW rating using 500 KW three phase standalone photovoltaic systems. The pumps are driven by an induction motor. The test is divided in three cases, the first case is done by using the PV system without MPPT technique, in the second case the system is tested using MPPT technique with aided of a conventional PID tuned using fuzzy logic and in the third case the FOPID is implemented. The FOPID in this article is tuned using type 1 and type 2 fuzzy logic. The simulation is done at constant temperature and radiation. The simulation results are indicated in figures. Figure 14, 15 and 15 represent the great effect of using MPPT technique for improvement of pumps response. Figure 17 indicate a complete comparison for the pumps response using MPPT when using different techniques for tuning the MPPT controller. The controller in this article is tuned using fuzzy logic technique. Conventional type of PID controller and FOPID are implemented. The old type of fuzzy logic technique and fuzzy logic type 2 are used. Figure 17 show that the best response is achieved when using MPPT based on FOPID tuned using fuzzy logic type 2. Also the figure show that the pump response is improved by using FOPID controller for MPPT instead of the conventional PID controller. The simulation results show that the fuzzy logic type 2 give slight improvement for the pump response.

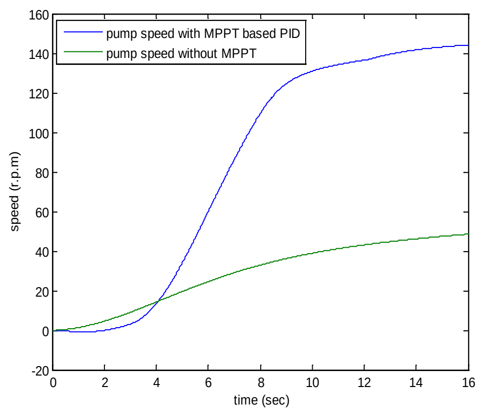

Figure 14. Pump speed response with and without MPPT

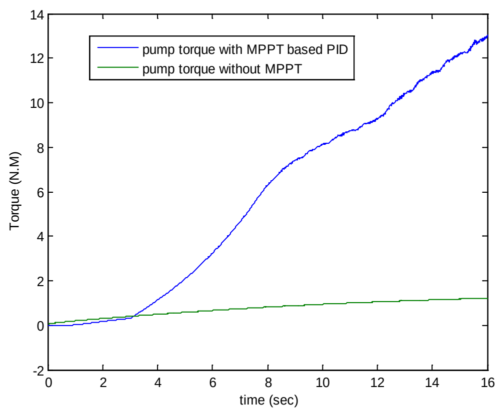

Figure 15. Pump Torque response with and without MPPT

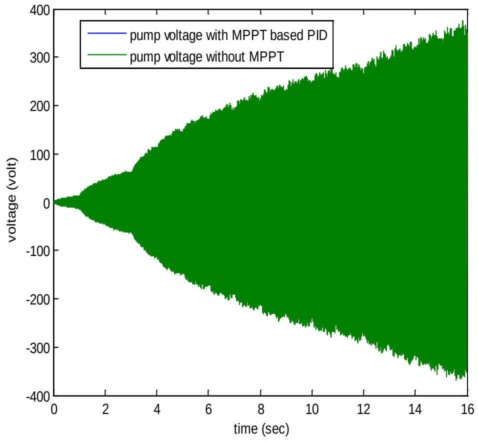

Figure 16. Voltage applied on the pumps with and without MPPT

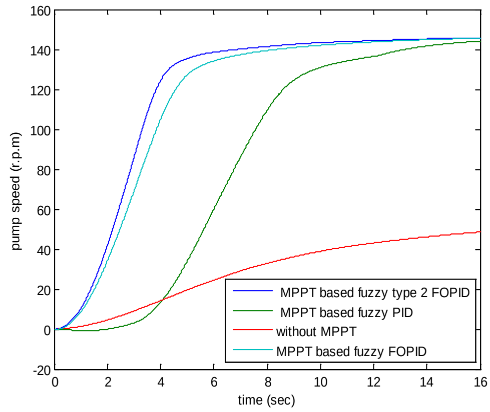

Figure 17. Comparison between pump speed response with and without MPPT using different tuning techniques

8. Conclusion

This paper presents 500 MW three phase standalone photovoltaic systems supplying pumping station instead of utility grid. The MPPT technique is applied for the PV system. The PID and FOPID controllers are used for MPPT. The fuzzy logic type 1 and type 2 are used for tuning the parameters of the controller The new techniques are tested using MATLAB Simulink The simulation result show that the new techniques are succeeded to improve the performance of the pumps. The simulations indicate that the FOPID controller give a great effect for system response improvement while the fuzzy logic type 2 give a slight effect rather than the effect of conventional fuzzy logic technique.

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