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EFFICIENT PERFORMANCE FOR PHOTOVOLTAIC PUMPING SYSTEM BASED ON MAXIMUM POWER POINT TRACKING UNDER MINIMUM CLIMATE STATUS

SAAD ESKANDER, AHMED SHAHIN, EID GOUDA, ALI ELTAMALY, HASSAN ABDULGHANI, MOHAMED AMMAR

Department of Electrical Engineering,
Faculty of Engineering,
Mansoura University, Mansoura, Egypt
Technical Institute of the Armed Forces, Ministry of Defense, Cairo, Egypt

ABSTRACT:

The research dealt with a subject of important and modern topics in the use of solar energy, especially in the applications of pumping water has been derived from the new equations to calculate the performance rates of photovoltaic pumping systems (PVPS). The structure of the proposed PVPS based on maximum power point tracking (MPPT) was presented. An integrated mathematical model was carried out for the solar cell system and connected to feeding management of pump. The model was applied to calculate performance with one type of electric motor that operated the pump. The system performance was calculated using appropriate simulation programs. There was also extensive work on projects of modeling solar photovoltaic generation, but there were still some basic aspects of designs that make them more flexible and more efficient for other research work. This work suggested an illustration of photovoltaic cells, suitable for the possibility of using it again in different designs. A model of three inputs, namely temperature, radiation and voltage, was designed, simulated, operated and analyzed. The similarities of the results were very satisfactory in spite of nearly small variances were observed at a model response to a various input.

KEYWORDS: System performance, PVPS, MPPT, power inverter, and experimental setup.

INTRODUCTION:

Main components of any PVPS are PV array, electrical drive, water pump and suitable converter. Normally the drive is directly coupled to the pump unit. A sufficient radiation level must be available to enable the system starting. The discharge rate of pumping system generally is low in high radiation levels. It is found the performance of the studied system has hard due to the nonlinearity relation between the pump flow and solar radiation density.A detailed developed model for the calculated radiation is introduced. With the description of PV panel itself in the first part. Then the second part is formed by using DC/DC converter. Further, the converter can be connected to the battery and also to the inverter through DC link. As for the third part is the control algorithm, which controls DC/DC converter to ensure of obtaining required amount of energy via MPPT controller. And the last part is the control of inverter by PWM which is fed to the motor-pump.From presented parts, it is likely that the overall efficiency of energy transfer is determined by the previous elements. The PV panel efficiency is given by the manufacturer, so it could not be influenced. The only things that can be influenced are the inverter, converter and the control algorithm efficiency. The article is mostly devoted to improving the effectiveness of the control algorithm. And while there is less substantial converter and so on inverter, they are briefly described later.To utilize the PV module adequately it is essential to coordinate the load to draw the maximum power at a given irradiance level and cell temperature. Therefore, controlled DC/DC converters are applied ensure source load match. The module operating point may be shifted by changing a duty cycle using tracker controller. An effective control strategy using perturb and observe (P&O) algorithm of MPPT has been introduced.

Several researchers published many papers in this field. For example, Kumar et al. designs the photovoltaic water pumping system [1]. Ghoneim presents the optimization performance of a photovoltaic powered water pumping system [2]. Dunlop experimentally investigates the photovoltaic systems performance [3]. Also, the system performance of stand-alone PV pumping systems has investigated with different weather conditions by Elgendy [4]. Taylor et al. analyzes the effect of PV array configuration on the PVPS performance [5]. Campana et al. illustrates the dynamic modelling of a PV pumping system [6]. Also, Albadi et al. studies the modeling and sizing of PVWP system [7]. Koner analyzes the PVPS performance by varying the motor characteristics [8]. They exhibited that the model presents noteworthy differences between prediction and measurements.This paper is classified into the following sections detail each component within the project, as well as how each section is constructed and interacts with other blocks to result in the production of the stand-alone PVPS.

STRUCTURE DESCRIPTION OF PVPS COMPONENTS:

The most used models of PVPS components are contained PV array, power electronic features, motor and pumps. Fig. 1 shows the block diagram of the PVPS components. Fig. 2 is illustrated the main structure of the proposed PVPS based on MPPT and PWM control scenarios, which consists of PV array, MPPT, DC/DC converter, PWM inverter, and AC load (induction motor built-in centrifugal pump).

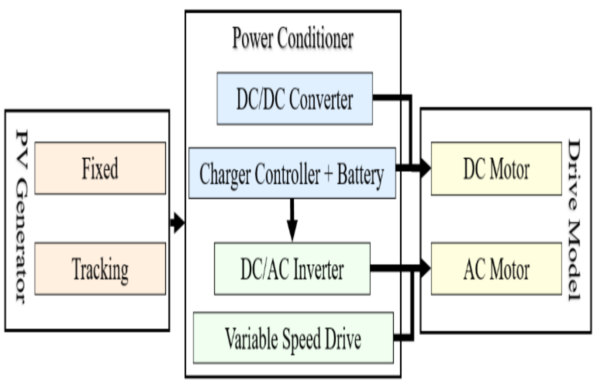


Fig. 1 Basiccomponents of PVPS model

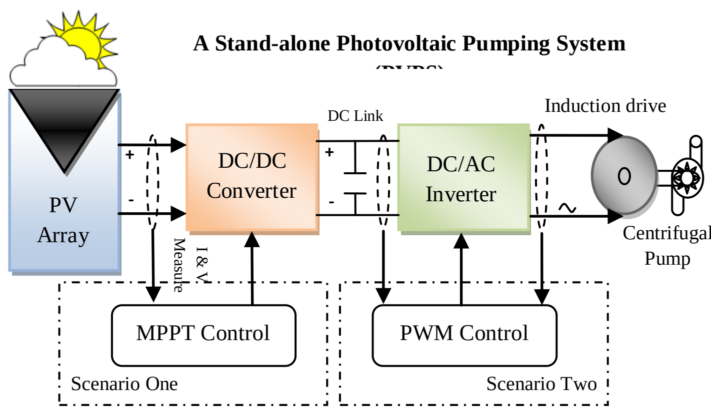


Fig. 2 Main structure of proposed PVPS

SIZING AND MODELING OF PROPOSED SYSTEM:

The motor – pump:

There are different types of pumps for PVPSs applications. By numerous of available pump on market, centrifugal structure.The suitable pump selection is required to water supply system relies on components prerequisite requirement, including water supply, power capacity, accessible storage, total dynamic head (TDH), and well diameter measurement.The PVPS sizing relies on the load. The head consists of static and dynamic component.

The system head is ordinarily considered to the system curve (head (H) versus flow rate (Q)) in the pumping system. The system head (H_{system}) is collected of static and dynamic head as depicted in Equation (1) [9].

$$H_{system} = H_{static} + H_{dynamic} \tag{1}$$

The pumping system can be either an open or closed-loop system [10].

$$H_{dynamic} = k \cdot Q^2 \quad (2)$$

where k is equivalent resistance coefficient of system and Q is total system discharge.

The relationship between the performance metrics (flow rate, head, and power) and the rotational speed (N) of the pump is expressed using affinity laws as given in Equation (3) [11].

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} = \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \quad \frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3 \quad (3)$$

There are sorts of electrical drives that may be used to operate the pump. On the off chance that DC drive is utilized, at that point the PV panels could be associated with the drive, anyway the brushes of the drive should be changed orderly. Utilizing AC drive will require the utilization of an inverter between the PV and the drive. Ordinarily, the drive and pump are worked in together for the sub and drifting pumping systems. In the surface pumping system, it is conceivable to choose the pump and drive independently and assess their performance. The pump size and the hydraulic system is calculated based on the next Equation (4) [12]:

$$P_{pump} = \frac{\rho g (H + \Delta H) Q}{\eta_p \eta_m} \quad (4)$$

where P_{pump} is power of pumping (W); ρ is water density (1000kg/m^3); g is gravity acceleration (9.81m/s^2); H is total head (m); ΔH is hydraulic losses (m); Q is water flow rate (m^3/s); η_p is efficiency of pump and η_m is motor efficiency.

The hydraulic energy required per day (kWh) is estimated based on the next Equation (5) [13]:

$$E_h = \eta_S E_{PV} = \rho g H V \eta_S \quad (5)$$

where V is water volume (m^3/day), η_s is subsystem efficiency and E_{pv} is energy of PV (kWh).

B. Photovoltaic systemsizing

The PV array power may be calculated based on irradiance as described in Equation (6) [14],

$$P_{PV} = A_{PV} G_r \eta_r \quad (6)$$

where P_{pv} is PV power (kW); A_{pv} is effective area of PV (m^2); G_r is radiation at reference temperature (1000W/m^2); and η_r is PV efficiency at reference temperature (25°C).

The daily energy output of the PV is determined from Equation (7) [12],

$$E_{PV} = A_{PV} \times G_T \times \eta_{PV} \quad (7)$$

where G_T is daily irradiance on PV surface (kWh/m^2) and η_{pv} is PV efficiency under the operating condition.

The PV area may be calculated from Equations (5, 7) as

$$A_{PV} = \frac{\rho g h V}{G_T \eta_{PV} \eta_S} \quad (8)$$

Thus, the required size of PV array may be given in Equation (9) [13],

$$P_{PV} = \frac{E_h}{G_T \times F \times E} \quad (9)$$

Where F is PV safety factor and E is daily system efficiency.

The overall PVPS efficiency may be calculated from the output hydraulic energy and input irradianceenergy as given in Equation (10) [14],

$$\eta_o = \frac{E_h}{E_{in}} = \frac{\rho g H V}{G_T A_{PV}} \tag{10}$$

Although there are many types of PV in the international market, the best type is the polycrystalline silicon. The efficiency of optimized cell of this type reaches 16.5% at STC as shown in Table 1. To optimize the PV array size, the hydraulic energy required per day must be specified. The parameters of system are represented at Table 2. The PV array size is found using the parameters calculation of system in the previous equations. Due to the effective role of system structure at the PVPS performance, the optimal configuration must be used in the system design to meet the water demand. The optimal configuration is concentrated on the basis of minimizing three objectives, namely load loss probability, life cycle cost and extra water objectives [15].

Table 1 ESP-150PPW PV panel specifications

Parameters	Value
Type of module	Polycrystalline (c-Si)
Rated current	8.26 A
Rated voltage	18.1 V
Short circuit current	9.10 A
Open circuit voltage	21.6 V
Nominal peak power	150W + 2 %
Operation temperature	− 35°C to +85°C
Maximum system voltage	1000 VDC (IEC)
Power temperature coefficient	− (0.43 ± 0.06) %/°C

Table 2 Proposed pumping system parameters

Parameters	Value
Total head, H	4.3m
Flow rate, Q	183L/min
Water density, ρ	$1000 kg/m^3$
Earth gravity, g	$9.81 m/s^2$
Water discharge, V	$52.5 m^3/day$
PV efficiency, η_{PV}	13%
System efficiency, η_S	50%
Average peak sun hour, G	$4.8 kWh/m^2/day$
Load speed dependent constant, D	$6.57 \times 10^{-4} N.m.s^2$
Distribution pipe diameter (PVC)	1"
Safety factor, F	0.9
Daily system efficiency, E	0.5

Power condition model:

The control system is essentially an electronic device incorporated between PV array and load. In this section, the architecture illustrated in Fig. 2 when DC/DC converter is connected to the PV array is called an array-integrated converter (AIC) [16]. In addition, as its control is distributed, the robustness and reliability of the system are increased. However, the complexity of the system is high, where the high processing microcontroller is required and the cost is increased. As it mentioned before, the control algorithm for PV systems is as important as converter. Also, the control algorithm change is much cheaper than electrical component change in the converter.

The optimal choice of DC/DC converter for PV system:

In PV systems, the maximum power transfer theorem states that to extract maximum external power from a PV array with finite internal impedance, the impedance of the load must equal the impedance of the PV array source as viewed from its output terminals. Furthermore, the output characteristics of PV array depend on many weather operating conditions such as: temperature and radiation change, spectral of sunlight intensities, dirt variation, and the shading effect. Therefore, a proper converter and selection of an efficient and proven MPPT algorithm are required to achieve and transfer the maximum power from the PV array to the load under any weather conditions. Recently, the converter is widely used in PV systems, as it has two functions: the first one is the adaptation of the PV array impedance with the load impedance R_L, and the second one is the raising/lowering of the PV output voltage to connect the PV array with various loads. Therefore, the choice and design of the converter has significant effects on the PV system efficiency.

MPPT:

The main goal of MPPT is match two parameters by adjust the converter duty cycle. There are various techniques to track the maximum power point (MPP) of PV system. The MPPT algorithms can be classified to two types: indirect control and direct control techniques. There are differences between these control techniques in terms of simplicity, sensor requirements, cost, efficiency range, convergence speed and hardware implementation. The steady-state error, dynamic response and tracking efficiency must be considered for a good design when verify the performance of modified MPPT control techniques. Generally, the main objectives of MPPT technique in the uniform conditions are: fast tracking, quick response with weather variations, low oscillation at steady states conditions and high efficiency over a wide power range. However, the development of new strategy is required to deal a partial shading conditions (PSC) problem.

Power Inverter:

The inverter should always operate in the MPP to maximize the efficiency. To find the MPP for all conditions a proposed tracking technique is used. Also, the right number of series connected PV modules has been selected to guarantee the operation for various environmental conditions where the PV array voltage is eligible by the operation mode of an inverter. As the PV array voltage must exceed the amplitude of load voltage always in the minimum case. If a string of the PV array is designed by this requirement the array voltage reaches high levels at low temperatures. So that is enough to the inverter renunciation of the transformer due to the previous fundamental characteristics. The full bridge seems to be a promising approach for the inverter compared with a conventional one for this high DC voltage. The harmonic components of current rely on the selection of switching frequency and filter inductors. To raise the efficiency of PV system optimization procedure, the choice of switching frequency for PWM inverter is usually a tradeoff between reducing the total harmonic distortion (THD) and reducing the switching loss.

NEW CONTROL ALGORITHM BASED ON MPPT:

Among all different MPPT techniques, the traditional P&O technique is the ease of implementation and most popular, widely used due to its simplicity and low cost. However, this technique fails tracking MPP during rapid radiation variation. The sudden change in environmental status causes the traditional P&O algorithm to swerve away from MPP. In this paper is presented the clear analysis of this aberration problem and an analysis of deviate such as when the divergence can come, the MPP movement. To fix this problem, the algorithm of P&O MPPT with variable step-size (ΔD_n) is proposed in this research and is called as adaptive perturb and observe (APO) MPPT technique. The step-size is tuned accord to the climate status variation, using the proposed algorithm which is intended for the MPPT of PVPS. This proposed strategy is based to use other parameter dI and variable step-size (ΔD_n) to enable the traditional P&O MPPT technique to realize the aberration reason coming from rapid radiation variation. The resulting control system has minimum complexity, easy tuning, and can be quickly developed and embedded in commercial solutions.

An APO MPPT technique is a suitable algorithm for proposed system under un-uniform environmental conditions. It is achieved by interposing a buck-boost converter between the PV array and Voltage Source Inverter (VSI), the MPPT strategy generates the optimum duty cycle (D) to maintain the parameters (V, I and P) at values identical to the MPP. The P&O MPPT is created dependent on the perception of dP and dV by considering the P–V qualities of the PV module. As said beforehand, traditional P&O has an endure of deviation in case of a varying in radiation because of confusion, and this confusion can be dispensed with by assessing another boundary dI (change in current). With dV, dP and dI values, the aberration can be stayed away from by recognizing the radiation variation. The current chart of PV module with the change in MPP because of a radiation variation are appeared in Fig.3. With a view to, there is a lessening in radiation while operating at point 2, at that point the operating point will settle to another point 3 in the new radiation curve.

Presently, the choice must be taken by the new algorithm at point 3, where dI< 0 as appeared in Fig.3. Simultaneously on the P-V qualities at point 3, both dP< 0 and dV< 0 as appeared in Fig.3. In this way, each of the three boundaries dP, dV, and dI are negative at point 3 as appeared in Fig.3 and 4. Along these lines, the negatives values of dP is because of whether perturb or because of lessening in radiation can be identified using the extra boundary dI. Both dP, dV and dI will be negative just for an abatement in radiation as viewed in Fig.3.So, a lessening in radiation can be recognized using the extra boundary dI, and in this manner, diminishing the duty ratio by variable step sizeanew (ΔD_n) where can wipe out the aberration issue by drawing the operating point nearer to the MPP as appeared in Fig.4. Also, similarly in the case of an increase in radiation, the APO control distinguished that dP, dV and dI are negative and subsequently increment the duty ratio by ΔD_n. The flow chart of an APO algorithm of MPPT technique is shown in Fig. 5.Whereas variable step size may be demonstrated by the next equation.

$$\Delta D_n = \pm M|\Delta G| \quad (11)$$

where, M is steady parameter and ΔG performs the radiation variation.

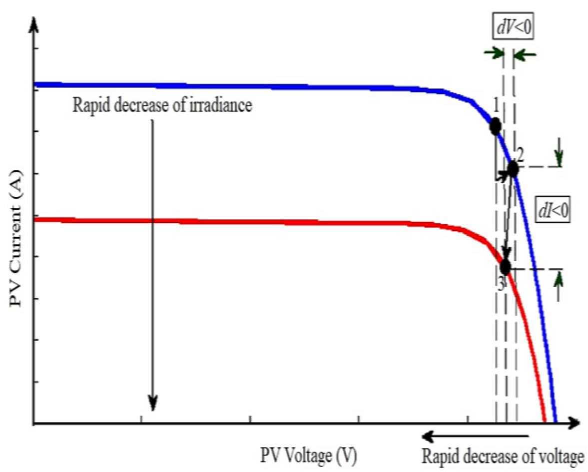


Fig. 3 Change observe in PV current

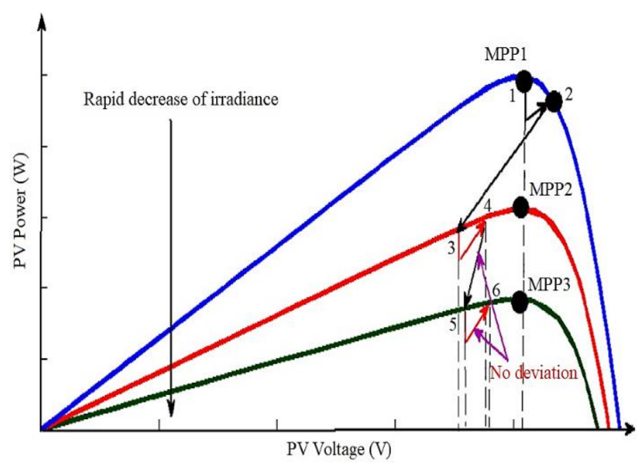


Fig. 4 Decrease in solar radiation both times

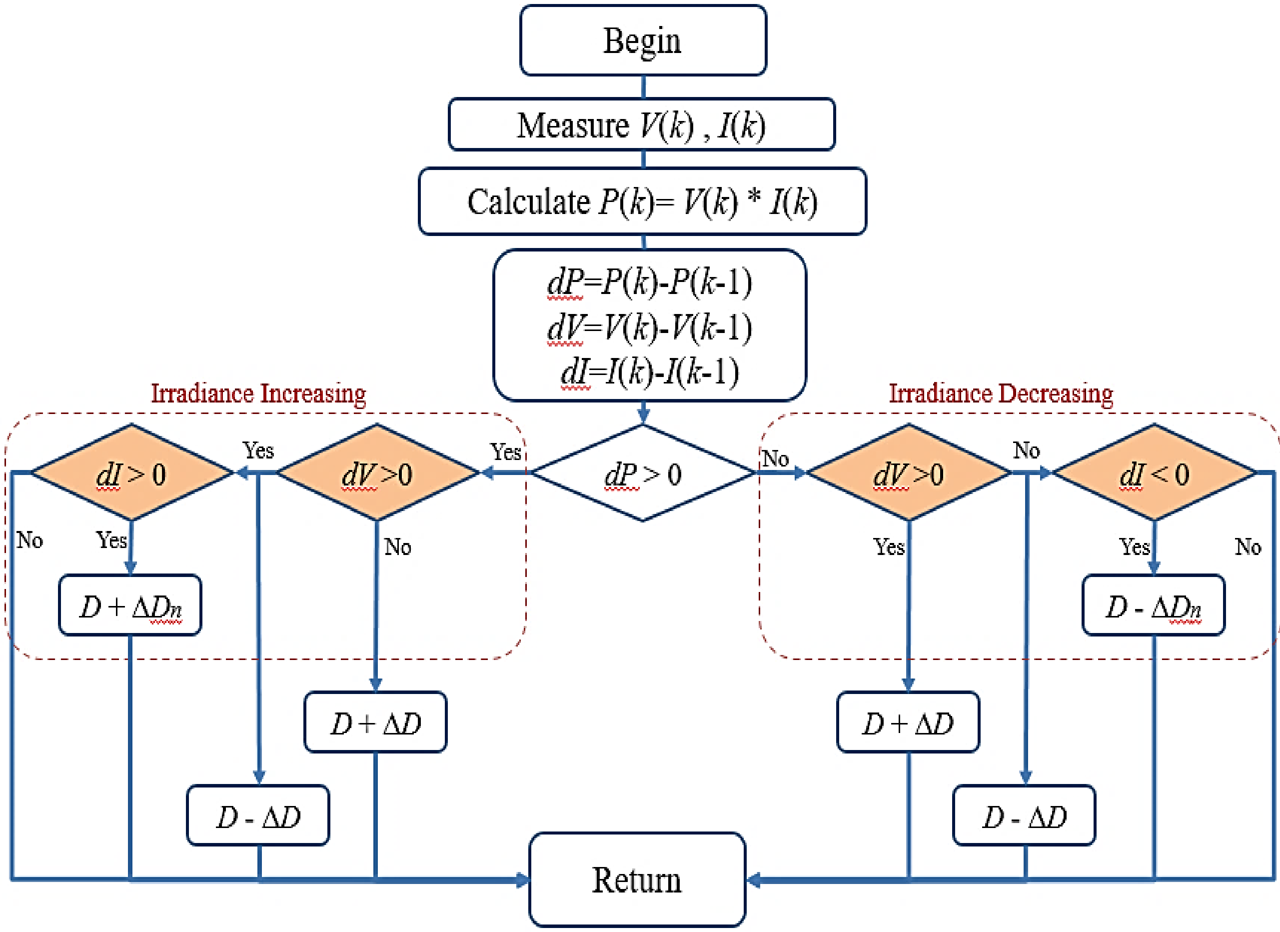


Fig. 5 APO MPPT algorithm flowchart

IMPLEMENT OVERALL PVPS SYSTEM SETUP:

Various DC/DC converters which used in the MPPT of PVPS are investigated. Thesystem control involves two major components as shown in Fig. 6.As the proposed PVPS in this work is a stand-alone system therefore, the focus was on the inverter is the suitable converter where the load comprises an AC drive coupled with pump. It was concluded that, the load pump driven by the drive is a centrifugal pump. In addition, the pump works for longer periods even for low insolation levels and its load characteristic is well matched to the maximum power locus of the PV array. Mathematical equations are derived to be implemented using several functional blocks develop the motor and the pump models. Through that a straightforward design with efficient performance is implemented for a PVPS based on MPPT to suitable with minimum climate status. The optimal schematic has implemented in a prototype as shown in Fig. 7. The model is implemented using simulation program to study the PV characteristics. The simulation made comparison amongst the proposed technique with optimum calculated results to evaluate the total efficiency of the PVPS gained by using the proposed MPPT technique to quantify the most efficient technique under rapidly changing minimum environmental conditions. Furthermore, the temperature and radiation effect on the I-V and P-V charts of PV cell to show the importance of MPPT in the PVPS.

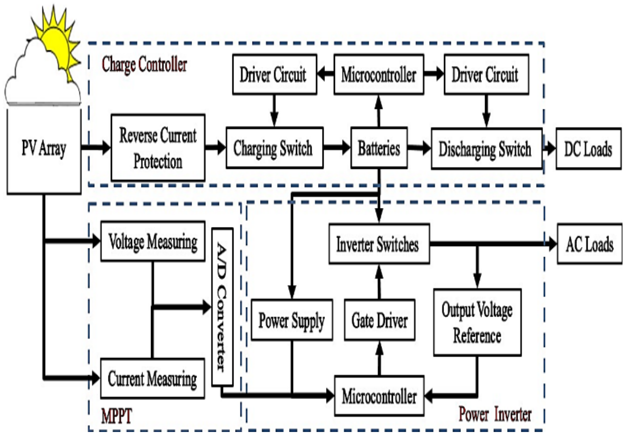


Fig. 6 Overall block diagram of the proposed system

Fig. 7 The prototype of proposed PVPS model

SIMULATION AND EXPERIMENTAL RESULTS:

PV model simulation results:

A PV model is built using simulation to illustrate and verify the nonlinear I-V and P-V chars of PV module. Furthermore, the solar radiation was kept steady and the temperature was changed apart from the standard temperature in order to determine the effect on the results. Fig. 8 shows the impact of temperature variation on the model. At constant temperature, the irradiance change has an obvious effect on the output PV current as shown in Fig. 9. The current characteristic of the prepared model represents for a fix temperature of 25^{o}C and for changing irradiance. As the current drawn by the PV model at any point along the charts with the effect of series R_S and shunt R_{Sh} resistances is illustrated in Fig. 10. These obtained results are very similar to empirical results known for PV system. Further, this confirms the effectiveness of the proposed model.

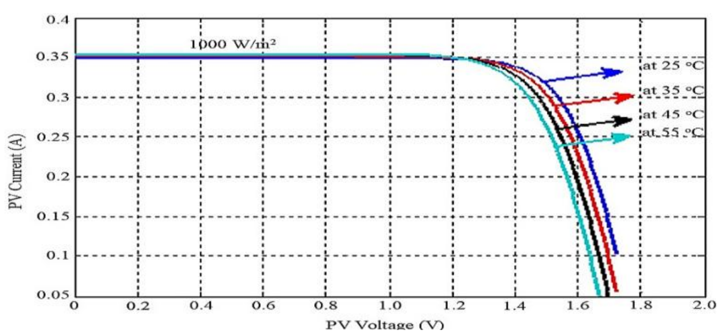


Fig. 8 Temperature effect at steady radiation

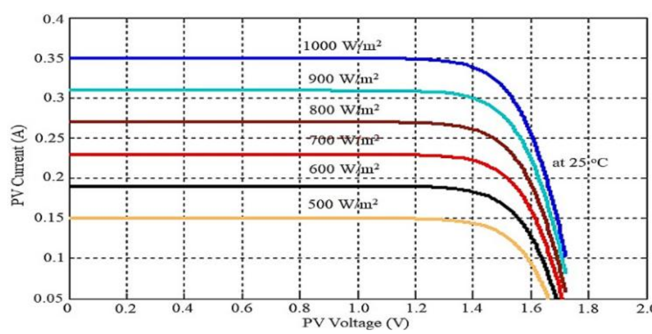
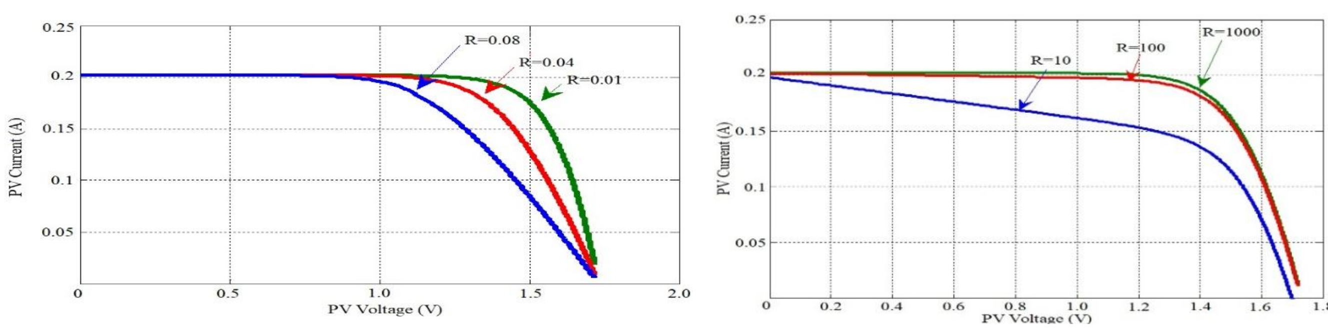


Fig. 9 Irradiance effect at steady temperature

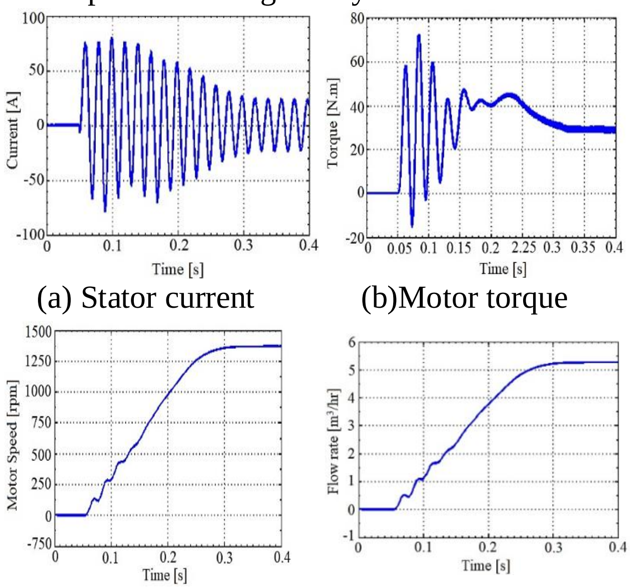


(a) (b)

Fig. 10 Effect of resistancesR_S, R_{Sh} on I-V characteristics

Motor-pump modeling results:

Most of the available analysis methods and models are based, on either the manufacturer's datasheet or a specific pump and motor for a specific site. Therefore, the current methods and models are mostly unsuitable for other locations. The proposed pump manufacture data which used in the previous section is viewed in Table 2. In the present work, the operational behavior of motor-pump model for PVPS applications was investigated, based on simulation to avoid the attested difficulties. If the system works at the area around the MPP, the dc power ripple is reduced. Where the inverter should always operate in the MPP to maximize the efficiency. Consequently, the simulation results of the pumping system are presented in Fig. 11. It is obvious that the PV array is ability to supply the pumping system continuously with the steady flow rate in spite of varying atmospheric conditions. As also the effect of cell temperature change on system flow rate over day is shown obviously in Fig. 12.



(a) Stator current (b)Motor torque

(c) Motor speed (d) Water flow rate

Fig. 11 System transient analysis results

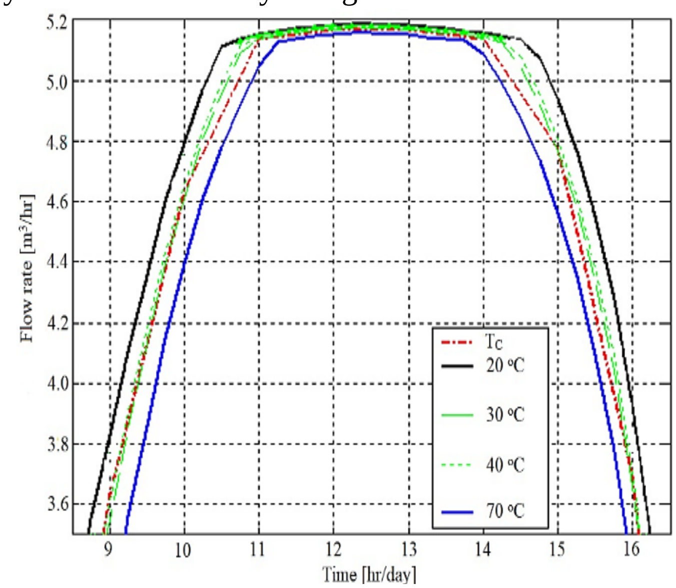


Fig. 12 Cell temperature effect on system flow rate

Finally, the importance of MPPT control illustrated by using the proposed method and compared with the obtained previous results. As it is noticed in Fig.13, the output flow in case of with MPPT is larger than without it. Where, the electrical motor is operated at larger speed which means larger flow rate of the pump. It is seen that the efficiency in MPPT system is increased about 1.2 % as demonstrated in Fig.14.

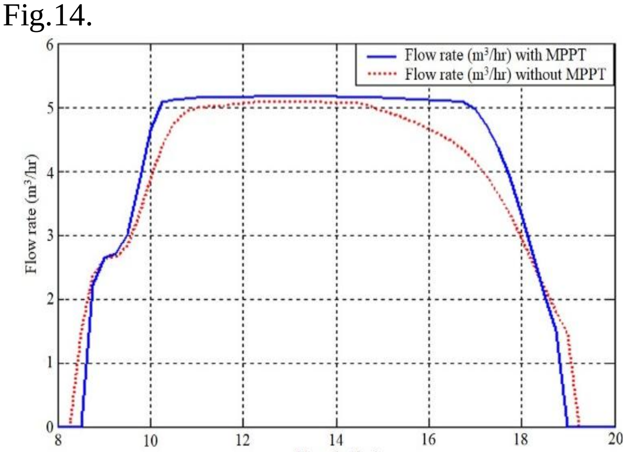


Fig. 13 Output flow rate

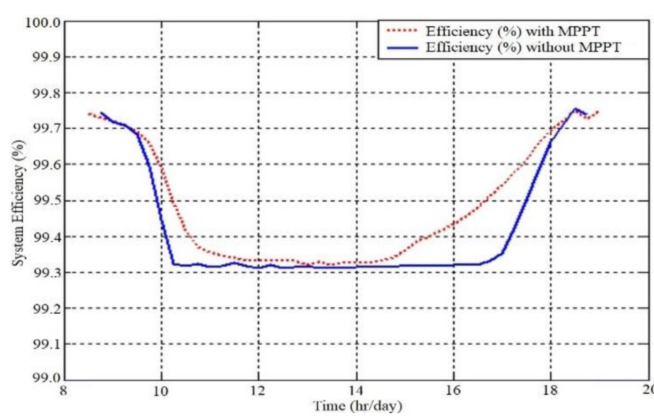
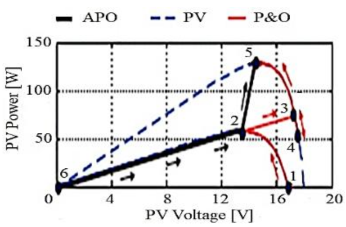


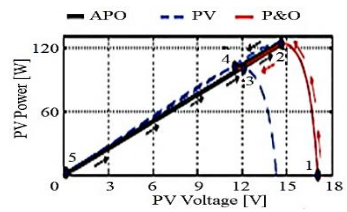
Fig. 14 Overall system efficiency

Proposed MPPT control algorithm

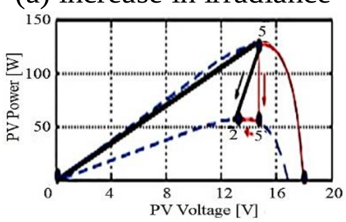
The developed MPPT technique is checked for abrupt changes in climate status. The perturbs which are deemed for the voltage and current are ΔV=1.25V and ΔI=0.06A, can be computed numerically. From the simulations, Fig. 15 is obvious that the developed MPPT technique successfully is lessened the continuous oscillations and tracked MPP quicker, independent of increment or abatement of temperatures and radiation.Fig. 16 illustrated the output power of PV array with P&O MPPT and with proposed MPPT operation, the blue line represents the output power with APO MPPT and the red line with P&O MPPT which are calculated based on the parameters in Table 3.As the system optimization rate of the efficiency of inverter for different switching frequencies and filter inductors is illustrated in Fig. 17.



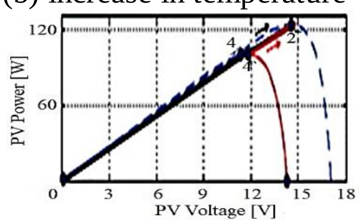
(a) increase in irradiance



(b) increase in temperature



(c) decrease in irradiance



(d) decrease in temperature

Fig. 15 Results of power curve for APO technique

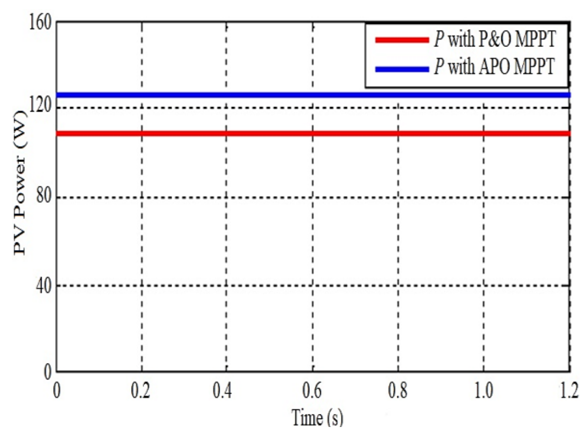


Fig. 16 The output power from the PV array

Table 3 The values of ΔV and ΔI with conventional and with proposed MPPT method

Season	Time/day	With P&O		With APO	
		ΔV	ΔI	ΔV	ΔI
Winter	08:00AM	1.246	0.0649	1.223	0.0638
	11:00PM	1.293	0.0691	1.247	0.0683
	02:00PM	1.281	0.0687	1.211	0.0677
	05:00PM	1.247	0.0644	1.229	0.0629
Summer	09:00AM	1.250	0.0653	1.225	0.0641
	12:00PM	1.222	0.0608	1.202	0.0696
	03:00PM	1.286	0.0693	1.234	0.0687
	06:00PM	1.275	0.0672	1.266	0.0603

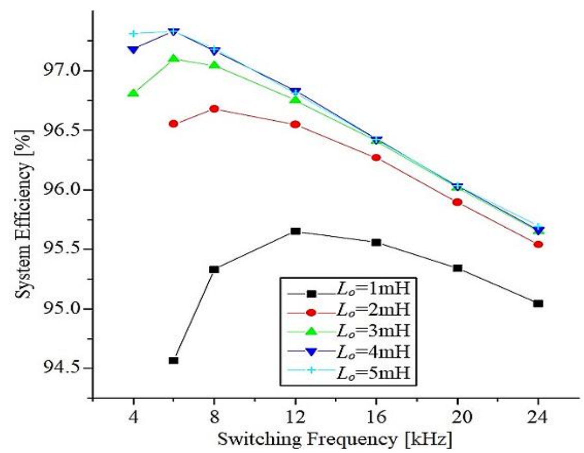


Fig. 17 Proposed system optimization rate

RESULTS DISCUSSION:

It was possible to study the effect and methods of obtaining maximum capacity for the overall performance and efficiency of the system. A dynamic model was also used to determine the effect of an expected change in values on the performance and electrical properties of the induction drives. It was also possible to make practical measurements with the study of the electrical performance of the working model, by continuous measurement of these variables over a time-related observation of change of frequency and distortion as a result of solar radiation change.

CONCLUSIONS:

This paper sums up the primary concerns introduced in that work with recommended future work on the proposed MPPT technique. Whereas it has introduced a new MPPT technique is proposed, which portends the adequate duty ratio for which the converter can hold with and along maximum power can be gotten from the PV system. A stand-alone PVPS model is also additionally evolved utilizing Matlab/Simulink program. Likewise, DC/DC converter model is simulated which is the change key of PV voltage to track the MPP. As inverter control schematic is created by using PWM technique which gives quick dynamic response and exact outcomes. This scheme keeps the DC link's voltage steady at any ideal worth and that encourages the job of DC/DC converter in tracking the MPP. The P&O MPPT algorithm is developed and tested with abrupt temperature and radiation variation and the new MPPT technique gave exceptionally quick and precise restraint. The PVPS was implemented in a practical model by the proposed APO MPPT strategy using microcontroller and tested it on the PV panels. The proposed control technique is verified and gave practically exact response than the conventional P&O and gave almost accurate typical results. Additionally, the inverter control design was tested under advance changes and demonstrated quick dynamic response and it could retain the DC-link voltage steady at any desirable value precisely. Finally, this work was presented an efficient performance for a stand-alone PVPS based on the developed MPPT technique under minimum case of various atmospheric conditions.As there by declare that this paper is based on the results that I have done personally. Contents of work found by other researchers are mentioned by references.

REFERENCES:

1. **R. Kumar and G. K. Dalal,** "Design and Simulation of Photovoltaic Water Pumping System", IJSR, ISSN:2319-7064, (2014).
2. **A. Ghoneim,** "Design optimization of photovoltaic powered water pumping systems", Energy Conversion and Management (47), 1449–1463, Elsevier Ltd., (2006).
3. **M. A. Elgendy, B. Zahawi and D. J. Atkinson,** "Assessment of perturb and observe MPPT algorithm implementation techniques for PV pumping applications"; IEEE Transactions on sustainable energy, Vol.3, No.1, 1949-3029, (2012).
4. **P. E. Campana, H. Li and J. Yan,** "Dynamic modelling of a PV pumping system with special consideration on water demand"; Applied Energy 0306-2619, Elsevier Ltd., Sweden, (2013).
5. **A. Al-Badi, H. Yousef, T. Al Mahmoudi, M. Al-Shammaki, A. Al-Abri and A. Al-Hinai,** "Sizing and modelling of photovoltaic water pumping system", International Journal of Sustainable Energy, Taylor & Francis Group, (2017).
6. **A. Kalaiselvan, U. Subramaniam, P. Shanmugam, and N. Hanigovszki,** "A comprehensive review on energy efficiency enhancement initiatives in centrifugal pumping system", Elsevier, (2016).
7. **A. Al-Badi, H. Yousef, T. Al Mahmoudi, M. Al-Shammaki, A. Al-Abri and A. Al-Hinai,** "Sizing and modelling of photovoltaic water pumping system", International Journal of Sustainable Energy, Taylor and Francis Group, (2017).
8. **W. Chang, J. Chang, H. Yin, W. Wang, H. Chung, Y. Chang, et al.,** "Energy saving algorithm for pumping systems based on fuzzy decision making", International Conference on Systems, Man and Cybernetics (SMC), IEEE; p.p. 2395–400, (2012).
9. **P. Campana, H. Li, J. Yan,** "Dynamic modelling of a PV pumping system with special consideration on water demand", Applied Energy; 112:635–45, (2013).
10. **M. Volk,** "Pump characteristics and applications", CRC Press; [Second edition], (2013).
11. **K. Meah, S. Ula, and S. Barrett,** "Solar photovoltaic water pumping – opportunities and challenges", Renewable and Sustainable Energy Reviews 12: 1162–1175, (2008).
12. **C. Fernandez, J. Francisco, and A. Bayod-Rujula,** "Power supply for pumping systems in northern Chile: Photovoltaic as alternative to grid extension and diesel engines", Energy 35: 2909–2921, (2010).
13. **T. Khatib,** "Deign of photovoltaic water pumping systems at minimum cost for Palestine: A review", Journal of Applied Sciences 10: 2773–2784, (2010).
14. **A. Al-Waeli, A. Al-Kabi, A. Al-Mamari, H. Kazem, and M. Chaichan,** "Evaluation of the economic and environmental aspects of using photovoltaic water pumping system", Springer Science, (2017).
15. **D. Muhsen, A. Ghazali, and T. Khatib,** "Multiobjective differential evolution algorithm-based sizing of a standalone photovoltaic water pumping system", Energy Conversion and Management, Elsevier Ltd., 118: 32–43, (2016).
16. **K. Raghavendra, K. Zeb, A. Muthusamy, T. Krishna, S. Kumar, D. Kim, M. Kim, H. Cho, and H. Kim,** "A comprehensive review of dc–dc converter topologies and modulation strategies with recent advances in solar photovoltaic systems", Advances in Power Electronics Technologies for Renewable Energy Systems, Vol. 9, Issue 1, MDPI, (2020).