PV Water Pumping System Using fuzzy logic controller based Induction Motor Drive with Reduced Sensors

[1]Bathalapalli Devaki (M. Tech) [2]Dr. Rushi Santosh Singh Thakur (Ph.D, Professor And HOD)
[1,2]M.V.R .College Of Engineering, Paritala, Krishna, Andhra Pradesh, INDIA
[1]devakidevibathalapallia99@Gmail.Com [2]rushib4u@Gmail.Com

ABSTRACT

A simple and efficient solar photovoltaic (PV) water pumping system utilizing an induction motor drive (IMD) is presented in this paper. This solar PV water pumping system comprises of two stages of power conversion. The first stage extracts the maximum power from a solar PV array by controlling the duty ratio of a DC-DC boost converter. The DC bus voltage is maintained by the controlling the motor speed. This regulation helps in reduction of motor losses because of reduction in motor currents at higher voltage for same power injection. To control the duty ratio, an incremental conductance (INC) based maximum power point tracking (MPPT) control technique is utilized. A scalar controlled voltage source inverter (VSI) serves the purpose of operating an IMD. The stator frequency reference of IMD is generated by the proposed control scheme. The proposed system is modeled and its performance is simulated in detail. The scalar control eliminates the requirement of speed sensor/encoder. Precisely, the need of motor current sensor is also eliminated. Moreover, the dynamics are improved by an additional speed feed forward term in the control scheme. The proposed control scheme makes the system inherently immune to the pump's constant variation. The prototype of PV powered IMD emulating the pump characteristics, is developed in the laboratory to examine the performance under different operating conditions. a Fuzzy Logic Controller (FLC) is introduced. The validity and the effectiveness of the proposed FLC is tested and confirmed by a simulation under various climate changes.

INTRODUCTION

In the modern area of development, renewable resources of energy, are being advocated by many countries to meet the increasing demand of electrical energy due to rapid depletion of non-renewable resources. Solar PV based energy generation, has come up as an important alternative for many purposes . The irrigation sector is one of the major sectors where solar PV power is extensively used for water pumping . Solar PV water pumping has been initially realized using the DC motor. However, with all due virtues associated with the induction motor in terms of mechanical simplicity, ruggedness, reliability, low cost, higher efficiency and lower maintenance than the DC motors, it has replaced DC motors. Here, a solar PV array fed induction motor drive using vector control is used . As one knows that solar PV power depends on solar insolation and temperature. The characteristic of PV module exhibits a single power peak.

The rising energy crises throughout the world and pollution of natural habitats, have been seeking attention from engineering and science fraternity since couple of decades. The knowledge for manifestation of renewable energy sources into useful form, has been maturing rapidly. The advent of fast switching power electronic devices and development in semiconductor technology, have majorly contributed to energy conversion methods. The renewable energy utilization, which started from converting the energy of running water, has travelled across to convert solar energy to electrical energy directly today. Solar photovoltaic (PV) energy converters earlier have been inefficient with the efficiency as low as 5-6 % and highly costly [1]. However, with increased technological research and advancements, the efficiency of PV array, at present, has reached 15-16%. Moreover, the prices have been reducing gradually. Today, PV energy conversion is viewed as one of the promising alternatives to fossil fuel based electricity generating systems, as there are no toxic emissions, no greenhouse gases emission, no fuel cost involvement, least maintenance cost, no water use etc. However, the technology is in developing phase and there are many challenges which need to be addressed such as, intermittency, high initial cost and low efficiency.

I. PV Module :Solar PV Module Solar panel absorbs the the photon energy from the sun and converts it into electricity using the photovoltaic (PV) effect principle. Thin-film or silicon material are used in the manufacturing of of PV modules. This will provide approximately constant power at low cost and also it is pollution free. A general PV cell produces maximum of 3 watts with nearly 1/2V dc. Number of PV cells connected in series or parallel to make a PV module.

II. SOLAR CELL CHARACTERISTICS The solar cell is mainly made of PV wafers, converts the light energy of solar irradiation into voltage and current directly for load, and conducts electricity without electrolytic effect. The electric energy is obtained from the PN interface of semiconductor directly; therefore, the solar cell is also known as PV cell .The equivalent circuit of solar cell as shown in Figure1

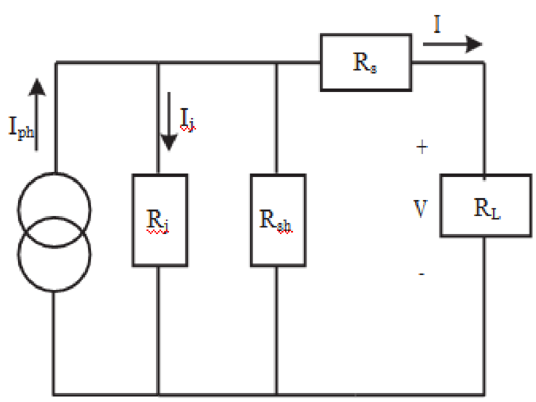


Fig.1 Equivalent circuit of PV array

The current source Iph represents the cell photovoltaic current, Rj is used to represent the nonlinear resistance of the p-n junction, Rsh and Rs are used to represent the intrinsic shunt and series resistance respectively. Normally value of Rsh is very large and Rs is very small. Hence both of them can be neglected to simplify the analysis. PV cells are grouped in larger units to form PV modules. They are further interconnected in series-parallel combination to form PV arrays. The mathematical model used to simplify the PV array is represented by the equation

$$I = n_p I_{ph} - n_p I_{rs}\left[e^{\left(\frac{q}{kTA}\cdot\frac{V}{n_s}\right)} - 1\right]$$

Where I is the PV array output current, V is the PV array output voltage, ns is the number of series cells, np is the number of parallel cells, q is the charge of an electron, k is the Boltzman constant, A is the p-n junction ideality factor, T is the cell temperature, and Irs is the cell reverse saturation current. The factor A decides the deviation of solar cell from the ideal p-n junction characteristics. Its value ranges from one to five. The photo current Iph depends on the solar irradiance and cell temperature as below

$$I_{ph} = [I_{scr} + K_i(T - T_r)]\frac{S}{100}$$

Where Iscr is the cell short circuit current at reference temperature and radiation, Ki is the short circuit current temperature coefficient and S is the solar irradiance in mW/cm2. The Simulink model of PV array is shown in Fig. 4. The model includes three subsystems. One subsystem to model PV module and two more subsystems to model Iph and Irs

III INCREMENTAL CONDUCTANCE MPPT Algorithm for PV array

The developed water pumping system powered directly from PV array, requires MPPT algorithms to operate under different irradiation levels and to extract the peak power from a solar PV array. Some of these, MPPT algorithms are recommended in [9]. A comparative study on different MPPT techniques is provided in [10]-[12]. From operational point of view, MPPT is a mandatory segment of a PV system. The substantial research is reported in past few years in the area of MPPT. In this paper, an INC (Incremental Conductance) based technique is used to obtain the peak power from the solar PV array. Therefore, the proposed PV fed water pumping system produces peak torque even at low radiation.

The INC technique is based on the comparison of output conductance of solar PV array to the incremental conductance. As compared to solar PV grid interfaced systems [13], the major challenge in PV water pumping is timely control of active power. This is due to the fact that the mechanical time constant of the motor pump system is much higher than that of aforementioned system. Under sudden fall in solar insolation, the PV array voltage tends to reduce drastically and consequently the level of flux in the motor falls rapidly. Once the flux has been fallen, the motor starts drawing higher current, which is limited by the short circuit current of the PV array in order to rebuild the flux. The operating point in the I vs V curves of PV array, shifts to current source region demonstrated by short circuit current and very low voltage. Due to insufficient power, the motor starts operating in an unstable zone of torque-speed characteristics near to a point where slip = 1. This particular condition is menacing for the motor health and once the motor enters this zone then there has to be a provision in the control, which can identify this condition and restart the motor from the standstill condition. The motor entering into such situations frequently, would reduce the overall duty of the pump, hence it's the responsibility of MPPT algorithm to take care of such events

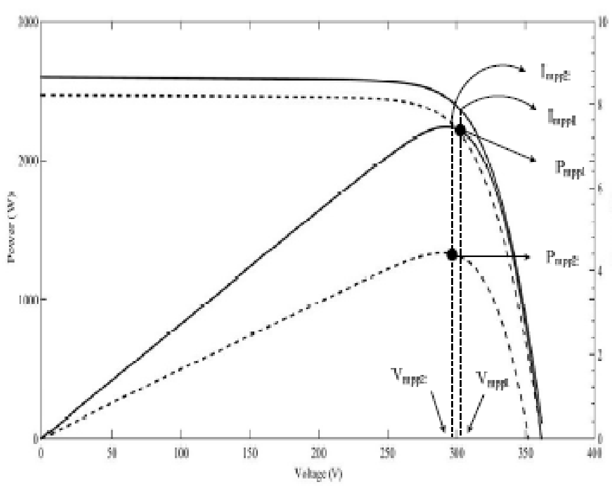


Fig. 2. P vs V and I vs V characteristics of the SPV array

Solar PV array has nonlinear bell shaped PPV versus VPV characteristics as shown in Fig. 2. At any moment, the operating point depends on the impedance of the load connected to the array terminals. A DC-DC converter is used to track the point of operation on the PV curve. There have been many algorithms in the literature for tracking of maximum power point. Most basic of all, is perturb and observe algorithm, which involves step change in the reference voltage or duty ratio to the DC-DC converter and monitoring of the power output. It faces several issues while radiation changes. An incremental conductance method works much better in dynamic changes in solar insolation. This is due to a fact mentioned in section I, that the mechanical time constant of the motor is much higher than the electrical time constant of the whole system. Proposed work uses an incremental conductance algorithm, which is based on the monitoring of slope of PPV versus VPV curve.

IV DESIGN OF PROPOSED SYSTEM The system configuration for PV water pumping system is depicted in Fig. 1. It consists of a PV array followed by a boost converter. A VSI is used to provide pulse width modulated voltage input to the motor and pump assembly. The power from a PV array is regulated using an incremental conductance method to attain its maximum value with available radiation. The V/f control is used to give reference speed to IMD. In PV pumping (PVP) systems, an induction motor drive (IMD) shows good performance as compared to other commercial motors because of its rugged construction. The evolution is intended to develop productive, reliable, maintenance-free and cheap PV water pumping system [7]. However, new permanent magnet motors such as brushless DC motor and permanent magnet sine fed motors are used into pumping, but are still overshadowed by induction motor because of cost and availability constraints [8]. Moreover, the manufacturing of the induction motor is in matured stage giving an edge to its use in developing countries for solar water pumping application. With the emergence of outperforming solid state switches, high speed processors and efficient motor control algorithms, IMD based water pumping systems have taken a step ahead to conventional water pumping systems. Moreover, PV array fed IMD has performed ruggedly in the field of pumping system by utilizing a VSI (Voltage Source Inverter). The proposed work deals with a three-phase IMD for solar water pumping, which meets the requirement of life without electricity in remote locations.

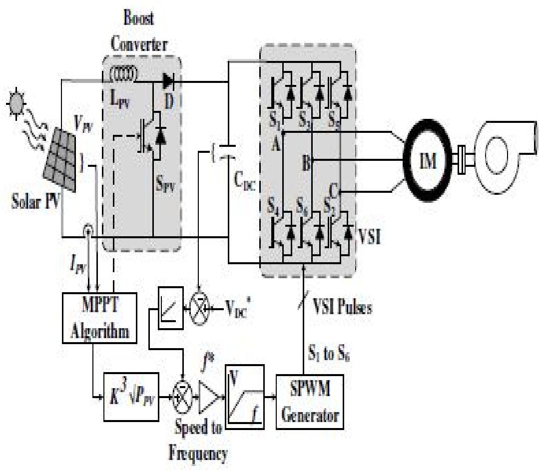


Fig. 3. System architechure for the standalone solar water pumping system

The proposed topology is a two stage power conversion system for a solar PV array fed water pumping. It embodies scalar control for IMD operation and an incremental conductance (INC) method for maximum power extraction from the PV array. The simplicity and ease of implementation of scalar control overshadows precise but computation intensive control algorithms such as vector control and direct torque control. Moreover, in later mentioned algorithms, the sensorless operation is itself an exhaustive task. The voltage and current of PV array are sensed and fed to the INC algorithm. Based on the change in voltage, current and power, this algorithm decides the duty ratio of the boost converter. The boost converter output voltage is maintained to a constant value using a proportional-integral (PI) controller. Since the pump characteristics are centrifugal in nature, the power absorbed and the speed of the pump have direct relation as mentioned in (6). A speed feed forward term is calculated from the available PV power from which, the PI controller output is subtracted. This is helpful in reducing the burden on the PI controller and improving the dynamic performance of the system. V/f control algorithm generates the switching logic for VSI using sinusoidal pulse width modulation. If DC link voltage is higher than the reference value, the PI controller increases the reference speed given to V/f control and vice versa. The sum of two quantities gives a resultant speed

V FUZZY LOGIC CONTROLLER

Fuzzy logic control mostly consists of three stages:
a) Fuzzification
b) Rule base
c) Defuzzification
During fuzzification, numerical input variables are converted into linguistic variable based on a membership functions. For these MPP techniques the inputs to fuzzy logic controller are taken as a change in power w.r.t change in current E and change in voltage error C. Once E and C are calculated and converted to the linguistic variables, the fuzzy controller output, which is the duty cycle ratio D of the power converter, can be search for rule base table. The variables assigned to D for the different combinations of E and C is based on the intelligence of the user. Here the rule base is prepared based on P&O algorithm.
In the defuzzification stage, the fuzzy logic controller output is converted from a linguistic variable to a numerical variable still using a membership function.

MPPT fuzzy controllers have been shown to perform well under varying atmospheric conditions. However, their influence depends a lot on the intelligence of the user or control engineer in choosing the right error computation and coming up with the rule base table. The comparison for error E and change in code C are given as follows:

$$E = \frac{P(K) - P(K-1)}{I(K) - I(K-1)}$$

$$C = V(K) - V(K-1)$$

The general structure of a complete fuzzy control system is given in Figure 9. The plant control ‘u’ is inferred from the two state variables, error (e) and change in error (Äe) The actual crisp input are approximates to the closer values of the respective universes of its course. Hence, the fuzzy fied inputs are described by singleton fuzzy sets. The elaboration of this controller is based on the phase plan. The control rules base are designed to assign a fuzzy set of the control input u for each combination of fuzzy sets of e and de. The Table 1 is as shown in below: Figure

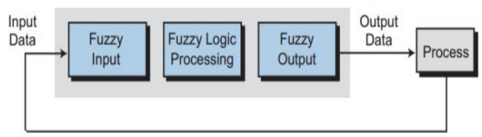


Figure 4. Basic structure of fuzzy control system

Table 1. Fuzzy Rules

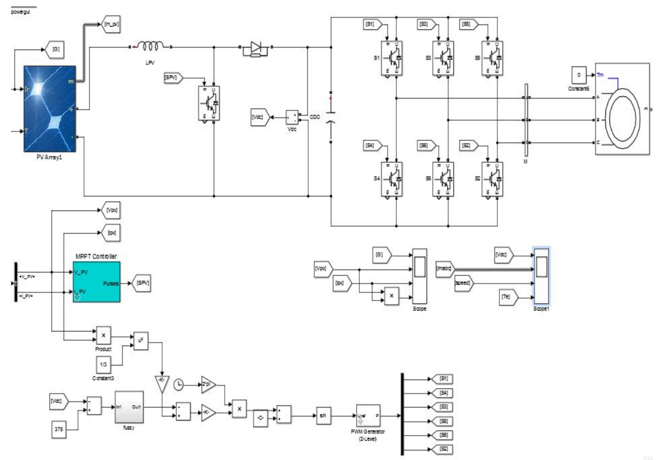
code / error	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PL	NM	Z	Z
NM	PL	PL	PM	PL	PS	Z	Z
NS	PL	PM	PS	PS	PS	Z	Z
Z	PL	PM	PS	Z	NS	NM	NL
PS	Z	Z	NM	NS	NS	NM	NL
PM	Z	Z	NS	NM	NL	NL	NL
PL	Z	Z	NM	NL	NL	NL	NL

Here, NL=Negative Large
NM=Negative Medium
NS=Negative Small
Z=Zero
PS=Positive Small
PM= Positive Medium
PL= Positive Large

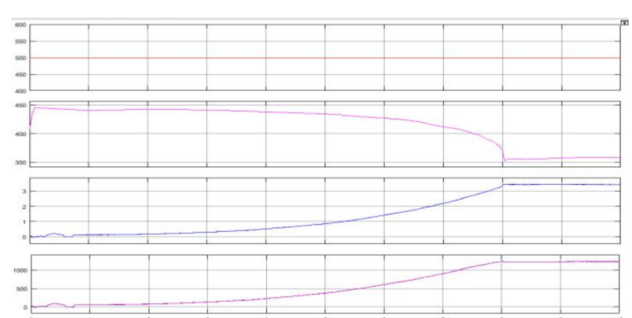
Fuzzy is more advantageous than PI controller because of its faster response. The operation of fuzzy logic is much simpler when the fault occurs at the source due to its rule during the type of fault obtained in the source voltage, need less space to establish and finally most important thing we have to concern it is very less in cost compared to PI controller.

VI SIMULATION RESULTS

SIMULINK MODELING OF PROPOSED SYETEM



A. Starting Performance of Proposed System Fig. 4 exhibits various parameters of the proposed water pumping system at 500 W/m2 radiation. The DC link of VSI is energized initially. Since the switching device of the boost converter is off, the voltage across the DC link of VSI is the open circuit voltage of PV array. It starts falling once the motor speed increases. The PV array current starts from zero and rises up to Imp. The PV voltage reaches Vmp once a threshold frequency is passed and the control of the boost converter is activated for MPPT. At t = 8 s, the boost converter is activated and the system reaches corresponding MPP. The DC link voltage is settled at reference value because of action of PI controller. It is verified from the figure that the motor current never exceeds the rated current, which is by the virtue of soft start. This practice improves the lifespan of the motor.



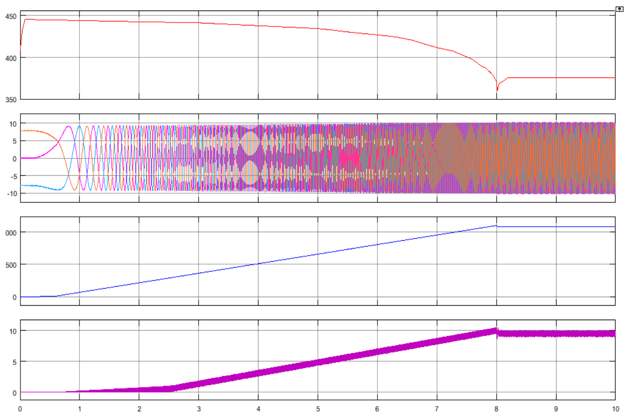


Fig. 4. Starting performance of the proposed system

B. Steady State and Dynamic Performances of Proposed System The behavior of the proposed standalone PV water pumping system is depicted in Fig. 5. This figure comprises simulation of varied solar insolation changes. From t = 1 s to 2 s, the solar insolation is constant at 800 W/m2. The PV indices are at the corresponding MPP. At t = 2 s, a slope decrement in the solar insolation is simulated to test the MPPT algorithm effectiveness. The PV voltage observes negligible change while the PV current varies proportional to the available insolation. Moreover, the DC bus voltage is also maintained at reference voltage of 400 V without any failure. The speed and torque of the motor are reduced with the reduction in PV power. This continues to happen till t = 4 s, from where the system experiences a slope increase in the solar insolation. Similar to the previous behavior, the PV current starts increasing proportional to the solar radiation, while there is not much change in the PV voltage

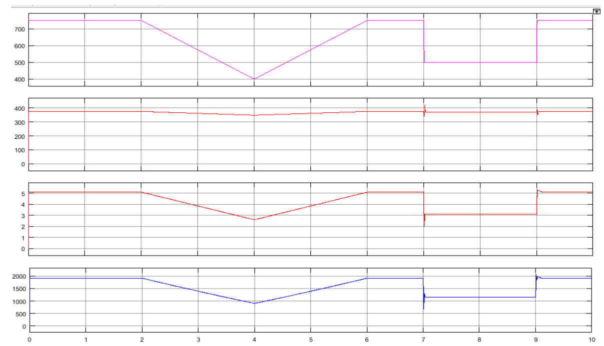


Fig. 5 Steady state and transient behaviour of proposed system

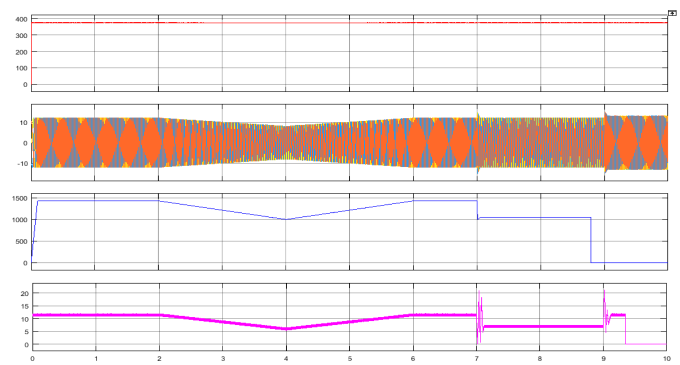


Fig. 13 Response under decrease in radiation from 1000 W/m2 to 500 W/m2

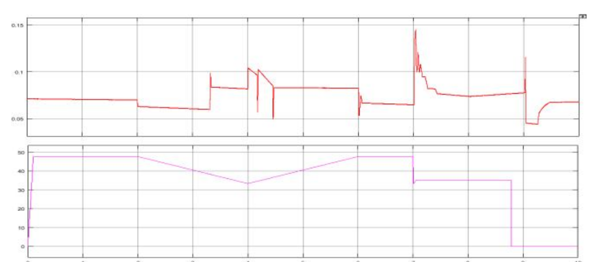


Fig. 11 Steady state characteristics of the system VSW, iL and VD

VII CONCLUSION

The standalone photovoltaic water pumping system with reduced sensor, has been proposed. It utilizes only three sensors. The reference speed generation for V/f control scheme has been proposed based on the available power the regulating the active power at DC bus. The PWM frequency and pump affinity law have been used to control the speed of an induction motor drive. Its feasibility of operation has been verified through simulation and experimental validation. Various performance conditions such as starting, variation in radiation and steady state have been experimentally verified and found to be satisfactory. The main contribution of the proposed control scheme is that it is inherently, immune to the error in estimation of pump's constant. The system tracks the MPP with acceptable tolerance even at varying radiation. Fuzzy is more advantageous than PI controller because of its faster response. The operation of fuzzy logic is much simpler when the fault occurs at the source due to its rule during the type of fault obtained in the source voltage, need less space to establish and finally most important thing we have to concern it is very less in cost compared to PI controller.

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Student Details :

Ms. Bathalapalli Devaki has graduated from B.Tech (EEE) degree from Vikas group of institutions, nunna ,Vijayawada. Presently she is studying M.Tech in power electronics and drives M.V.R. College of Engineering, Paritala Krishna dist, A.P. Her special fields of interest included Electrical Circuits, power electronics & drives.

Faculty Details:

Name: Dr. Rushi Santosh Singh Thakur

Dr. Rushi Santhosh Singh Thakur, has received his B.Tech degree from Sir C.R Reddy College of Engg, Eluru. M.TECH in J.N.T.U Hyderabad and Ph.D from SATHYABAMA university, Chennai. At present he is working as Professor and HOD , Dept of EEE in M.V.R. College of Engineering, Paritala Krishna dt, A.P. His areas of interest are Drives, Power Electronics, Electrical Circuits, and Control Systems, power systems.