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A C O MPPT BASED WATER PUMPING SYSTEM USING IMD

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Abstract - An effective and sufficiently qualified water pumping system usingIMDhas beenproposed in this paper. ACO MPPT based water pumping system contains 2 stages of power transformation. The main power conversion is extracting maximum power from Photovoltaic panel by managing the duty ratio of DC-DC boost converter. Then motor speed managed by controlling the DC voltage.Ant Colony optimization MPPT technique is used to control DC-DC boost converter duty ratio.Second power conversion is to operate Induction Motor Drive(IMD) with help of scalar controlled VSI. This scalar control eliminates the usage of motor current sensors in the system. The proposed control strategy will make the system innate and helps to get pumps constant will not change with the variation in the voltage levels.

Index Terms- ACO MPPT, IMD, scalar control, water pump.

I. INTRODUCTION

Solar Photovoltaic energy has beenconsider as the best substitute to conventional based method of generating electricity, because there are no pollution and environmental disadvantages.

The solar PV water pumps using different techniques [4]-[6] are best utilized in villages and rural areas, agriculture areas where there is no proper electricity transmission happened. This type renewableis best to the remote areas for irrigation, flooding, and drinking water treatment plant. In our country most people depend on the agriculture therefore, water irrigation is necessary. Most of the countries are using the renewable energy sources to meet the agriculture needs. The solar Photovoltaicwater pumping system is more preferable as compared with conventional energy source water pumping system with respect to cost, efficiency and environmental friendly. In the solar water pumping systems, because of rugged construction and ease of controlling techniques Induction Motor Drive (IMD) has been considered. With cost and characteristics comparison IMD is preferred than brushless DC motor and some conventional motors. In developed countries solar radiation utilization is improved a lot and characteristics of IMD is getting modified or controlled with respect to the different technologies. Therefore, the induction motor manufactureis improved a lot because of the pumping application with solar radiation. To get the desired output performance in the induction motor drive, controlled switches are utilized. To get AC voltage from DC voltage there are different types of converters are there but Voltage Source Inverter stood out because of easy switching and easy controlling. In VSI also different types of semiconductor devices are using but the IGBT are better because of minor charge carriers, so in this proposed system IGBT's are used in VSI to convert AC power from the DC. VSI gives proper 3 phase input to the IMD to run the solar pump. With proper input given to the IMD the sensors in the machine can be neglected.

The voltage coming from the solar panel is not sufficient to drive the IMD so to get the improvement in the solar DC voltage the DC to DC boost converters are used. Then solar radiation will be changed with the time because of sun. To know the maximum power point of the solar photovoltaic panel is difficult but not anymore with the MPPT (Maximum Power Point Tracking) method. This technique of algorithm will help to get maximum voltage radiation point to get maximum voltage in solar panel. Then peak power of solar array will be given to the system to run the water pump.

There are main 3 different types of MPPT techniques to get maximum power from the solar array. Those are

1) Incremental conductance method (INC),
2) Hill climbing method (HC),
3) Perturb and observe method (P&O).

And also there are soft computing MPPT algorithms which are Non-linear and inspired from the ambient network solution models those are PSO (Particle swarm optimization), Flow pollination (FP), Ant colony optimization (ACO) and Firefly algorithm (FA). In this proposed system ACO based technique has been used to get the peak motor torque even at the low solar radiation in panel. ACO algorithm is selected because ACO algorithm will give the maximum power out when compared to the incremental conductance algorithm.

The challenging control in this system is timely controlling of the duty cycle and voltage at the end of VSI. Sudden down fallor change in the radiation will effect on Photovoltaic array. Then array voltage will be decreased immediately from that motor magnetic flux will fall down and pump will be stopping because time constant of pump is greater. When the motor flux decreased it will draw the high amount of I (current) which is limited by the short circuit current which is outcome of solar panel in the process of producing the flux.Because of low voltage in the solar panel I-V characteristics shifts to current region. The motor will not operate in stable region of speed-torque characteristics near slip equal to 1because of insufficient amount of power in system. Motor entering into this condition will reduce the lifespan of the motor because there should be particular control which will find the situation and shutdown the motor and start again. To avoid this condition Maximum Power Point Track(MPPT) algorithm will take care of this type of situations.

Control of IMD which is controlled by the voltage source inverter (VSI) uses the scalar voltage to frequency (V/f) control. This method of control is very easy and simple. To run the VSI inverter triggering pulses are required these will be get from the sinusoidal PWMmethod. Not only voltage to frequency control, direct torque and vector control are difficult to implement. In this method, the current and voltage from the solar array and DC bus voltage are sensed.

ACO MPPT will sense the V & I from the solar array to control IMD for getting unaltered torque and speed of water pump even at the low or different solar radiation. With this impeccable proposed water pumping system will pump more water compared with the other motors by utilizing the scalar control of IMD. The pumps will continuously from morning to evening with help V/f control which is improved the performance of IMD. This also improves efficiency& lifespan of the motor.

II. SCHEME OF PROPOSEDSYSTEM

The mainlayout for ACO MPPT based water pumping system is shown in Figure. 1. The main parts in the scheme are solar array connected to a DC to DC boost converter and it is connected VSI (voltage source inverter) and it is used to run the motor with help of SPWM. The power output from solar panel is regulated using Ant Colony Optimization method to get maximum power with available radiation. The scalar Voltage to frequency control is used to get reference speed to IMD.

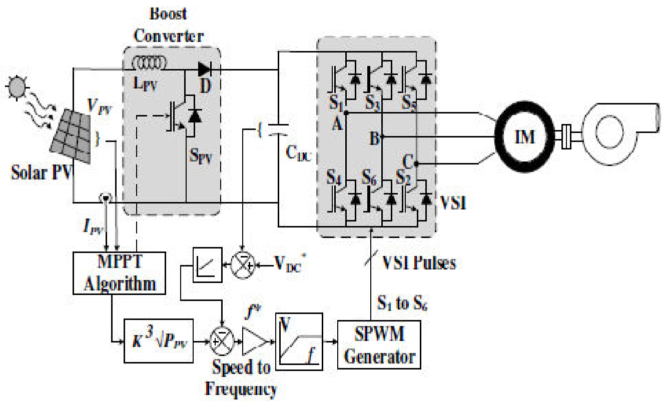

Figure 1. Architecture for the ACO MPPT based water pumping system.

2.1. Selection of SPV Array

The proposed system contains Induction Motor Drive rating of a 2.2 kW. The rating of the SPV array will be equivalent to the motor rating when motor and water pump losses neglected. In this proposed systemSPV array rating should be 2.4 kW.

$$P_{mp} = (N_p \times I_{mp}) \times (N_s \times V_{mp}) = 2.4KW \qquad (1)$$

N_p = No. of modules connected in parallel,

Ns = No. of modules connected in the series.

To get particular amount of power as output of solar panel N_p and N_s place main role, V_{mp} is a solar panel voltage at maximum power tracking point. In proposed ACO MPPT basedsolar water pumping system using IMD to get desired power output P_{mp} from solar panel i.e. 2.4KW, number of series and parallel modules should be 11 and 1. Below Table-1 shows the specifications of the individual module.

TABLE I

Technical rating of the SPV Array

Maximum power	250 W
OC voltage (V_{oc})	41.8 V
SC current (i_{sc}) of module	7.3 A
Maximum power point voltage (v_{mp}) of module	34 V
Maximum power point Current (i_{mp}) of Module	6.7 A
maximum power (P_{mp})	2.5 kW
OC voltage (V_{oc}) of array	460 V
SC current (I_{sc}) of Array	7.10 A
Maximum power point voltage(V_{mp}) of Array	373 V
Maximum power point Current (I_{mp}) of Array	6.7 A

2.2. Selectingthe voltage of DC Link

The Voltage of a DC Bus to give to VSI can be calculated as,

$$\mu \times \frac{V_{DC}}{2\sqrt{2}} = \frac{V_{L-L}}{\sqrt{3}} \qquad (2)$$

Here, μ = modulation index;

V_{L-L} =line voltage across the motor terminals and

V_{DC}=DC Link voltage.

Then take values as, V_{L-L}=230V and μ =1.

Then $V_{DC}$is,

$$V_{DC} = \frac{2\sqrt{2}}{\sqrt{3}} \times 230 = \frac{2.828}{1.732} \times 230 = 375V$$

The $V_{DC}$is takenas 400 V.

2.3. Selection of DC Link capacitor

To supply sufficient capacitance at the time of changing in voltages such as reduction in radiation of SPV and an improvement in the load DC link capacitor has to be placed. This value is calculated as [24],

$$\frac{1}{2} C_{DC}[V^{*2}{}_{DC} - V^2{}_{DC}] = 3\alpha VIt \qquad (3)$$

Here,

$\mathbf{V_{DC}^*}$isDC bus reference voltage and take it as 400V,

$\mathbf{V_{DC}}$is lower mostacceptable voltage during transients and take it as 375V,

α is an overloading factor and take it as 1.2,

V is the voltage across link and takes it as 133V,

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Iis the link current and take it as 8.2A,
T is transient duration and considers it as 0.005 sec.
Then,

$$\frac{1}{2}C_{DC}[400^2 - 375^2]$$
$$= 3 \times 1.2 \times 133 \times 8.2 \times 0.005$$
$$C_{DC} = 2026\mu F.$$

2.4. Selection of DC to DC Boost Converter

To select perfect DC to DC boost converter, duty cycle selection is important; duty cycle is donated as D.

$$D = \frac{V_{DC} - V_{mp}}{V_{DC}} \quad (4)$$

V_{DC} is acceptable transient voltage and
V_{mp} is solar panel voltage.
Series inductor L_m of DC-DC boost converter value is,

$$L_m = \frac{V^* \times (V_{DC} - V_{mp})}{\Delta I_L \times f_s \times v_{out}} \quad (5)$$

Here,
L_m= series inductor of DC-DC boost converter,
ΔI_L = Inductor Ripple Current,
F_s = Frequency Switching,
V_{out}= expected output voltage.
Then,

$$L_m = \frac{372.9 \times 0.0677}{(0.2 \times 7.6 \times 10000)} = 1.875mH$$

But assume inductance value as L =3mH.

2.5. Designing Pump Characteristics

To select characteristics of water pump main thing to concentrate is pump constant. Radiation of water quantity is proportional to pump constant**K_{pump}**and pump constant value is proportional to the load torque of water pump. Then

$$K_{pump} = \frac{T_L}{\omega_r{}^2} \quad (6)$$

Where,
T_L = Water Pump Load Torque and alsotorque driven by an IMD under steady state condition,
ω_r = Rotational speed of the rotor in rad/sec.

Since the rated torque is 14.69 N-m and IMD rated speed 1430 rpm. Generally it will be 1500 rpm but take it as 1430 rpm.Then Pump constant (K_{pump}) , by substituting T_L and ω_r values in equation (6) as,

$$K_{pump} = \frac{14.69}{\left(2 * \pi * \frac{1430}{60}\right)^2} = 6.55 \times 10^{-4} \frac{N - m}{\left(\frac{rad}{s}\right)^2}$$

So that for ACO MPPT based water pump constant value is$6.55 \times 10^{-4} \frac{N-m}{\left(\frac{rad}{s}\right)^2}$.

III. CONTROL STRATEGY OF SYSTEM

This system has 2 stage power conversions in ACO MPPT based water pumping using IMD.
1. Scalar control for IMD operation,
2.Ant colony optimization (ACO) MPPT method togain maximum power from the SPV panel.
Thisprocedure is easy to designing and implement, the scalar control is appearing as more prominent.From SPV array current and voltage are observed and given to the ACO MPPT algorithm.Ant'smoments noted to achieve V_{out} which are getting back to colony after those works complete. Moreover, the V_{out} and ant travel distance is treated as D for the DC-DC boost converter.

Output voltage of DC boost converter is maintained as constant value by using PI controller. With the equation (6) the power observed and pump speed are directly proportional to output voltage of boost converter. So that pump characteristics are centrifugal nature.

Motor speed = SPV power – PI output

It is help to improve dynamic performance of water pump & decrease burden on proportional integral (PI) controller. With sinusoidal pulse width modulation switching logics are given to VSI to generator Voltage to frequency control. If the reference value is lower than DC link voltage, reference speed given to voltage to frequency control is increased by PI controller and vice versa. Two quantities summation gives a speed reference f* for the Induction Motor Drive which is

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controlled by scalar V/f control algorithm. Then the DC link voltage difference is defined as,

$$V_{DCref} = V_{DC}^{*} - V_{DC} (7)$$

The DC link voltage PI controller output is as,

$$\omega_{DC(n)} = \omega_{DCr(n-1)} + K_P\{V_{DCr} - V_{DCr(n-1)}\} + K_i V_{DCr(n)} (8)$$

Term of speed corresponding to solar panel power is as,

$$\omega_p = K\sqrt[3]{P_{PV}} \quad (9)$$

Here, K =pump constant.

Thenfrequency reference of the IMD is as,

$$f^* = \frac{1}{2\pi}(\omega_r - \omega_{DCr}) \quad (10)$$

Initially boost converter pulses areoff, and it act as normal system.When speed is increased up to a rated speed, activated the boost converter and from ACO algorithm duty ratio is calculated. At starting high current avoided since ACO MPPT algorithm get maximum power even at starting point. With starting ramp frequency, motor current is limited initially.

3.1. AntColony Optimization MPPT

ACO MPPT technique is executed by considering V_{PV} and I_{PV} values and those are sensed by MPPT and generate the desired voltage output (V_{dc}). Flowchart of ACO MPPT has been in fig.2. Ants will travelled randomly and those pheromones are taken into consideration to get V_{out}, it return back to own place i.e. colony after getting food.

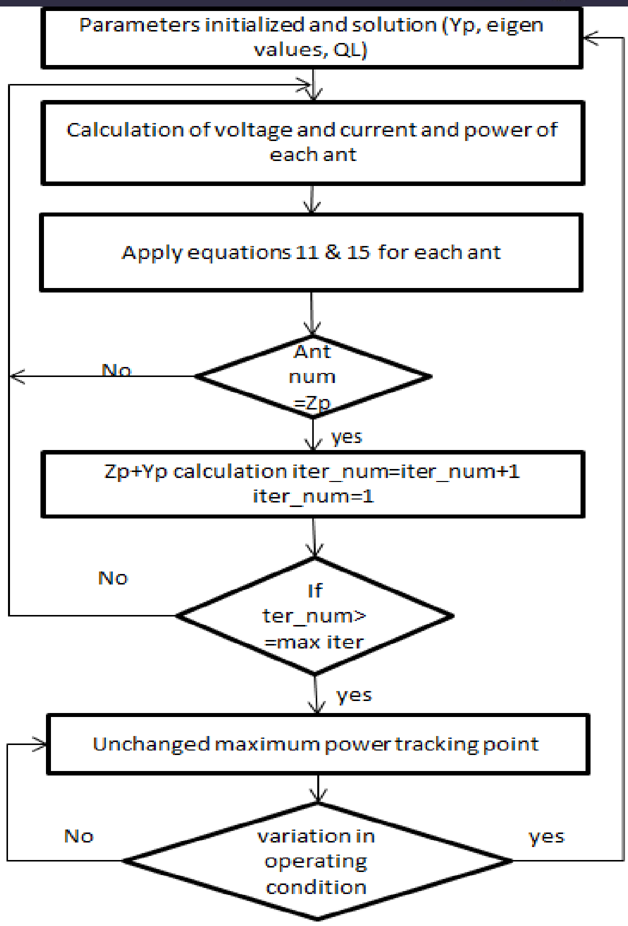

Figure 2.Flow chart of ACO MPPT algorithm

The V_{DC}& colony distance = D of DC-DC boost converter. Then takeZ_P variables are targeted to optimize those comprises $Y_P$matrix produced for randomly solutions (Y_P>=Z_P). Sampling Gaussian Kernel methodology is used for calculation. Total Z_P+$Y_P$matrix will calculate in those Y_P best are represents and total method was recapitulated for all iterations. Table 2 belowshows ACO MPPT parameters used as,

$$H_j(y) = \sum_{L=1}^{X} \omega_L h_L^j(y) = \sum_{L=1}^{X} \omega_L \frac{1}{\sigma_L^j \times \sqrt{2\pi}} \times e^{-\frac{(x-\mu_L^j)^2}{2\sigma_L^{j2}}} \quad (11)$$

For random variable mean value is

$$\mu_j = [\mu_1^j, \ldots\ldots, \mu_1^j, \ldots., \mu_1^j] \quad (12)$$

Standard deviation value of random variable is

$$\sigma_L^j = \varepsilon_{conv} \sum_{j=1}^{X} \frac{|\mu_i^j - \mu_L^j|}{Y_p - 1} \quad (13)$$

Weight of the related random variable of each ant

$$\omega_L = \frac{1}{\sqrt{2\pi} \times Q_L \times Yp} e^{-\frac{(L-1)^2}{2Q_L^2 K_L^2}} \quad (14)$$

And the probability of the Gaussian selection function is

$$P_L = \frac{\omega_L}{\sum_{R=1}^{x} \omega_R} \quad (15)$$

TABLE II

ACO parameters for proposed system

S.No	Parameters	value
1.	Best rank solution	0.8
2.	Rate of convergence	0.35
3.	Processed random solution	8
4.	Size of population	10
5.	Total iterations	25

The characteristics of voltage and power output of a ant colony optimization (ACO) Maximum Power Point Tracking.

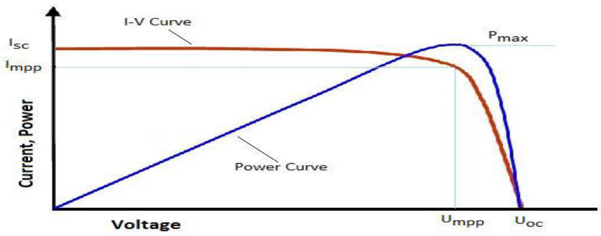

Figure.3 Power and Voltage characteristics of solar module

3.2. Induction Motor Scalar (V/f) Control

The simple and efficient control for the IMD is scalar.For the operation of induction motor input voltage frequency is 50 Hz. The induction motors at low speed, voltage has to be reduced. The change in the voltage magnitude of IMD and frequency should be constant to get the constant flux distribution in the system. Voltage Vαf*,

So that magnitude of flux is constant becauseof $\varphi_s = V/\omega$.

A 3 phase sinusoidal (SPWM) will give pulses to VSI and VSI output is given as input to the IMD. Then motor speed will be maintained as constant to run the water pump efficiently. For that one speed reference has to be taken and it should integrate to angle generator θ. And it used to generate the sinusoidal reference voltage. The small changes in the slip is has to be neglected and that should be same to the reference value of speed.Value of reference voltage is compared with the triangular wave and produces the switching pulses to trigger VSI. The VSI output is given to the IMD. The reference speed is approximated from the control scheme.

$$\theta = \int \omega^* \, dt$$

3-Φ reference voltages are,

$$V_a^* = \sin(\theta) \times \mu(12)$$
$$V_b^* = \sin(\theta - 120°) \times \mu(13)$$
$$V_c^* = \sin(\theta - 240°) \times \mu \quad (14)$$

$\mu = k_f \omega^*$,μ is modulation index which is equal to one.

IV. RESULTS &ANALYSIS

Using MATLAB/Simulink environment ACO MPPT based water pumping system using IMD has been simulated. When there is change in radiation of solar panel, the system characteristics are also calculated to know the performance of system under normal stage and dynamic stage.

4.1. Proposed System Initial Performance

The radiation of the solar panel is set as 500 W/m^2 for the system. Initialize the dc link voltage for VSI. First DC to DC boost converter is switched off. The SPV array OCvoltage is voltage at terminals of the DC link of voltage source inverter. The DC voltage is starts to decrease when speed of motor is increased. That means DC voltage is indirectly proportional to the motor speed, but solar array current is starting from zero and increase up to maximum level i.e. $I_{mp.}$ The MPPT will be activated when SPV voltage increase to $V_{mp.}$

In the fig. 4 shown below, at time t=8 sec boost converter will get activated & MPPT reaches to the calculatedpoint. Because of PI controller the voltage of DC link value will reaches to value of reference and settled down. Motor life span will be increased because I_m will never increased more

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thanI_m. Motor torque will be improved with the solar panel voltage and motor speed follows the same.

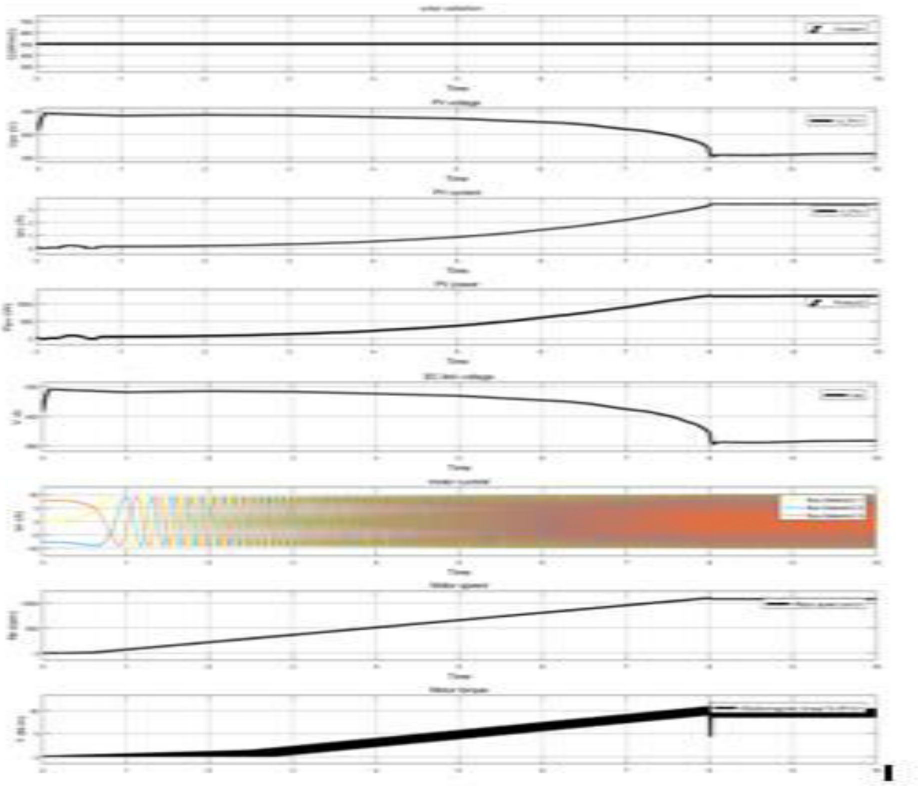

Figure 4. Initial performance of the system

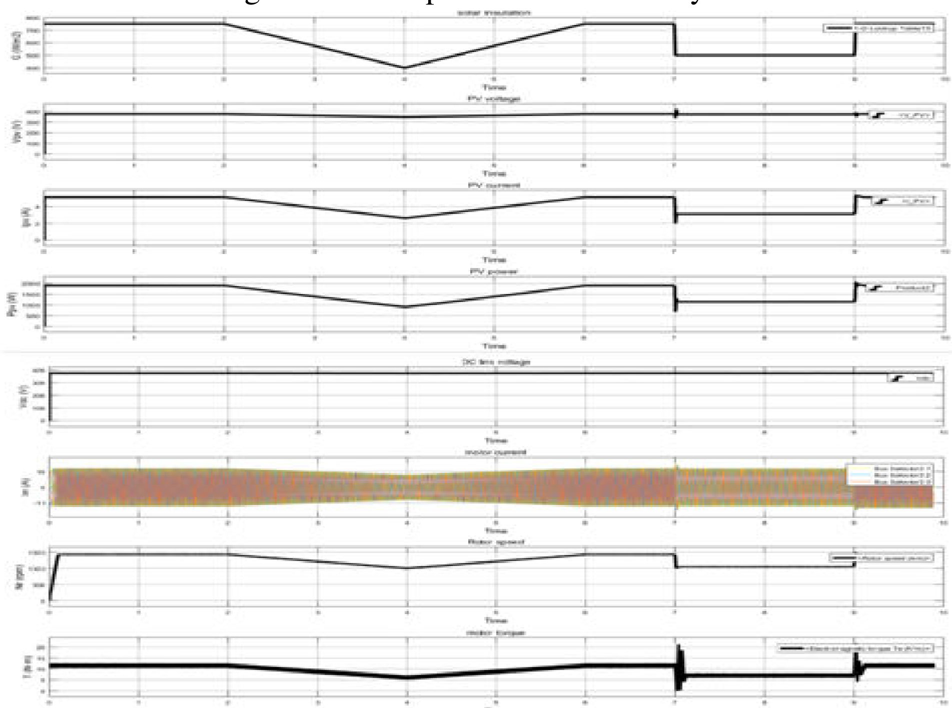

Figure 5. Steadystate &Dynamic Performances of System

4.2. Steady State and Dynamic Performances of Proposed System

The nature of the proposed ACO MPPT based water pumping system using IMD is represented in Fig.5. In this solar radiation changes from t = 1 sec to 2 sec, keep constant solar insulation as 800 W/m2. ThenSPV computesthe following MPPT. At t = 2 sec, slopewill decrease in the solar radiation is simulated to know the MPPT algorithm activation. Solar array current changes with the available insulation proportionally when solar array voltage gain is minimum and it will be neglected. Maintain the reference DC voltage at 400 V. when solar array power reduces the motor speed and torque will be reduced, this will continue up to t reaches 4 sec. then in dead clock increase the solar radiation up to 6 sec. but solar PV voltage will not be change drastically, because it reaches to reference voltage there will be only small changes.
Then current will be increase with the improvement in solar radiation till t=7 sec. power willchange linearly with current, power will increase from t=4sec to t=6 sec. When solar power changes there will be change in the 3 phase motor current, speed & torque. From t=7 sec to t=9 sec solar radiation will decrease up to 500 W/m2 means 50% of radiation is decreased but there will be not that much change in the DC voltage and PV solar voltage will experience the slight change then it will restore to reference voltage value. Then increase the solar radiation at the t=9 sec, as experienced previous behaviour solar current, power, motor current, motor speed and torque will increase.

V. CONCLUSION

ACO MPPT based water pumping system using IMD is proposed. Scalar V/f control and SPWM pulsetriggering at VSI will control the IMD current and speed with respect to the changes in the solar radiation.

ACO MPPT and PI control are able to maintain the DC to DC boost converter D value because of that input to the voltage source inverter (VSI) has been maintained constant. This is verified through the simulation results. Systems starting stage performance, steadystate &dynamic state characteristics have been studied. The ACO MPPT based water pumping system using IMD is able to maintain the constant pump constant to get efficient pump characteristics.

The system tracks the ant colony optimized MPPT within the acceptable value of tolerance even at different radiation. Incremental conductance and ant colony optimization MPPT technique exhibits same characteristics but output power of ant colony technique is more than incremental conductance MPPT.

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