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Solar PV based Permanent Magnet Synchronous Motor Drive for Water Pumping Application

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***Abstract:** In remote and hilly areas water pumping for domestic usage can induce heavy cost due to high cost of power transmission to those areas. The utilization of solar photo voltaic (SPV) energy is progressive at these areas. The conversion efficiency of SPV is increased efficiently by improving Maximum power-point tracking (MPPT) techniques which are easier, low cost and can be implemented on existing SPV systems. Moreover, using PMSM drive for water pumping will reduce the size requirement of SPV compared to Induction motors (IM) and brushed DC motors and also PMSM provides almost no maintenance. Keeping in view the present requirement, this project proposes an SPV powered PMSM water pumping drive with Perturb&Observe(P&O) and Incremental-Conductance (INC) MPPT techniques for optimizing the efficiency of SPV.*

Index Terms: **solar photo-voltaic systems, maximum power-point tracking, perturb&observe, incremental-conductance, PMSM drive**

I. INTRODUCTION

The conventional sources like oil, gas and coal undergone compression due to the ever-growing energy demand of the world. Besides the utilization of fossil fuels have an adverse effect on the environment. More than 7700 million tons of co_2 emitted by the consumption of fossil fuels every year by Global electricity supply sector which addresses 37.5% of total co_2 emissions [1-2]. Moreover, the fossil fuel availability is also limited. The increase in worldwide demand for energy consumption motivated scientists to search for environmentally friendly energy source. Sun's energy gave a promising source of clean energy. About $1.8*10^{11}$MW solar power is interloped on the earth [3]. The solar energy which is available throughout the world can be used with added advantages by converting it to electrical energy by SPV systems. SPV systems has added advantages like less weight, simple structural equipment, can be used over wide areas, noise free operation, less maintenance [4]. The SPV standalone application is quite predominant in remote areas where transmission of power is difficult or impossible. The SPV energy is used in domestic appliances, fans, water pumping, air-conditioning lighting, heating and drying etc. [5-6]. The utilization of SPV energy will contribute 7% by the year 2030 and will rise to 25% by 2050 with an annual growth rate of 35-40% SPV is the rapidly developing technologies across the earth [7]. The standalone SPV system gives a promising solution with low maintenance and low-cost solicitation for water pumping system in remote areas [8]. MPPT conversion system is used to efficiently use the SPV system. Generally the dc-dc conversion-system is a dc-dc converter of which duty cycle is controlled in a way such that SPV system operates at maximum power [9-10]. The MPPT techniques that are prominent in tracking MPP are opencircuit-voltage method, shortcircuit-current method, perturb&observe method, incremental-conductance method, neural network&fuzzy techniques. In spite of simplicity opencircuit-voltage method and shortcircuit-current needs regular load shedding, whereas artificial neural network increases complexity. Perturb&observe and incremental-conductance techniques are simple linear techniques that can be implemented by low cost and has fast convergence speed [11-13]. Choosing a befitting DC-DC converter plays a crucial role for optimum performance of the system. a non-isolated DC to DC converter gives optimum performance for low voltage conversion than isolated converter by exempting conduction losses that occur during energy transfer between primary and secondary windings. Among various DC-DC converter topologies Cuk converter gives better performance than buck, boost, buck boost, SEPIC, zeta, luo and canonical switching cell converters as Cuk converter gives ripple free input & output currents thereby external filters are eliminated. it also provides unbounded MPPT region, the contrast of different converters is shown in Table 1.[14-19]. For solar pumping systems below 5 kW DC motors are generally used. for high power systems PMSM motor gives better performance than induction motors and DC motors as they provide optimal efficiency, high torque to size ratio and dynamic response

Table 1. comparison of dc-dc converters

Converter	MPPT region	Input-current	Output-Current
?uck	?ounded	pulsating	non-pulsating
?oost	?ounded	non-pulsating	pulsating
?uck-boost	un-?ounded	pulsating	pulsating
Cuk	un-?ounded	non-pulsating	non-pulsating
SEPIC	un-?ounded	non-pulsating	pulsating
zeta	un-?ounded	pulsating	non-pulsating
Csc	un-?ounded	pulsating	pulsating
Luo	un-?ounded	pulsating	non-pulsating

along with system ruggedness reliability, maintenance free and helps in optimal sizing of SPV array and voltage source inverter (VSI) [20-23].

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II. PROPOSED-SYSTEM

The suggested system architecture is provided in Fig.1. The PMSM motor with waterpump is fed from the VSI in which the 3 built-in hall effect sensors are playout to generate gate pulses of the VSI for electronic commutation in which the windings are energized in a sequential manner guided by a decoder such that dc-current is taken from dc bus of VSI at 120^o which will be positioned in phase with the back-emf. this VSI is fed by dc supply provided by SPV array through the Cuk-converter which is handled for SPV-array control by incremental-conductance and perturb&observe MPPT techniques which coerces the SPV array operate at maximum power by adjusting duty ratio.

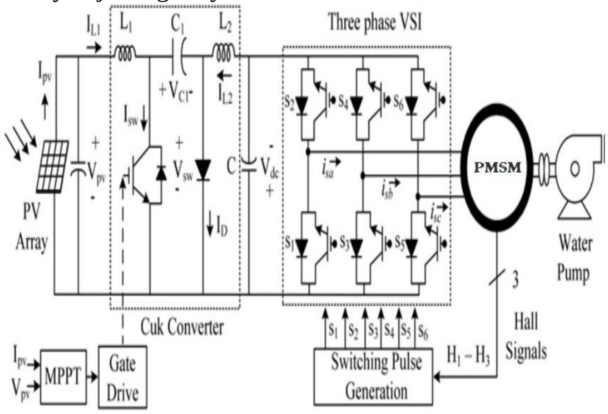

Fig. 1. Representational Diagram of Proposed PMSM Drive

2.1 Control strategy

The proposed system control is categorized into two portions: SPV array output power control by using MPPT-technique and PMSM electronic-commutation. These controls approaches are described below

2.1.1 MPP Tracking

The MPP tracking is done by the below provided algorithms whose flow charts are shown in Fig. 2. and Fig. 3**.**

P&O Algorithm: The duty ratio is perturbed with appropriate size to achieve MPP. SPV generated power is Less than previously generated power the perturbation is reversed otherwise it is maintained in same direction and the MPP is achieved when $\Delta P/\Delta V=0$.

INC Algorithm: MPP is got by comparing incremental conductance and instantaneous conductance. MPP is achieved when $\Delta I/\Delta V=0$ means the slope of IV curve is 0 at MPP. The tracking is initiated at 0 duty cycle which helps in soft starting of the motor.

2.1.2 Commutation in PMSM

The inbuilt hall sensors generate hall signals(h1-h3) with respect to rotor position at 60^o intervals as shown in Table 2. Which are decoded to get the sequence in which the phases have to be energized. the Table 3. gives switching states of VSI.at any instant one phase is Low and remaining two are at high states. This electronic commutation makes PMSM advantageous over dc motors by eliminating brushes and commutator segments and helps in smooth operation of the motor.

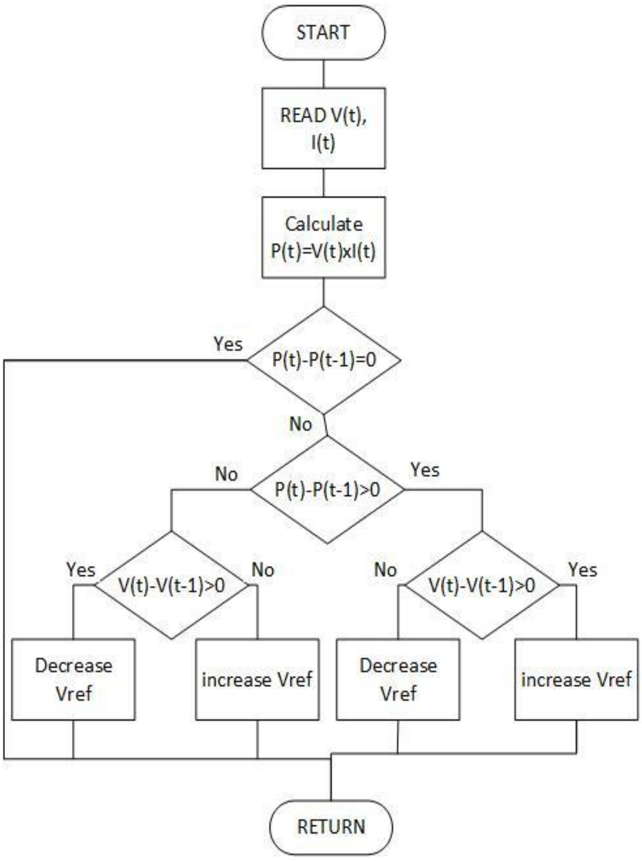

Fig. 2. P&O Algorithm

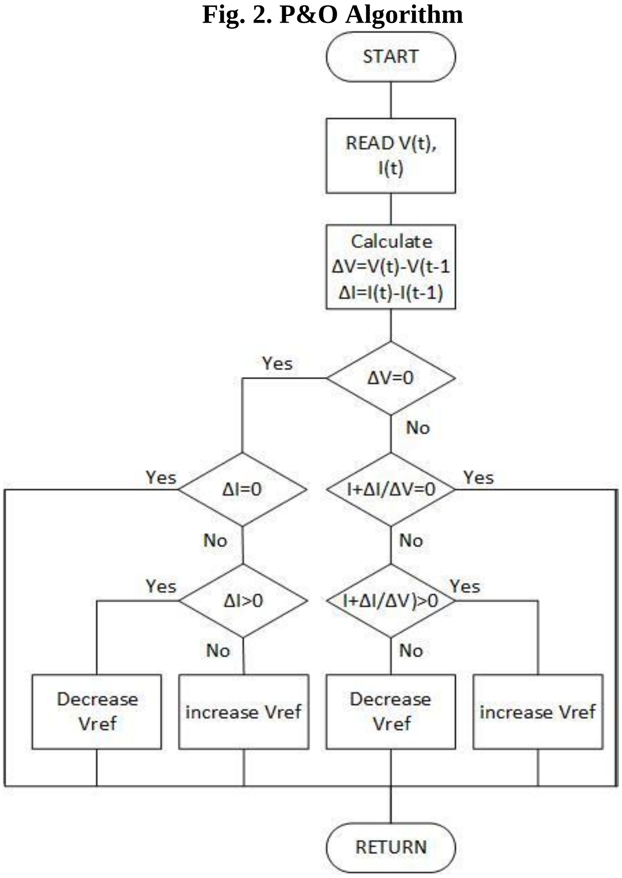

Fig. 3. INC Algorithm

Table 2. Phase Sequence

Hall signal			Phase Sequence		
h1	**h2**	**h3**	**emf a**	**emf b**	**Emf C**
0	0	1	0	-1	1
0	1	0	-1	1	0
0	1	1	-1	0	1
1	0	0	1	0	-1
1	0	1	1	-1	0
1	1	0	0	1	-1

Table 3. Switching States

Deg	Phase Sequence			Switching States					
	emf a	**emf b**	**emf c**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
0-60	0	-1	1	0	0	0	1	1	0
60-120	-1	1	0	0	1	1	0	0	0
120-180	-1	0	1	0	1	0	0	1	0
180-240	1	0	-1	1	0	0	0	0	1
240-300	1	-1	0	1	0	0	1	0	0
300-360	0	1	-1	0	0	1	0	0	1

2.2. SYSTEM DESIGN

Proper architecture and designspecifications of PMSM, SPVarray and converter plays a predominent role in the performance and working of pumping system. A 6 pole PMSM motor with 3000 rpm and 6kW power is selected. the converter, pump and SPV are designed accordingly to get an uncompromised operation under any disturbance in atmospheric condition.

2.2.1 SPV array Design

The SPV array is designed for 6.75kW to provide supply for the system. SPV module (DJ Solar DJS-T250ST) is considered for the structure of the array whose specifications at 1000w/m2 are tabulated in Table 4.

2.2.2 Cuk-Converter Design

The Cuk-converter is structured in such a way that it works continuously in any of the climatic conditions. The converter runs as either buck/boost-converter. The estimated parameters of the converter are described as follows which are calculated at 1000W/m2 irradiance [24-25]. With change in irradiance the converter duty cycle will be changed such that maximum-power is extracted from the SPV system. The Duty cycle is calculated using the expression

$$D=\frac{Vdc}{Vdc+Vmpp} \quad (1)$$

The Cuk converter parameters capacitance C1, inductance L1 and L2 are expressed as

$$C1=\frac{Impp\,(1-D)}{fsw.\Delta Vc1} \text{ where } Vc1=\frac{Vmpp}{1-D} \quad (2)$$

$$L1=\frac{DVmpp}{fsw.\Delta L1} \text{ where } \Delta IL1=8\% \text{ of } IL1 \quad (3)$$

$$L2=\frac{DVmpp}{fsw.\Delta L2} \text{ where } \Delta IL2=8\% \text{ of } IL2 \quad (4)$$

Table 4. design of SPV array

SPV module(DJ Solar DJS-T250ST)	
Ns	60
Vo	37.62
Io	8.59
Vm	30.6
Im	8.17
SPV array design	
peak power Pmpp	6750
MPP voltage, Vmpp	275
current at MPP, Impp	24.54
modules in series, Ns	9
modules in parallel, Np	3
open circuit voltage, Voc	338.6
short circuit current, Ioc	25.77

2.2.3 PMSM nominal data

The 6 kW PMSM using for the pumping system nominal specifications are tabulated in Table 5. below. It has three phases and rated speed and torque are 3000 rpm and 19 N. m respectively

2.2.4 Water Pump Design

A centrifugal-pump is attached with PMSM shaft which pumps the water which is designed to operate at its rated power and speed in a way that full volume of water is pumped at STC. Torque of centrifugal pump is $T_m=c_1\omega^2+\text{sign}(\omega).(c_2e^{-c_3|\omega|})+c_4$ (5) which is derived from affinity laws of power equation [26,27] $P_m=k_1\omega^3-k_2\omega^2+k_3\omega$ in which lower order terms are neglected then

$P_m=k_1\omega^3$

$$k_1=P_m/\omega^3=1.94e^{-4} \quad (6)$$

The rated torque is given as

$$T_r=P_m/\omega=\frac{6000}{2*pi*3000/60}=19 \text{ N-m} \quad (7)$$

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TABLE 5. PMSM NOMINAL DATA

Number of phases	3
Stator-phase-resistance	0.70
Armature-inductance	0.0008351
PM flux-linkage	0.1051
Rotor-inertia	0.000801 kg · m2
Vicious-damping	0.0011N.m.s
Back EMF waveform	Sinusoidal
Rotor type	Round
Nominal speed	3000 rpm
Nominal torque	19 N · m

III. SIMULATION RESULTS

The IV & PV characteristics are provided in Fig.4. at 600,800and 1000 irradiations and at 25ºC temperature. Simulation results of Cuk converter at 1000W/m2 irradiance that is observed in Fig.5. And the specifications of Cuk-converter are calculated from the described expressions in Cuk converter design. the obtained values at 1000W/m2 irradiance are D=0.52, C1=5µF, L1=4mH, L2=4mH. Fig.6. and Fig.7. shows the performance of PVsystem and PMSM using P&O and INC techniques on the system at STC. For analysis at dynamic conditions the system is simulated at dynamic conditions of varied irradiances of 600,800 and 1000 W/m^2 and at 25°C by using P&O and INC whose results are shown in Fig.8. and Fig.9. respectively.

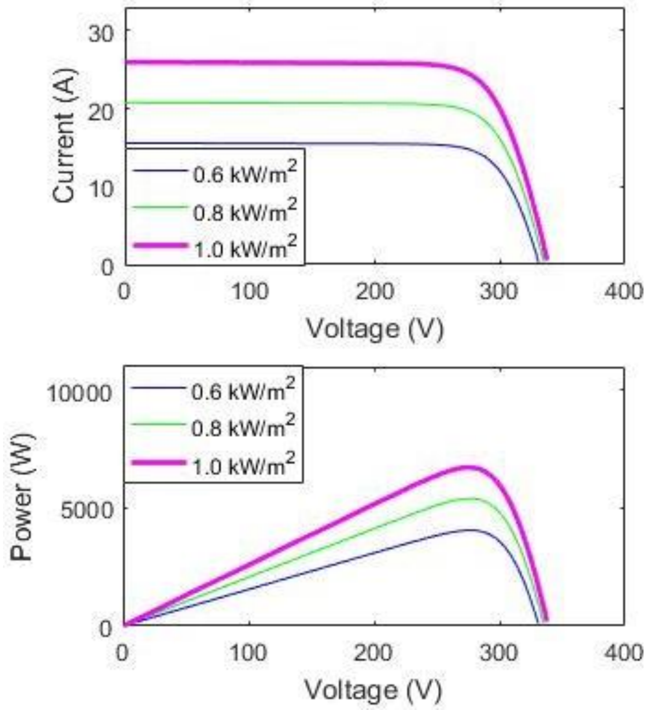

Fig. 4. IV & PV Characteristics at different irradiances

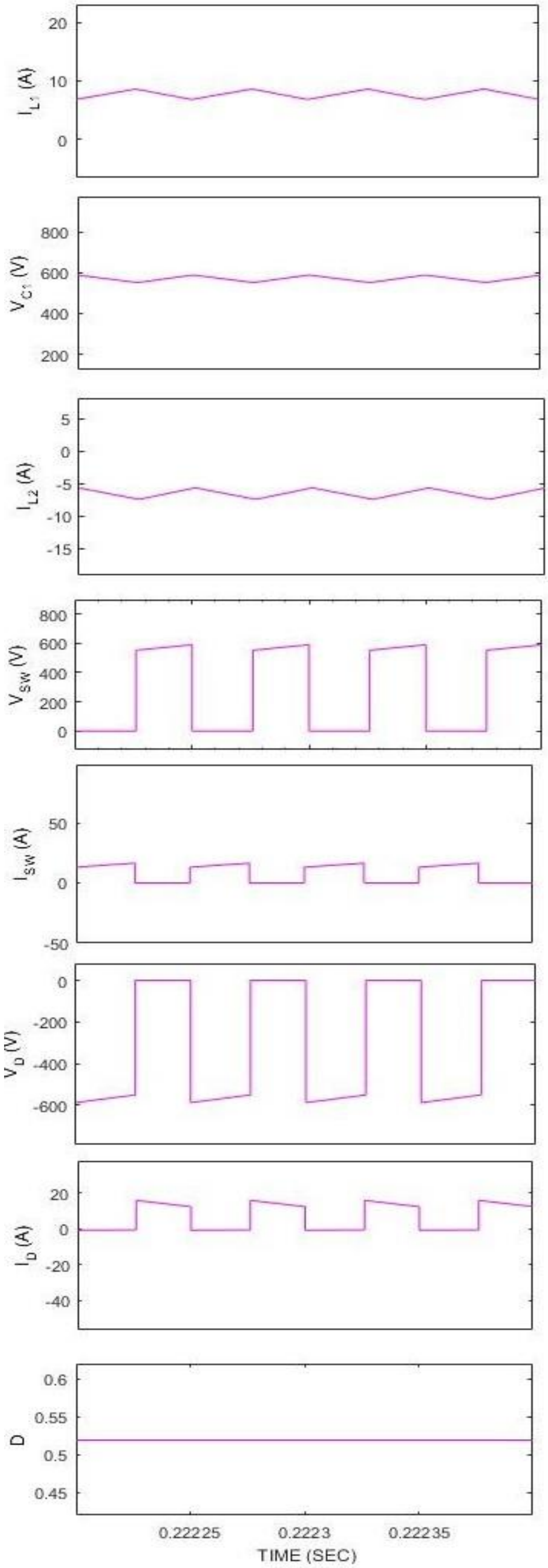

Fig. 5. Simulation results of Cuk converter

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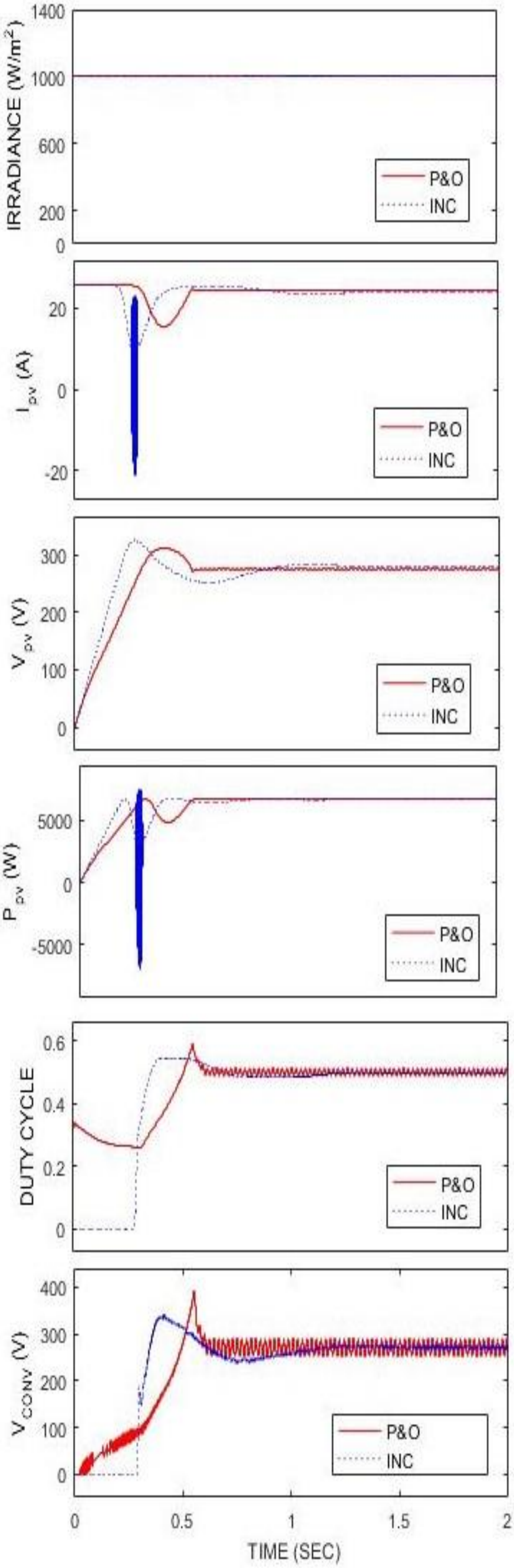

Fig. 6. Performance of SPV system and converter with P&O & INC at1000W/m2

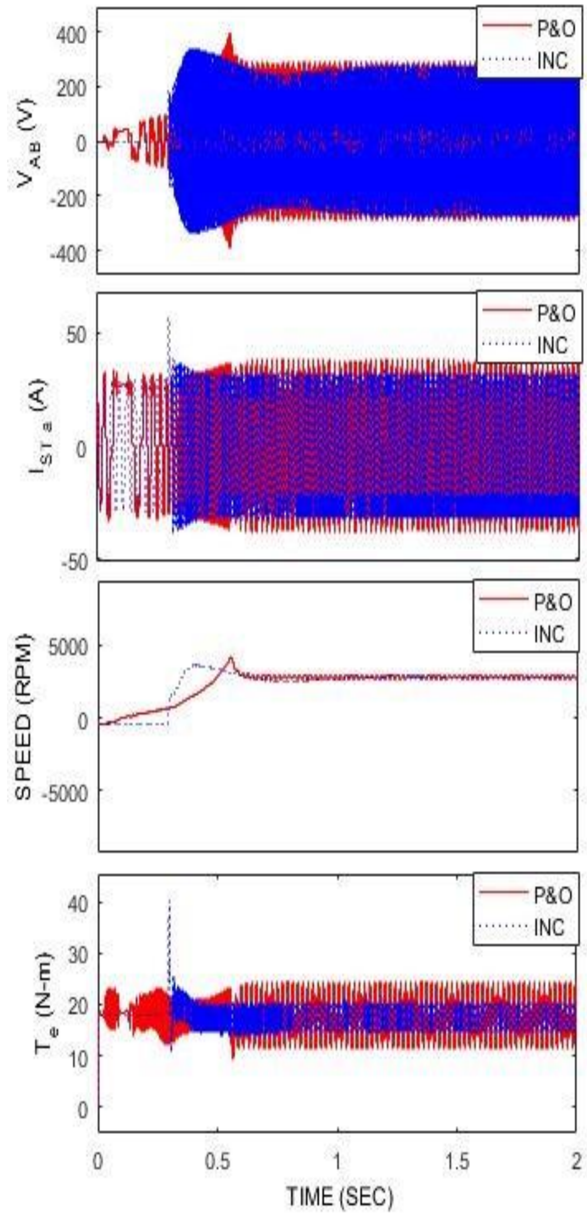

Fig.7. Performance of PMSM with P&O and INC at1000W/m2.

IV. RESULTS ANALYSIS

The performance of PV system is evaluated for P&O and INC through the simulated results observed in Fig.8. and Fig.9. The maximum-power available of PV at 600,800 and 1000 W/m^2 irradiances are 4062,5408 and 6750 watts respectively. The power extracted from SPV system using P&O and INC at the various specified irradiances are 5259 watts and 5117 watts, the electromagnetic torque developed is 18.45N*m and 18.35 N*m and the speed of the motordrive is 2067rpm and 2003rpm respectively. from the simulation-results P&O has fast convergence at MPP than INC but the power fluctuates at the MPP whereas with INC the power fluctuations are less.

The efficiency of the MPPT technique is evaluated by using the formula [28]

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$$\eta=\frac{\Sigma Extracted\ SPV\ power}{\Sigma Available\ SPV\ power} \quad (8)$$

by using INC η=94.6%

by using P&O η=97.3%

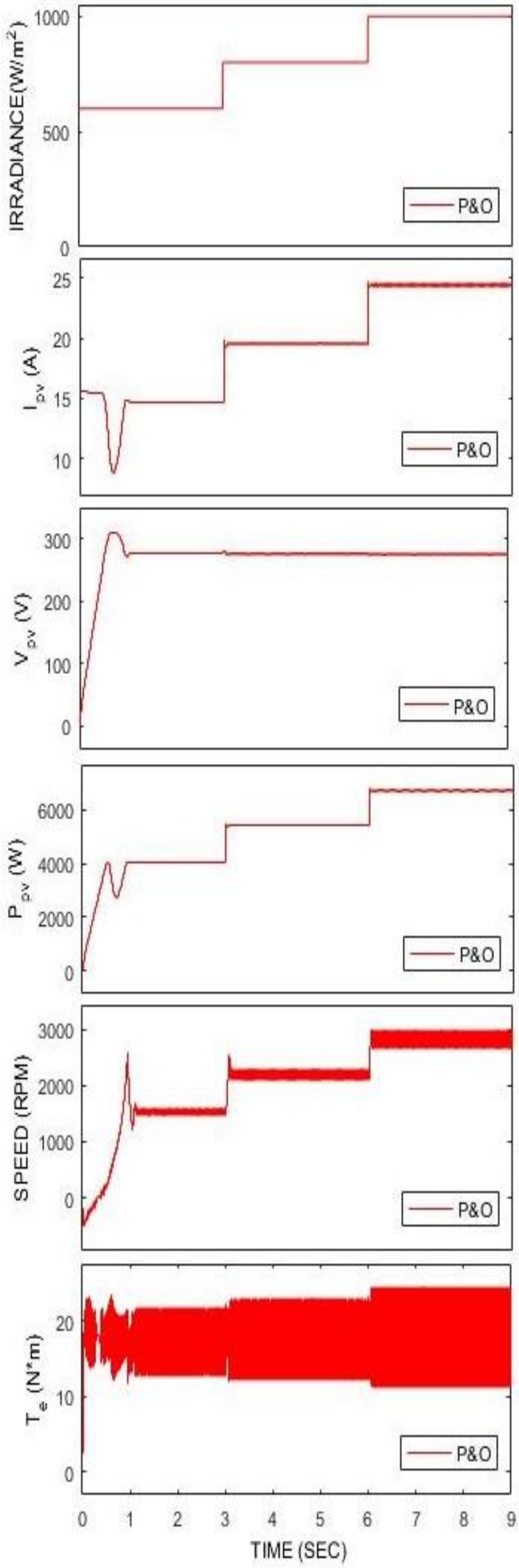

Fig. 8. Performance of system at varied irradiances using P&O

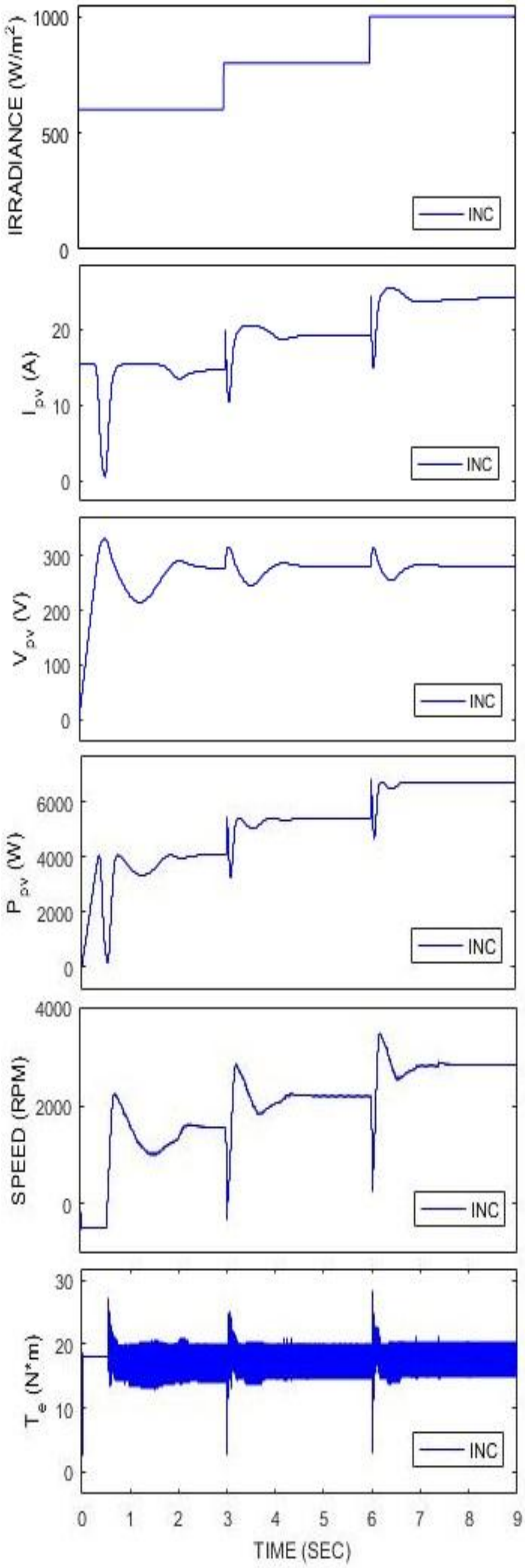

Fig. 9. Performance of system at varied irradiances using INC

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V. CONCLUSION

The proposed system is simulated under steady and dynamic states using MATLAB R2016 b toolboxes, the P&O technique provides better performance under rapid changes in irradiation but the power has small fluctuations whereas INC provides better performance under steady states as it provides constant output power at steady state and using PMSM Gives better performance for water pumping with almost no maintenance compared to induction and brushed DC pumping systems.

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