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# Single Stage Improved in C Algorithm for Tracking the MPPT of A Solar PV Panel Fed Speed Sensorless Vector Control of Induction Motor Drive for Water Pumping

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**ABSTRACT:** Solar photovoltaic (PV) systems may be utilised to produce power, and this work provides an adaptive and optimum control strategy. In order to maximise the amount of energy that can be harvested from the solar PV panel, the control method guarantees that the panel runs at its maximum power point (MPP). An MPP tracker (MPPT) and a sun tracker (ST) may greatly increase the amount of energy produced by solar PV systems. Open and closed-loop drives are examined in relation to the ST system as a whole. Solar PV panel MPP tracking is enhanced using an improved incremental conductance (InC) technique, and an algorithm is provided to ensure that the operating point continues to move towards the MPP. As a result of the simulations, it has been shown that the concept works in a variety of weather circumstances.

**KEYWORDS:** Photovoltaic cells, MPPT, water pumping, scalar Improved InC Algorithm control, induction motor drives.

## I. INTRODUCTION

Energy is a crucial part of our daily lives, and demand has risen dramatically over the globe in recent years. These problems may be solved by research activities devoted to the development of renewable energy. Renewable energy sources offer the following significant benefits over traditional fossil fuel energy sources: they are non-polluting, sustainable, and free. There are several types of renewable resources, such as solar irradiation; wind; waves; tidal currents; rainfall; and snowfall. The usage of solar energy for heating, lighting, and power generation is on the rise as a result of this. It has a lot going for it: plenty, renewability, cleanliness, and a concern for the environment. Photovoltaic (PV) technology, which utilises the PV effect to convert solar radiation directly into electricity, is an essential component of solar energy production. There are several obvious downsides, including low conversion efficiency (9 percent to 17 percent) and the influence of changing weather conditions [1]. The materials used in solar panel manufacture and collecting methods must be upgraded in order to overcome these difficulties. Indeed, it is quite difficult to achieve significant advancements in solar PV panel materials. Since solar PV panels may be improved by increasing the amount of sunlight they are exposed to, this is a feasible approach. A sun tracking system is one of the most common ways to maximize power extraction from solar PV systems. In [2]-[3], microprocessor-based sun tracking systems were developed, and in [4], programmable logic controller-based systems were presented. Systems with double axes, horizon single axes, and fixed axes were studied in [5]. The closed-loop control techniques were contrasted. It was also suggested in [6] that a solar tracking method may be designed and optimised. [1] As previously stated, the V-I characteristic of the solar cell is non-linear and fluctuates with irradiance and temperature. Maximum Power Point (MPP) refers to a point on the V-I or VP curve when the power is at its greatest (MPP). When this condition is satisfied, the output power and efficiency are assured to be at their maximum levels. There are a number of different search techniques that may be used to locate the MPP. Tracking an MPP based on the PV panel's V-I characteristics has been enhanced in this study using a better InC algorithm. The following is a rough plan for the remainder of the essay. Section II delves into the mathematics of solar photovoltaic (PV) panels in more depth. The combined use of the ST and MPP trackers (MPPT) with the upgraded InC algorithm, as described in Section III of this study, may allow solar PV panels to be managed to their optimum performance. The results of the simulation are then used to support Sections IV and V of the plan, respectively. When attempting to convey the virtues of the plan, a comparison with other solar PV panels is employed. Tracking the Maximum Power Point (MPP) of a Solar PV Panel using an Improved Incremental Conductance Algorithm costly [1] PV array efficiency has already reached 15-16

percent thanks to recent improvements in technology research and development. In addition, the costs have been steadily decreasing. The absence of toxic pollutants, greenhouse gas emissions, fuel costs, maintenance costs, water consumption, and other drawbacks make PV energy conversion an attractive alternative to traditional power generation methods based on fossil fuels. As a result, there are still numerous issues to be worked out, like as the technology's intermittent nature, the expensive initial investment required, as well as its poor overall efficiency. When electricity isn't readily accessible, people in rural regions are turning to the solar-powered water pumps [2]-[4]. Water pumps powered by solar photovoltaics (PV) are becoming more popular in rural regions for irrigation, water treatment, and agriculture. Irrigation is essential in a country like India, where the agricultural sector employs 70% of the population. Many water pumps across the globe are powered by electricity or other non-renewable sources of energy. due to limitations in terms of both price and supply [8]. It is also possible to use an induction motor for solar water pumping in developing countries since its manufacturing is improved. IMD-based water pumping systems now outperform traditional water pumping systems because to improvements in solid state switches, CPU speed, and motor control algorithms. PV array-fed IMD has shown its use in pumping systems with the implementation of a VSI pumping system (Voltage Source Inverter). Three-phase IMD solar water pumping is suggested as part of this project so that people living in rural areas with no access to electricity may satisfy their needs. Solar power plants have a significant up-front cost. As a result, once the facility is up and running, the primary objective will be to maximise the installed solar panel capacity's peak output. Under varied degrees of irradiance, the designed water pumping system uses MPPT algorithms to run and harvest the peak power from solar PV arrays. According to [9], certain MPPT algorithms are suggested. In [10]-[12], a comparison of several MPPT approaches is offered. In terms of functionality, a PV system cannot function without MPPT. Significant research in MPPT has emerged in the last several years. In this study, the peak power of the solar PV array is calculated using an INC (Incremental Conductance)-based approach, which is based on the measurement of incremental conductance. As a consequence, even at low radiation levels, the proposed PV-fed water pumping system provides the highest amount of torque possible. Water pumping from a PV system has its own set of challenges, which are explored in further detail below. The IMD's beginning performance may be increased even with lesser solar insolation by using V/f control. As a result, water is continuously pumped from dawn till dusk. The initial current of an induction motor connected to a fixed voltage alternating current main is around 5 to 6 times the maximal load current of the motor. Since the motor cannot be controlled, more solar panels are needed. In contrast, V/f regulation of the induction motor allows for a smooth start without requiring a large amount of beginning current. This also increases the motor's lifespan. In addition, gridinterfaced PVPs may be used in regions where electricity is available. It's still commonplace in India for many rural areas and interior communities to go without electricity.

## II. DESIGN OF PROPOSED SYSTEM

Fig. 1 depicts the PV water pumping system's system setup. After the PV array, the boost converter completes the system. The VSI is responsible for providing the PWM voltage input to the pump and motor assembly. It is necessary to manage the amount of power produced by a PV array in order to maximise the quantity of radiation that may be absorbed. IMD receives a reference speed from the V/f control.

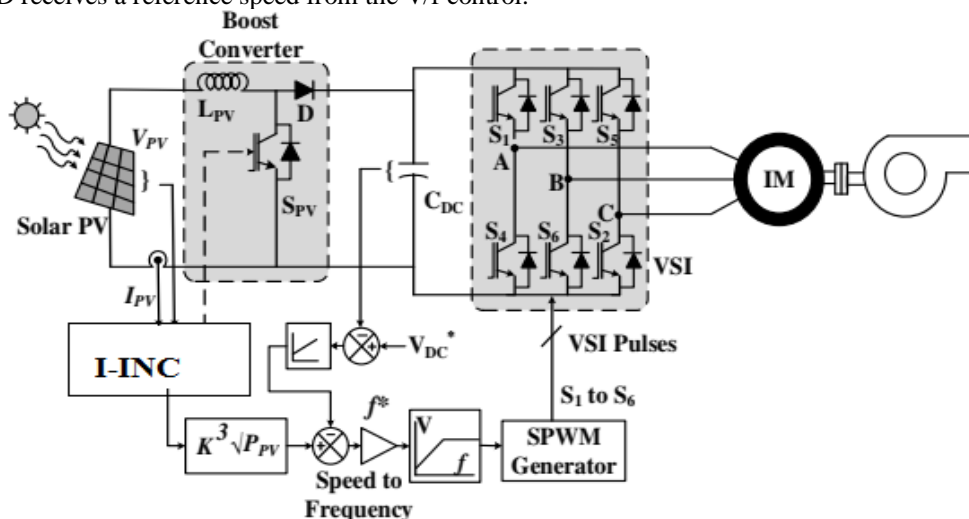


Fig.1: System architecture for the single stage solar water pumping system





**Design of Solar PV Array**

A 2.2 kW induction motor is used for the proposed system. If the losses of the motor and pump are taken into account, the PV array capacity should be equal to the motor capacity. In this scenario, a 2.4 kW PV array is used.

$$P_{mp} = (N_p \times I_{mp}) \times (N_s \times V_{mp}) = 2.4 \text{ kW} \tag{1}$$

the maximum power draw from a PV panel at a particular radiation level, the voltage of the PV panel at MPP, and Imp is the current draw from that PV panel. Series and parallel connections are counted by the number of modules that are linked in each. The power used by a 2.4 kW panel are used to determine the number of modules in series and parallel. Module and array details are shown in Table I.

TABLE I  
SPECIFICATIONS OF THE SOLAR MODULE AND ARRAY

Module peak power of the single module	225 W
Module open circuit voltage (v <sub>oc</sub> )	41.79 V
Module short circuit current (i <sub>sc</sub> )	7.13 A
Module voltage at MPP (v <sub>mp</sub> )	33.9 V
Module current at MPP (i <sub>mp</sub> )	6.63 A
Array peak power (P <sub>mp</sub> )	2.4 kW
Array open circuit voltage (V <sub>oc</sub> )	459.69
Array short circuit current (I <sub>sc</sub> )	7.13 A
Array voltage at MPP (V <sub>mp</sub> )	372.9 V
Array current at MPP (I <sub>mp</sub> )	6.63 A

**Selection of DC Link Voltage**

According to this equation, the DC bus voltage of VSI may be determined.

$$m \times \frac{V_{DC}}{2\sqrt{2}} = \frac{V_{L-L}}{\sqrt{3}} \tag{2}$$

A line voltage across the motor terminals is VL-L.

Hence,

$$V_{DC} = \frac{2\sqrt{2}}{\sqrt{3}} \times 230 = 375 \text{ V ,}$$

In this case, modulation index is 1. A 400 V DC connection voltage was selected.

**Design of DC Link Capacitor**

During transients, such as a decrease in radiation and a rise in load, the DC link capacitor is designed to deliver enough energy to maintain the system. According to the formula, is its value.

$$\frac{1}{2} C_{DC} [V_{DC}^* - V_{DC1}] = 3\alpha VIt \tag{3}$$

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

$$C_{DC} = 2026 \mu\text{F}$$

Specifically, in the preceding formula, VDC\* refers to the set DC bus voltage, while VDC1 refers to the lowest permissible value during transients. Furthermore, α is a factor of overloading, and t is the length of the transient.

**Selection of DC-DC Boost Converter**

The boost inductor duty cycle, D is given as,

$$D = \frac{V_{DC} - V_{mp}}{V_{DC}} = \frac{400 - 373}{400} = 0.0675 \tag{4}$$

$$L_m = \frac{V_{mp} D}{\Delta I_1 f_s} = \frac{372.9 \times 0.0677}{(0.2 \times 7.6 \times 10000)} = 1.875 \text{ mH} \tag{5}$$

As a result, the value of inductance L is chosen to be 3 mH. where fs is the switching frequency and ΔI1 is the amount of ripple current.

**Pump Design and Construction**

The proportionality constant (K<sub>pump</sub>) for a particular water pump is given as follows:

$$K_{pump} = \frac{T_L}{\omega_r^2} \tag{6}$$



the torque provided by an induction motor in steady state operation is referred to as  $T_L$ , and  $r$  is the rotor's rotational speed in revolutions per second (radians per second). According to the induction motor's stated torque of 14.69 N-m and rated speed of 1430 rpm, Finally, using (6), the proportionality constant ( $K_{pump}$ ) may be estimated in the following manner:

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

So proportionality constant is selected as  $6.55 * 10^{-4} \text{ Nm/(r/s)^2}$ .

### III. CONTROL SCHEME FOR PROPOSED SYSTEM

This concept suggests a two-stage power conversion system to provide electricity to a solar-powered water pump. It employs an INC technique for PV array operation, as well as scalar control for IMD operation, in order to extract as much power as feasible from the array. Scalar control is a basic and straightforward control approach that is simple and straightforward to apply. Vector control and direct torque control are accurate but computationally expensive control techniques, but scalar control is simple and straightforward. Furthermore, the sensorless operation in the algorithms outlined later is a time-consuming activity in and of itself. The INC algorithm processes the PV array's voltage and current. The duty ratio of the boost converter is determined by this method, which takes into account variations in voltage, current, and power. This is accomplished by using a proportional integral controller to manage the boost converter's output voltage, which maintains the output voltage at a constant value. A direct correlation exists between the absorbed energy and the pump's velocity due to centrifugal pump characteristics, as described in (6). The PI controller output is deducted from the available PV power to create a speed feed forward term. Improved dynamic performance and less stress on the PI controller may be achieved by this method. The V/f control algorithm is fed the resulting speed reference  $f^*$  for IMD as a consequence of the addition of two values. The expected DC link voltage error is:

$$V_{DCr} = V_{DC}^* - V_{DC} \tag{7}$$

The following is the output of the DC link voltage PI controller:

$$\omega_{DCr(n)} = \omega_{DCr(n-1)} + k_p \{ V_{DCr(n)} - V_{DCr(n-1)} \} + k_i V_{DCr(n)} \tag{8}$$

The speed term that corresponds to PV power is expressed as follows:

$$\omega_p = K \sqrt[3]{P_{PV}} \tag{9}$$

The boost converter pulses are initially deactivated in order to maintain the system's operation as a single stage system. Once the threshold speed has been achieved, the INC method is used to calculate the duty ratio of the boost converter, which is then applied. This is due to the fact that the MPPT algorithm makes it possible to get maximum power even when you are just getting started. Direct online starting (DOL) at the specified frequency results in a starting current for the motor that is 5-6 times the rated current; however, ramp frequency beginning may lower this starting current by as much as 50%. (RFS). In addition, since the current taken by the DOL is so high at startup, the solar PV array prevented from entering the current source area.

#### A. Improved Incremental Conductance Method for MPPT

Figure 2 shows the solar PV array's PPV against VPV characteristics in a nonlinear bell shape. A DC-DC converter keeps note of where the PV curve intersects with the point of operation. A number of strategies may be used to keep track of the highest concentration of power. The simplest approach is the perturb and observe one, which includes changing the DC-DC converter's reference voltage or duty ratio and then monitoring the output power output as a result of the change. Radiation fluctuations pose a number of challenges. A approach based on incremental conductance is substantially more successful when there are dynamic fluctuations in solar insolation. This is the situation because the motor's mechanical time constant is far larger than the system's electrical time constant. Using the slope of the PPV vs VPV curve, an incremental conductance approach will be used to compute the conductance.

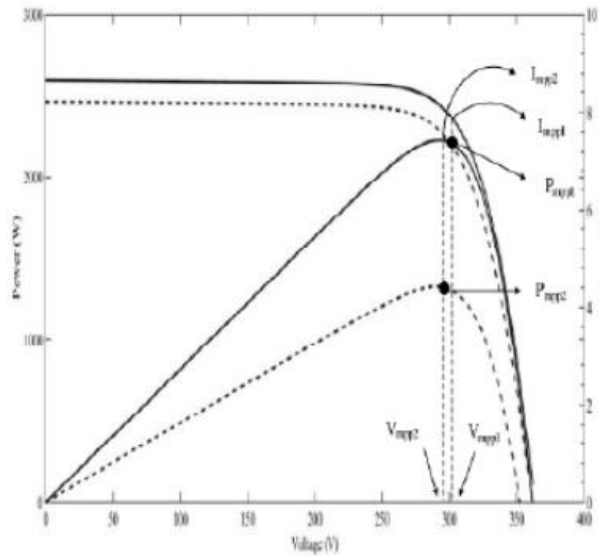


Fig.2: P vs V and I vs V characteristics of the SPV array

Right-hand slopes are negative and left-hand ones are positive in this MPP graph. The slope of the curve is zero at the point on the graph when the array is transmitting the greatest amount of electricity. IPV and VPV are also affected by variations in radiation at MPP, although only IPV varies significantly. This equation may be used to determine the connection between a linear increase in conductance and a linear increment in conductance throughout different sections of the curve.

$$P_{PV} = V_{PV} \times I_{PV} \tag{11}$$

$$\frac{dP_{PV}}{dV_{PV}} = I_{PV} + V_{PV} * \frac{dI_{PV}}{dV_{PV}} = 0 \tag{12}$$

$$\frac{dI_{PV}}{dV_{PV}} = - \frac{I_{PV}}{V_{PV}} \tag{13}$$

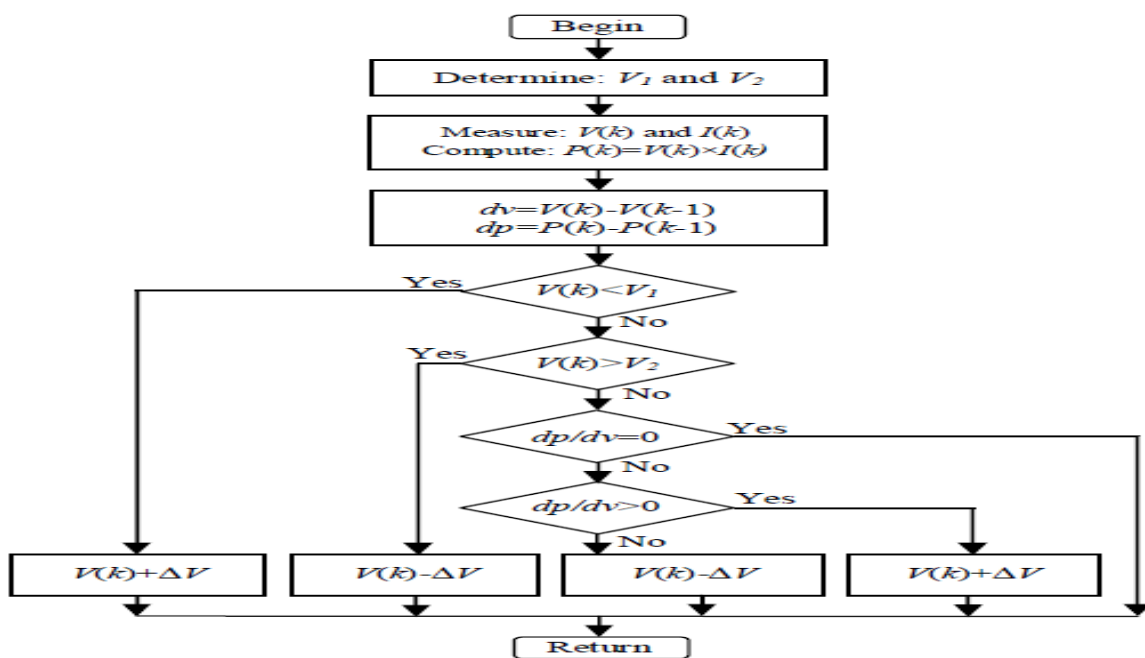


Figure 3: Flowchart for improved incremental conductance algorithm for MPPT



**B. Scalar (V/f) Control of Induction Motor**

Scalar control is the most common and simplest way of controlling an induction motor. Induction motors are normally designed to run at a frequency of 50 hertz. Low-speed operation requires lower voltage. Constant flux operation requires both frequency and voltage magnitude control. Because the voltage should be proportional to the frequency, it should be possible to keep the flux magnitude constant, as in  $\psi_s = V/\omega$ . A three-phase PWM VSI is the most common source of power for an IM. The reference speed can be found only in the input. Even when the minor slip speed is taken into account, the motor runs at a rate that is very close to that of the reference speed.

$$\theta = \int \omega^* dt \tag{14}$$

Three phase reference voltages are as,

$$V_u^* = m \times \sin(\theta) \tag{15}$$

$$V_v^* = m \times \sin(\theta - 120^\circ) \tag{16}$$

$$V_w^* = m \times \sin(\theta - 240^\circ) \tag{17}$$

where,  $m = k_f \omega^*$ ,  $m$  is the modulation index.

**IV. RESULTS OF SIMULATION**

Simulating a single-stage PV-fed water pumping system was used by the researchers to assess its performance. MATLAB/Simulink is used to build, simulate, and test the proposed system. Step changes in solar radiation imitate the system's performance under dynamic conditions.

**A. Starting Performance of Proposed System**

The open-circuit voltage between the DC connection of VSI and the PV array is the same. The battery voltage begins to drop as soon as the motor speed rises. Continuously increasing, the PV array's current  $I_{pv}$ . The boost converter control is initiated when the PV voltage exceeds the maximum power point tracking ( $V_{mp}$ ) (MPPT). The system reaches its maximum power point about 8 seconds after the boost converter is activated (MPP). As a consequence of the PI controller's actions, the needed DC link voltage has been stabilised.

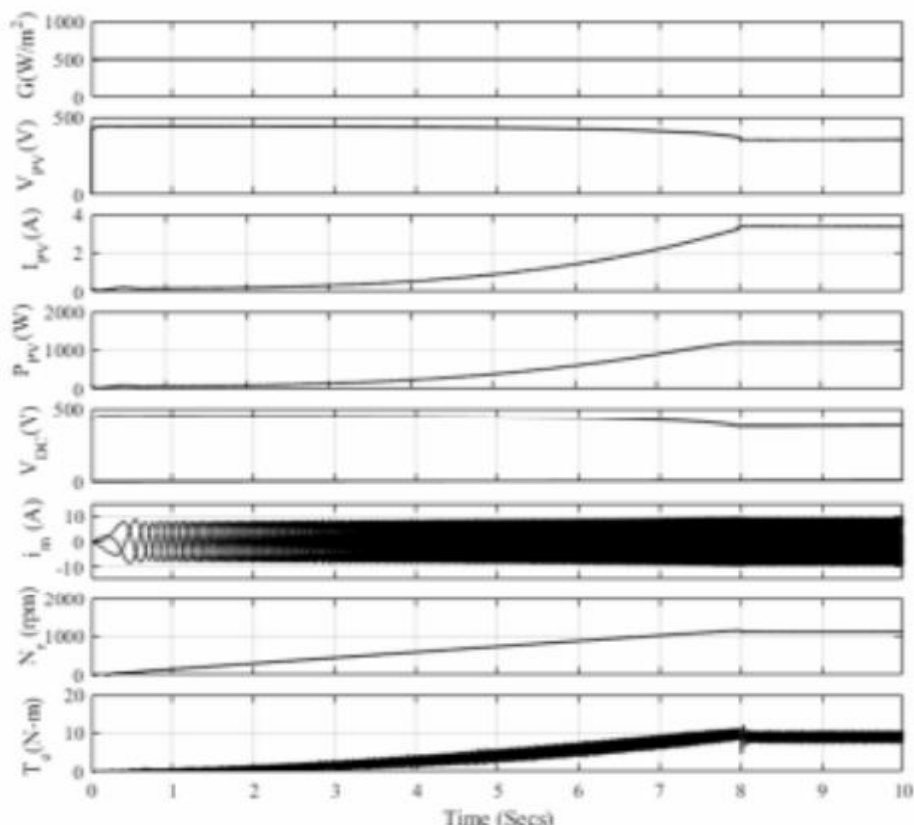
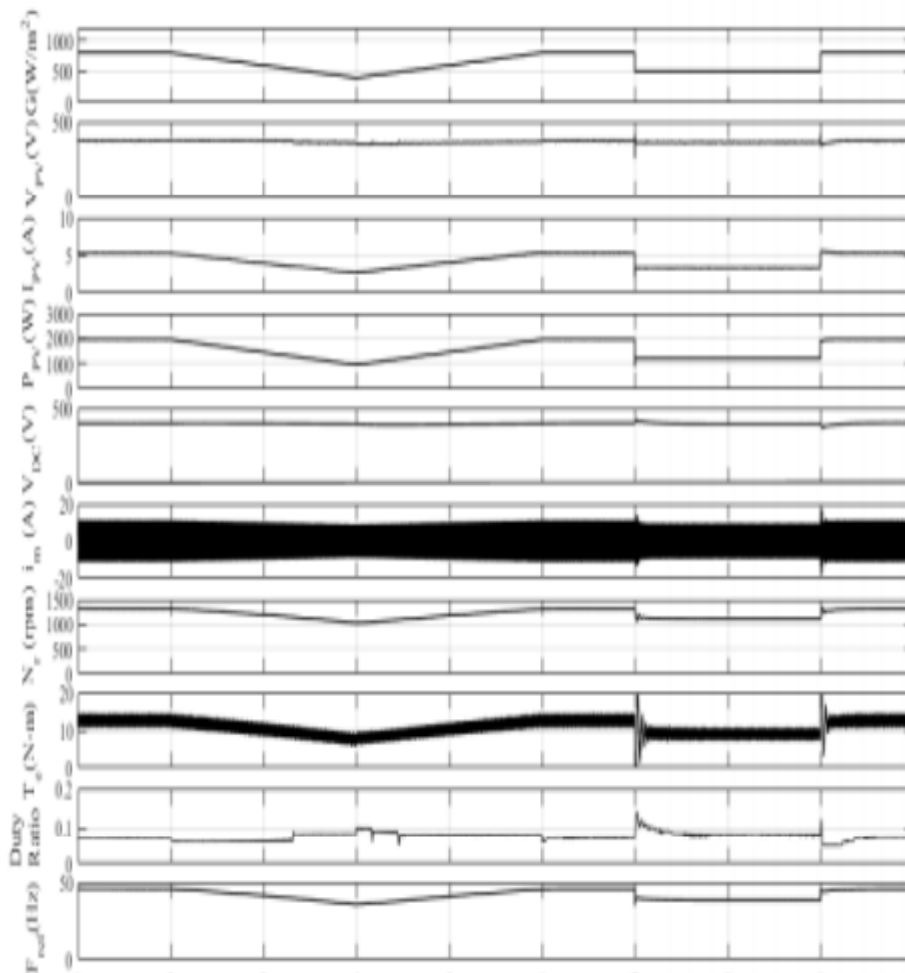


Fig.4: Starting behaviour of proposed system



**B. Stability and Dynamic Capabilities of the Proposed System**

The suggested stand-alone photovoltaic (PV) water pumping system is shown in Figure 5, which shows how it operates. The insolation of the sun is seen in this graphic as it changes throughout time. Currently, there is an MPP for the PV indexes in effect. A slope reduction in solar insolation is simulated at  $t = 2$  s in order to evaluate the efficiency of the MPPT algorithm at that time. Unlike the PV voltage, which does not vary greatly, the PV current fluctuates in response to the quantity of sunshine available. In addition, the DC bus voltage is maintained at 400 V without interruption throughout the whole system design. Solar insolation continues to climb sharply until  $t = 4$  s, at which time the system experiences a significant decrease. PV current increases in direct proportion to solar radiation, as it has in the past, while the PV voltage stays mostly static. The ability of a PV source to provide energy to a motor and generate torque rises in line with the rate of rotation and torque output of the PV source. After 6 seconds, the system has reached a steady state under  $1000 \text{ W/m}^2$  of solar light exposure. The PV voltage, on the other hand, is not subjected to a great deal of fluctuation. The DC bus voltage fluctuates for a brief period of time, but it immediately returns to its reference value. Despite a reduction in power of half, the DC bus voltage may be kept constant. During the time span  $t = 9$  s, there is a significant rise in solar insolation. Both the DC bus voltage and PV output voltage remain stable at a predetermined level. This is consistent with historical system behaviour. When a source of power is present, the motor's speed and torque rise in proportion.



**Fig.5: Steady state and transient behaviour of proposed system**

**V. CONCLUSION**

For solar PV panels, the study presents a new incremental conductance (InC) method that might speed up the MPP monitoring while simultaneously assuring that the operating point would always progress toward the MPP. Because the





suggested control mechanism is intrinsically, error-proof, it is the most significant contribution of this work. Even in the presence of fluctuating radiation levels, the system is able to accurately monitor the MPP. It has been suggested to use a smaller sensor in a stand-alone solar water pump. Three sensors are all that are needed. The suggested reference speed generation for the V/f control system is dependent on the DC bus's available power. For an induction motor drive, the PWM frequency and pump affinity law have been employed. It has been shown to be safe and effective via simulation and testing. Experiments have shown that a wide range of performance conditions—from beginning to steady state—are acceptable.

#### APPENDIX

Parameters of the proposed system: 2.2 kW(3HP), 230 V, 8.2 A, 50 Hz three phase, 1430 rpm, 4 pole,  $R_s = 0.603 \Omega$ ,  $R_r = 0.7 \Omega$ ,  $X_s = 1.007 \Omega$ ,  $X_r = 0.9212 \Omega$ ,  $X_m = 23.56 \Omega$

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