

# A New Modified MPPT Controller for Indirect Vector Controlled Induction Motor Drive with Variable Irradiance and Variable Temperature

B. Pakkiraiah G. Durga Sukumar

Department of Electrical and Electronics Engineering,

Vignan's Foundation for Science Technology and Research University, Guntur, A.P, India-522213

## Abstract

Due to the increase in power demand and the earth natural resources are depleting day by day, renewable energy sources have become an important alternate and solar energy is mainly used. In order to track the radiations from the sun in an efficient manner the maximum power point tracking (MPPT) controller is used. But the existed MPPT controllers were developed based upon the ideal characteristics of constant irradiance and temperature. To overcome the above problem a practical data is considered for designing of MPPT controller which is based upon variable irradiance under various temperatures. The output obtained from the MPPT is given to the boost converter with an inverter to find the performance of an indirect vector controlled induction motor drive under different operating conditions. For inverter control, a SVM algorithm in which the calculation of switching times proportional to the instantaneous values of the reference phase voltage. It eliminates the calculation of sector and angle information. The torque ripple and the performance of induction motor drive with ideal and practical data MPPT controllers are compared under different operating conditions. An experimental validation is carried out and the comparison is made with the simulation results.

**Keywords:** maximum power point tracking, variable irradiance, indirect vector controlled, total harmonic distortions, space vector modulation, induction motor drive and torque ripple.

## 1. Introduction

Among the renewable energy sources, the energy through the solar photovoltaic system can be considered the most prerequisite sustainable resource because of ubiquity. However the transfer of energy resulting from photovoltaic conversion remains relatively weak. Therefore the tracking control strategies have to be proposed for the PV system to avoid non linear V-I and V-P characteristics of PV module [1-2]. The loss of energy conversion is not only in the PV system also with the loads connected to the PV systems with. The criterion of reducing such loss mainly depends on DC-DC switched mode converters maintaining isolation to the connected load by providing of maximum operating voltage  $V_{MPP}$  with the help of a MPPT controller [3]. An analog circuitry based MPPT controller with the sliding mode controllers introduced to enhance the output and to get better performance under dynamic conditions have been presented [4]. The output voltage is sampled several times for switching frequency to oversample the ratio. Here multiple sampling is used to reduce the phase lag as the last sampling instant and the time of switching can be no longer. In multi sampled case PI controller is used for higher controller bandwidths. These circuits are seems to be more susceptible to limit cycle oscillations [5].

A fast and unconditionally stable maximum power point tracking is introduced to attain the fast dynamics and all range stability by the sliding mode control to acquire high tracking efficiency. The controller can operate as a voltage source or a current source maintaining stability all across the photo voltaic curve which is analyzed by using the stability region method [6-7]. The sliding mode MPPT controller is to study the performance on a synchronous SEPIC converter. And its extension to various classes of dc/dc converters has been studied. The dynamic response of a MPP tracker can be improved by constant frequency PWM controller [8]. Neural network and fuzzy logic based MPPT controller is used to extract maximum available power from PV panel to boost converter to reduce the over shooting, time response and oscillations in increasing the stability and efficiency of the system [9].

A MPPT controller with the inverter is connected to the indirect vector control induction motor drives with space vector modulation technique to get the better performance due to PV system. Various strategies for selecting the order of vectors with zero vectors to reduce the harmonic content and the switching losses [10-11]. The fault tolerant operation of a high power 7-level CHB inverter is implemented based on SVM algorithm. Here the inverter drives medium voltage 2.3 KV/2250 hp induction motor using rotor flux oriented control strategy. The indirect rotor flux oriented control is used for induction motors to achieve good dynamic performance [12]. The space vector modulation diagram of a inverter is composed of number of sub hexagons. The sector identification can be done by determining the triangle which encloses the tip of the reference space vector diagram with forming of six regions [13-14].

To overcome the distortions in the output voltage and currents of multi level inverter (MLI) the single phase SVM based CHBMLI is introduced for PV system to improve the quality of power even under non ideal

conditions [15]. The relationship between SVM and carrier based PWM are observed to achieve SVM's performance with the use of carrier based PWM. Common mode injection technique is used in carrier based PWM to develop SVM. Because SVM technique is the popular one due to its simplicity and better performance at low modulation ratio. Some times SVM technique becomes difficult to achieve when the number of levels increases [16]. Fuzzy logic controller gives the superior dynamic and steady state performance compared to PI controller [17]. A torque ripple and better performance is obtained with the help of genetic algorithm-particle swarm optimization based indirect vector control for optimal torque control of induction motor [18]. A comparison of neuro fuzzy based space vector modulation with neural network and conventional based system has been presented [19]. In this paper, section 2 discusses the modeling of induction motor and indirect vector control. Section 3 explains about the mathematical modeling of solar PV array. Section 4 describes the overview of proposed MPPT algorithm. Section 5 explains about the proposed SVM for two level inverter. Matlab-simulation & experimental results are presented in section 6 and the concluding remarks are stated in section 7.

## 2. Modeling of induction motor and indirect vector control

The mathematical model of a three-phase, squirrel-cage induction motor can be described in stationary reference frame as

$$V_{qs} = (R_s + pL_s)i_{qs} + pL_m i_{qr} \quad (1)$$

$$V_{ds} = (R_s + pL_s)i_{ds} + pL_m i_{dr} \quad (2)$$

$$0 = pL_m i_{qs} - \omega_r L_m i_{ds} + (R_r + pL_r)i_{qr} - \omega_r L_r i_{dr} \quad (3)$$

$$0 = \omega_r L_m i_{qs} + pL_m i_{ds} + \omega_r L_r i_{qr} + (R_r + pL_r)i_{dr} \quad (4)$$

Where  $\omega_r = \frac{d\theta}{dt}$ ,  $p = \frac{d}{dt}$

Suffixes s and r represents stator and rotor respectively

$V_{ds}$  and  $V_{qs}$  are d-q axis stator voltages respectively,

$i_{ds}$ ,  $i_{qs}$  and  $i_{dr}$ ,  $i_{qr}$  are d-q axis stator currents and rotor currents respectively,

$R_s$  and  $R_r$  are stator and rotor resistances per phase respectively,

$L_s$ ,  $L_r$  are self inductances of stator and rotor and  $L_m$  is mutual inductance

Stator and rotor flux linkages can be expressed as in-terms of inductances as

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr} \quad (5)$$

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr} \quad (6)$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs} \quad (7)$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds} \quad (8)$$

From the above equations (1)-(4), Squirrel-cage induction motor can described by following equations in stator reference frame as

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + pL_s & 0 & pL_m & 0 \\ 0 & R_s + pL_s & 0 & pL_m \\ pL_m & -\omega_r L_m & R_r + pL_r & -\omega_r L_r \\ \omega_r L_m & pL_m & \omega_r L_r & R_r + pL_r \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \quad (9)$$

The electromagnetic torque  $T_e$  of the induction motor is given by

$$T_e = \frac{3}{2} \left( \frac{p}{2} \right) (\lambda_{qr} i_{dr} - \lambda_{dr} i_{qr}) \quad (10)$$

From the dynamic model of induction machine, the rotor flux is aligned along the d-axis then the q-axis rotor flux  $\lambda_{qr}=0$ . So from the equations (7) and (10) described in the previous section and putting  $\lambda_{qr}=0$ , the electromagnetic torque of the motor in the indirect vector control can be expressed in indirect vector control as

$$T_e = \frac{3}{2} \left( \frac{p}{2} \right) \frac{L_m}{L_r} (\lambda_{dr} i_{qs}) \quad (11)$$

If the rotor flux linkage  $\lambda_{dr}$  is not disturbed, the torque can be independently controlled by adjusting the stator q component current  $i_{qs}$ .

As the rotor flux aligned on d-axis, this leads to  $\lambda_{qr}=0$  and  $\lambda_{dr}=\lambda_r$ , then

$$\omega_{sl} = \frac{L_m R_r}{\lambda_r L_r} i_{qs} \quad (12)$$

The rotor angle  $\theta_e$  is estimated using the measured rotor speed  $\omega_r$  and slip speed  $\omega_{sl}$

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl} \quad (13)$$

## 3. Mathematical modeling of solar PV array

Photovoltaic technology converts solar energy directly into electricity through solar cells. A photovoltaic generator, also known as a photovoltaic array, is the total system consisting of all PV modules connected in series or parallel with each other. A solar cell constitutes the basic unit of a PV generator which in turn, is the main component of a solar generator. For a photo voltaic system power generated is calculated as  $P = V \cdot I$

Where  $P$  representing power in watts (W),  $V$  the voltage in volts (V), and  $I$  the current in ampere (A). Fig. 1 shows a model of a solar cell equivalent circuit.

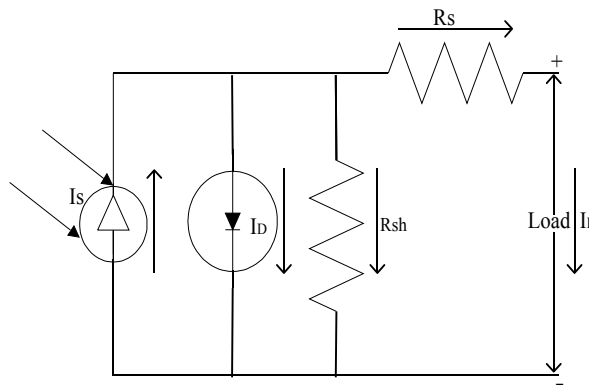


Fig. 1 model of solar cell equivalent circuit.  
 From the V-I characteristic of a PV cell

$$I_L = I_S - I_D - I_{sh} \quad (14)$$

Where  $I_S$  refers to the sun light current and  $I_D$  is the diode current.

From the Shockley equation, the diode current can be expressed as

$$I_D = I_0 \left[ \exp\left(\frac{q(V_L + I_L R_s)}{\gamma K T_s}\right) - 1 \right] \quad (15)$$

Where  $I_0$  refers to actual reverse saturation current,  $q$  electron charge,  $\gamma, K$  are the shape factor and Boltzmann Constant

Substituting (15) in (14)

$$I_L = I_S - I_0 \left[ \exp\left(\frac{q(V_L + I_L R_s)}{\gamma K T_s}\right) - 1 \right] \quad (16)$$

Where  $\gamma = Z \cdot N_A \cdot N_{SC}$

$Z$  is the completion factor,  $N_A$  is the number of modules in an array,  $N_{SC}$  is the number of series connected cells.

$$I_S = \frac{G}{G_R} \left( I_{S,R} + \mu_{ISC} (T_s - T_{S,R}) \right) \quad (17)$$

In the equations above,  $I_{S,R}$  refers to the sun light current at reference condition;  $G, G_R$  the irradiance, actual and at reference condition respectively,  $\mu_{ISC}$  the manufacturer supplied temperature coefficient of short-circuit current,  $T_s, T_{S,R}$  the solar cell temperature, actual and at reference condition respectively and

$$I_0 = I_{0,R} \left( \frac{T_s}{T_{S,R}} \right)^3 \exp \left[ \left( \frac{q \epsilon G}{k Z} \right) \left( \frac{1}{T_{S,R}} - \frac{1}{T_{CS}} \right) \right] \quad (18)$$

$I_{0,R}$  refers to reverse saturation current at reference condition

The module photo current  $I_S$  of the photovoltaic module depends linearly on the solar irradiation and is also influenced by the temperature according to the equation (17). The value of module short-circuit current  $I_{S,R}$  is taken from the data sheet of the reference model.

#### 4. Proposed maximum power point tracking

Maximum power point tracking control technique is used mainly to extract maximum capable power of the PV modules with respective solar irradiance and temperature at particular instant of time by Maximum Power Point Tracking Controller. A number of algorithms are developed to track the maximum power point efficiently. Most of the existing MPPT algorithms suffer from the drawback of being slow tracking. Due to which the utilization efficiency is reduced. There are several types MPPT Control techniques to improve the solar energy efficiency such as Incremental Conductance (INC), Hill Climbing or Perturbation & Observation (P&O) are the most conventionally used methods.

The appearance of multi peak output curves of partial shading in PV arrays is common, where the development of an algorithm for accurately tracking the true MPPs of the complex and non-linear output curves is crucial. A typical solar panel converts only 30-40 percent of the incident solar irradiation into electrical energy. Maximum power point tracking is used to increase the efficiency of the panel. The requirement to get the maximum power is that the source resistance should be equal to that of the load resistance. In the source side, a boost converter is connected to a solar panel in order to enhance the output voltage so that to use for different applications like motor loads by changing the duty cycle of the boost converter

The proposed MPPT algorithm takes the practical obtained values from the PV array i.e  $V, I_L$  and calculates the maximum tracked available power  $P_1$ . This calculated power  $P_1$  is considered as a initial reference value in the algorithm for this iteration. After a time instant 0.01 seconds it takes another set of values  $V$  &  $I_L$  and calculates  $P_2$ . After  $P_1$  and  $P_2$  differential power  $dp = P_2 - P_1$  is calculated. This calculated  $dP$  is used for the formation of duty cycle  $D$  and this can be used for providing of gating pulse for boost converter. For the next

iteration P2 is consider initial reference and the process is repeated. The flow chart for the algorithm is given in Fig. 2

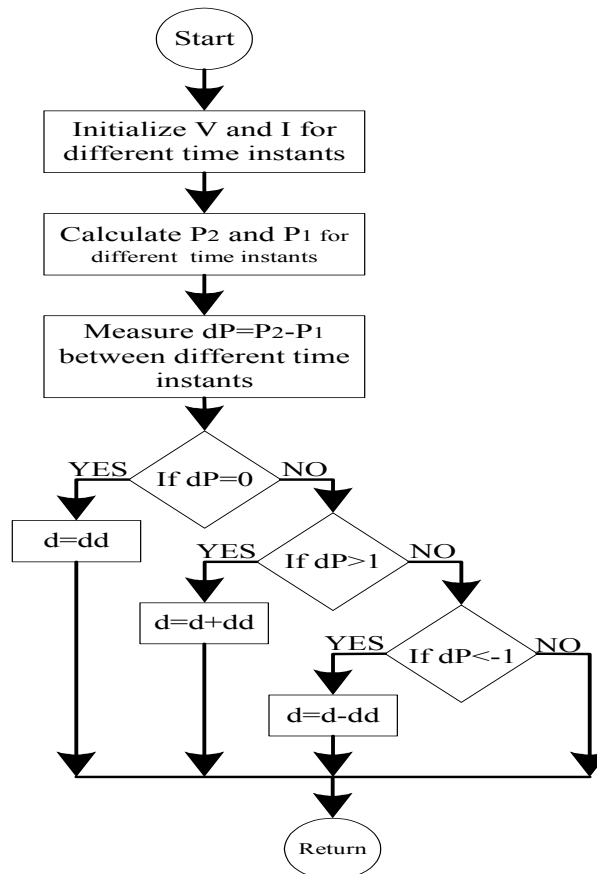


Fig.2 Flow chart of proposed MPPT Controller

Where  $dd$  is the differential duty ratio corresponding to the differential power of particular iteration and  $d$  is the duty ratio of the prior time instant.

From the proposed MPPT controller it is observed that  $I_S \gg I_O$  and that the Maximum Power Point current  $I_{MPP}$  is also calculated at MPP with thermal voltage is

$$I_{MPP} = I_S - I_O e^{\left(\frac{V_{MPP}}{V_{TH}}\right)} \quad (19)$$

Then  $I_O$  becomes as

$$I_O = \frac{I_{S,R}}{e^{\left(\frac{V_{OC}}{V_{TH}}\right)}} \quad (20)$$

With the consideration of  $V_{OC}$  and  $V_{TH}$  the calculation of  $I_{MPP}$  is

$$I_{MPP} = I_{S,R} \left[ 1 - e^{\left(\frac{V_M - V_{OC}}{V_{TH}}\right)} \right] \quad (21)$$

Then the thermal voltage  $V_{TH}$  is calculated as

$$V_{TH} = \frac{V_{MPP} - V_{OC}}{\ln \left( \frac{I_{S,R} - I_{MPP}}{I_{S,R}} \right)} \quad (22)$$

So Array power can be calculated as

$$P_{ARRAY} = V_{MPP} \times I_{MPP} = I_S \times V - I_O \left[ e^{\left(\frac{V}{V_{TH}}\right)} - 1 \right] \times V \quad (23)$$

From this by deriving the above equation w.r.t. the voltage we get the maximum array power as

$$P_{ARRAY MAX} = \frac{\partial P_{ARRAY}}{\partial V} = I_O \left[ e^{\left(\frac{V}{V_{TH}}\right)} - 1 \right] + I_O \times \frac{V}{V_{TH}} \left[ e^{\left(\frac{V}{V_{TH}}\right)} - 1 \right] \quad (24)$$

From above equation we are observing for the maximum voltage that gives the maximum array power is  $V = V_{MPP}$ .

So that

$$\frac{\partial P_{ARRAY}}{\partial V} \text{ at } V = V_{MPP} = 0 \quad (25)$$

Then it gives the

$$I_{MPP} - \frac{V_{MPP}}{V_{TH}} \times I_D = 0 \quad (26)$$

### 5. Proposed SVM for two level inverter

SVM is applied to minimize the overall switching changes when the nearest three space vectors are used. The identical properties of switching states and their redundancies enable the improvement of the SVM technique in order to reduce the switching loss and operating under fault conditions. In PWM technique each phase voltage is produced separately according to its reference, while SVM technique transforms three phase reference voltage into a rotational vector in space vector domain and synthesizes it through the appropriate switching states of the inverter. Through this strategy it is possible to use the redundancy in switching states to minimize the converter loss and to operate under fault conditions.

In this the space vector modulation algorithm for two level inverter is introduced for which the solar panels are connected to provide the dc supply. SVM basic principle and switching sequence is given in order to get symmetrical algorithm pulses and voltage balancing. This scheme is used to control the output voltage of the two level inverter with the MPPT controller. In the SVM algorithm, the d-axis and q-axis voltages are converted into three-phase instantaneous reference voltages. Then the imaginary switching time periods proportional to the instantaneous values of the reference phase voltages which are defined as

$$T_{us} = \left(\frac{T_s}{V_{dc}}\right) V_{us}^*, T_{vs} = \left(\frac{T_s}{V_{dc}}\right) V_{vs}^*, T_{ws} = \left(\frac{T_s}{V_{dc}}\right) V_{ws}^* \quad (27)$$

Where  $T_s$  and  $V_{ds}$  are the sampling interval time and dc link voltage respectively. Here, sampling frequency is the twice the carrier frequency. The maximum (*MAX*), middle (*MID*) and minimum (*MIN*) imaginary switching times can be found in each sampling interval by using (28) - (30).

$$T_{max} = MAX(T_{u1}, T_{v1}, T_{w1}) \quad (28)$$

$$T_{min} = MIN(T_{u1}, T_{v1}, T_{w1}) \quad (29)$$

$$T_{mid} = MID(T_{u1}, T_{v1}, T_{w1}) \quad (30)$$

The active voltage vector switching times  $T_1$  and  $T_2$  are calculated as

$$T_1 = T_{max} - T_{mid} \text{ and } T_2 = T_{mid} - T_{min} \quad (31)$$

The zero voltage vectors switching time is calculated as

$$T_z = T_s - T_1 - T_2 \quad (32)$$

The zero state time will be shared between two zero states as  $T_0$  for  $V_0$  and  $T_7$  for  $V_7$  respectively, and can be expressed as [31].

$$T_0 = K_0 T_z \quad (33)$$

$$T_7 = (1 - K_0) T_z \quad (34)$$

The various SVM algorithms can be generated by changing  $k_0$  between zero and one. However, in this SVM algorithm, the zero voltage vector time distributed equally among  $V_0$  and  $V_7$ . Hence, here  $k_0$  is taken as 0.5 to obtain the SVM algorithm.

### 5.1 Block diagram of vector control induction motor

The block diagram of the proposed indirect vector control induction motor drive with two-level inverters is as shown in Fig. 3. From the field control and speed control the reference values of currents  $i_{d1}^*$  and  $i_{q1}^*$  are obtained and these values are compared with the respective  $i_{d1}$  and  $i_{q1}$  currents generated by the transformation of phase currents with the unit vector. From the respective errors, d-axis voltage  $V_d$  and q-axis voltage  $V_q$  are generated through PI controllers. These voltages are then converted into stationary frame and then given to SVM block.

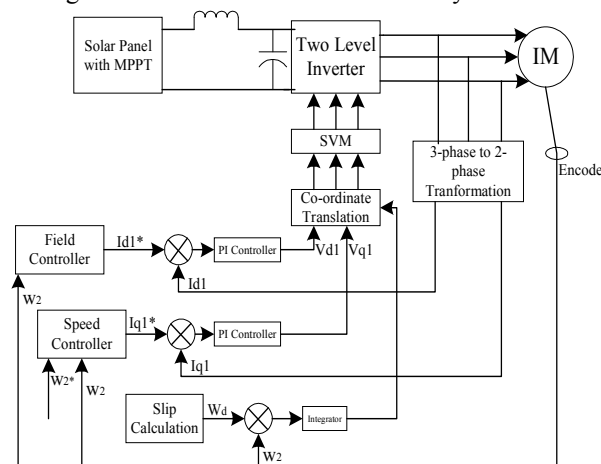


Fig. 3 Vector control of motor with proposed MPPT technique

## 6. Results and discussion

### a) Theoretical and Practical characteristics of PV array

When both the temperature and irradiance are variable then it increases the PV current and decreases the PV voltage drastically as the temperature rises. When irradiance is considered, PV current and voltage increases with respect to the irradiance rise. Comparing to theoretical values practical output values have drooping nature due to variable irradiance and variable temperature for instant to instant. The observations voltage, current and power are shown in Figures 4-5 at different instants of time.

### b) Theoretical and Practical calculated readings of PV array

In practical working conditions maintaining of constant temperature and irradiance is not possible these are going to vary from instant to instant. Considering variable irradiance and temperature the following values are calculated with the experimental validation from 8 A.M to 5.30 P.M shown in

From the above analysis, the maximum power is obtained from the array through MPPT is 1500 watts with the maximum power point voltage ( $V_{MPP}$ ) of 61.36 Volts and the maximum power point current ( $I_{MPP}$ ) of 24.42 Amps under the open circuit voltage of 75.96 Volts and the short circuit current of 26.01 Amps.

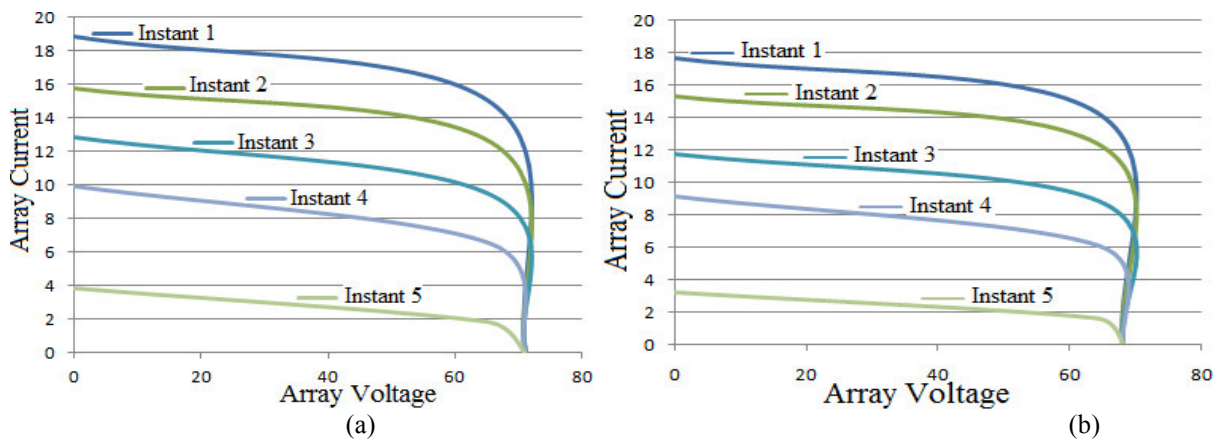


Fig. 4 V-I characteristics of an array at different instants of time a) Theoretical b) Practical

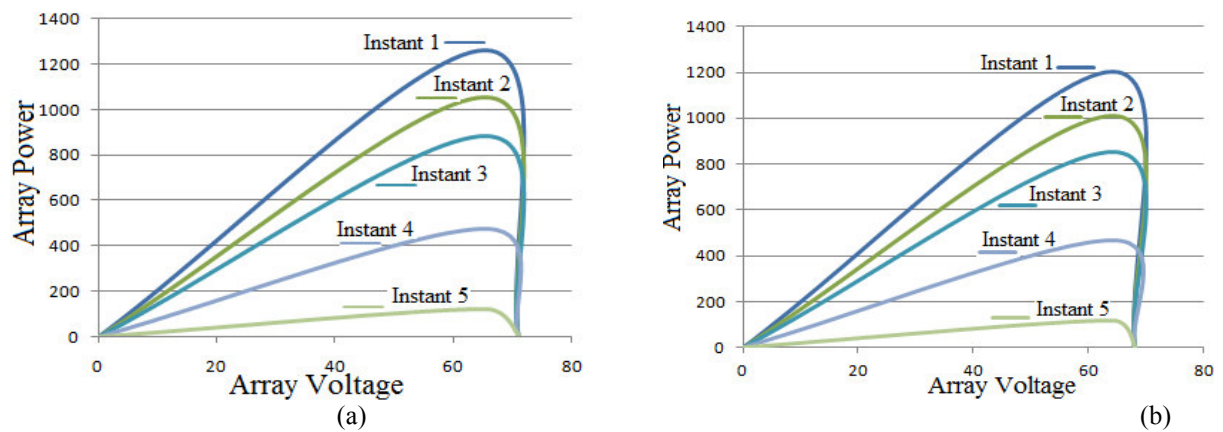


Fig. 5 P-V characteristics of an array at different instants of time a) Theoretical b) Practical

Table.1  
 Theoretical and practical values of Irradiance, Voltage, Current and Power for variable temperature and irradiance

Time in (am/pm)	Temperature in ( $^{\circ}$ C)	Irradiance in ( $W/m^2$ )	Voltage in (Volts)		Current in (Amps)		Power in (Watts)	
			Theoretical	Practical	Theoretical	Practical	Theoretical	Practical
08.00	30.75	142.50	66.48	60.90	3.7080	3.90	233.41	237.51
08.30	32.55	284.59	68.42	61.60	7.4060	7.70	478.94	474.32
09.06	33.35	407.45	69.43	62.30	10.6036	10.90	695.68	679.07
09.30	35.25	474.68	69.86	63.80	12.3547	12.40	815.96	791.12
10.00	38.25	493.06	69.95	64.20	12.8358	12.80	848.49	821.76
10.30	39.35	512.43	70.05	64.70	13.3409	13.20	883.33	854.04
11.00	39.55	551.60	70.27	65.20	14.3609	14.10	954.96	919.32
11.30	40.02	604.05	70.53	65.80	15.7270	15.30	1048.07	1006.74
12.00	40.50	630.60	70.65	66.10	16.4187	15.90	1096.48	1050.99
12.10	40.68	665.34	70.81	66.40	17.3233	16.70	1159.15	1108.88
12.30	41.10	694.55	70.93	67.30	18.0843	17.20	1212.19	1157.56
13.00	41.35	723.24	71.05	68.10	18.8315	17.70	1264.69	1205.37
13.30	40.45	665.34	70.81	66.80	17.3230	16.60	1159.15	1108.88
14.00	40.08	607.08	70.54	65.70	15.8057	15.40	1053.86	1011.78
14.30	39.00	551.70	70.27	64.30	14.3630	14.30	953.56	919.49
15.00	38.42	478.51	69.86	63.80	12.4570	12.50	822.25	797.50
15.30	37.95	383.00	69.22	63.20	9.9703	10.10	652.05	638.32
16.00	37.32	307.27	68.59	61.70	7.9986	8.30	518.54	512.11
16.30	37.06	146.86	66.46	59.70	3.8229	4.10	240.73	244.77
17.08	33.25	73.58	64.55	58.40	1.9149	2.10	122.74	122.64
17.30	32.85	27.79	61.79	57.90	0.7235	0.80	46.35	46.32

**c) PV array characteristics with conventional and proposed MPPT Techniques**

From the observation of conventional and proposed MPPT technique I-V and P-V characteristics it is observed that the conventional MPPT current obtained is 17.70 Amps where as the proposed MPPT current is about is 18.83 Amps. Similarly the conventional MPPT voltage and the power are found as 68.10 Volts and 1205.37 Watts with that of the proposed MPPT voltage and the power are about 72.74 Volts and 1366.76 Watts. These results are presented in Figures 6-8.

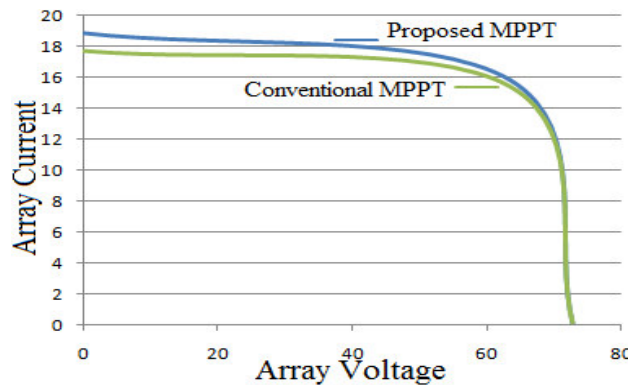


Fig. 6 Conventional and Proposed I-V characteristics of PV array

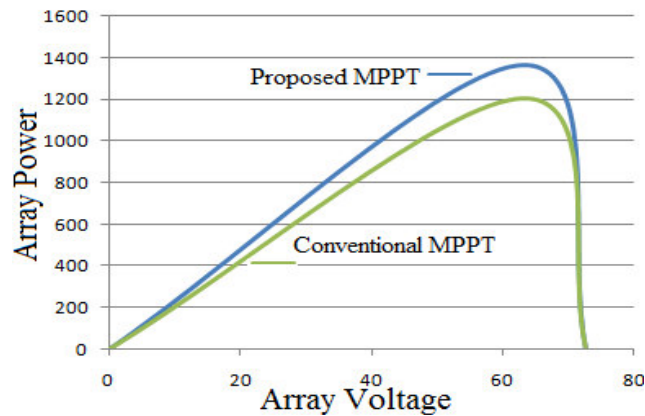


Fig. 7 Conventional and Proposed P-V characteristics of PV array

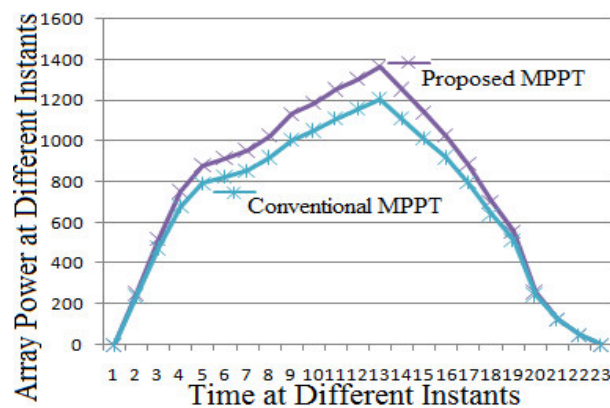


Fig. 8 Power curves of PV array with conventional and proposed MPPT techniques

**d) Simulation results of induction motor**

Simulation results are obtained under different conditions considering the reference value of speed as 1300 rpm and using the switching frequency 5 KHz. The performance of induction motor parameters such as stator phase currents, torque and speed are obtained with the two-level inverter controlled drive are shown in Figures 9-12.

*i) Performance during starting*

The performance of the indirect vector controlled induction motor drive during the starting with two-level inverter is shown Figure 9(a), 9(b) and 9(c). As shown in the figures maximum current during the starting is reduced, the ripple contentment in the torque is reduced, drive reaches steady state earlier in case of proposed MPPT controller. The maximum torque obtained with the conventional MPPT is 12.5 N-m where as proposed method it is 13.75 N-m. Torque is increased with the proposed MPPT controller. The speed response also reaches steady state earlier with the proposed MPPT than that of conventional method.



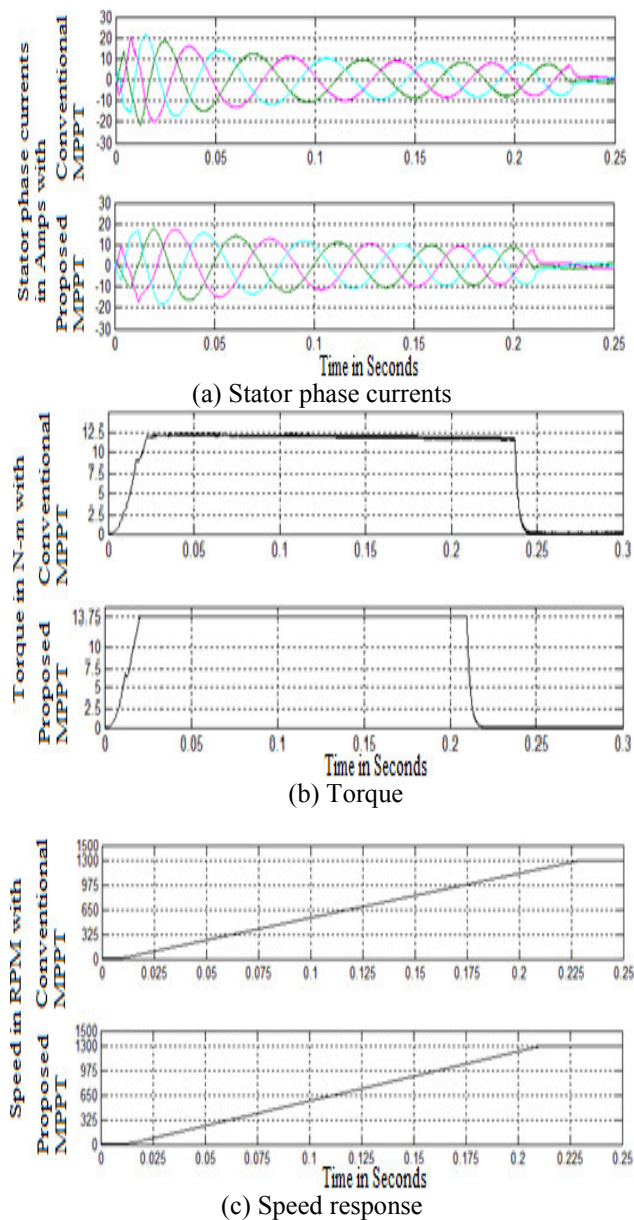


Fig. 9 Performance of indirect vector controlled induction motor during starting

*ii) Performance during steady state*

The steady state phase currents, torque and speed responses of indirect vector controlled drive with two-level inverter are shown Figure 10(a), 10(b) and 10(c). It is observed that the torque ripple of the two level inverter with the conventional MPPT method is 0.35 where as with the proposed MPPT is 0.03. Lot of ripple improvement is found with the proposed MPPT method. Also the better speed response is obtained with the proposed MPPT compared to conventional method of the indirect vector controlled induction motor drive.

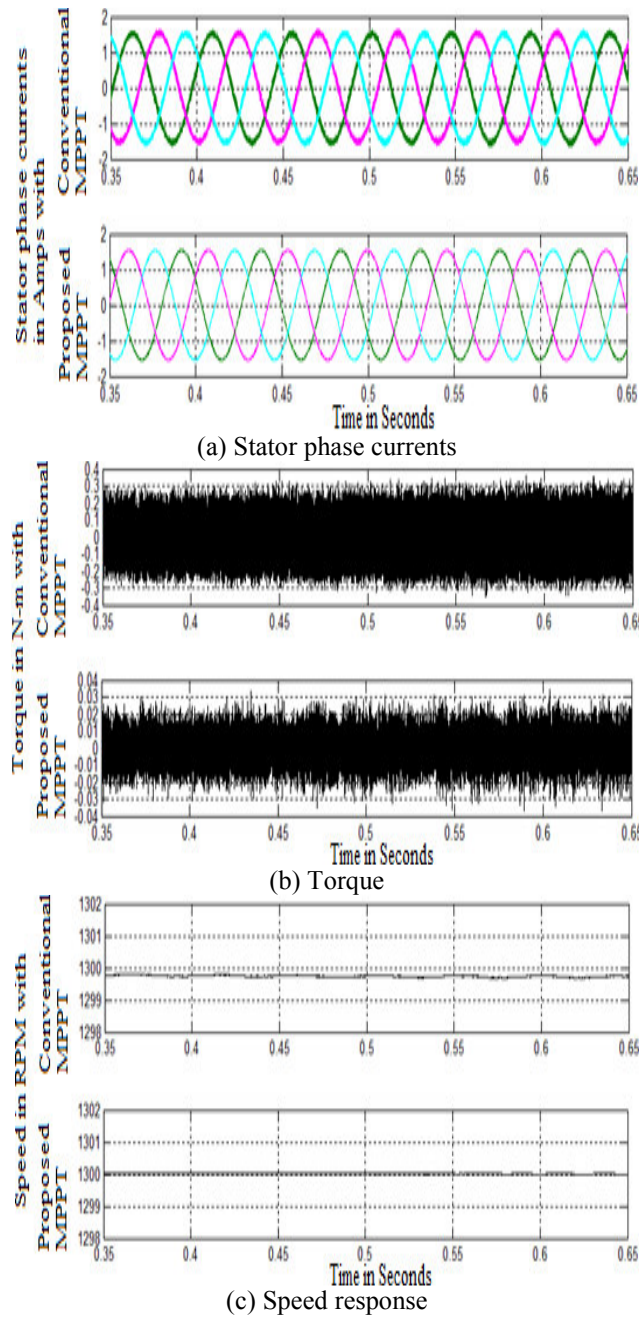


Fig.10 Steady state Performance of indirect vector controlled induction motor

*iii) Performance during transient step change*

The response during the step change in load torque command (the load torque of 8 N-m is applied at 0.7 sec and removed at 0.9 sec) is shown in Figure 11(a), 11(b) and 11(c). The ripple content in current waveforms and torque is less with the proposed MPPT method of indirect vector controlled induction motor drive. Also the speed decrement is little less with the proposed MPPT during the load change.

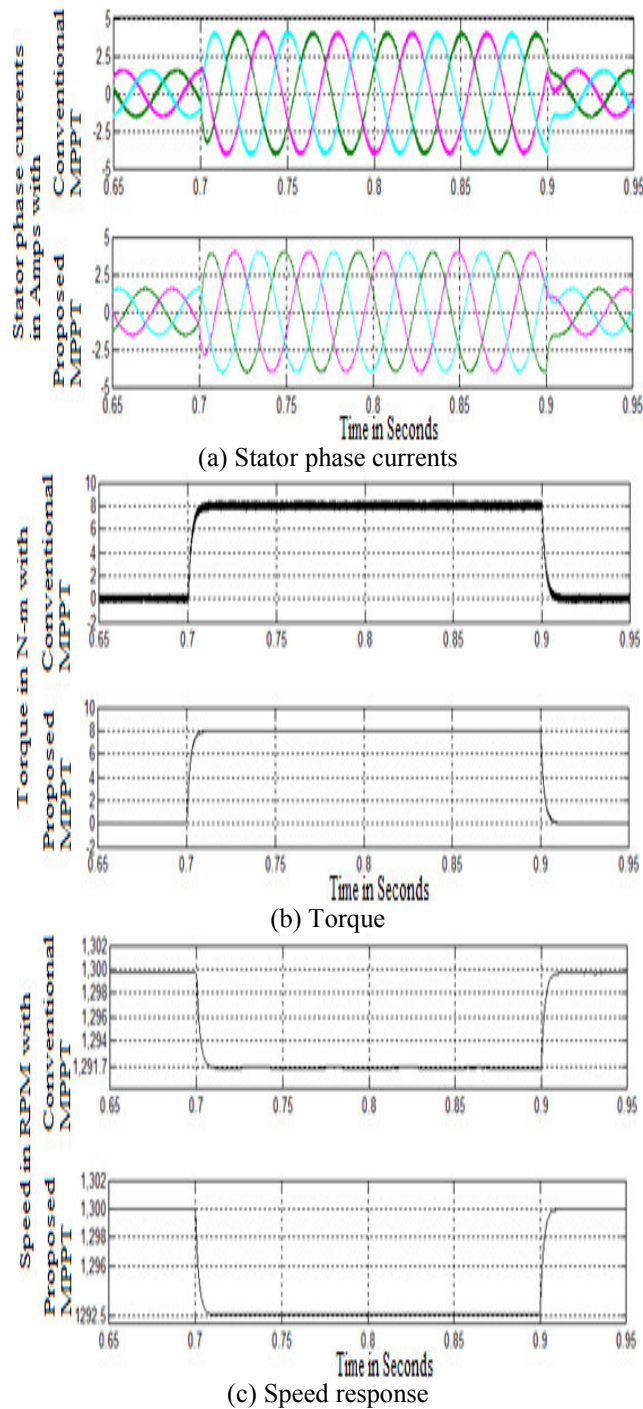


Fig.11 Transients during step change in load torque

*iv) Performance during transient speed reversal*

The results of the drive during speed reversals (From +1300 to -1300) are shown in Figure 12(a), 12(b) and 12(c). The drive gives less ripple content in the phase currents, torque of an induction motor and speed response reaches the reference value little earlier with the proposed MPPT and experimental validation during the speed reversal.

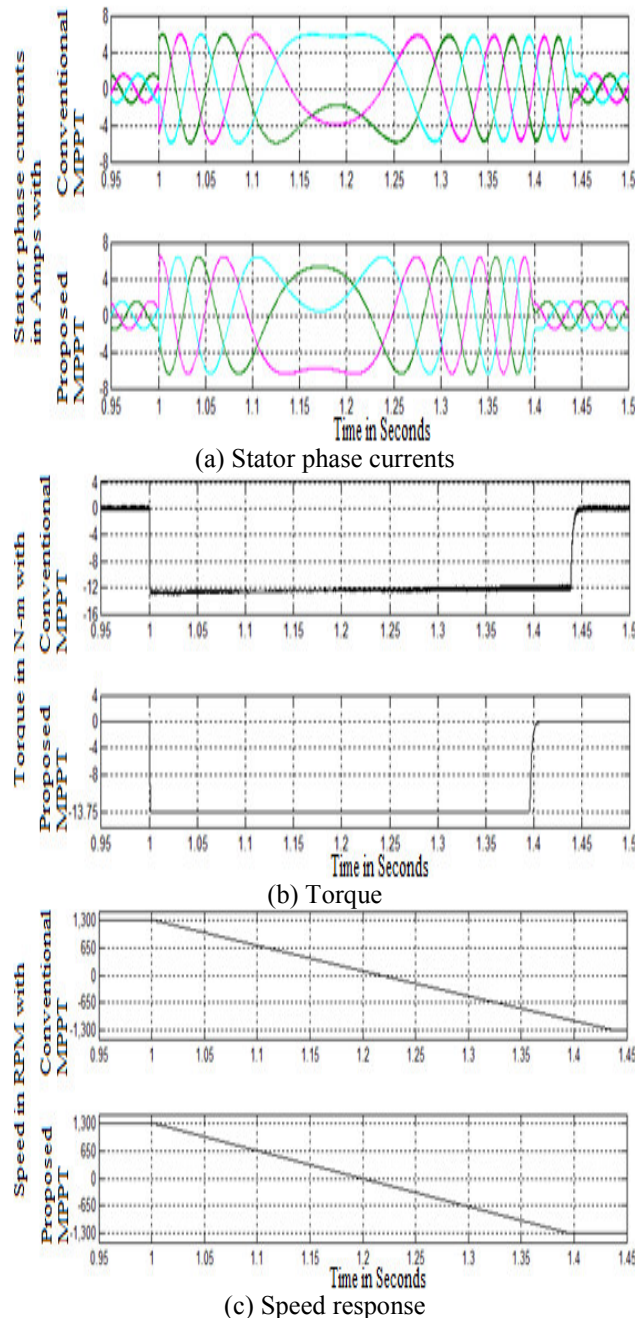


Fig. 12 Transients during speed reversal operation (Speed is changed from +1300 rpm to -1300 rpm)

#### e) Experimental Validation Results

A dSPACE (DS1104) is used for the real time implementation of vector controlled induction motor drive using the proposed and conventional MPPT Controller. The control algorithm is first developed in Matlab/Simulink. The real time workshop of Matlab generates the C code for the real time implementation. The interface between Matlab and DS1104 allows the controller to be run on the hardware which is an MPC-8240 processor.

In the present case, the optimized C code of the simulink model of the control algorithm is automatically generated by the real time workshop of Matlab in conjunction with the dSPACE hardware, where it is implemented in the real time and the gating pulses are generated. The gating signals for the power switches of the inverter are outputted via the master bit I/Os are available on the dSPACE board. The CLP1104 Connector/Led Combination panel provides easy to use the connections between DS1104 board and the devices is to be connected to it. The panel also provides an array of LEDs indicating the states of digital signals (gating pulses). The gating pulses are fed to various IGBT driver circuits via the Opto-isolation circuit boards. Sensed signals fed to the ADCs and the generated gating pulses are outputted at master bit I/Os. The block diagram of dSPACE controlled inverter is shown in Fig. 13

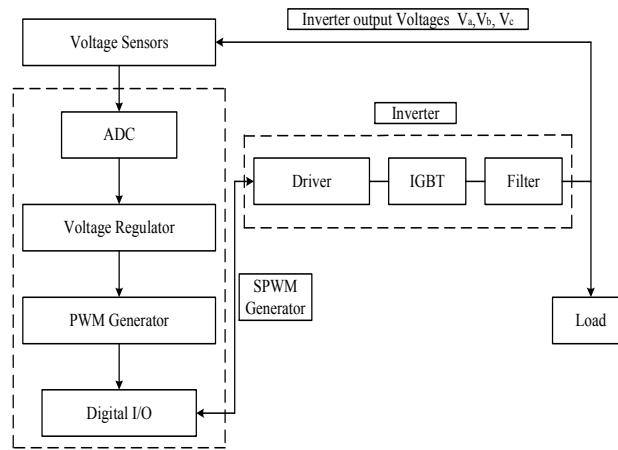


Fig. 13 Block diagram of dSPACE controlled inverter

The schematic diagram gives the clear information of the experimental setup in detail. Here, the speed of the IM is sensed using DC-Vector control. In addition, currents, and the speed of IM are taken into the feedback using sensors via ADC and Mux ADC channels of the dSPACE DS-1104 connector panel. Thereafter, the speed and currents of the IM are estimated and given to the respective controllers. Moreover, the speed and current PI-controllers generate the current and slip speed, respectively as shown in Figure 14.

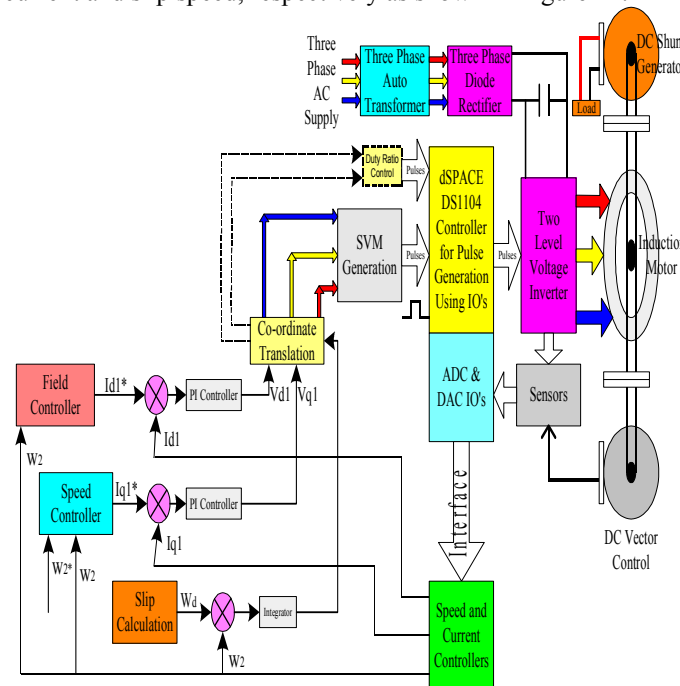


Fig. 14 Vector control of Induction motor with dSPACE DS-1104

Initially, the reference speed set to 1300rpm in both conventional and proposed MPPT of the IM drive at no-load. The PWM pulses are provided to the inverter by a click on the incremental build. The DC-link voltage 500V is applied to the inverter by adjusting three-phase auto-transformer using uncontrolled rectifier. Hence, the IM picks up its speed up to required value, i.e., 1300rpm and reach to steady state under no-load condition. The corresponding waveforms (torque ( $T_e$ ), speed ( $N_r$ ), flux ( $\psi_e$ ), and current ( $i_a$ )) during starting for conventional are taken from the digital storage oscilloscope (DSO) as shown in Figure 15(a&b).

Compared to conventional MPPT that the proposed MPPT has the better percentile ripple improvement in the induction motor parameters during its starting. Such as in torque it is 25%, in flux it is 25%, in current it is 18% and in speed it is about 8% ripple improvement.

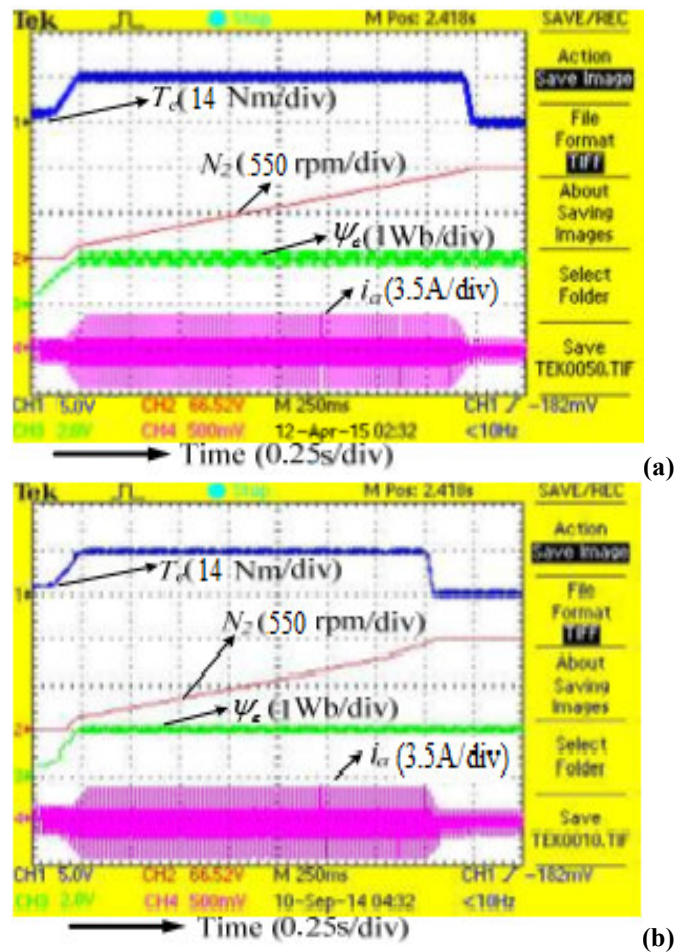


Fig. 15 starting performance of induction motor a) conventional b) proposed

A sudden load of 8N-m is applied/removed at 0.2s and 0.7s then the corresponding changes in IM waveforms are shown in Figure 16 (a&b). The torque and currents suddenly rise/fall due to load perturbation. Proposed MPPT has good ripple improvement from induction motor parameters during load change when compared to the conventional MPPT. Such that it improved in torque about 25%, in flux it is 25%, in current it is 19.33% and in speed it is found to be 8.16%.

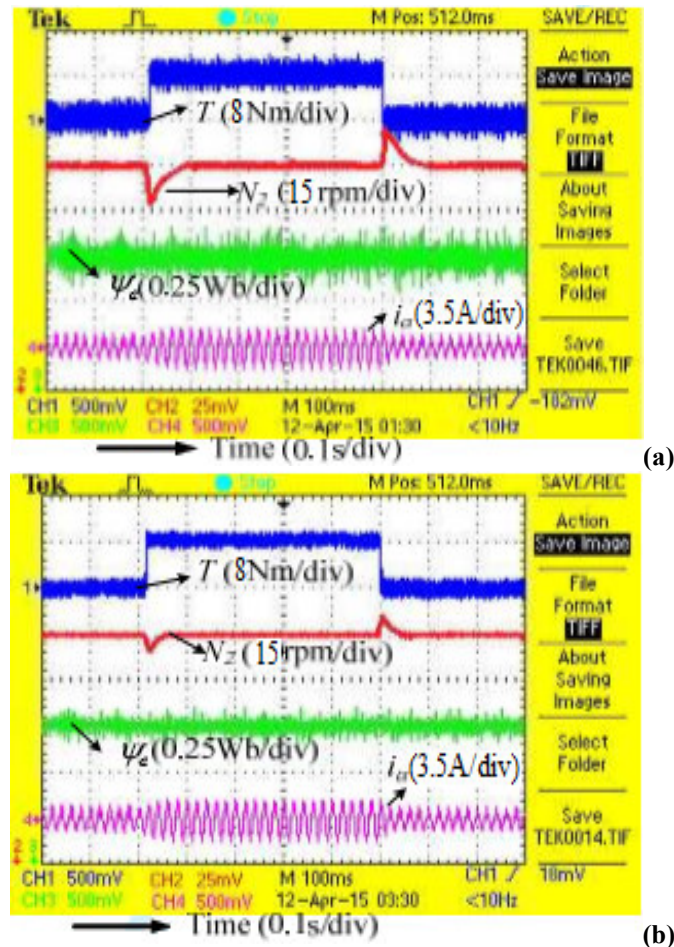


Fig. 16 performance of induction motor during sudden change in load a) conventional b) proposed

## 7. Conclusion

In this MPPT controller for PV system under variable irradiance and variable temperature is presented. The performance of MPPT controller is compared with conventional MPPT controller using vector controlled induction motor drive. The practical characteristic V-I and P-V under variable irradiance and variable temperature is compared with theoretical calculated values under constant temperature variable irradiance and vice versa. It observed 20% variation compared to already existed method. From this obtained practical values MPPT controller is developed to obtain better performance when compared to the conventional methods already existed. The proposed MPPT controller calculates the power of a PV system for every 0.01 seconds and gives the more output. It is observed that it gives 25% more output with the proposed MPPT under variable irradiance and variable temperature. The better dynamic performance two-level inverter fed induction motor drive under various conditions with the proposed MPPT. For inverter control, SVM algorithm calculates switching times proportional to the instantaneous values of the reference phase voltage to eliminate the calculation of sector and angle information. The %THD is 25% less compared to with proposed MPPT with SVM algorithm compared to conventional based system.

## Appendix

Three-phase, 400 V, 1.3 hp, 1480 rpm induction motor parameters:

Stator resistance  $R_s = 4.1 \Omega$ ,

Stator inductance  $L_s = 0.545 \text{ H}$ ,

Rotor resistance  $R_r = 2.5 \Omega$ ,

Rotor inductance  $L_r = 0.542 \text{ H}$ ,

Mutual inductance  $L_m = 0.51 \text{ H}$ ,

Moment of inertia  $J = 0.04 \text{ Kg-m}$ .

Theoretical power obtained with variable temperature and variable irradiance = 1264.69 Watts

Practical power obtained with variable temperature and variable irradiance = 1205.37 Watts

Theoretical voltage obtained with variable temperature and variable irradiance = 71.05 Volts

Practical voltage obtained with variable temperature and variable irradiance = 68.10 Volts  
Theoretical current obtained with variable temperature and variable irradiance = 17.80 Amps  
Practical current obtained with variable temperature and variable irradiance = 17.70 Amps

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