International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 08 | Aug 2018 www.irjet.net p-ISSN: 2395-0072

ANALYSIS OF PV FED VECTOR CONTROLLED INDUCTION MOTOR DRIVE

S. Sakthivel

Lecturer (Senior Grade), Dept. of Electrical & Electronics Engineering, Sakthi Polytechnic College, Erode, Tamil Nadu, India

---***---

Abstract - *Induction Motor drives are broadly used in various industries for adjustable speed applications. Induction Motor drives are preferred for its simple and easy control. Vector control of an Induction Motor is suitable to attain good dynamic performance. The Proportional Integral Controller (PID) is proposed in this paper to develop the dynamic performance of the drive. Conventional open loop system with Space Vector Modulation (SVM) is easy to implement but it is not suitable and instable for the change in load. The additional feature in this system is photo Voltaic (PV) power source. Energy demand in India imposes going for renewable energy. This paper intends PV powered PI based vector controlled induction motor drive which produces a good dynamic response. The whole system is analyzed using Matlab / Simulink and compared with the conventional SVM controls.*

Key Words: **Induction Motor, Vector control, Proportional Integral controller, Space Vector Modulation, Voltage Source Inverter and Photovoltaic power.**

1. INTRODUCTION

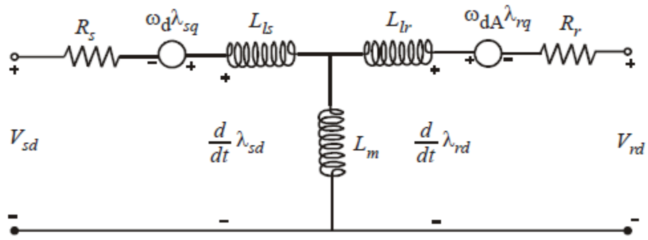
Induction motors (IM) are broadly used in many industries for its better self-starting capacity, simple and rugged structure, reliability and low cost. In general, Induction Motors are connected with the Voltage Source Inverters (VSI) for variable speed control [1]. Open loop control system is simple to implement but difficult to vary the required speed. Adjustable speed drive is the main application of IM drive for industries. The adjustable speed may be obtained using scalar control and vector control. Scalar control methods are variable frequency control and variable voltage and frequency (V/Hz) control.

The adjustable speed is analyzed in IM drive using scalar method [2], V/Hz method using PI controller, V/Hz method using a Fuzzy Logic Controller [4] and V/Hz method using PID controller [5]. The disadvantage of V/Hz method using PID controller is the uncontrolled magnetic flux. This problem can be rectified by vector control method. This method improves the dynamic performance of Induction Motor [6] like fast response which makes this drive suitable for many applications. Performance of Vector control drive mainly depends on the speed controller used in it.

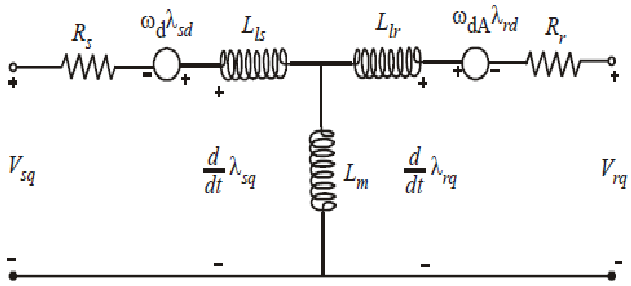
Electrical energy demand is the major problem faced by many countries which makes the researchers passions for renewable energy. Photovoltaic energy generation offers many advantages compared to other renewable energy sources in terms of reliability, low maintenance and eco-friendly. The applications are water pumping, electric vehicles, space applications [7] and grid-connected configurations [8] like hybrid systems [9]. So, this paper proposes PV source for IM drive.

2. DYNAMIC MODEL OF AN INDUCTION MOTOR

The equations of an IM are developed in a rotating reference frame. Squirrel cage type rotor is used for IM. The equivalent circuit for obtaining the mathematical model [10] of an IM is shown in the Figure 1 with the assumption of neglected saturation.



a) d-axis



a) q-axis

Fig -1: Equivalent circuit of induction motor in d -q frame

The IM model is established using a rotating (d, q) field reference concept. It is used to predict the voltage level which is required to drive the flux and torque to the demanded values within a specified time period.

$$V_{sd} = R_s i_{sd} + \frac{d}{dt}\lambda_{sd} - \omega_d \lambda_{sq}$$

(1)

$$V_{sq} = R_s i_{sq} + \frac{d}{dt}\lambda_{sq} - \omega_d \lambda_{sd}$$

(2)

$$V_{rd} = R_r i_{rd} + \frac{d}{dt}\lambda_{rd} - \omega_{dA}\lambda_{rq}$$

(3)

$$V_{rq} = R_r i_{rq} + \frac{d}{dt}\lambda_{rq} - \omega_{dA}\lambda_{rd}$$

(4)

V_{sd}, V_{sq}, V_{rd} and V_{rq} are the direct axes & quadrature axes stator and rotor voltages. The flux linkages to the currents are given by the equation (5)

$$\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\\ \lambda_{rd}\\ \lambda_{rq}\end{bmatrix} = M \begin{bmatrix} i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix}; M = \begin{bmatrix} L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix}$$

(5)

The electrical part of an Induction Motor can be described, by combining the above equations we get equation (6).

$$\begin{bmatrix} i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix} = \frac{1}{L_m^2 - L_r L_s} \times \left(A \begin{bmatrix} i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix} + \begin{bmatrix} L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix} \begin{bmatrix} V_{sd}\\ V_{sq}\\ V_{rd}\\ V_{rq}\end{bmatrix}\right)$$

(6)

Where, A is given by

$$A = \begin{bmatrix} L_r R_s & (\omega_{dA} L_m^2 - \omega_s L_r L_s) & -L_m R_r & -L_r L_m(\omega_s - \omega_{dA})\\ -(\omega_{dA} L_m^2 - \omega_s L_r L_s) & L_r R_s & L_r L_m(\omega_s - \omega_{dA}) & -L_m R_r\\ -L_m R_s & L_s L_m(\omega_s - \omega_{dA}) & L_s R_r & (\omega_s L_m^2 - \omega_{dA} L_r L_s)\\ -L_s L_m(\omega_s - \omega_{dA}) & -L_m R_s & -(\omega_s L_m^2 - \omega_{dA} L_r L_s) & L_s R_r \end{bmatrix}$$

(7)

The instantaneous torque is given by,

$$T_{em} = \frac{P}{2}\left(\lambda_{rq} i_{rd} - \lambda_{rd} i_{rq}\right)$$

(8)

The electromagnetic torque is given by,

$$T_{em} = \frac{P}{2} L_m\left(i_{sq} i_{rd} - i_{sd} i_{rq}\right)$$

(9)

The mechanical part of the motor is modeled by the equation,

$$\frac{d}{dt}\omega_{Mech} = \frac{T_{em} - T_L}{J_{EQ}} = \frac{\frac{P}{2} L_m\left(i_{sq} i_{rd} - i_{sd} i_{rq}\right) - T_L}{J_{eq}}$$

(10)

3. SVM CONTROL OF AN INDUCTION MOTOR IN OPEN LOOP

Space Vector Modulation (SVM) is an algorithm for the control of Pulse Width Modulation (PWM). With various forms of PWM, the SPWM and SVPWM are the most general two forms. SVPWM can raise the maximum output voltage with maximum line voltage approaching 70.7% of DC link voltage in the linear modulation range when compared to SPWM (11). It is proposed to control Voltage Source Inverter supplied Induction Motor. The figure 2 shows the three phase VSI.

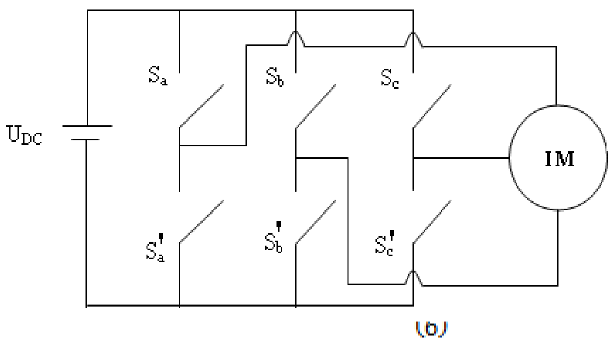


Fig -2: Three phase VSI

From the figure 2, it is clear that, two switches in same arm never be activated simultaneously because it will lead to short circuit of DC source. So, the signals are created for upper switches in the arm and its complementary is given to the lower switches. The possible combinations of switching are stated in figure 3.

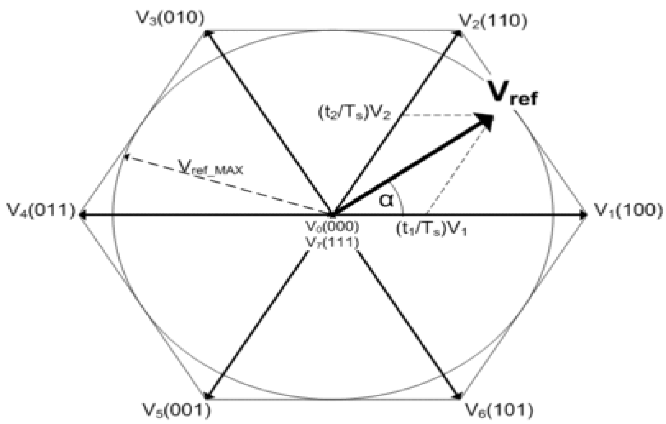


Fig -3: Vectors of SVM

The switching sequences are shown in table 1. The switching state 0 represents OFF and 1 is for ON.

Table -1: Switching sequences of SVM

Vector	Sa	Sb	Sc	Sa'	Sb'	Sc'	V_{AB}	V_{BC}	V_{CA}	Status of vector
V_0 = {000}	0	0	0	1	1	1	0	0	0	zero vector
V_1 = {100}	1	0	0	0	1	1	$+V_{dc}$	0	$-V_{dc}$	active vector
V_2 = {110}	1	1	0	0	0	1	0	$+V_{dc}$	$-V_{dc}$	active vector
V_3 = {010}	0	1	0	1	0	1	$-V_{dc}$	$+V_{dc}$	0	active vector
V_4 = {011}	0	1	1	1	0	0	$-V_{dc}$	0	$+V_{dc}$	active vector
V_5 = {001}	0	0	1	1	1	0	0	$-V_{dc}$	$+V_{dc}$	active vector
V_6 = {101}	1	0	1	0	1	0	$+V_{dc}$	$-V_{dc}$	0	active vector
V_7 = {111}	1	1	1	0	0	0	0	0	0	zero vector

In the possible eight vectors first and last vector are zero vectors. In zero vectors, all the three switches either in upper or lower arm is activated. Thus, it produces zero voltage. The other six vectors are active vectors. In this paper, VSI is controlled using Space vector modulation to drive the induction motor.

In this method no signals are feedback to the SVM to control the inverter voltage. So it is an open loop control and runs motor in single speed. It necessitates the controller in closed loop system to run adjustable speed drive.

4. Vector Control of an Induction Motor Drive

Vector control of an Induction motor drive essentially consists of two parts such as speed controller and hysteresis current controller. The block diagram of a drive is shown in figure 4.

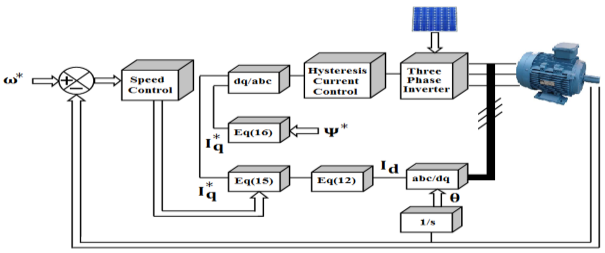


Fig -4: Block diagram of Vector controlled Induction motor drive

Induction motor is motorized from Voltage Source Inverter supplied by PV source. The Induction motor speed and three phase current from inverter are sensed inputs for vector control. In a Speed controller, the actual speed of machine is compared with the reference speed. The error speed is processed by PI to generate reference torque T*. Meantime, the three phase inverter current Iabc is converted into dq frame using (11). In balanced circuits, usage of dqo transform reduces three AC magnitudes into two DC quantities. Calculations may be made on imaginary DC quantities before the inverse transform in order to develop the actual results. The dqo transform is called as Park's transformation.

$$I_{dqo} = TI_{abc} = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (11)$$

From the I_d the actual flux is calculated using (12),

$$\Psi = L_m * \frac{I_d}{1 + T_r} \quad (12)$$

Where, L_m - Mutual Inductance, T_r - Torque. From the flux, the Electrical angle θ is calculated using (13)

$$\theta = \int (w_r + w_m) \quad (13)$$

$$w_r = L_m * \frac{I_q}{T_r * \Psi} \quad (14)$$

ω_r is the Rotor frequency (rad/s) and ω_m is the Rotor mechanical speed (rad/s).

The reference I_q^* is calculated from flux and reference torque T* as shown in (15).

$$I_q^* = (2/3) * (2/p) * (L_r/L_m) * (T_e^*/\Psi) \quad (15)$$

Where, P – No. of poles and L_r - Rotor Inductance. The reference Id* is calculated from reference flux Ψ* shown in (16)

$$I_d^* = \frac{P_{hir}^*}{L_m} \quad (16)$$

The reference I_d^* and I_q^* are converted into an I_{abc}^* using inverse park transform (17)

$$I_{abc} = T^{-1} I_{dqo} = \sqrt{\frac{2}{3}} \begin{bmatrix} cos(\theta) & -sin(\theta) & \frac{\sqrt{2}}{2} \\ cos\left(\theta - \frac{2\pi}{3}\right) & -sin\left(\theta - \frac{2\pi}{3}\right) & \frac{\sqrt{2}}{2} \\ cos\left(\theta + \frac{2\pi}{3}\right) & -sin\left(\theta + \frac{2\pi}{3}\right) & \frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ I_o \end{bmatrix} \quad (17)$$

The reference three phase current I_{abc}^* is compared with actual current I_{abc} in Hysteresis current controller and generates pulses to three phase hex bridge inverter to feed induction motor drive. So, the motor is controlled to set speed with controlled magnetic flux.

5. SPEED CONTROL USING PI CONTROLLER

PI controller is the simplest control method and widely used in industries. Proportional plus Integral (PI) Controller increases the speed of response of the system [12] and produces low steady state error. PI controller is proposed in this paper for T* and speed Error (e) is given as input to both PI controllers. The general equation of the PI controller is given by [13],

$$U(s) = K_p E(s) + \frac{k_i}{s} E(s) \quad (18)$$

Where K_p is proportional gain, K_i is the integral gain, E(s) is the controller input and U(s) is the controller output. Figure 5 shows the block diagram of PI controller.

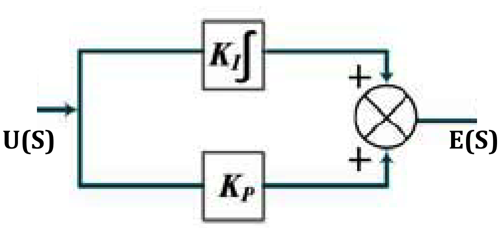


Fig -5: Block diagram of PI controller

In this paper Ziegler Nichols' method of tuning is implemented to find the optimum value of K_p & K_i values. But high overshoot and long settling time are the drawback of this controller.

6. PV PANEL

The solar modules (photovoltaic PV cell) generate DC electricity whenever sunlight falls in solar cells. Solar radiation sustains all forms of life on earth. According to estimates, the sun radiates 1.74 x 10^{17} W of power/hour to earth the daily solar energy radiation varies from 4-7 kWh/m^2 and there are 270-300 sunny days in a year. The single PV cell produces a rather small voltage that has a less practical use. The PV panel uses many cells to generate a large amount of voltage [14].

The following parameters were used to calculate the net current of a PV cell.

Saturation current of the diode, Io, Net current I, Light-generated current inside the cell I_L, Series resistance Rs (internal resistance of panel), Shunt resistance Rsh, Diode quality factor, n.

In an ideal cell Rs is 0 and Rsh is infinite. The net current of the PV cells is the difference between the output current from the PV cells and the diode current is given by [15],

$$I = I_L - I_O \left[e^{\left(q \frac{(V+IRs)}{nKT} \right)} - 1 \right] \quad (19)$$

Where, V - Voltage across PV cell, k - Boltzmann's constant (1.381 x 10^{-23} J/K), T - Junction temperature in Kelvin, q - Electron charge (1.602 x 10^{-19}C), n - Diode ideality factor (1.62). In this paper, PV panel supplies voltage source inverter [16].

7. SIMULATION RESULTS AND ANALYSIS

To analyze the performance of Vector controlled induction motor 5 HP Cage Induction Motor is taken. It is analyzed with PI and Fuzzy Logic Controller under various speeds and loads. Induction Motor parameters are shown in table 2.

Table -2: Motor Parameters

Line Voltage	415
Frequency	50 Hz
Stator Resistance (R_s)	1.15Ω
Rotor Resistance (R_r)	1.083Ω
Stator inductance (L_s)	5.974 mH
Rotor inductance (L_r)	5.974 mH
Mutual inductance (L_m)	0.2037H
Moment of Inertia (J)	0.02 Kg.m^2
Number of poles (P)	4

The performance of the motor using space vector modulation is shown in figure 6. The performance is analyzed under no load while the machine is running.

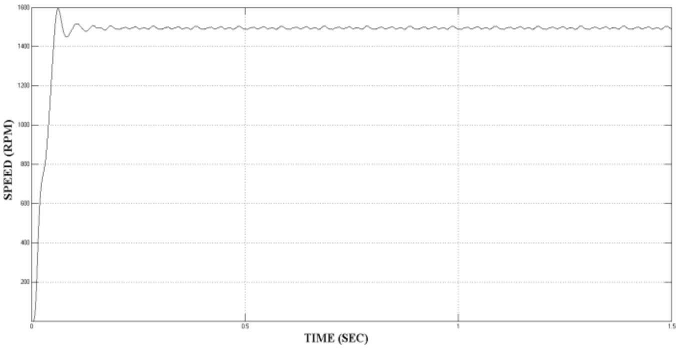


Fig -6: Speed performance of SVM based open loop control

The performance of the motor using PI based vector control is shown in figure 7. The performance is analyzed under no load while the machine is running.

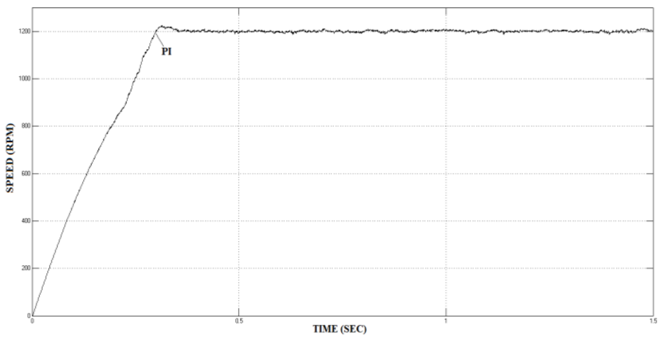


Fig -7: Speed performance of PI based vector control

The performance of the motor using SVM is shown in figure 8. The performance is analyzed under change in load while the machine is running.

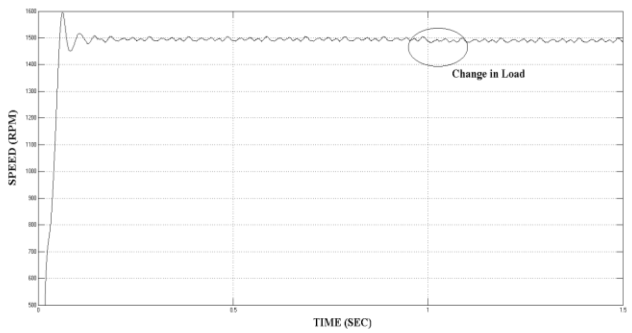


Fig -8: Speed performance of SVM based open loop control with change in load

The figure 8 shows the speed response of the SVM controller during changes in load it produces a large drop in speed.The performance of the motor using PI based vector control is shown in figure 9. The performance is analyzed with same conditions as in SVM.

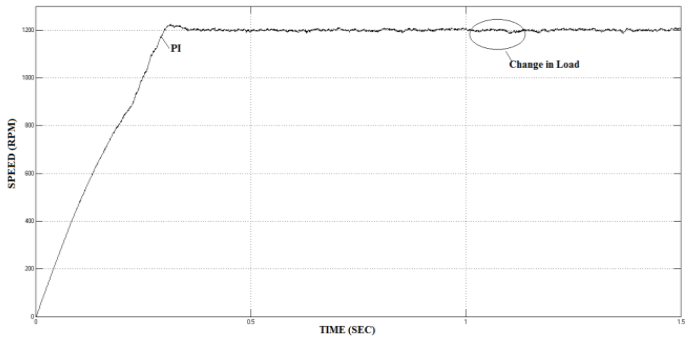


Fig -9: Speed performance of PI based vector control with change in load

The performance comparison of open loop using SVM and closed loop with PI controller is shown in table 3.

Table -2: Performance comparison of SVM and PI Controller

Controllers	Vector drive (PI)	Open loop (SVM)
Overshoot (%)	1.67	6
Steady state error (%)	2	2.1
Settling time (Sec)	0.42	0.18
Drop in speed during the change in Load (%)	1.17	1.27

8. CONCLUSIONS

Induction motors are widely used in many industries and for pumping in domestic applications. PV power reduces more power consumption from the power grid and pollution free source in all application places. Adjustable speed drive is the most used application of an induction motor. The vector control method produces good dynamic performance in an induction motor because of its magnetic flux control. In this paper, simulation results of a drive in open loop using SVM and closed loop vector drive using PI controller are compared. The entire system is simulated using Matlab/Simulink. From the results it is confirmed that the vector drive using PI controller reduces peak overshoot, steady state error and speed drop during a change in load. So it declares that PI based vector controlled drive is optimized for startup, steady state and dynamic state.

REFERENCES

[1] Islam N., Haider M. and Uddin M. B., ,(2005) "Fuzzy logic enhanced speed control system of a VSI- fed three phase induction motor", Proceedings of 2nd International Conference on Electrical And Electronics Engineering, pp. 296-301,2005.

[2] Ustun S.V. and Demirtas M. (2008), "Optimal tuning of PI coefficients by using fuzzy-genetic for V/f controlled induction motor", Expert System with Application, vol. 34, no. 4, pp. 2714-2720,2008.

[3] Xiang-Dong Sun, Kang-Hoon Koh, Byung-Gyu Yu, and Mikihiko Matsui,(2009.)"Fuzzy-Logic-Based V /f Control of an Induction Motor for a DC Grid Power-Leveling System Using Flywheel Energy Storage Equipment" IEEE Transactions On industrial Electronics, Vol. 56, No. 8,2009.

[4] Da Silva, I.N., Goedtel, A. (2011) "Embedded DSP-Based Compact Fuzzy System and Its Application for Induction-Motor V/f Speed Control "IEEE Transactions on Industrial Electronics, Vol 58, Issue: 3 pp 750 – 760, 2011.

[5] Subhankar Dam, Abhrajit Saha, Dr. Pradip Kumar Saha, Dr. Goutam Kumar Panda "PID controller based closed loop control of L- matrix based induction motor using V/f constant method" Journal of Scientific Theory and Methods ,Vol 2012,1-21,2012.

[6] Mohan Krishna S, (2013), "Vector Controlled Induction Motor Drive with Constant Dc-Link Voltage", International Journal of Electrical and Electronics Engineering Research, Vol 3 (1), pp: 221-230.

[7] Sam C. M. Huiand Miss S. C. Chan, **"**Integration of green roof and solar photovoltaic systems", Integrated Building Design in the New Era of Sustainability, 2011.

[8] Jain S, Agarwal V. A Single-stage grid connected inverter topology for solar PV Systems with maximum power point tracking, IEEE Transactions on Power Electronics, 2007; 22:1928–40.

[9] M. Kalantar, S.M. Mousavi G, "Dynamic behavior of a stand-alone integrated power generation system of wind turbine, micro turbine, solar array and battery storage", Applied Energy, vol 87, 2010, pp. 3051–3064.

[10] Ashok Kusagur, S. F. Kodad and B V. Sankar Ram, 2009, **"**Modeling of Induction Motor & Control of Speed Using Hybrid Controller Technology", Journal of Theoretical and Applied Information Technology**,** pp: 117-126.

[11] Wei-Feng Zhang and Yue-Hui Yu, "Comparison of Three SVPWM Strategies" Journal of Electrical Science and Technology of China, Vol. 5. No.3, September 2007. pg. 283 -287.

[12] CedomirMilosavljevi´c, DraganAnti´c, DarkoMiti´c and Goran Djordjevi´, 1995, "comparative analysis of variable structure systems (VSS) with proportional plus integral (PI) control", Electronics and Energetics vol. 14, pp.1–9.

[13] C. Mohan Krishna M. Tech, G. Meerimatha M.Tech, U. Kamal Kumar M. Tech, 2013, "Indirect Vector Control of Induction Motor Using Pi Speed Controller and Neural Networks", International Journal of Modern Engineering Research (IJMER), Vol.3 (4), pp.1980-1987.

[14] Surya Kumari.J and Ch. SaiBabu, "Mathematical Modeling and Simulation of Photovoltaic Cell using Matlab-Simulink Environment", International Journal of ElectricalandComputerEngineering",Vol.2,No.1,2012,pp. 26-34.

[15] DorinPetreus, CristianFarcas, IonutCiocan, "Modelling and simulation of photovoltaic cells ACTA", Technicanapocensis Electronics an, Vol.48, No.1, 2008, pp.42-47.

[16] Rameshkumar N and Dr. Md. Zubair Rahman A.M.J., "Hybrid BELBIC based PV Powered Vector controlled Induction Motor Drive," Asian Journal of Research in Social Sciences and Humanities, Vol. 6, No. 10, pp. 994-1014, 2016.