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Vector Controlled 3Phase Induction Motor Drive using Photovoltaic

Karthika M[1], Anitha.A[2]
[1,2]Asst.professor[1], Asst.professor[2]New Horizon College of Engineering Bangalore

Abstract: In this paper, the nonlinearity in the Torque-Voltage relationship of an induction motor (IM) analysis is performed. Development of Vector Control analysis has enabled to get a good dynamic performance from an IM as a dc motor. The dynamic model of the induction motor is done by converting the 3-ø quantities into 2-axes system called the d-axis and the q-axis. The torque and the flux components can be controlled independently using vector control like in a dc motor. Vector control offers a number of benefits including speed control over a wide range, precise speed regulation, and fast dynamic response. The simulation result support that vector method settled quickly and has better performance. The proposed method offers good tracking efficiency, high response and well control for the extracted power.
Index Terms: Boost converter, Incremental conductance, v/f control, Inverter

I. INTRODUCTION

Global warming and energy policies have become a hot topic on the international agenda in the past years. Developed countries are trying to reduce their greenhouse gas emissions. For example, the EU has committed to reduce the emissions of greenhouse gas to at least 20% below 1990 levels and to produce no less than 20% of its energy consumption from renewable sources by 2020. In this context, photovoltaic (PV) power generation has an important role to play due to the fact that it is a green source.

MPPT algorithms are necessary because PV arrays have a nonlinear voltage-current characteristic with a unique point where the power produced is maximum. This point depends on the temperature of the panels and on the irradiance conditions. Both conditions change during the day and are also different depending on the season of the year. Furthermore, irradiation can change rapidly due to changing atmospheric conditions such as clouds. It is very important to track the MPP accurately under all possible conditions so that the maximum available power is always obtained. In this paper incremental conductance method is proposed.

The induction motor, which is the most widely used motor type in the industry, has been favored because of its good self-starting capability, simple and rugged structure, low cost and reliability, etc. Along with variable frequency AC inverters, induction motors are used in many adjustable speed applications which do not require fast dynamic response. The concept of vector control has opened up a new possibility that induction motors can be controlled to achieve dynamic performance as good as that of DC or brushless DC motors.

II. PROPOSED TOPOLOGY

The induction motor is the most widely used electrical motor due to its rugged structure, low cost and reliability. However, the nonlinearity in the Torque-Voltage relationship of an IM makes its analysis difficult. Also it is a fifth order system making its dynamic response poor. Development of Vector Control analysis has enabled us to get as good dynamic performance from an IM as a dc motor. The torque and the flux components can be controlled independently using vector control just like in a dc motor. In order to analyses vector control, we need to develop a dynamic model of the IM. This is done by converting the 3-ø quantities into 2-axes system called the d-axis and the q-axis. Such a conversion is called axes transformation. The d-q axes can be chosen to be stationary or rotating. Further, the rotating frame can either be the rotor oriented or magnetizing flux oriented. However, synchronous reference frame in which the d-axis is aligned with the rotor flux is found to be the most convenient from analysis point of view. A major disadvantage of the per phase equivalent circuit analysis is that it is valid only if the three phase system is balanced. Any imbalance in the system leads to erroneous analysis. Even this problem is eradicated if we use the d-q model. The present single-switch type soft-switching boost converter which is used in PV power conditioning system can minimize the switching loss by adopting a resonant soft-switching method. However, the drawback of this converter is that the voltage across the switch is very high during the resonance mode. The voltage across the switch depends on the parameters of the resonant components and the resonant inductor current.

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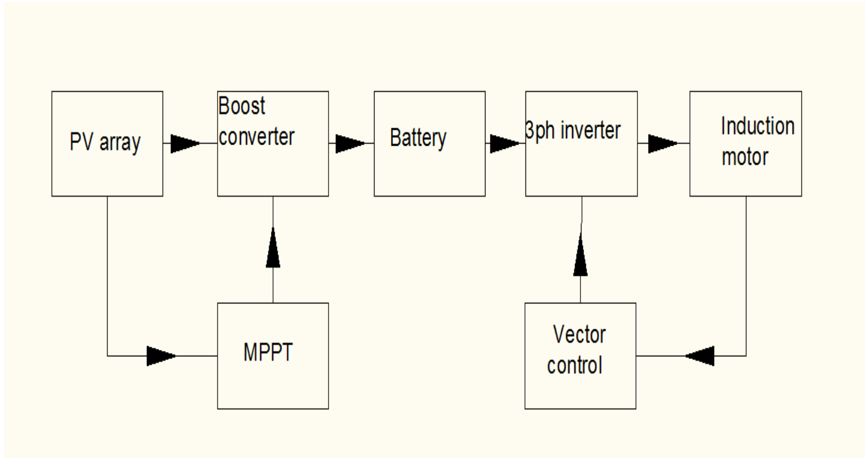


Fig. 1 Block diagram representation of proposed topology

The v/f control principle adjust constant volt-per –Hertz ratio of the stator voltage by feed forward control. It serves to maintain magnetic flux in the machine at desired level .it satisfy only moderate dynamic requirement .High dynamic performance is achieved by field orientation ,also called Vector control. The technique called vector control can be used to vary the speed of an induction motor over a wide range. In the vector control scheme, a complex current is synthesized from two quadrature components, one of which is responsible for the flux level in the motor, and another which controls the torque production in the motor. Essentially, the control problem is reformulated to resemble the control of a DC motor.

Vector control offers a number of benefits including speed control over a wide range, precise speed regulation, fast dynamic response, and operation above base speed. The vector control algorithm is based on two fundamental ideas. The first is the flux and torque producing currents. An induction motor can be modeled most simply (and controlled most simply) using two quadrature currents rather than the familiar three phase currents actually applied to the motor. These two currents called direct (Id) and quadrature (Iq) are responsible for producing flux and torque respectively in the motor. By definition, the Iq current is in phase with the stator flux, and Id is at right angles. Of course, the actual voltages applied to the motor and the resulting currents are in the familiar three-phase system. The move between a stationary reference frame and a reference frame, which is rotating synchronous with the stator flux, becomes then the problem. This leads to the second fundamental idea behind vector control. The second fundamental idea is that of reference frames. The idea of a reference frame is to transform a quantity that is sinusoidal in one reference frame, to a constant value in a reference frame, which is rotating at the same frequency.

A. Proposed Incremental Conductance algorithm.

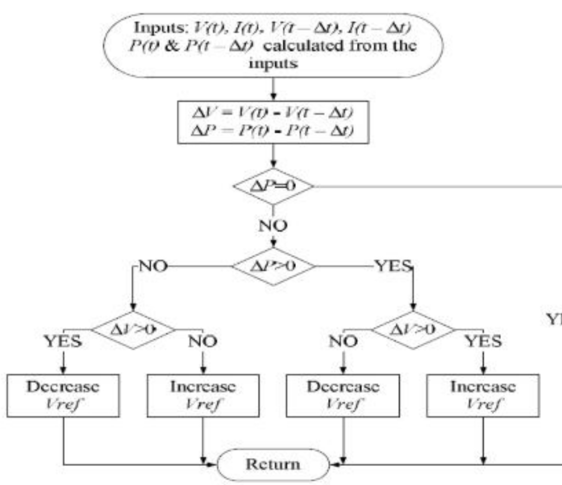


Fig.2 Incrementa Conductance algorithm.

Fig2. Shows Incremental Conductance algorithm proposed in this paper.

The incremental conductance algorithm is based on the fact that the slope of the curve power vs. voltage (current) of the PV module is zero at the MPP, positive (negative) on the left of it and negative (positive) on the right, as can be seen in Figure 3.3 and 3.4.

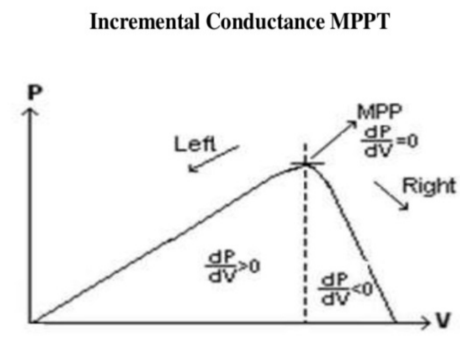


Fig3. PV Characteristics.

dP/dV=0 (ΔI/ΔV= -I/V), at the MPP.
dP/dV>0 (ΔI/ΔV> -I/V), left of MPP.
dP/dV<0 (ΔI/ΔV< -I/V), left of MPP.
dP/dV= d(IV)/Dv = I+VdI/dV = I+VΔI/ΔV By comparing the increment of the power vs. the increment of the voltage (current) between two consecutives samples, the change in the MPP voltage can be determined.
This method exploits the assumption of the ratio of change in output conductance is equal to the negative output Conductance Instantaneous conductance. We have,

$$P = V I$$

Applying the chain rule for the derivative of products yields to ∂P/∂V = [∂(VI)]/ ∂V At MPP, as ∂P/∂V=0The above equation could be written in terms of array voltage V and array current I as ∂I/∂V = - I/V .The MPPT regulates the PWM control signal of the dc – to – dc boost converter until the condition: (∂I/∂V) + (I/V) = 0 is satisfied. In this method the peak power of the module lies at above 98% of its incremental conductance.

B. Principle of operation of Boost converter

The main working principle of boost converter is that the inductor in the input circuit resists sudden variations in input current. When switch is OFF the inductor stores energy in the form of magnetic energy and discharges it when switch is closed. The capacitor in the output circuit is assumed large enough that the time constant of RC circuit in the output stage is high. The large time constant compared to switching period ensures a constant output voltage $V_o(t) = V_o(\text{constant})$.
Fig 4.illustrates the circuit action during the initial high period of the high frequency square wave applied to the MOSFET gate at start up. During this time MOSFET conducts, placing a short circuit from the right hand side of L1 to the negative input supply terminal. Therefore a current flows between the positive and negative supply terminals through L1, which stores energy in its magnetic field. There is virtually no current flowing in the remainder of the circuit as the combination of D1, C1 and the load represent a much higher impedance than the path directly through the heavily conducting MOSFET.

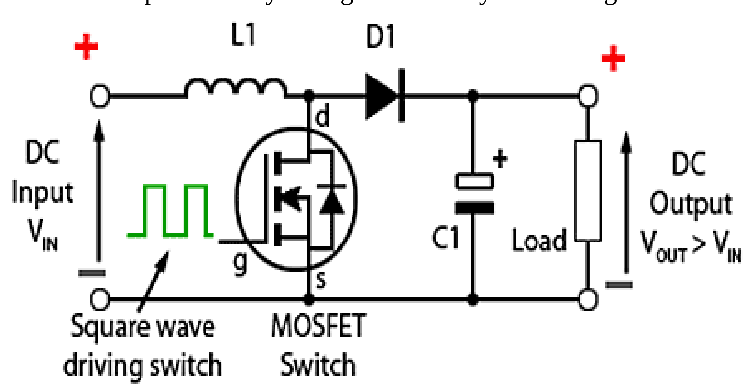


Fig 4. Boost Converter Operation at Switch On.

C. Inverter

A solar inverter, or PV inverter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. It is a critical component in a photovoltaic system, allowing the use of ordinary commercial appliances.

In string inverter, panels are connected in series to produce an array. The power then runs to an inverter, which converts it into standard AC voltage. The main problem with the "string inverter" approach is the string of panel acts as if it were a single larger panel with a max current rating equivalent to the poorest performer in the string. If a panel is shaded its output drops dramatically, affecting the output of the string, even if the other panels are not shaded. Even slight changes in orientation can cause output loss in this fashion. Additionally, the efficiency of a panel's output is strongly affected by the load the inverter places on it. The same issues that cause output to vary from panel to panel, affect the proper load that the MPPT system should apply.

a single panel operates at a different point, a string inverter can only see the overall change, and moves the MPPT point to match. This results in not just losses from the shadowed panel, but the other panels too. Another issue, though minor, is that string inverters are available in a limited selection of power ratings. This means that a given array normally up sizes the inverter to the next largest model over the rating of the panel array. Other challenges associated with centralized inverters include the space required to locate the device, as well as heat dissipation requirements. Large central inverters are typically actively cooled. Cooling fans make noise,

Micro-inverters produce grid-matching power directly at the back of the panel. Arrays of panels are connected in parallel to each other, and then to the grid. This has the major advantage that a single failing panel or inverter cannot take the entire string offline. Combined with the lower power and heat loads, and improved MTBF, some suggest that overall array reliability of a micro-inverter-based system is significantly greater than a string inverter based one. Additionally, when faults occur, they are identifiable to a single point, as opposed to an entire string. This not only makes fault isolation easier, but unmasks minor problems that might not otherwise become visible – a single underperforming panel may not affect a long string's output enough to be noticed. Being small amounts of shading, debris or snow lines on any one solar panel, or even a complete panel failure, does not disproportionately reduce the output of the entire array. Each micro-inverter harvests optimum power by performing maximum power point tracking for its connected panel. They are also simple to design and stock, as there is normally only a single model of inverter that can be used with any size array and a wide variety of panels..

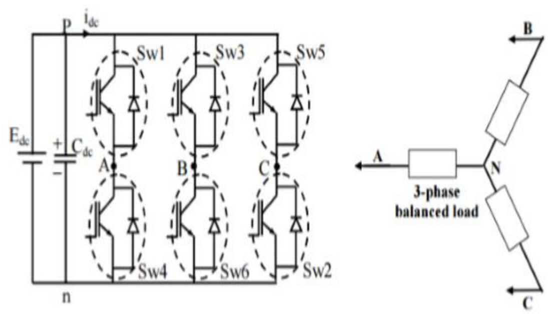


Fig5. Three-Phase Inverter.

D. Implementation Of A Vector Controlled Induction Motor Drive

The control is based on the speed and flux of motor. So the flux and speed values are given as reference signals. By using these reference signals the controlled pulses are generated by using SPWM technique.

High dynamic performance, which is obtained from dc motors, became achievable from induction motors with the recent advances in power semiconductors, digital signal processors and development in control techniques. By using field oriented control, torque and flux of the induction motors can be controlled independently as in dc motors. The control performance of field oriented induction motor drive greatly depends on the correct stator flux estimation. In this thesis voltage model is used for the flux estimation. Stator winding resistance is used in the voltage model. Also leakage inductance, mutual inductance and referred rotor resistance values are used in vector control calculations.

1) *Vector or Field oriented control:* The scalar control is somewhat easier to implement, but the inherent coupling effect (i.e. both torque flux are functions of voltage or current and frequency) gives sluggish response and the system is easily prone to instability because of higher order system effect. To make it more clear, if, for example, if the torque is increased by incrementing the slip (i.e. the frequency), the flux tends to decrease. Note the flux variation is always sluggish. The decrease is then compensated by the sluggish flux loop by feeding in additional voltage. This temporary dip in flux reduces the torque

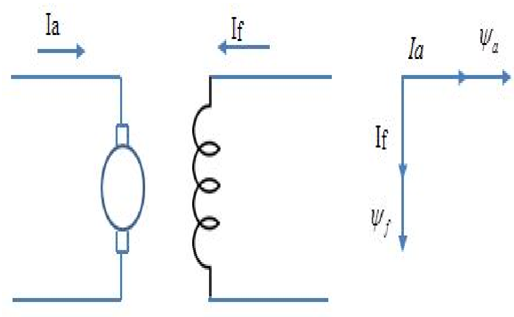
sensitivity with slip and lengthens the response time. This explanation is also valid for current fed inverter drives. The foregoing problems can be solved by vector control or field – oriented control. The invention of vector control is in the beginning of 1970s, and the demonstration that the induction motor can be controlled like a separately excited dc motor, brought a renaissance in high performance control of ac drives. Because of dc machine like performance, vector control is also known as decoupling, orthogonal or trans vector control. Vector control is applicable to both induction and synchronous motor drives. Undoubtedly, vector control and the corresponding feedback signal processing, particularly for modern sensor less vector control, are complex and the use of powerful microcomputer or DSP is mandatory. It appears that eventually, vector control will oust scalar control, and will be accepted as industry standard control for ac drives.

2) *DC drive analogy:* Ideally, a vector-controlled induction motor drive operates like a separately excited DC motor drive, as mentioned above; Figure 8.1 explains this analogy. In a DC machine, neglecting the armature reaction effect and field saturation, the developed torque is given by,

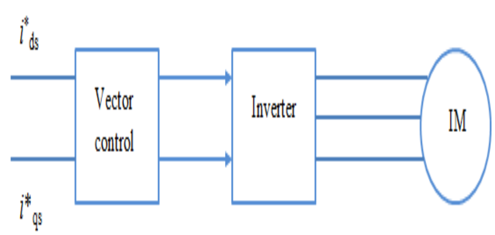
$T_d = K'I_aI_f$

Where ia = armature current and if= field current

DC machine like performance can also be extended to an induction motor if the machine control is considered in a synchronously rotating reference frame [de-qe], where the sinusoidal variables appear as DC quantities in steady state. In figure, the induction motor with the inverter and vector control in the front end is shown with two control inputs ids and iqs.



(a)



(b)

Fig6. (a) Separately excited DC motor, (b) Vector controlled Induction motor

The current is divided into two components. These currents are the direct axis component and quadrature axis component of the stator axis component, respectively, in a synchronously rotating reference frame. With vector control, ids is analogous to field current if and iqs is analogous to armature current ia of a dc machine. Therefore, the torque
torque can be expressed as,

T = Kt'*Ir*Iqs

This DC Machine like performance is possible if I_{ds} is oriented in the direction of flux and I_{qs} is established perpendicular to it. This means I_{qs} is controlled and which is not affecting the flux. Similarly, if I_{ds} is controlled then which only affect the flux.

This vector or field orientation of currents is essential under all operating conditions in a vector-controlled drives. Note that when compared to dc machine space vectors, induction machine space vectors rotate synchronously at a frequency (ω_e). as indicated in the figure. In summary, vector control should assure the correct orientation and equality of command and actual currents.

The developed torque may be expressed as,

$$\mathbf{T_{em} = K_a\varphi(I_f)I_a}$$

K_a = Constant Co-efficient.
$\varphi(I_f)$ = Field Flux.
I_a = Armature Current.

The Torque angle naturally 90 degrees, Flux may be controlled by the varying the Field current. I_f and the Torque is controlled by independently of flux by adjusting the armature current.

3) *Principles of Vector Control:* The fundamentals of vector control implementation can be explained with the help of figure 3.4 where the machine model is represented in a synchronously rotating reference frame. The inverter is omitted from the figure, assuming that it has unity current gain, that is it generates currents ia, ib and ic as dictated by the corresponding command currents *ia*, *ib*and *ic* from the controller.

The machine terminal phase current is converted into Ids and Iqs by 3-phase and 2-phase transformer. These are then converted into synchronously rotating frame by unit vector components $\cos\theta_e$ and $\sin\theta_e$ before applying them to a d^e-d^q machine model.

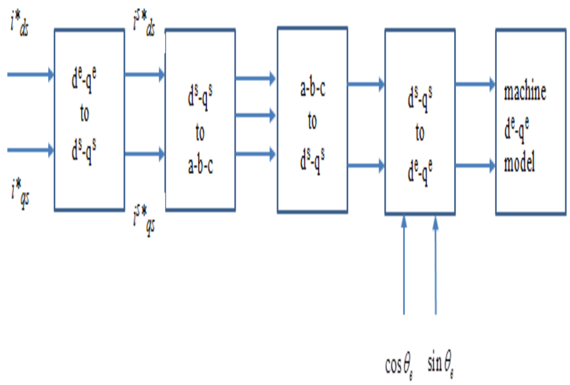


Fig7. Vector Control Implementation Principle with Machine de-qe Model

4) *There are 2 types of Vector Control*
a) Direct or Feedback method
b) Indirect or Feed-Forward method

These methods are different essentially by how the unit vector is generated for the control. Orientation with rotor flux, air gap flux and stator flux is possible in vector control. However, rotor flux orientation gives natural decoupling control, whereas air gap or stator flux orientation gives a coupling effect which has to be compensated by a decoupling compensation current. Vector control methods based in the orientation of the machine‘s magnetic field along one of the rotating reference axis makes it possible to uncouple the rotor magnetic field from the electromagnetic torque. The equations obtained within the reference framework selected permit the implementation of a control scheme for the induction motor, thus achieving dynamic response similar to that given by a separately excited dc motor.

The possibility to use the squirrel cage motor in high performance control systems in which a dynamic response similar to that given by dc motor opens up new applications in industry for this type of motors. In both methods, it is necessary to determine correctly the orientation of the rotor flux vector, lack of which leads to degradation in the speed
control of the motor.

Vector control is the most popular control technique of AC induction motors. In special reference frames, the expression for the electromagnetic torque of the smooth-air-gap machine is similar to the expression for the torque of the separately excited DC machine. In the case of induction machines, the control is usually performed in the reference frame (d-q) attached to the rotor flux space vector. That‘s why the implementation of vector control requires information on the modulus and the space angle (position) of the rotor flux space vector. The stator currents of the induction machine are separated into flux- and torque- producing components by utilizing transformation to the d-q coordinate system, whose direct axis (*d*) is aligned with the rotor flux space vector. That means that the *q*-axis component of the rotor flux space vector is always zero:

$$\psi_{rq} = 0 \text{ and } d/dt\psi_{ra} = 0$$

The rotor flux space vector calculation and transformation to the d-q coordinate system require the high computational power of a microcontroller; a digital signal processor is suitable for this task. This section deals with the software implementation of the vector control of induction motor drive.

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5) *AC Induction Motor Vector Control :*Fig8.shows the basic structure of the vector control of the AC induction motor. To perform vector control, follow these steps :

a) Measure the motor quantities (phase voltages and currents)
b) Transform them to the 2-phase system (α,β) using a Clarke transformation.
c) Calculate the rotor flux space vector magnitude and position angle.
d) Transform stator currents to the d-q coordinate system using a Park transformation.
e) The stator current torque- (isq) and flux- (isd) producing components are separately controlled.
f) The output stator voltage space vector is calculated using the decoupling block.
g) An inverse Park transformation transforms the stator voltage space vector back from the d-q coordinate system to the 2-phase system fixed with the stator.
h) Using the space vector modulation, the output 3-phase voltage is generated.
i) Forward and Inverse Clarke Transformation (a,b,c to αβ and backwards) :

The forward Clarke transformation converts a 3-phase system (a, b, c) to a 2-phase coordinate system (α, β). Figure 8 shows graphical construction of the space vector and projection of the space vector to the quadrature-phase components α, β.

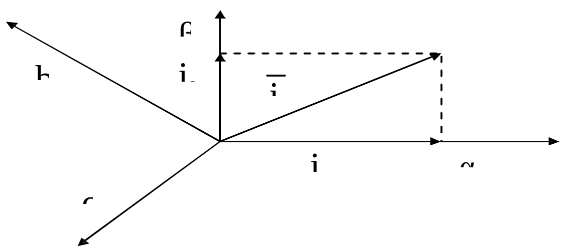

Fig8. Stator current space vector and its components in (α,β)

6) *Forward and Inverse Park Transformation (αβ to d-q and backwards) :*

The components *is*α and *is*β, calculated with a Clarke transformation, are attached to the stator reference frame α, β. In vector control, all quantities must be expressed in the same reference frame. The stator reference frame is not suitable for the control process. The space vector $i_s$is rotating at a rate equal to the angular frequency of the phase currents. The components *is*α and *is*β depend on time and speed. These components can be transformed from the stator reference frame to the d-q reference frame rotating at the same speed as the angular frequency of the phase currents. The *isd* and *isq* components do not then depend on time and speed. If the *d*-axis is aligned with the rotor flux, the transformation is illustrated in Figure 8.4, where ϴ is the rotor flux position.

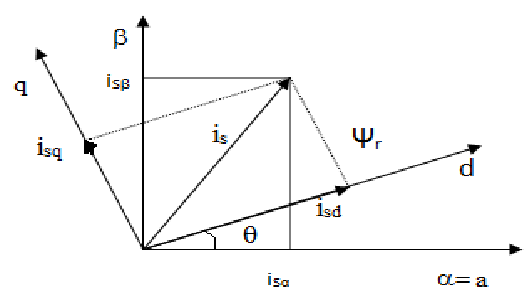

Fig9.Stator current space vector and its component in (α,β) and in the d,q rotating reference frame

The components *isd* and *isq* of the current space vector in the d-q reference frame are determined by the following equations:

$$I_{s\beta} = I_{sd}\sin\theta + I_{sq}\cos\theta$$

$$I_{sq} = -I_{s\alpha}\sin\theta + I_{s\beta}\cos\theta$$

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The component *isd*is called the direct axis component (the flux-producing component) and *isq*is called the quadrature axis component (the torque-producing component). They are time invariant; flux and torque control with them is easy. To avoid using trigonometric functions on the hybrid controller, directly calculate sinθ and cosθ using division, defined by the following equations:

$$\psi_{rd} = \sqrt{\psi_{r\alpha}^2 + \psi_{r\beta}^2}$$

$$\sin\theta = \frac{\psi_{r\beta}}{\psi_{rd}}$$

$$\cos\theta = \frac{\psi_{r\alpha}}{\psi_{rd}}$$

The inverse Park transformation from the d-q to α, β coordinate system is found by the following equations:

$$i_{s\alpha} = i_{sd}\cos\theta - i_{sq}\sin\theta$$

$$i_{s\beta} = i_{sd}\sin\theta + i_{sq}\cos\theta$$

III. SIMULATION RESULTS

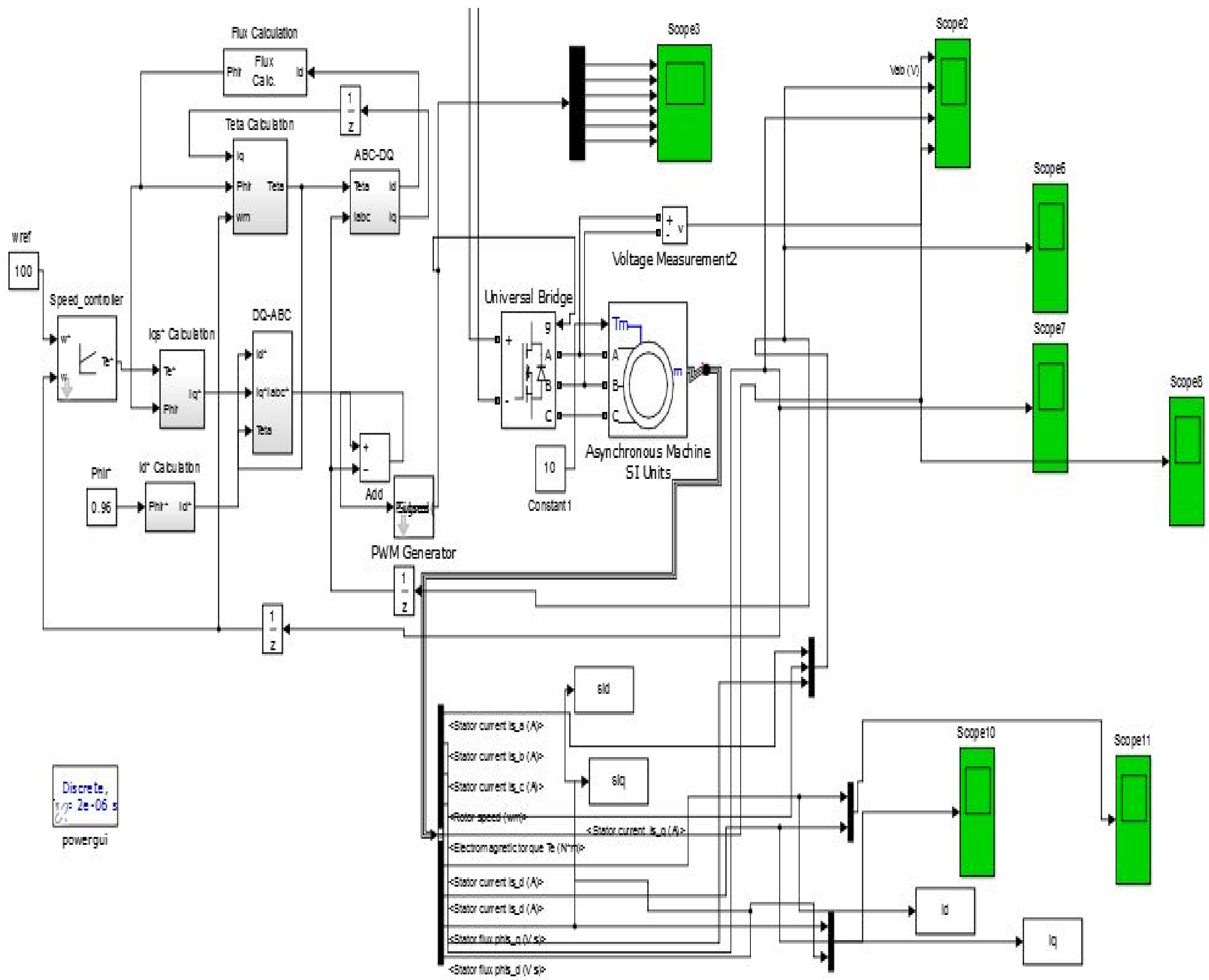

Fig.5 SimuLink Diagram Of Proposed Converter for the speed control of dc motor

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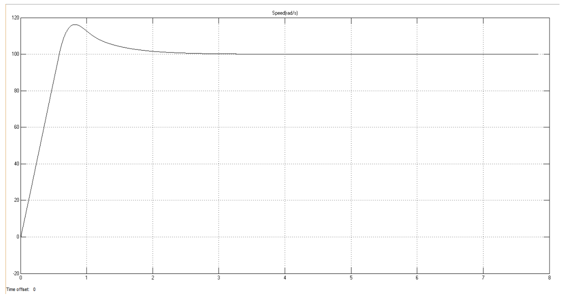

Fig10.Speed response of vector control IM

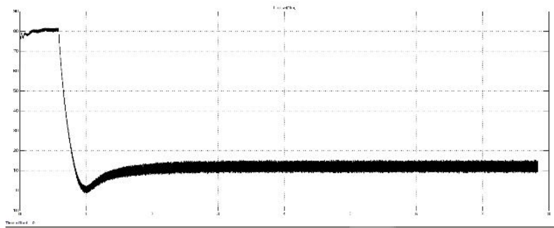

Fig11.Torque response of vector control IM

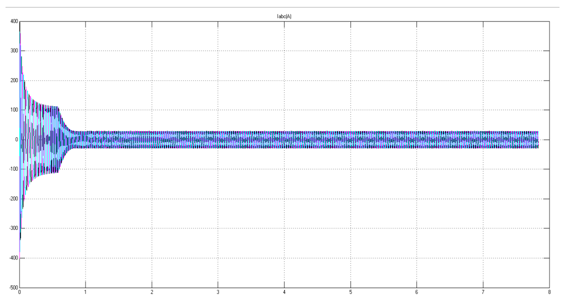

Fig12.Current response of vector control IM

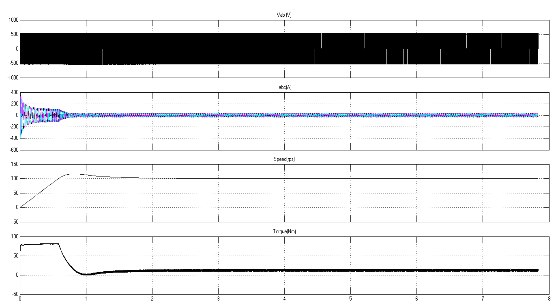

Fig.9Simulation response of vector control of IM

IV. CONCLUSION

The report proposes a simple MPPT algorithm called Incremental conductance Method. This method computes the maximum power and controls directly the extracted power from the PV. The proposed method offers different advantages which are: good tracking efficiency, response is high and well control for the extracted power.

The vector control method or the d-q axes model leads to a simpler analysis of an induction motor. A d-q axes model with the d-axis aligned along the synchronously rotating rotor frame, leads to the decoupled analysis where the torque and the flux components can be independently controlled just like in case of a dc motor.

Vector control offers a number of benefits including speed control over a wide range, precise speed regulation, fast dynamic response. The simulation result support that vector method settled quickly and has better performance.

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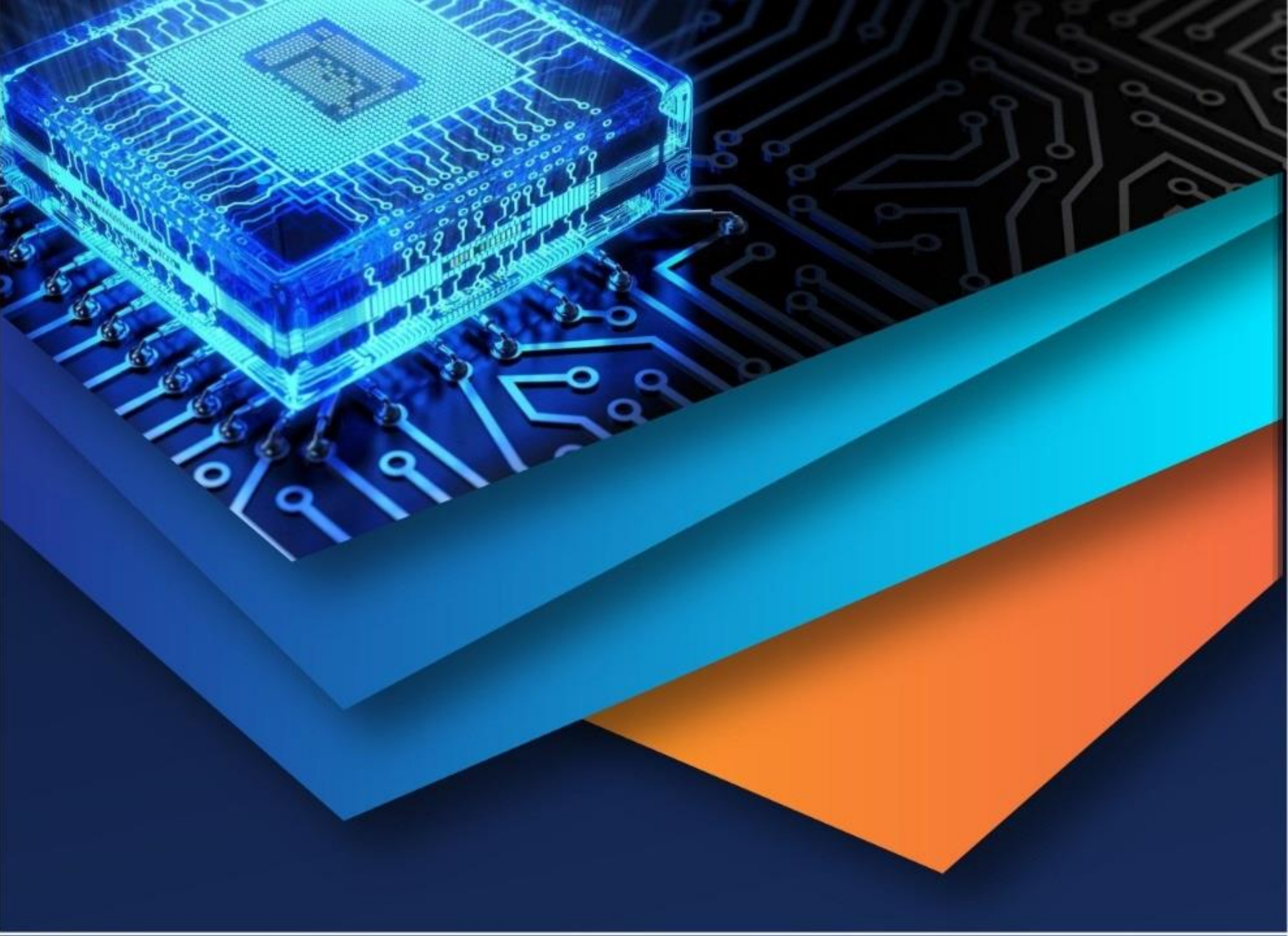

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ISRA JIF IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL IMPACT FACTOR: 7.429

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