# DESIGN AND DEVELOPMENT OF CONTROLLER FOR THREE-PHASE INDUCTION MOTOR WORKING ON SINGLE-PHASE SUPPLY

**A DISSERTATION**

***Submitted in partial fulfillment of the requirements for the award of the degree***

***of***

MASTER OF TECHNOLOGY

***in***

ELECTRICAL ENGINEERING

(With Specialization in Power Apparatus and Electric Drives)

***By***


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# CANDIDATE'S DECLARATION

I hereby declare that the work presented in this dissertation entitled ***"Design and Development of Controller for Three-phase Induction Motor Working on Single-Phase Supply"*** submitted in partial fulfillment of the requirement for the award of the degree of Master of Technology with specialization in **"Power Apparatus and Electric Drives"** in the department of Electrical Engineering, Indian Institute of Technology, Roorkee, Roorkee-247667 is an authentic record of my own work carried under the guidance of Dr. S.P. Singh, Associate Professor, Department of Electrical Engineering, I.I.T. Roorkee.

Date: 30 JUNE 2006
Place:Roorkee

(Subhash Garg)

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## CERTIFICATE

This is certified that the above statement made by the candidate is correct to the best of my knowledge and belief.

30/6/06
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**(Subhash Garg)**

# ABSTRACT

Three phase induction motor is supplied from a single phase public utilities using a new unique connection of the machine windings and three capacitors to provide balanced currents and voltages in all of the windings for its efficient operation in single phase system. By change of the capacitor value in response to load change so that the efficiency in single phase operation of three-phase induction motor is close to the efficiency when motor connected to three-phase supply, for all shaft loads between 20 to 120 percent of full load, and single phase line power factor was near unity for wide range of load variation. This method is applicable to both high efficiency and standard three phase motors without motor modification, where a three-phase supply is not available, this method is applicable. This connection is called a smith connection.

The smith connection is essentially a asymmetric winding connection but the suitable choice of the capacitances, balanced current can be injected in to the motor and g windings for a given speed and load. Inspection equations are established and solved using the method of symmetrical components to simulate the motor performance analysis. Using a phase diagram approach the values of capacitances required for balanced operation can be computed.

In remote and rural region where only single-phase power supply is available standard three-phase motors can be used in place of single-phase motors. Low cost, short delivery time superior electrical performance and large power rating are the main reasons favoring the use of three phase machines in favor of single phase machine.

Experimental work has done to verify the theoretical result on a 3.7 Kw induction machine, and also describes the multi-mode operation of three-phase induction motor with the smith connection. This operation involves the selection of appropriate phase balancing capacitances that give minimum voltage and current imbalance in the motor as the rotor speed changes. A simple switching strategy is adopted by using stator input current as the control signal that determines the mode selection. A prototype multimode system (namely L-mode, M-mode and H-mode) is implemented by using a controller as a voltage comparator and relay contactor. Experimental performed on a small induction motor confirm the feasibility of the proposed controller.

# List of Figures

# List of Tables

# LIST OF SYMBOL

| | |
|---|---|
| $V$ | Applied single-phase voltage across the machine terminal |
| $I$ | Line current taken by machine |
| $I_{ph}$ | Phase current |
| $a$ | Complex operator exp $(j2\pi/3)$ |
| $\omega$ | Angular frequency component = $2\pi f$ |
| $N_b$ | Speed corresponding to perfect phase balance |
| $N_c$ | Cut-in speed |
| CS | Starting capacitor |
| $I_A$, $I_B$, $I_C$ | Phase current in A, B, and C phase winding |
| $V_A$, $V_A$, $V_C$ | Phase voltage across A, B, and C phase winding |
| $C_1$, $C_2$, $C_3$ | Value of capacitances being used for phase balancing. |
| $I_1$, $I_2$, $I_3$ | Current flowing through capacitor $C_1$, $C_2$, and $C_3$ |
| $V_1$, $V_2$, $V_3$ | Voltage across capacitor $C_1$, $C_2$ and $C_3$ |
| $Y_1$, $Y_2$, $Y_3$ | Admittance of balancing capacitors. (Motor) |
| $B_1$, $B_2$, $B_3$ | Admittance of phase balancing capacitors (Generator) |
| $V_0$, $V_p$, $V_n$ | Sequence components of voltage |
| $I_0$, $I_1$, $I_2$ | Sequence components of current |
| $Y_p$, $Y_p$, $Y_n$ | Sequence components of admittance. |
| $\Phi_p$ | Impedance angle (power factor angle of machine) |
| $\alpha$ | Angle between $I_C$ and $I_2$ |
| $\beta$ | Angle between $I_C$ and $I_1$ |
| $\varepsilon$ | Angle between $I_2$ and $I_1$ |
| $\delta$ | Angle between $V$ and $-I_B$ |
| $\xi$ | Angle between $I_2$ and $-I_B$ |

# Contents

# CHAPTER-1

# INTRODUCTION

## 1.1 GENERAL

A large number of fractional-Kw a.c motor are design to operate from a single-phase supply. Uses of fractional-Kw a.c motors are required to do the useful work, as for example in home office, business premises, agriculture etc. where only a single-phase supply is available.

A comparative study of single phase and poly phase induction motor for the same speed and the same stator and core dimensions is presents:-

- Rotor core losses in single-phase induction motor are more because of backward rotating field as compared to those in three-phase motor.
- Rotor ohmic losses, because of the double frequency current induced by backward field, is higher in single phase motors.
- For the same size, single phase induction motor output is less, because backward field torque opposes the forward field torque. As given above single-phase motor has more losses. In view of this, for the same size single phase motor has higher temperature rise and lower efficiency as compared to a poly phase induction motor.
- The stator winding of single phase motor carries magnetizing current for both the forward and backward fields. As a result of it, the ratio of magnetizing to active component of the stator current is much greater in a single-phase induction motor , in view of this, the single-phase induction motor operates at a poor power factor as compared to a poly phase induction motor [15]

For the same power and speed rating, single-phase motor requires larger frame size than a poly phase induction motor. Therefore single-phase induction motor require more iron and the necessarily of providing auxiliary windings make more costlier as compare to three-phase induction motor of the same power rating and speed. Numerous type of a.c motor has developed to meet the requirement of various applications. When the single-phase supply is available than use of three-phase induction machine is restricted.

Bust examining advantages of three-phase induction motor over single-phase induction motor, single-phase operation of three-phase induction machine has been a subject of interest among engineers and academics in electrical engineering.

## 1.2 Literature review:-

Many authors have discussed about single-phase operation of three-phase induction motor, there uses, advantage and disadvantages. The significant contributions in this field are discussed in this section.

T.F. Chan and L.L. Lai, describes a systematic analysis of the smith connection that enables perfect phase balance to be achieved in a three-phase induction motor when operating on a single-phase supply. The smith connection is essentially an asymmetrical winding connection, but by suitable choice of terminal capacitances balanced currents can be injected into the motor winding for a given speed and load. A single-phase induction motor drive with three-phase machine efficiency is thus possible. [1]

O.J.M Smith describes a different mode of operation of three-phase induction motor was supplied from a single-phase public utility using a new unique reconnection of the machine windings and three capacitors to provide balanced current and voltages in all of the windings and the corresponding three-phase high-efficiency. Zero-crossing relays changed the capacitor values in response to load changes so that the single-phase efficiency was within three percent of the three-phase efficiency for all shaft loads between 20 percent and 120 percent. The single-phase power line power factor was near unity for a wide range of powers. [2]

J.E. Brown and C.S. Jha describes a'steinmetz connection' in which power supply and power phase converters (usually a capacitor) are connected across different phase, enable the three-phase motor to start and run on a single-phase supply system. symmetrical component theory is used to express the relationship between the starting performance of a 3-phase induction motor, when connected to a single-phase supply system, and its normal starting performance in terms of two dimensionless parameters. Performance characteristics applicable to machine of any rating are computed for a range of values of two parameters, and various conditions for optimum operation are established. The disadvantage of Steinmetz connection is that balance operation of motor is possible only when motor impedance angle is $\pi/3$ radian. [3]

Otto J.M. Smith describes a low cost single-phase motors are 3-phase high efficiency induction motors with the SEMTHX™ connection of the windings to 2 run capacitors. The single-phase winding currents at full load are the same if the motor were connected to a 3-phase source. The single-phase full load efficiencies are the same as the 3-

phase efficiencies. The line starting current is unity power factor and its approximately two time the full load current for motors between 10-Hp and 100-Hp. [4]

Tindal and Monteith [10]. It was found perfect phase balance could be achieved irrespective of motor and speed phase angle. A draw back two element balancer scheme however is, that one of phase converter element must be an inductance when the motor impedance angle is less than $\pi/3$ radian. This means that over most of the normal motor speed range, an inductance need to be used. Additional ohamic losses and consumption of reactive power are incurred together with a higher system cost. [5]

J.E Brown and O.I. Butler describes a systematic application of the theory of symmetrical components to the phase quantities of a symmetrically wound induction motor provides a general method of analysis which can be used to predetermine the performance characteristics of the motor for any form of asymmetrical primary connection. [6]

M.A. Badr and A.I. Alolah describes a scheme for fast starting of three-phase induction motors. This scheme based on starting the motor from a single phase supply with the help of phase balancer properly selected for achieving maximum starting torque. as the speed reaches a predetermined value, a simple centrifugal switch is used to reconnect the motor to three phase supply.[8]

T.F. Chan and L.L. Lai describe the operating principle and steady-stae analysis of a novel excitation scheme for a stand-alone three-phase induction generator tht supplies single-phase loads. The phase windings and excitation capacitances are arranged in the form of the smith connection and the excitation scheme is referred to as the SMSEIG. Capacitances act as phase balances. With the novel excitation scheme, isolated single-phase loads can be supplied with good phase balance in the induction machine, resulting in high efficiency, large power output and quite machine operation.[13]

T.F. Chan and Loi Lei Lai describes a practical method for computing the minimum capacitance required to initiate voltage build up in a three-phase induction generator self-excited with a single capacitances and supplying a single-phase load. Attention is focused on the Steinmetz connection which gives superior performance over the plain single-phasing mode of operation. [14]

T.F. Chan and L.L. Lai describes a single-phase operation of a three-pase induction generator with the smith connection is analyzed using the method of symmetrical components, it is shows that, despite the symmetrical nature of the winding connection, balanced current can be made to flow in the three-phase stator winding.[15]

In this dissertation report the system will referred to as the smith connection is that only capacitive element need to be used for single phasing when motor impedance angle is between $\pi/6$ radian and $\pi/3$ radian [1]. Motor rating up to 40-kw have been tested, mainly in rural and agricultural applications. How high starting torque, as it is facilitaty in three-phase induction motor, can be achieved in this connection.

# SMITH CONNECTED 3-PHASE IM

## 2.1 Winding Connection

Fig 2.1 show the smith connection for three phase induction motor operating on single phase supply. A, B, C are the three phase windings of the induction machine. The start of the stator phase A, B, C denoted by 1, 2, 3 While the finish are denoted by 10, 11, 12 or sometime denoted by 4, 5, 6. These windings are not internally connected any way they are connected asymmetrically using different phase balancing capacitors. Capacitor $C_{1-10}$, $C_{10-12}$, and $C_{2-12}$ are phase balancing capacitors used in connection. L1and L2 are the two terminal of single phase supply across which three phase induction motor connected through smith connection. It has designated the winding by their circuit positions and role. Winding 3-12 called the driven lag (DL). Winding 2-11 is called the line lag (LL). Winding 1-10 is called the centre lag (CL).

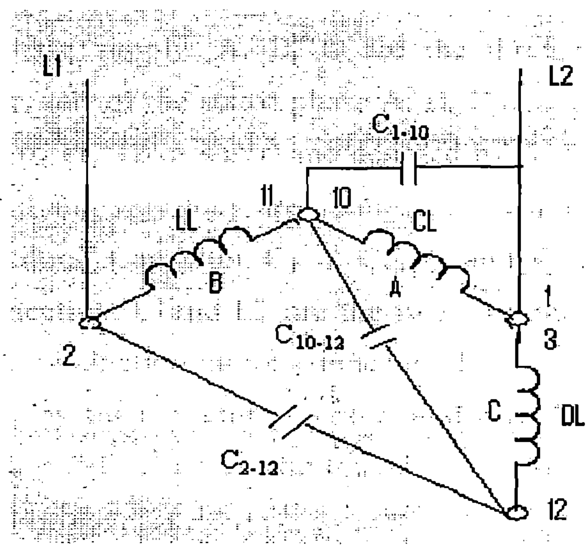



*Fig: 2.1 Winding diagram of smith connection*

## 2.2 Principle Of Smith Connection

Fig 2.1 shows the circuit for balanced voltage and current in all 3 winding at full shaft power. The phasor diagrams of these voltages are shown in fig 2.2 (a). The corresponding flux is of constant magnitude and rotating uniformly at synchronous speed in the air gap. There is no negative sequence component. The current through capacitor 2-12 is driven into winding 3-12 (DL) and lags the voltage in (DL) by 30°. The current through capacitor 10-12 is also driven in to winding (DL) and lag the voltage in (DL) by 60°.The sum of these two current components is the full load winding current I lagging the winding voltage by the $\phi$ angle corresponding to full load power factor of cos $\phi$

$$I_{30} = 2\ I \sin (60° - \phi). \qquad (1)$$

$$I_{60} = 2\ I \sin (\phi - 30°). \qquad (2)$$

These two current components form an oblique coordinate system with two axes 30° apart. Given the nameplate full load current full load power factor cos $\phi$, where $\phi$ is between 30° and 60°, the balanced full load current can always be generated by two components above. Since terminal 12 was disconnected from terminal 10. in order to keep all of the winding current balance, a current must be driven in to terminal 10 which is exactly opposite in phase and magnitude to the $I_{12}$ Current being driven in to terminal 12 .The capacitor 10-12 drive in to terminal 10 the correct 60° component. Capacitor 1-10 drives terminal 10 with a correct of 30° current .The three capacitors in figure 2.1 therefore drive the three-phase motor with exactly balanced winding voltages and currents, with exactly full load torque on the shaft and with rated full load efficiency .In fig 2.2 (b) the winding current for DL, LL, CL, are $-I_{12}$, $I_2$, and $I_1$ respectively .The three current are equal in magnitudes, add together to zero, just as though terminals 10,11 and 12 has been connected together at neutral of the three phase wye.

$$I_1 + I_2 - I_{12} = 0$$

The three voltages $V_{1\text{-}10}$, $V_{2\text{-}11}$ and $V_{3\text{-}12}$, are equal in magnitude, and have phase displacement by 120°. This balanced current and voltage condition result in single-phase operation having a full load efficiency of the same as it would have had if it were supplied from a three-phase public utility. [2]

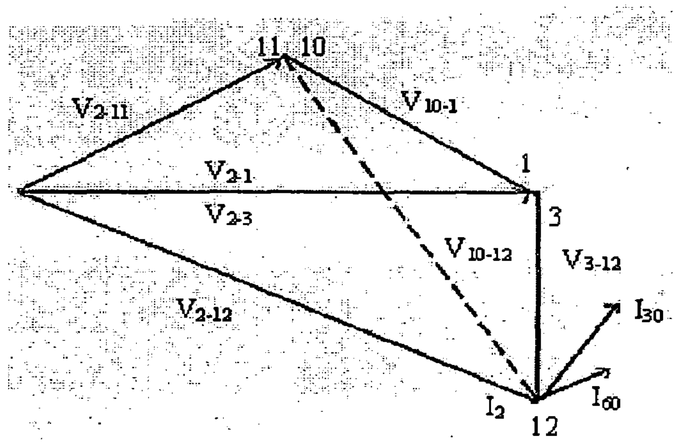



*Fig-2.2(a) Voltage phasors, full load balanced current*

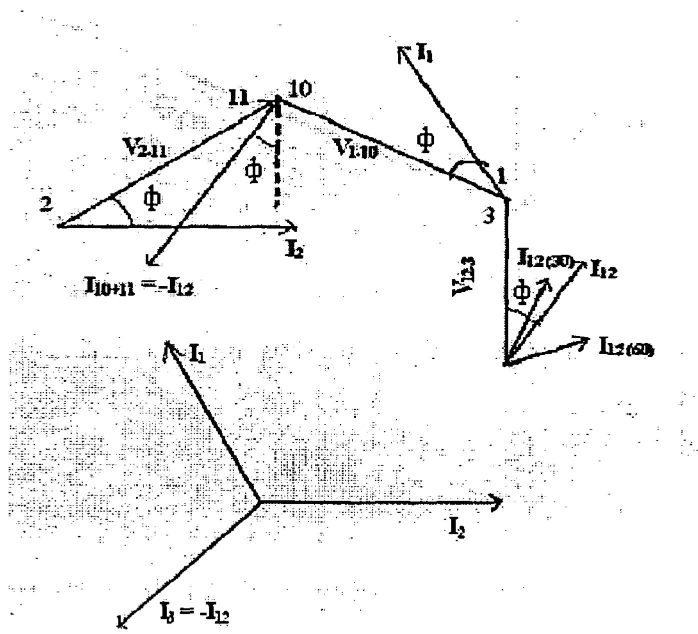



*Fig 2.2(b) Current phasors, full load balanced current*

## 2.3 Motor Performance Analysis:

Fig 2.3 (a) shows the smith connection for three phase induction motor operating on a single-phase supply. The start of the stator phase A, B, C are denoted by 1,2,3 while the finish are denoted by 4,5,6. Terminal 1 and 3 are common and connected to one line of the supply, while terminal 2 is connected to the second supply line. Terminal 6 is connected via capacitance $C_1$, to the pseudo-neutral point N formed by terminals 4 and 5. there are two more capacitances in the circuit: $C_2$ connected between terminal 2 and 6, and $C_3$ across phase A-phase. It is seen that the current $I_c$ in C phase comprises the capacitor current $I_1$ and $I_2$, while the current flowing in to the pseudo-neutral point N comprises $I_A$, $I_B$, $I_1$, $I_3$ [1]

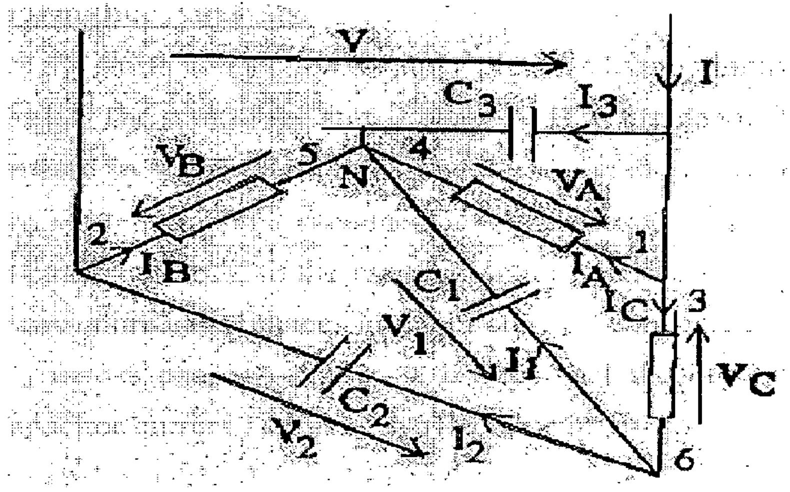



*Fig 2.3(a) Circuit Connection for Balance Operation*

Smith connection is essentially an asymmetrical winding connection. But with an appropriate choice of the terminal capacitances, it is possible for the induction motor to operate with balanced phase current and phase voltages. This is illustrated by the phasor diagram in Fig 2.3 (b) drawn for the special case for the perfect phase balance. The current I lead V (or $V_{AB}$) by $\pi/6$ rad and hence lag $V_C$ by $\pi/3$ rad. The voltage $V_2$ (which is equal to $V_{AB} - V_C$). Which is equal to $2V_A$ . The capacitor current $I_2$ leads $V_2$ by $\pi/2$ rad and hence lag $V_C$ by $\pi/6$ rad. Provided that motor impedance angle is between $\pi/6$ rad and $\pi/3$ rad, It is theoretically possible to synthesize the current Ic with the required power factor angle to give phase balance, by using suitable value of $C_1$ and $C_2$. Furthermore to ensure proper phase balance, the sum of current flowing in to pseudo neutral point N must be equal to zero .For this condition to satisfied, $I_3$ must be equal to $I_2$ which implies that $C_3$ must be equal to twice of $C_2$. With the balanced current flowing in the stator phase, a perfect rotating magnetic field is created in the motor. The air gap voltage per phase, and hence the phase voltages, will also be balanced. The balanced condition is for a given set of capacitance value and speed only. When the load and speed changes, the motor will be unbalanced and new sets of capacitance values need to be used in order to balance the motor again.

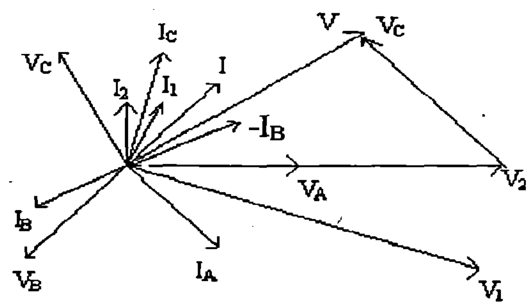



*Fig 2.3(b) Phasor Diagram of Induction Motor in Smith Connection*

A general performance analysis of smith connection can be carried out using method of symmetrical components, the circuit being considered as a special case of winding asymmetry. Referring to fig 2.3 (a) and adopting the motor convention for the induction machine, the following inspection equation may be established. [3]

$$V = V_A - V_B \quad (1)$$

$$I_C = I_1 + I_2 \quad (2)$$

$$I_A + I_B + I_1 + I_3 = 0 \quad (3)$$

$$I_1 = V_1 Y_1 = (V_A - V_C) Y_1 \quad (4)$$

$$I_2 = V_2 Y_2 = (V_A - V_B - V_C) . Y_2 \quad (5)$$

$$I_3 = V_A . Y_3 \quad (6)$$

$$I = I_2 - I_B \quad (7)$$

$$Y_3 = 2\,Y_2 \qquad (8)$$

Where $Y_1 = jwC_1$, $Y_2 = jwC_2$, and $Y_3 = jwC_3$

The following symmetrical component equation for the star connected system may also be written: [6]

$$\begin{vmatrix} V_A \\ V_B \\ V_C \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix} \begin{vmatrix} V_0 \\ V_p \\ V_n \end{vmatrix} \qquad (9)$$

$$\begin{vmatrix} I_A \\ I_B \\ I_C \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix} \begin{vmatrix} I_0 \\ I_p \\ I_n \end{vmatrix} \qquad (10)$$

Where a is the complex operator exp ($j2\pi/3$)

from (2) and (3)

$$I_A + I_B + I_C - I_2 + I_3 = 0 \qquad (11)$$

Using (5), (9), (11) can be rewritten as:

$$3I_0/\sqrt{3} - (V_A - V_B - V_C).Y_2 + V_A.\ Y_3 = 0 \qquad (12)$$

from (8), (9) and (12), the following equation is obtained:

$$3I_0/\sqrt{3} + (3V_0/\sqrt{3}).\ Y_2 = 0 \qquad (13)$$

Since $I_0 = V_0.\ Y_0$

Where $Y_0$ is the zero sequence admittance of the motor, may be written as:

$$V_0 . (Y_0 + Y_2) = 0 \qquad (14)$$

The sum of admittance $Y_0$ and $Y_2$ is nonzero in general; hence the zero sequence voltage $V_0$ must vanish according to (14). Hence, if the condition prescribed by (8) is satisfied, zero sequence voltage and current are absent in three-phase induction motor with smith connection. There are thus no zero sequence losses, and phase imbalance is contributed solely from negative sequence quantities.After the solving the 'inspection' equations for the positive sequence voltage $V_p$ and negative sequence voltage $V_n$ can be determined:

$$V_p = [V / -a (1-a)]. \{a^2 Yn - 2 Y_2 - (1-a^2)Y_1 \} / \{3Y_1 + 2Y_2 + Yp + Yn \} \qquad (15)$$

$$V_n = [V / -a (1-a)]. \{2Y_2 + (1-a) Y1 - aYp\} / \{3Y_1 + 2Y_2 + Yp + Yn \} \qquad (16)$$

The positive and negative sequence equivalent circuit can be used to compute the sequence currents $I_p$ and $I_n$. the machine performance, such as phase voltages, line currents, electromagnetic torque, power factor and efficiency, can be obtained.

## 2.4 Capacitances for Perfect Phase Balance:

Negative sequence voltage and current are absent when the induction motor is balanced. Equating $V_n$ in equation (16) to zero and solving the resulting complex equation, the capacitance to give perfect phase balance in smith connection can be determined. A simpler approach using the phasor diagrams is by fig 2.3 (b) and 2.4. Referring fig 2.4 the following angular relationship can be deduced

$$\alpha = \phi_p - \pi/6$$

$$\beta = \pi/3 - \phi_p$$

$$\epsilon = 5\,\pi/6$$

$$\delta = \phi_p - \pi/6$$

$$\xi = 5\,\pi/6 - \phi_p$$

Where $\phi_p$ positive sequence impedance angle of the induction motor

Applying sine rule to $\Delta$ opq in fig 2.4

$$I_1 = (I_C \sin\alpha / \sin\epsilon) = 2\, I_C \sin(\phi_p - \pi/6) \qquad (17)$$

$$I_2 = (I_C \sin\beta / \sin\epsilon) = 2 I_C \sin(\pi/3 - \phi_p) \qquad (18)$$

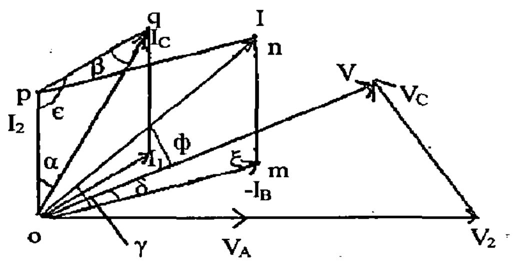



*Fig 2.4 Angular relationship between voltage and current phasor under balance condition*

In Δ opq the currents are related to phase voltage $V_{ph}$ as follows

$$I_1 = V_1 . Y_1 = \sqrt{3}.V_{ph}.Y_1$$

$$I_2 = V_2\, Y_2 = 2.V_{ph}\, Y_2$$

From (17) and (18), the following admittance can be obtained

$$Y_1 = 2/\sqrt{3}\, Y_p \sin(\phi_p - \pi/6) \qquad (19)$$

$$Y_2 = Y_p \sin(\pi/3 - \phi_p) \qquad (20)$$

For a given speed, $Y_p$ and $\phi_p$ can be computed from the equivalent circuit parameters(Appendix-E). Equation (19) and (20) can then be used to determine the value of $Y_1$ and $Y_2$ (hence $C_1$, $C_2$ and $C_3$). Alternatively, the experimental values of $Y_p$ and $\phi_p$ can be used directly for computation of the capacitances. [1]

## 2.5 Input Power Factor:

Under perfect balance, the input power factor of the induction motor with smith connection can be computed using the phasor diagram. Applying cosine and sine rule to Δ omn in fig 2.4 and using (18) the following relation can be deduced.

$$I = I_{ph} \sqrt{[1 + 8\sin^2(\pi/3 - \phi_p)]} \qquad (21)$$

And $\gamma = \sin^{-1} [\sin 2 (\pi/3-\phi_p)/ \sqrt{} [1+ 8\sin^2 (\pi/3-\phi_p)]$ (22)

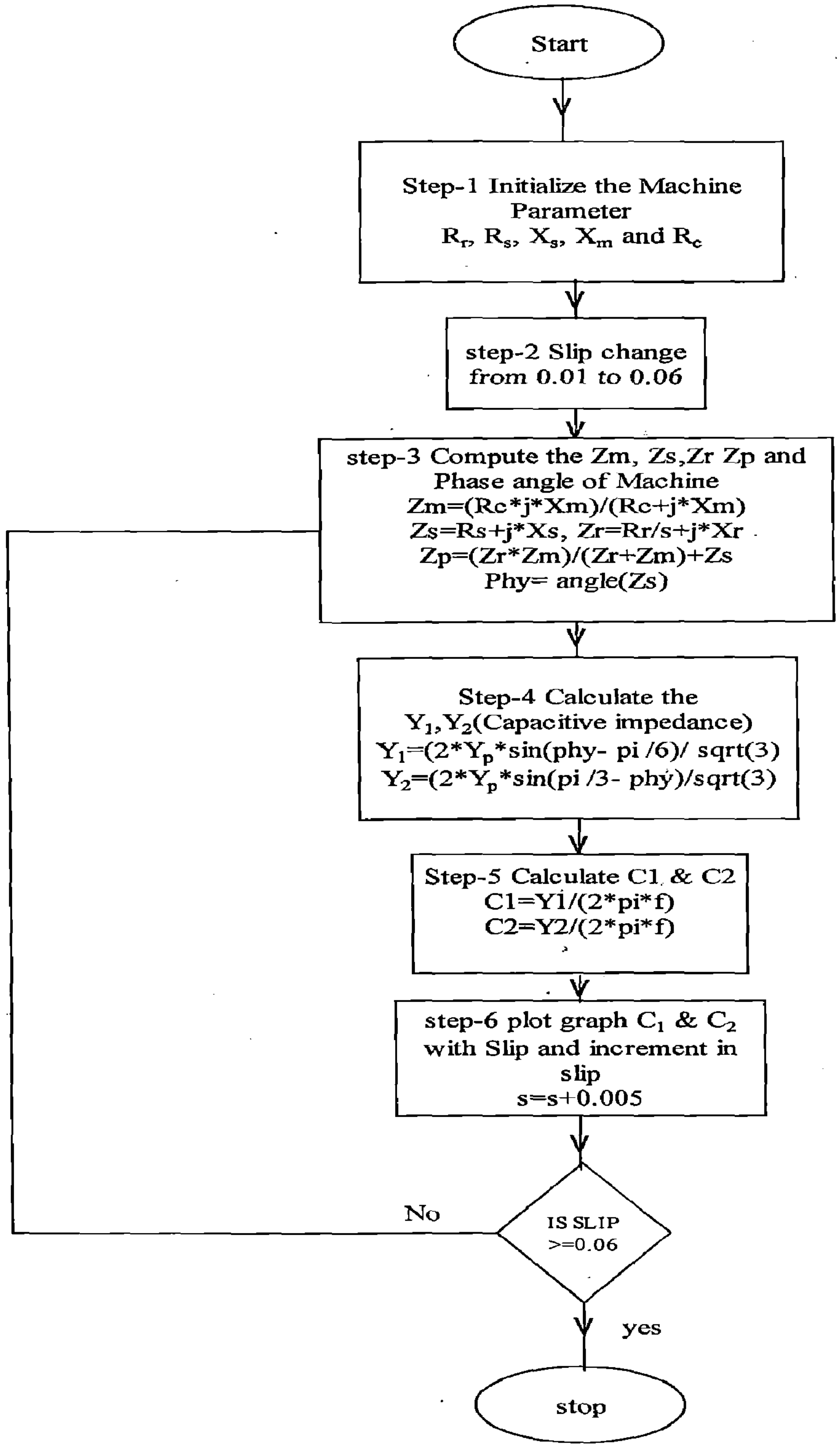
If the input power factor angle $\Phi$ is defined to be positive when the line current I leads the supply voltage V, then

$$\Phi = \gamma - \delta = \gamma - \phi_p + \pi/6 \quad (23)$$

Equation (22) and (23) shows that input power factor of the induction motor under prefect phase balance is a function of motor impedance angle only.

## 2.6-CHARACTRICTICS OF RESULT MOTOR

**2.6.1** Flow Chart for Calculate the Value of Capacitance for Different Load Condition, and Calculate the Starting Capacitance. Program referred to Appendix-E1.



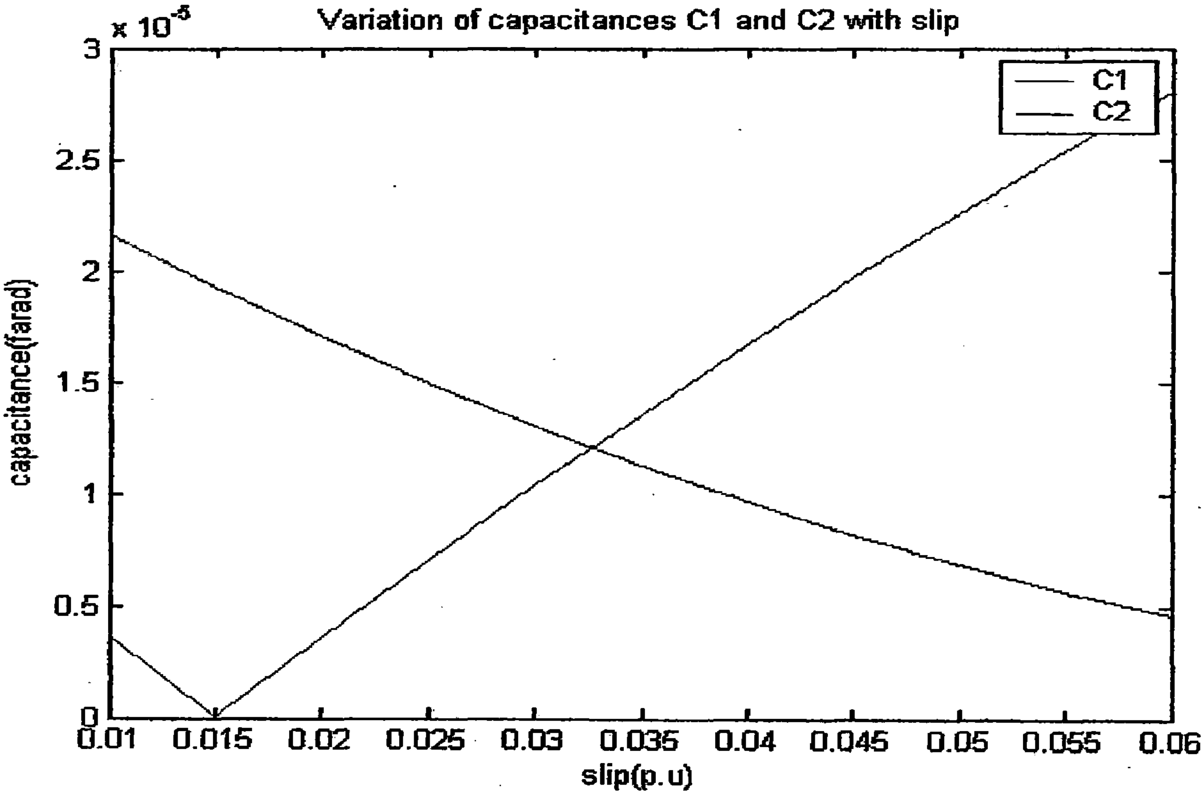



*Fig2.6 (a) Variation of Capacitances C1 and C2 with slip*

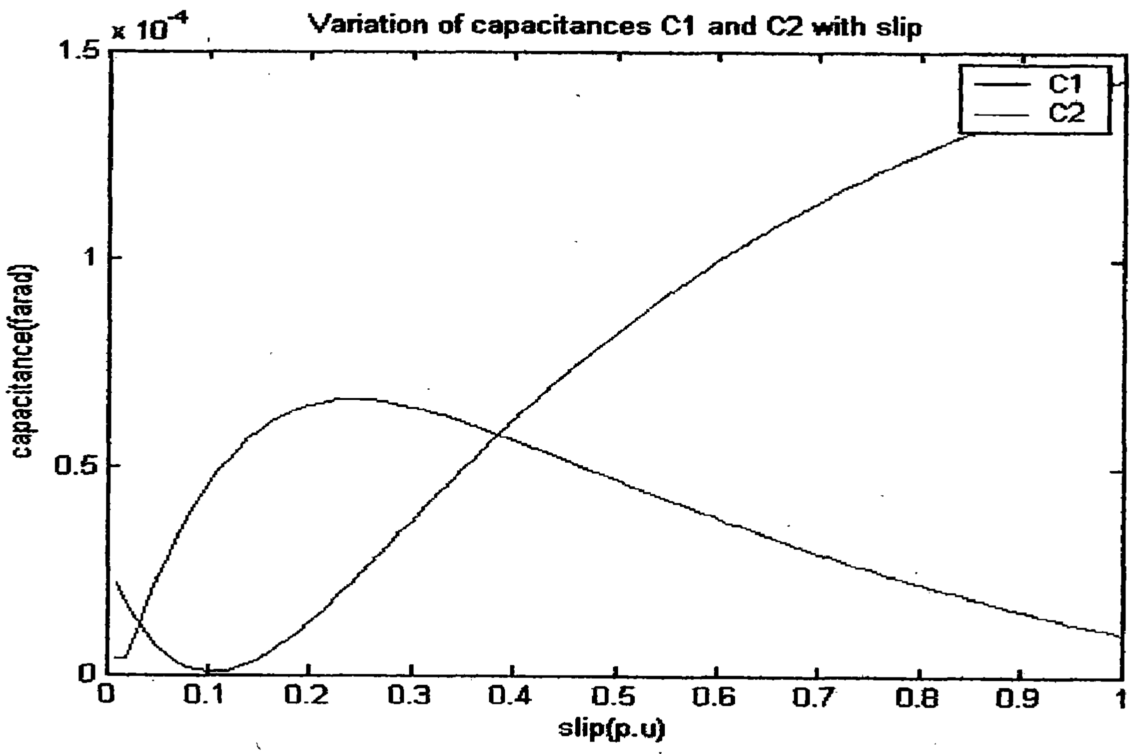
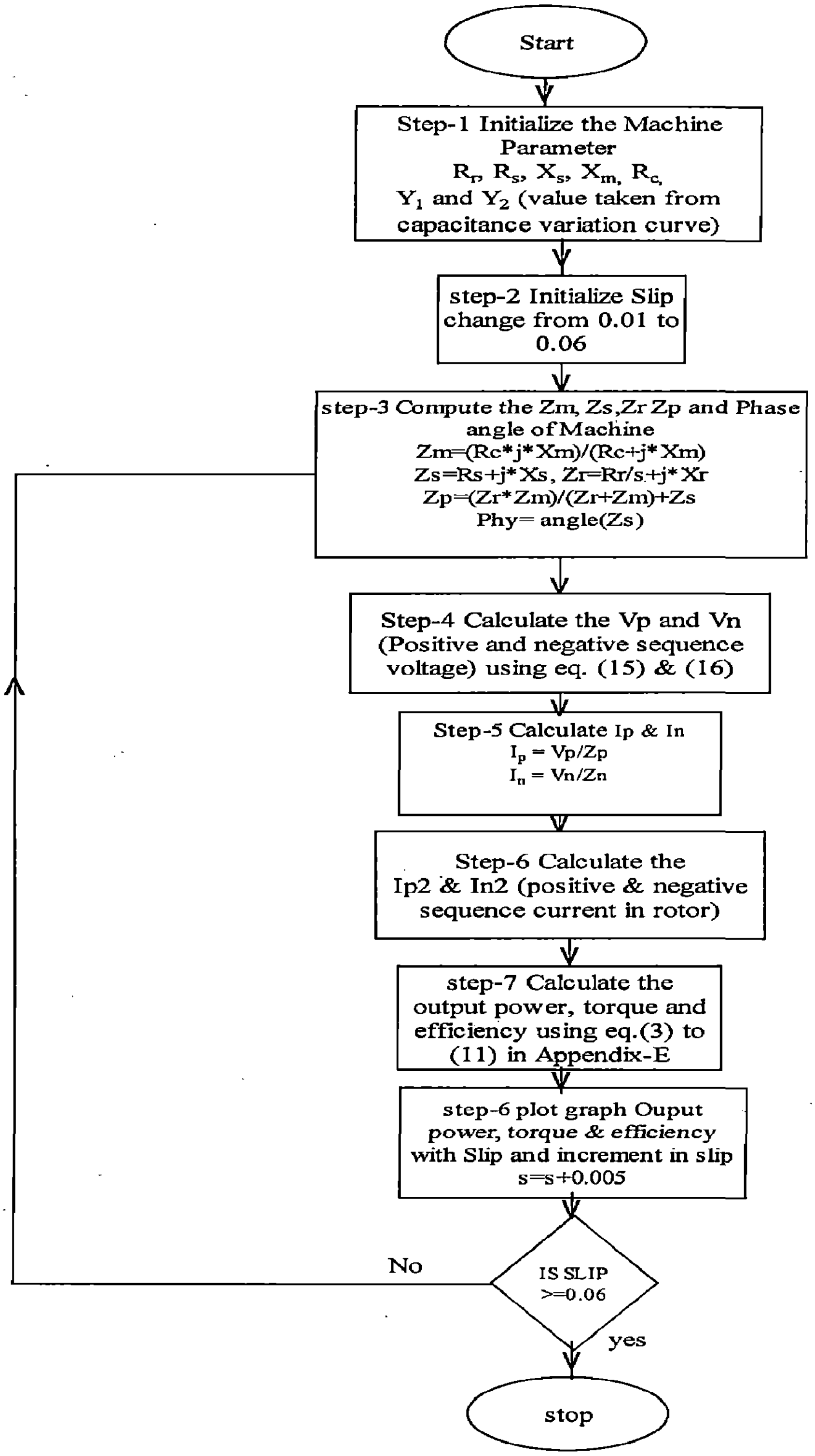



***Fig 2.6 (b) Starting capacitances for smith connected induction motor***

**2.6.2** Flow Chart for Calculating the Phase Voltage and Current in Smith connected 3-Phase Induction Motor. Program Referred to Appendix-E2.



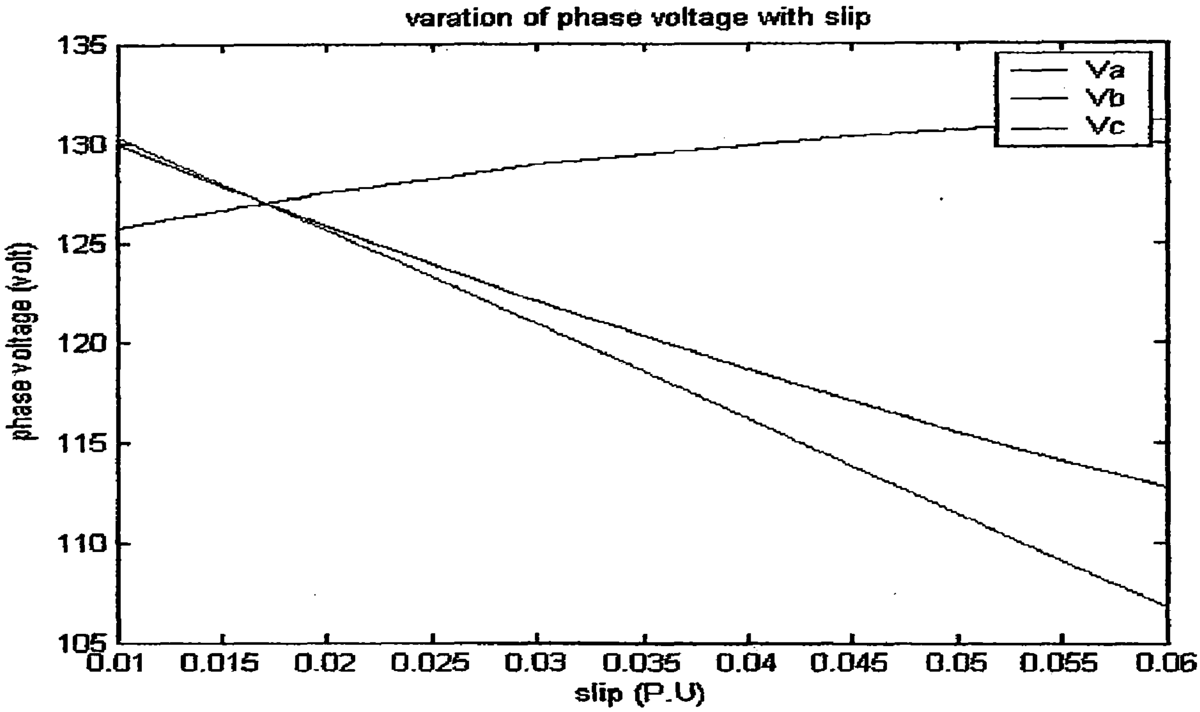



*Fig2.6(c) Variation of phase voltage with slip using no load capacitances*

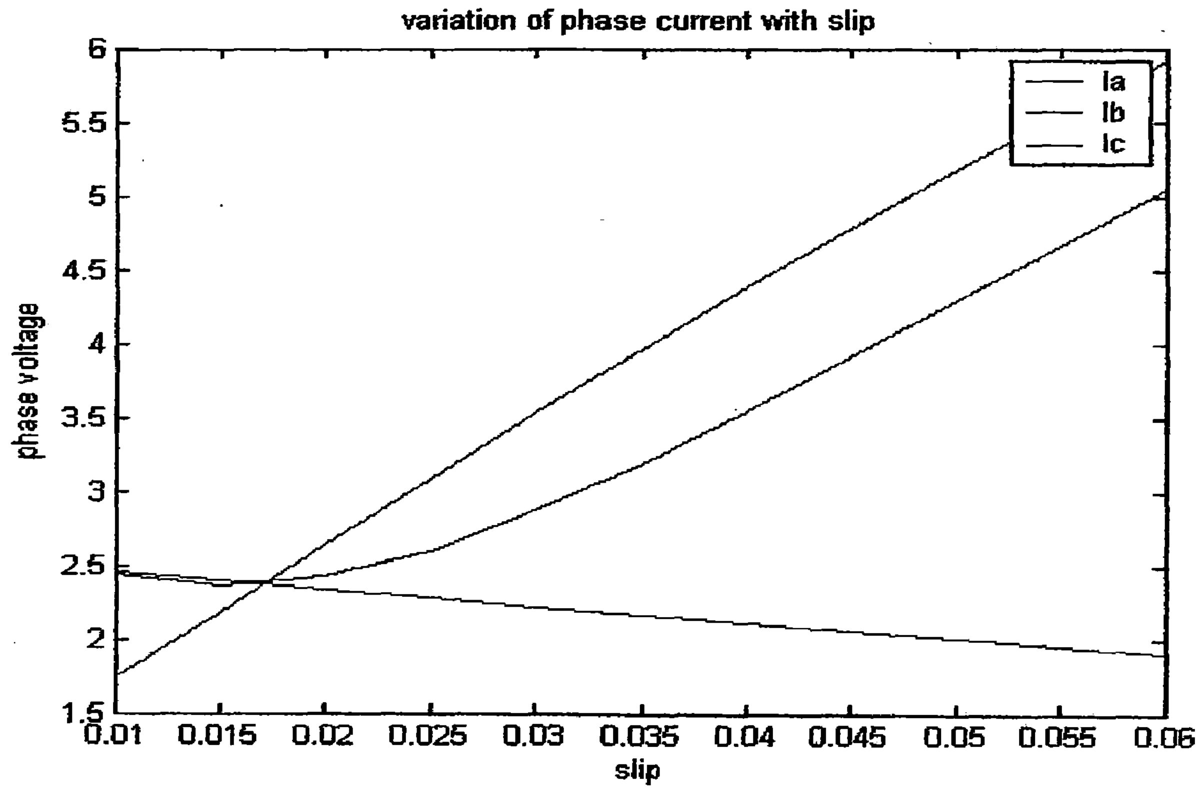



*Fig 2.6(d) Variation of phase current with slip using no load capacitances*

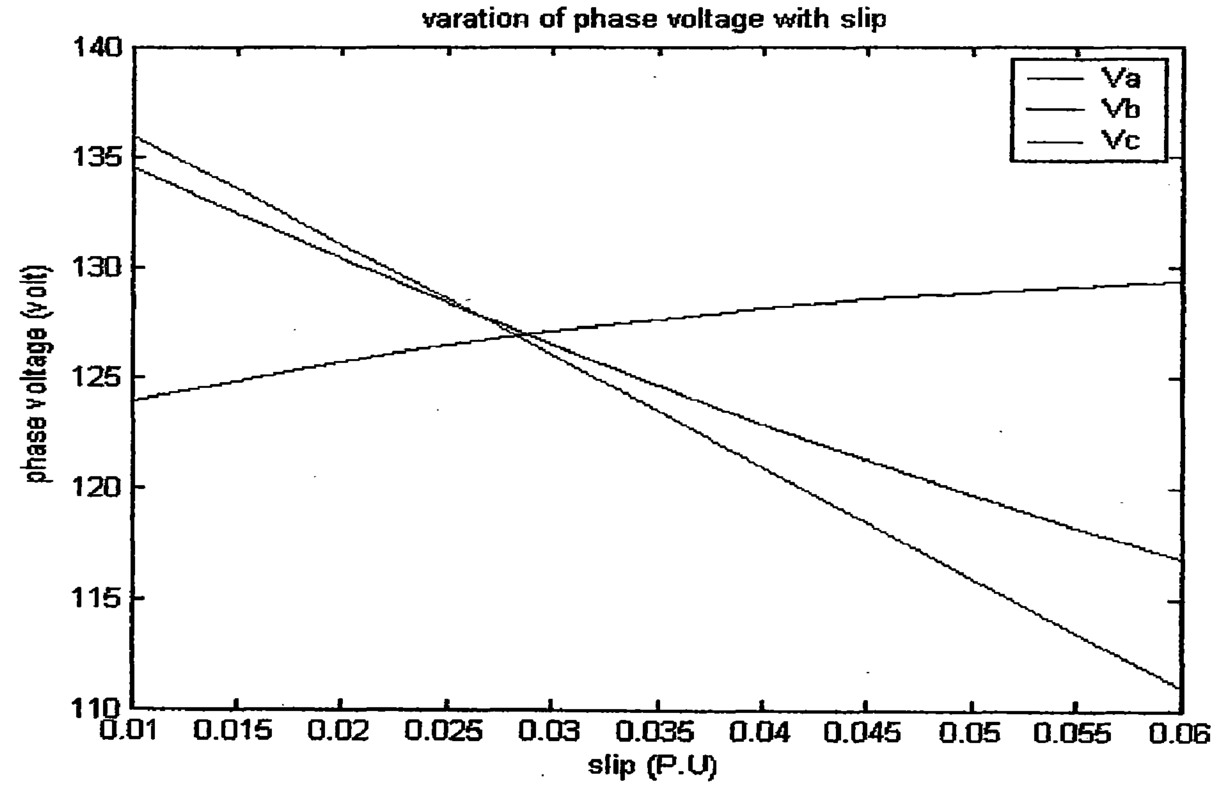



*Fig 2.6(e) Variation of phase voltage with slip using medium load capacitances*

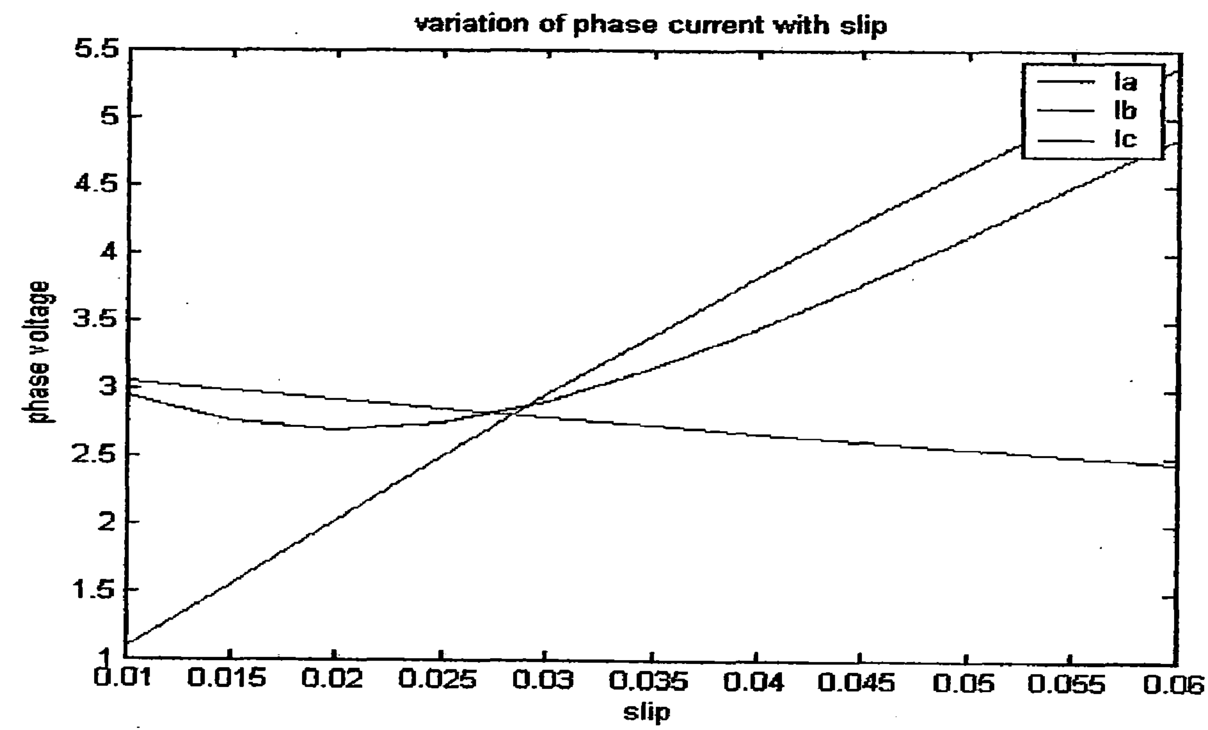



*Fig 2.6(f) Variation of phase current with slip using medium load capacitances*

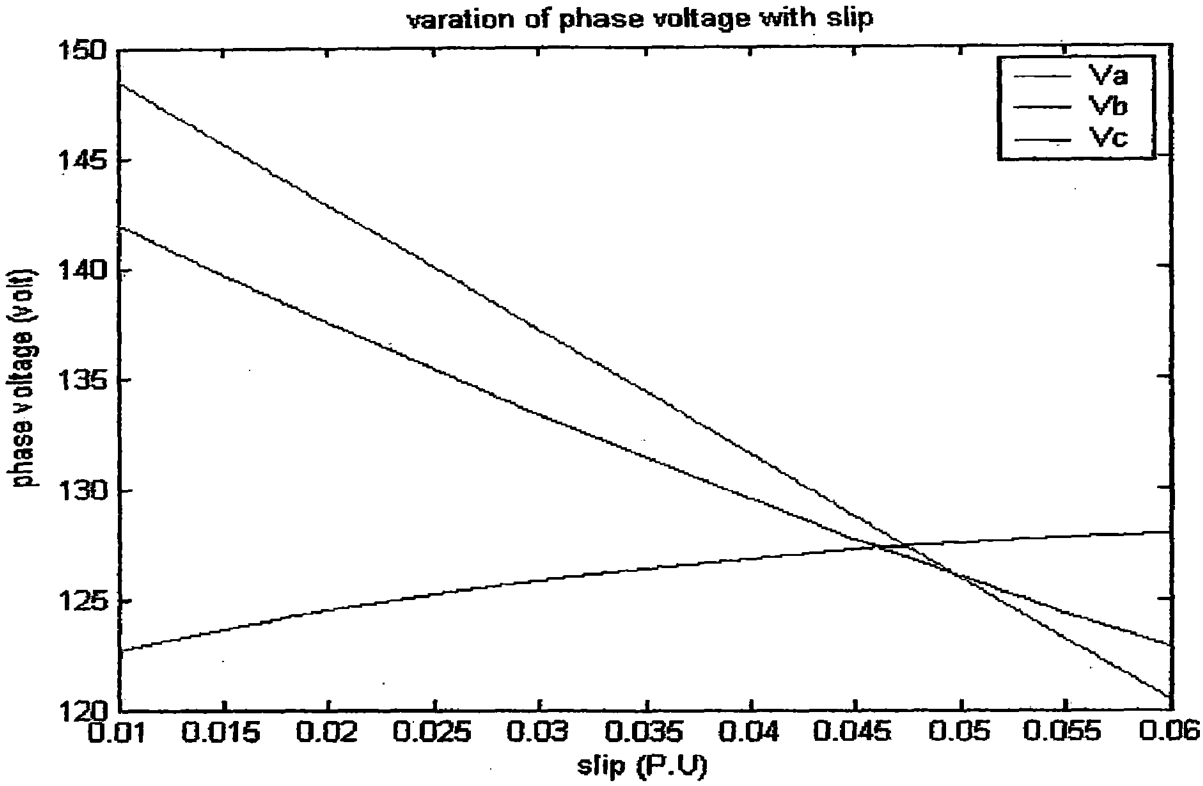



*Fig 2.6(g) Variation of phase voltage with slip for using full load capacitances*

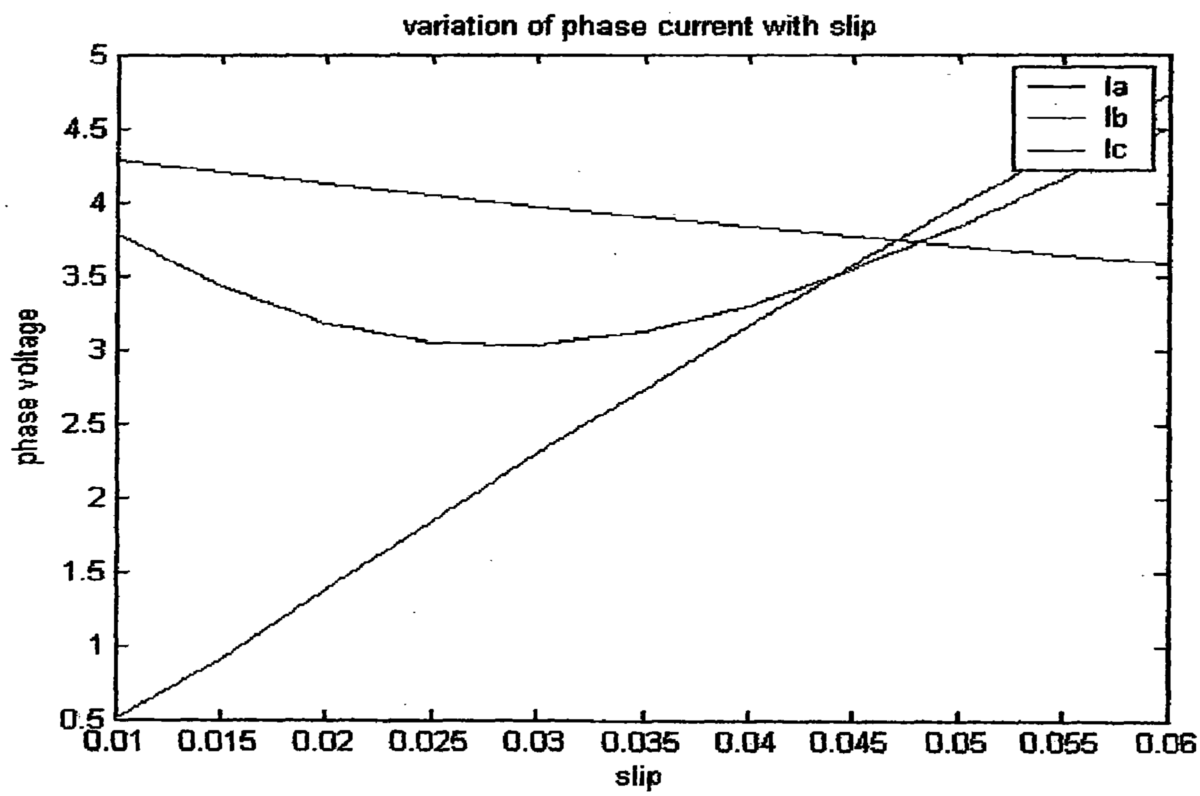



*Fig 2.6(h) Variation of phase current with slip using full load capacitances*

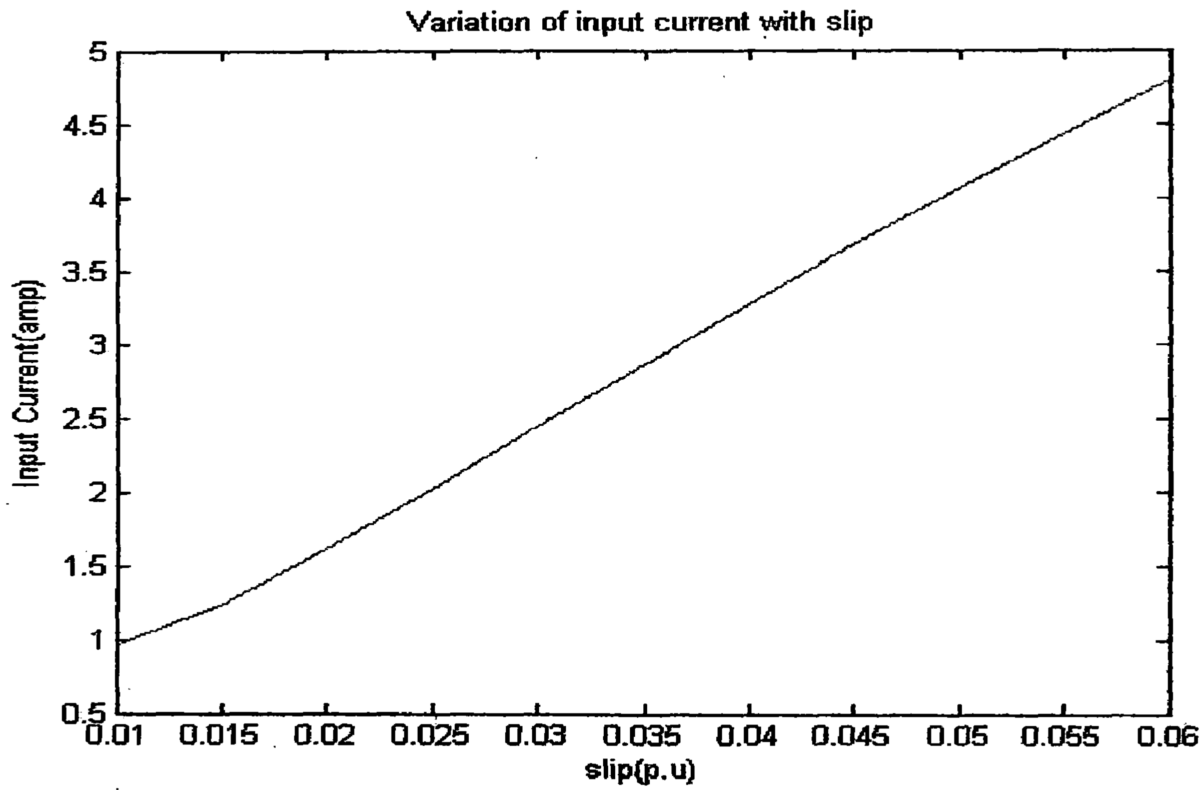



*Fig 2.6(I) Variation of input current with slip*

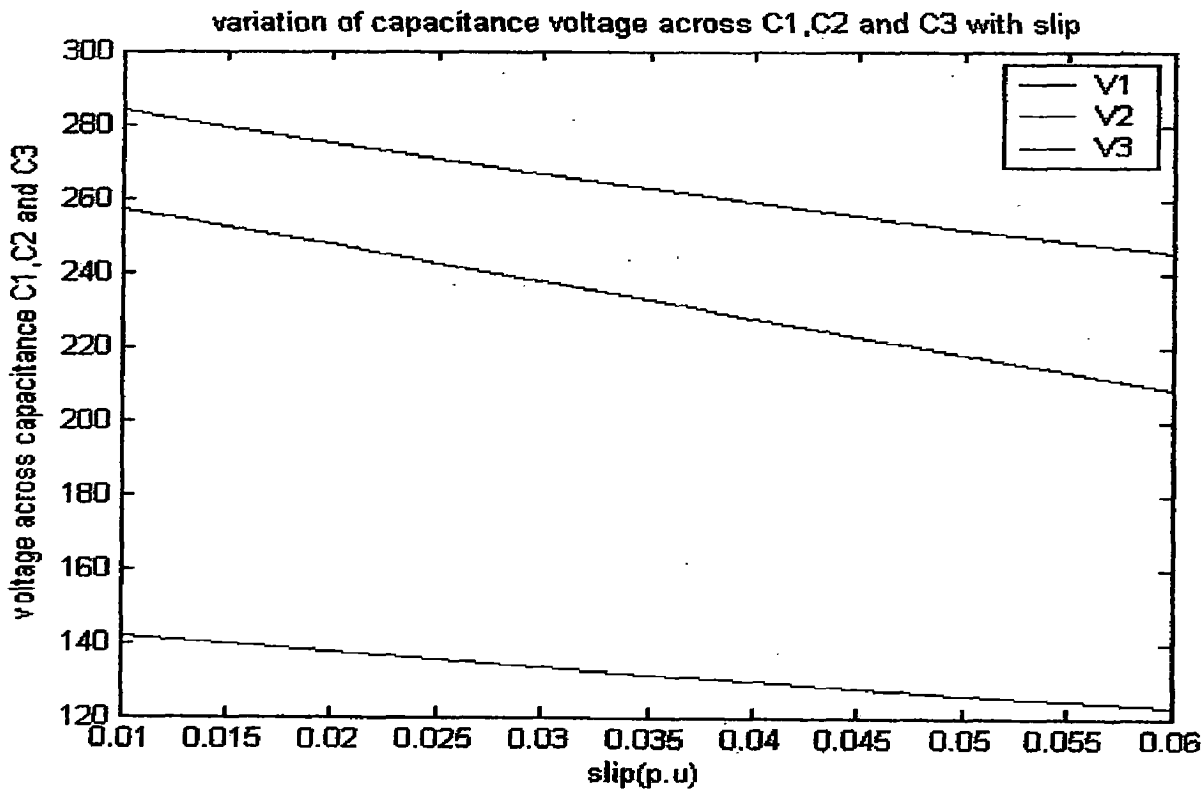



*Fig 2.6(J) Variation of capacitances voltage*

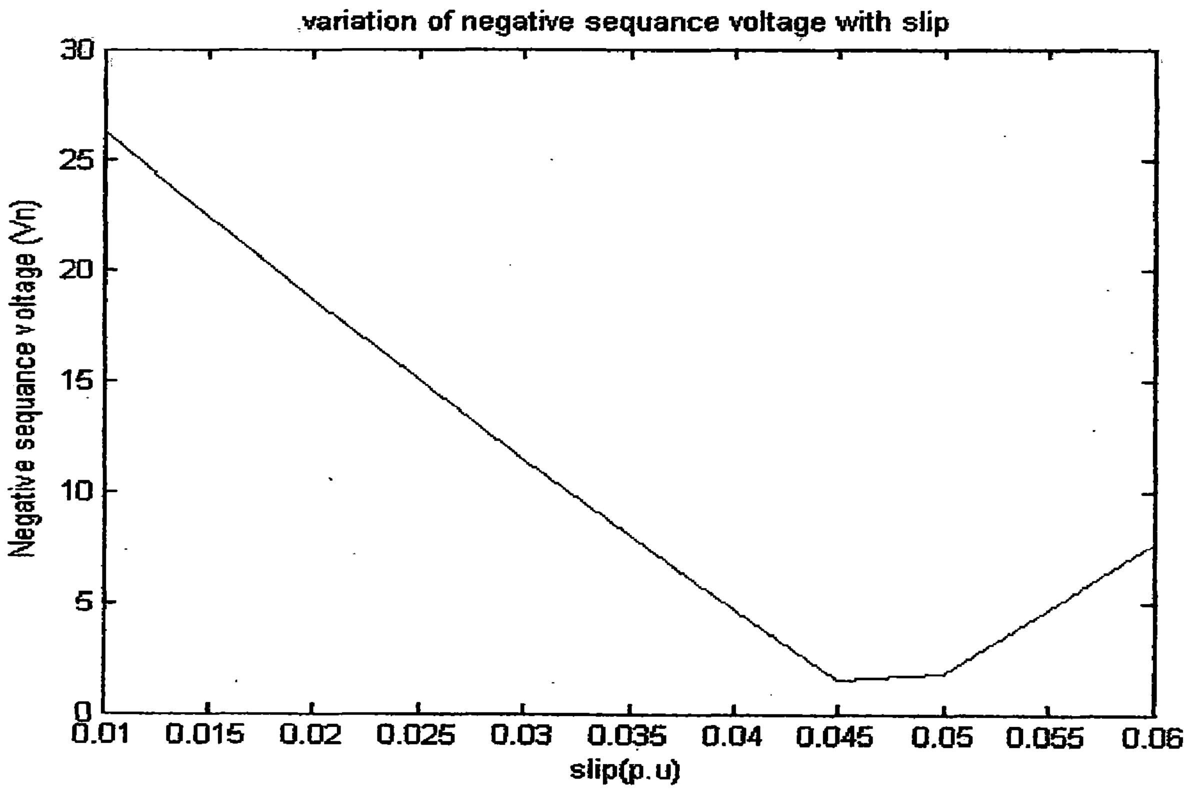



*Fig 2.6(K) Variation of negative sequence voltage with slip*

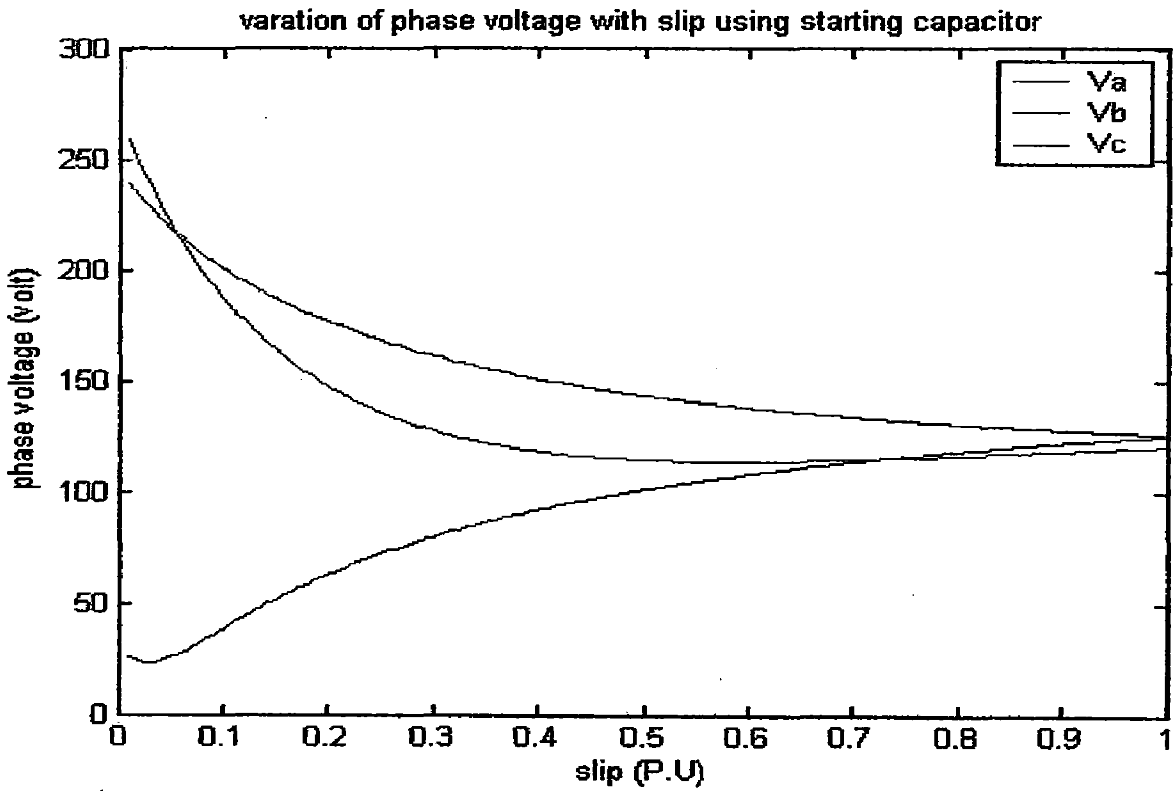



*Fig 2.6(l) Variation of phase voltage with slip using starting capacitor*

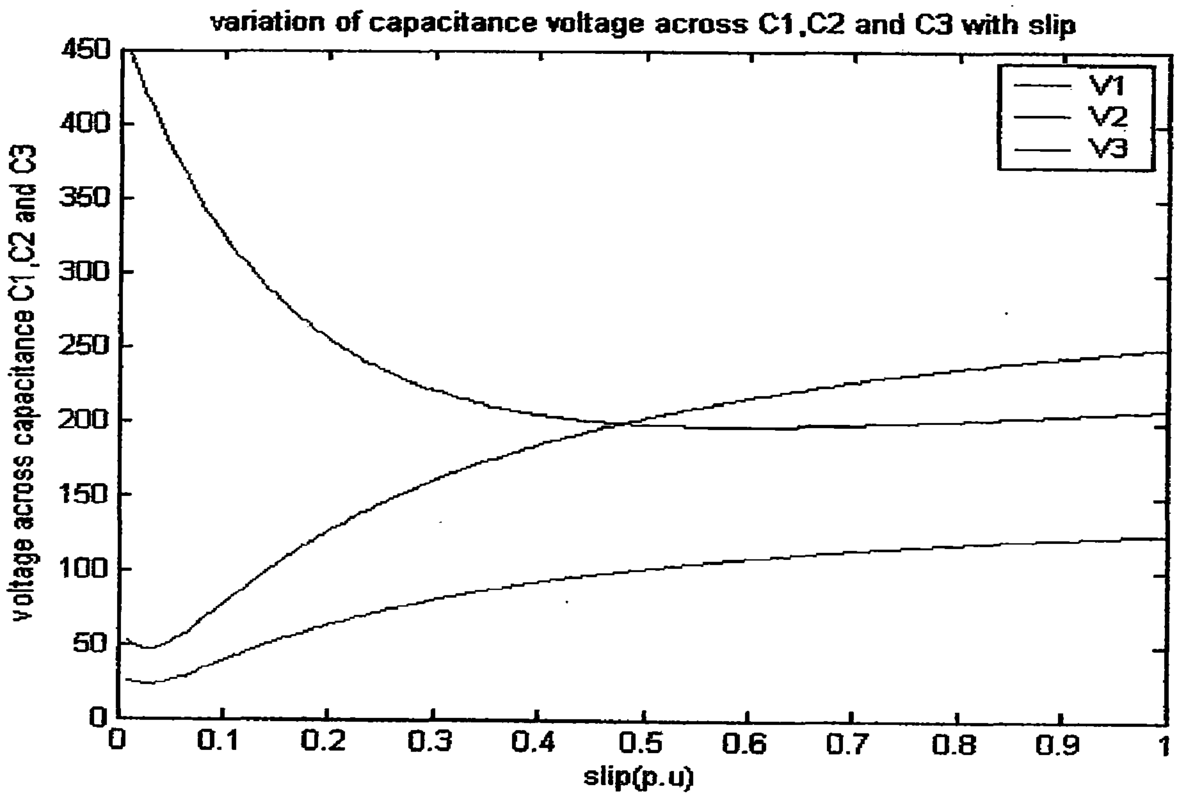
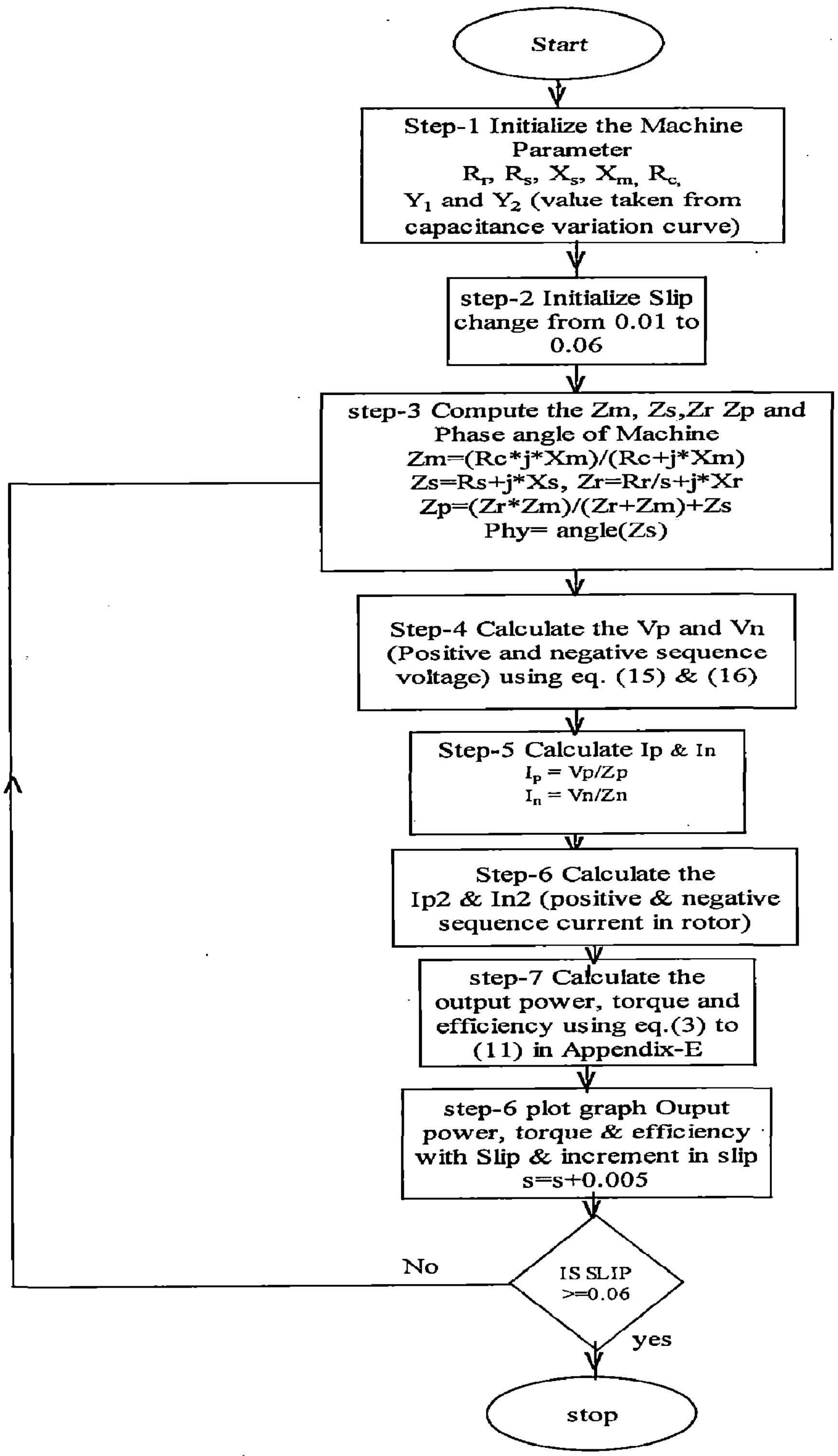



***Fig 2.6(m) Variation of capacitances voltage with slip using starting capacitance***

**2.6.3** Flow Chart for Calculating the Output Power, Shaft torque, and Efficiency in Smith connected Induction Motor. Program referred to Appendix-E3 and E4



Here given the output power, shaft torque and efficiency characteristics of three phase induction motor when connected with smith connection and gives the comparisons with three-phase induction motor connected to 220-V supply.

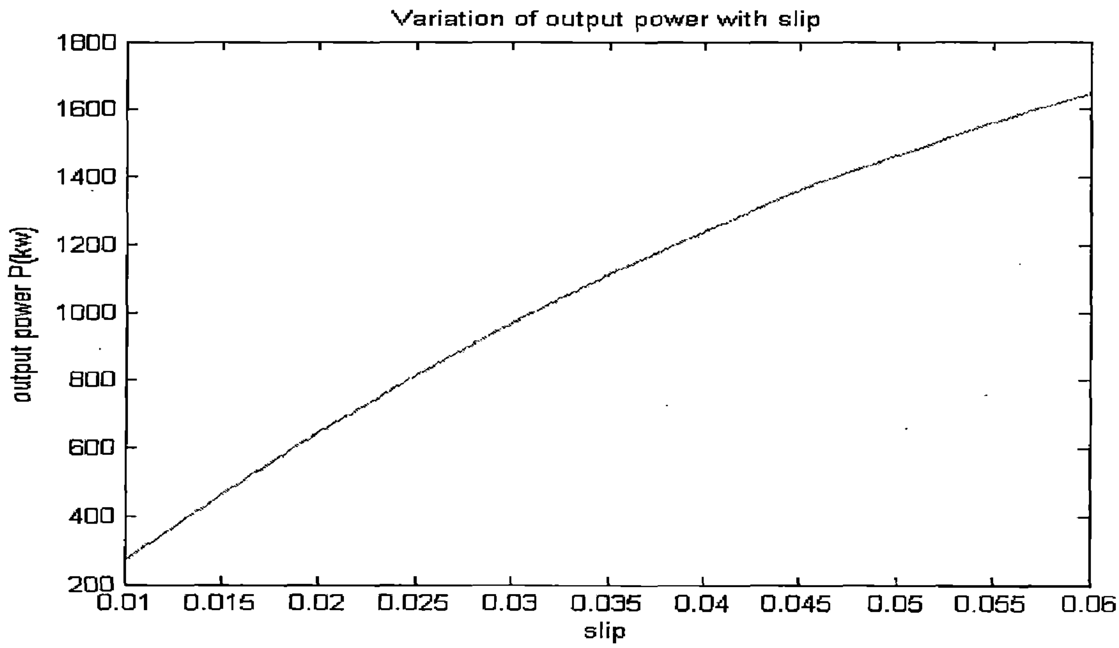



*Fig 2.6(n) Variation of output power with slip for smith connected IM*

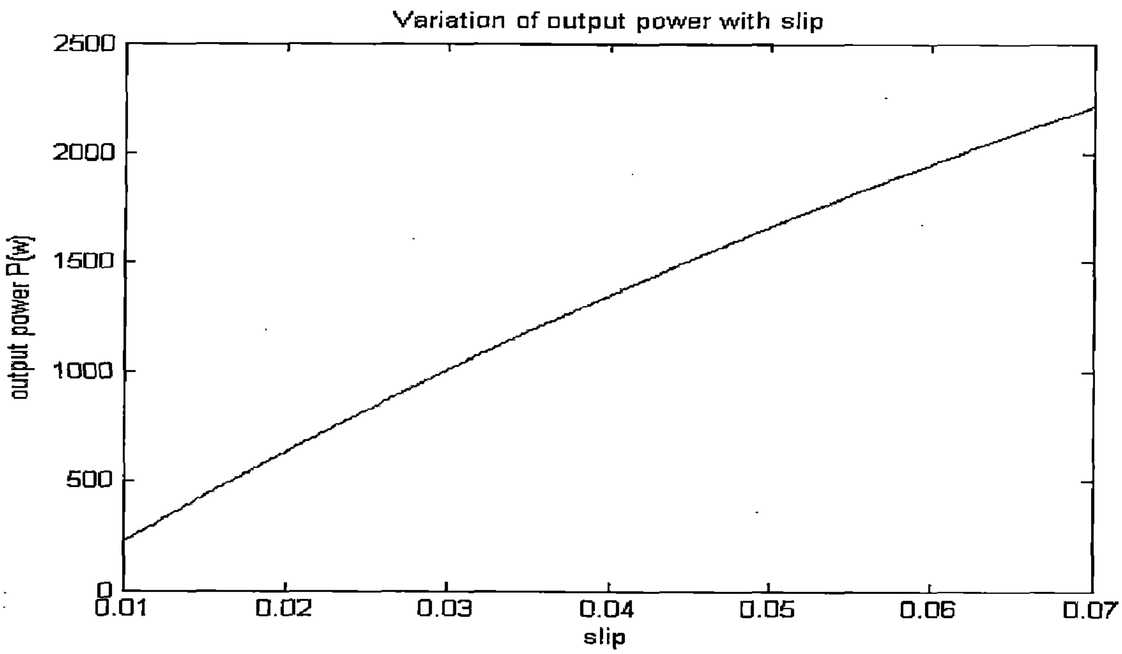



*Fig 2.6(o) Variation of output power in case 3-phase IM connected to 220-V supply*

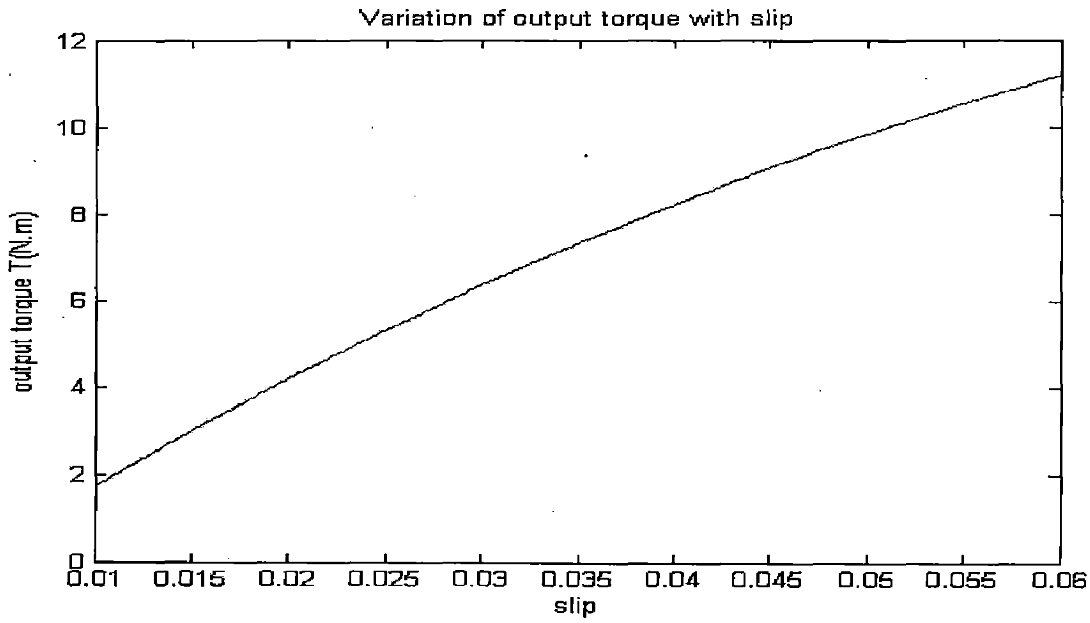



*Fig 2.6(p) Variation of output torque with slip for smith connected IM*

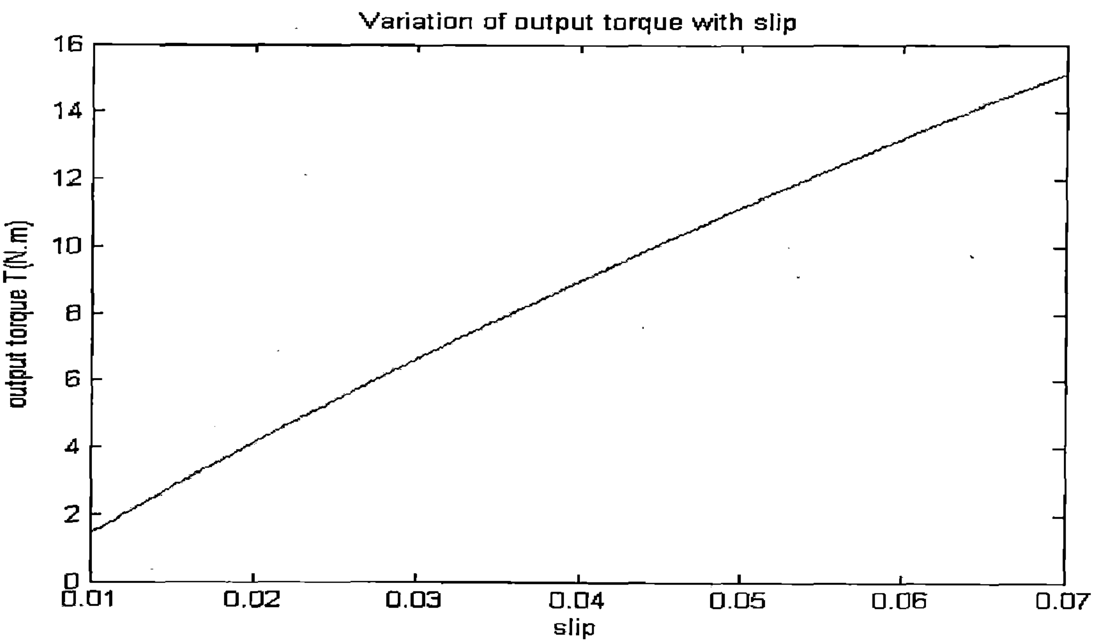



*Fig 2.6(q) Variation of output torque in case 3-phase IM connected to 220-V supply*

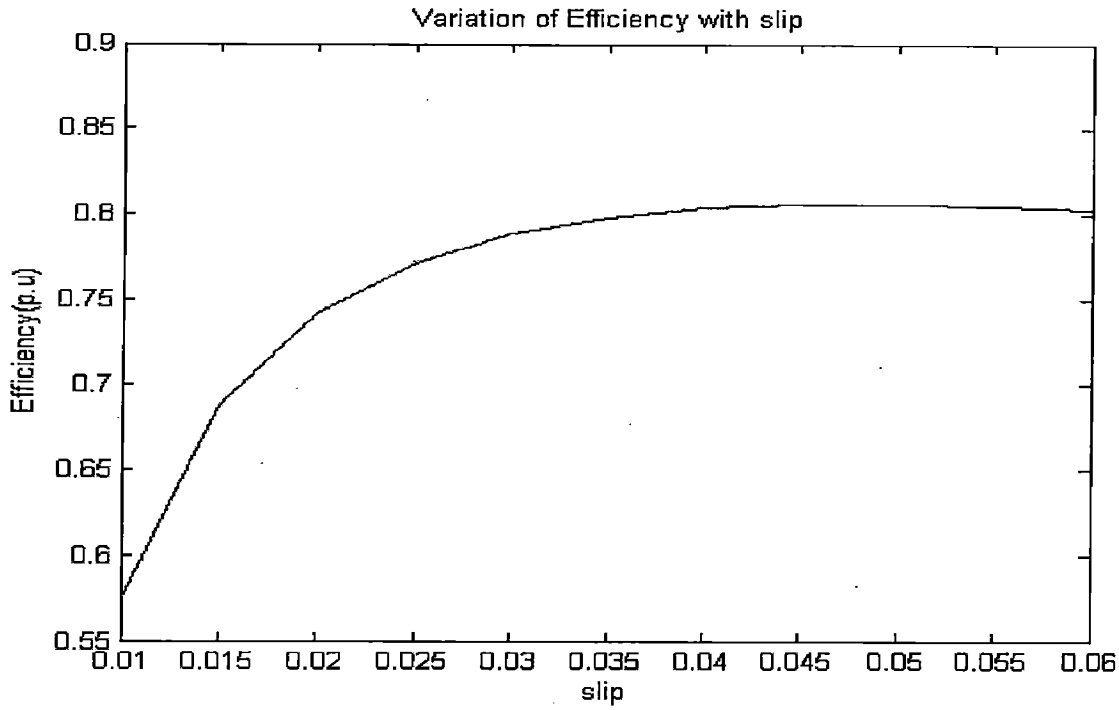



Fig 2.6(r) Variation of efficiency with slip for smith connected IM

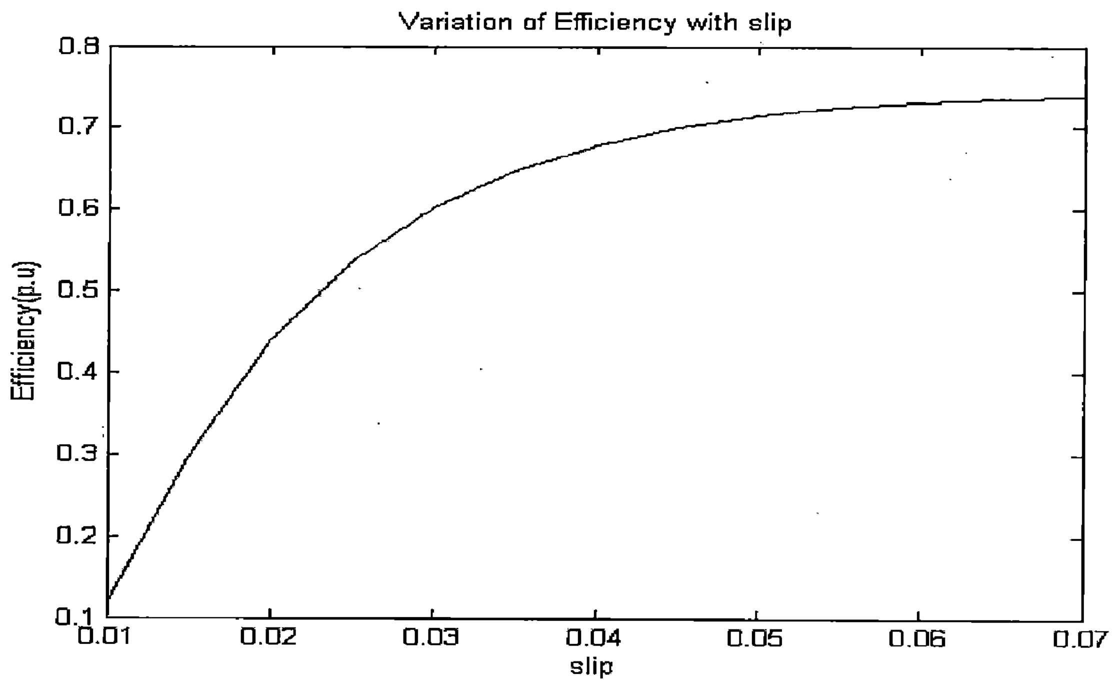
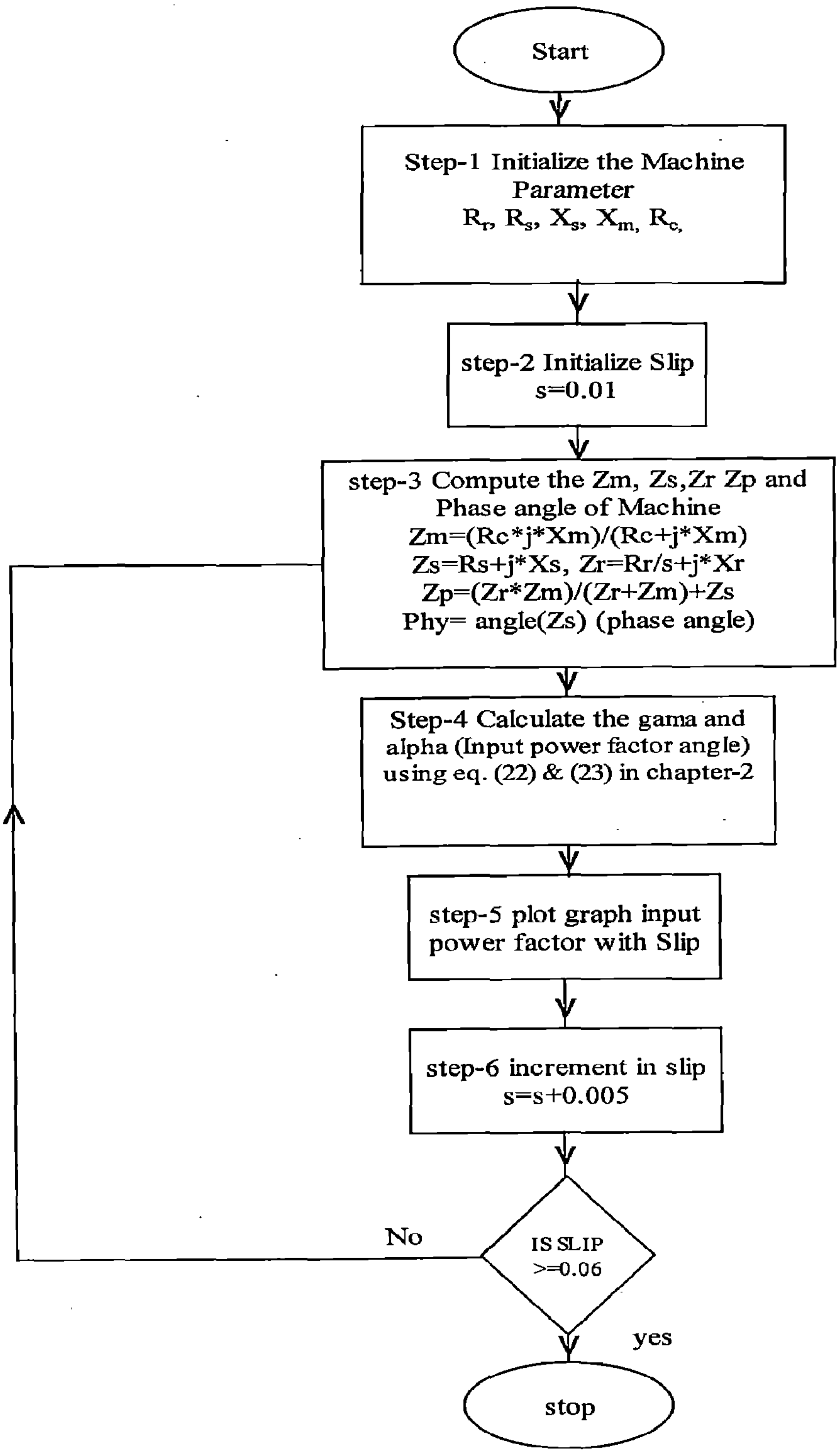



*Fig2.6(s) Variation of efficiency in case 3-phase IM connected to 220-V supply*

**2.6.4** Flow Chart for Calculate the Input Power Factor with the Change of Impedance angle which depends on Load of Motor. Program referred to Appendix-E5.



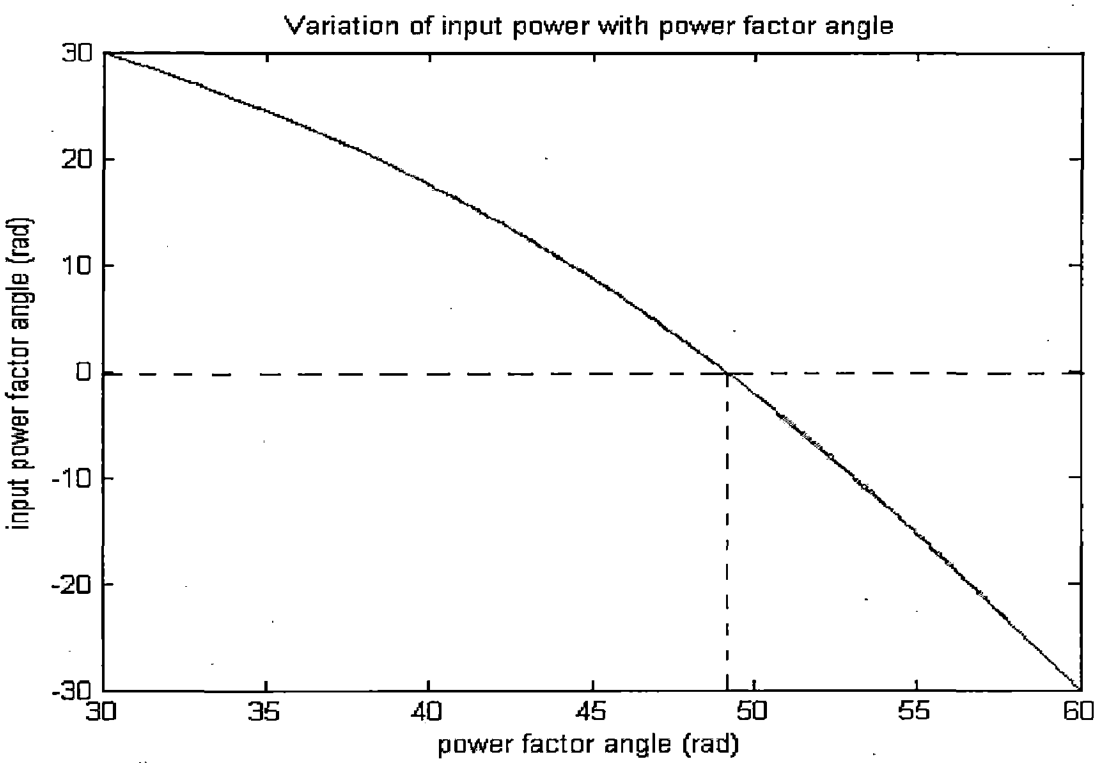



*Fig 2.6(t) Variation of input power factor with power factor angle*

# ᴊᴊıFFERENT MODE IN SMITH CONNECTED IM

## 3.1Introduction:-

In the previous two chapters we have discussed need and winding connection of the smith connected three-phase induction motor.. Balancing capacitors value, power factor and different property has been discussed. In smith connection a balanced conditions are valid for a given set of capacitance values and speed only. When the load or speed changes, the motor will be unbalanced and a new set of capacitance values need to be used in order to balance the motor again. In this charter describes the multi-mode operation of a three-phase induction motor with smith connection. This operation involves the selection of appropriate phase balancing capacitances that give minimum voltage and current imbalance in the motor as the rotor speed changes. In order to get high starting torque its required feature is given. Different possible mode of operation and its requirement with different set of capacitor and feature of capacitors is used.

## 3.2 Starting: -

In order to start the motor, a torque current component must be introduced in to the phase C. On starting, the starting capacitor CS is connected between terminal 10 and 12.voltage across capacitor CS is approximately equal to line-to-line voltage and lag by 60°. The current through CS is driven in to winding lag the voltage in the phase C winding by approximately 60°.This is approximately the condition for locked rotor balanced voltage and currents. The starting torque is the same as it would be three-phase supply.

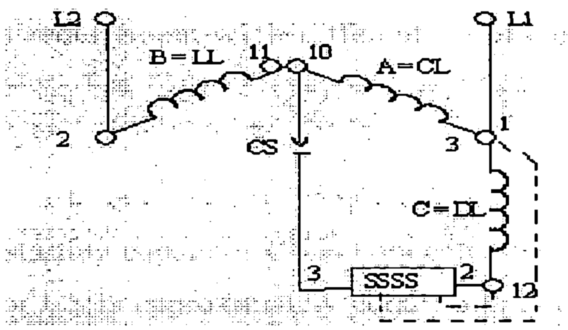



*Fig (3.2) Starting circuit, for a single-phase supply*

The solid state starting switch (sss) is closed, but it opens when the shaft speed reaches 80% of full load speed. Acceleration time is approximately the same as it would be on three-phase supply .The expert can choose the value of the starting of the capacitor CS When it is chosen to carry five times rated winding current on blocked rotor, the performance is similar to that previously described. A larger value for CS will carry a larger current, with a larger starting torque, and accelerating time will be reduced. The starting torque can be greater than that available from a balanced 3-phase supply. After the starting switch (ssss) is opens the motor is operating with only two windings energized and carrying current. Maximum load is limited by rated current in the winding. The motor can carry satisfactorily shaft loads between no load and above half load.

**3.3 Experimental Results and Discussion: -**

To check the validity of the above analysis, experiments were performed on a 3.7-Kw, 415-V, 50 Hz, 4.2-A 4-pole, star connected induction machine whose parameters are given in the appendix-A. It was found that minimum unbalance could be obtained with an appropriate choice of capacitances when the motor run at different load condition. Fig 3.3 (b) and 3.3 (c) shows that the $C_1$ decreases and $C_2$ increases with increase in per unit slip, good correlation between the experimental work and computed performance characteristics is observed. The results confirm that perfect phase balance can be achieved over a wide range of slip using the smith connection. Fig 3.3 (b) shows the calculate value of capacitances for balance operation and fig 3.3 (c) gives the experimental value of capacitances.

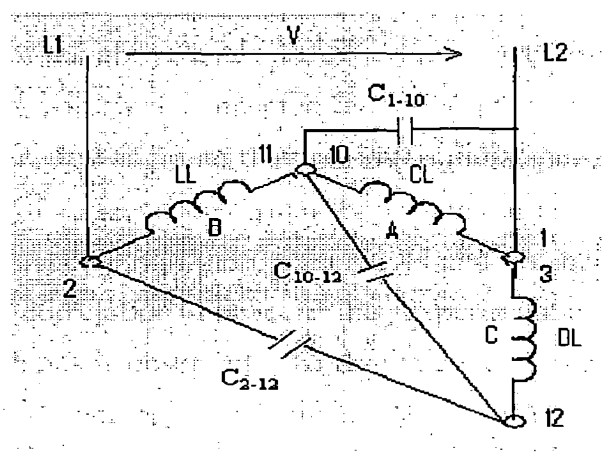



*Fig 3.3(a) smith winding connection for three phase induction motor*

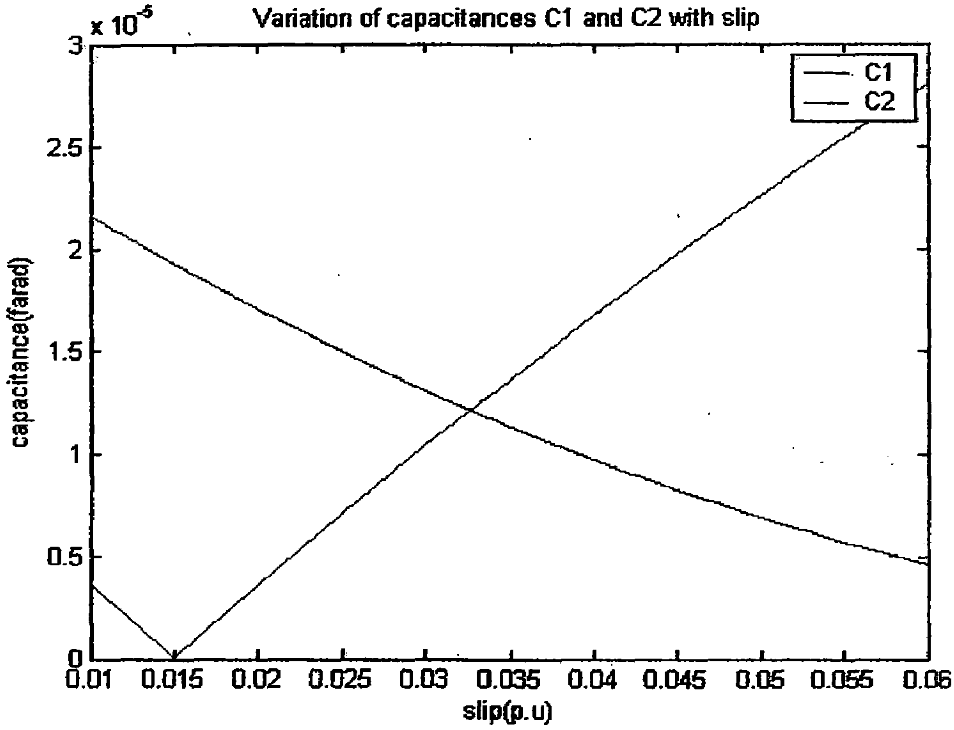



*Fig 3.3(b) Variation of capacitances to give perfect phase balance (Simulated)*

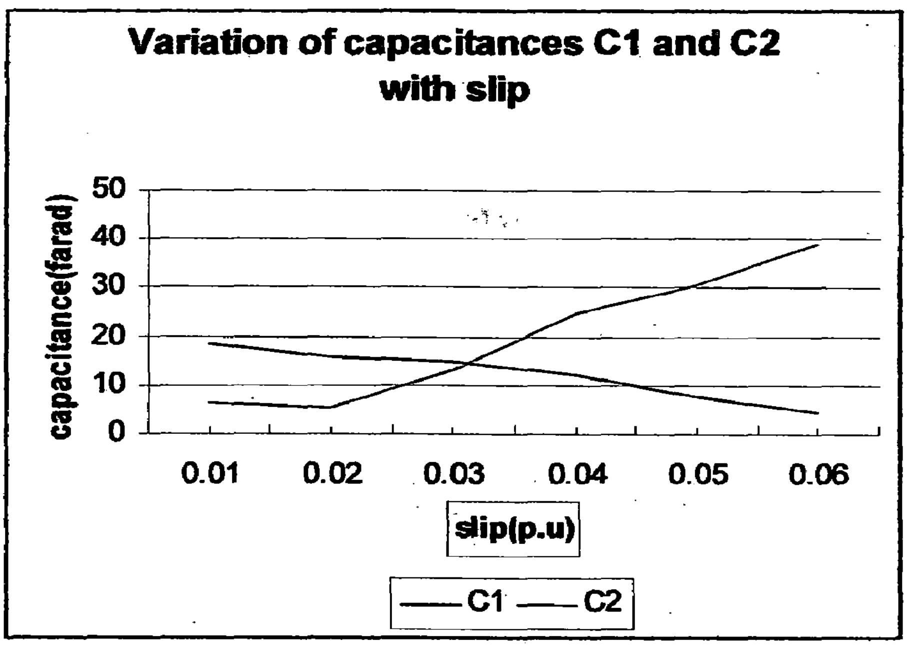



*Fig 3.3(c) Variation of capacitances to give perfect phase balance (Experimental)*

### 3.3.1 Capacitors For Full Load:

performance tests were conducted on the experimental machine with the capacitances given in table-3.1. These capacitances enabled the induction motor to be balanced at a per unit slip of 0.047 and a phase current of 4.2-A. under these condition, the motor delivered an output power of 1.4-Kw at an efficiency of 80%. Stable motor operation possible over the practical slip range. Fig 3.4 (b) shows that both $V_A$ and $V_C$ increase when the slip is reduced, whereas $V_B$ remains approximately constant. Fig 3.4 (c) shows the variation of phase currents with slip. For lower values of per unit slip, overcurrent occurs in C-phase. Both $I_A$ and $I_B$ decrease with reduction in slip initially.

Table-3.1 Capacitor Microfarad for Full Load

| Capacitors across winding | Experimental value of capacitors( Microfarad) | Calculated value of capacitors (Microfarad) |
|---|---|---|
| $C_{10-12}$ ($C_1$) | 10 | 8.3 |
| $C_{2-12}$ ($C_2$) | 30.2 | 20.5 |
| $C_{1-10}$ ($C_3$) | 60.4 | 41 |

Table-3.2 Voltage and current in phase winding at Full load condition

| $V_A$ | $V_B$ | $V_C$ | $I_A$ | $I_B$ | $I_C$ |
|---|---|---|---|---|---|
| 138 V | 142V | 154 V | 4.4A | 4.4A | 4.8A |

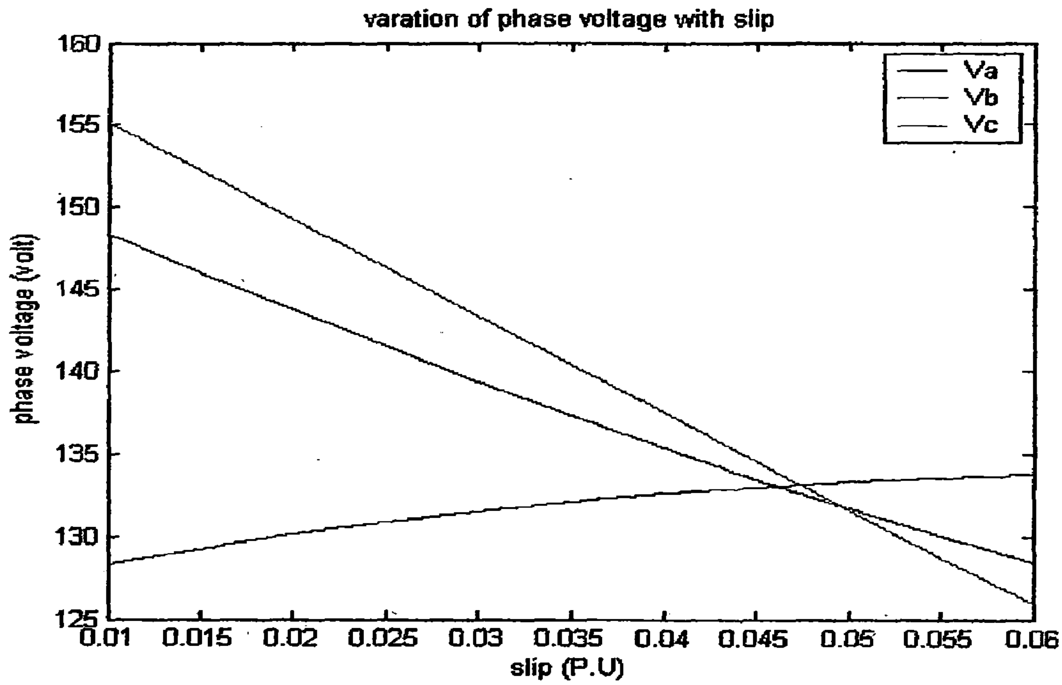



*Fig 3.4(a) Variation of phase voltage with slip for using full load capacitances (simulated Result)*

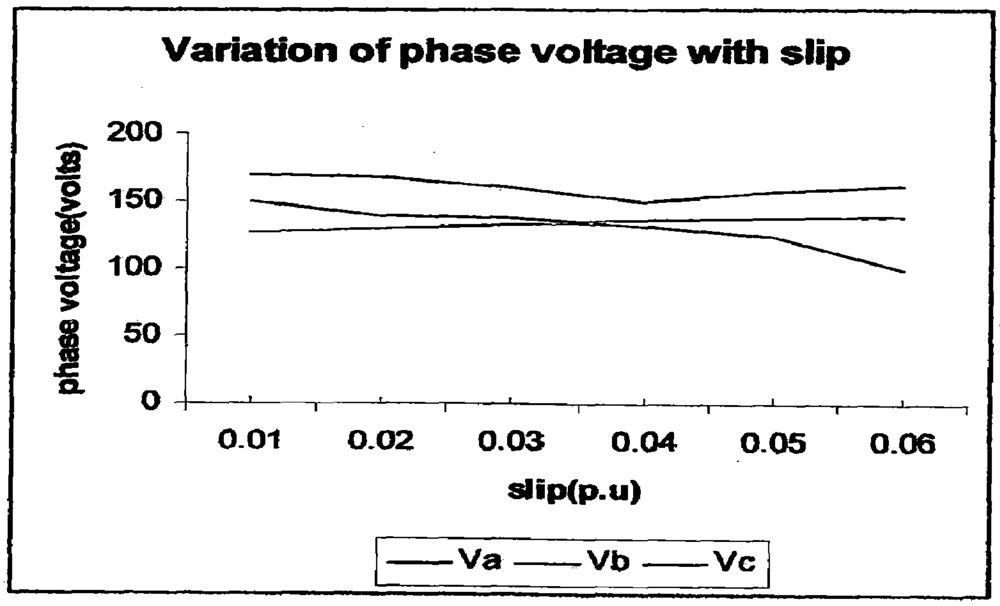



*Fig 3.4(b) Phase voltages Variation of three-phase induction motor with the smith connection (Experimental Results)*

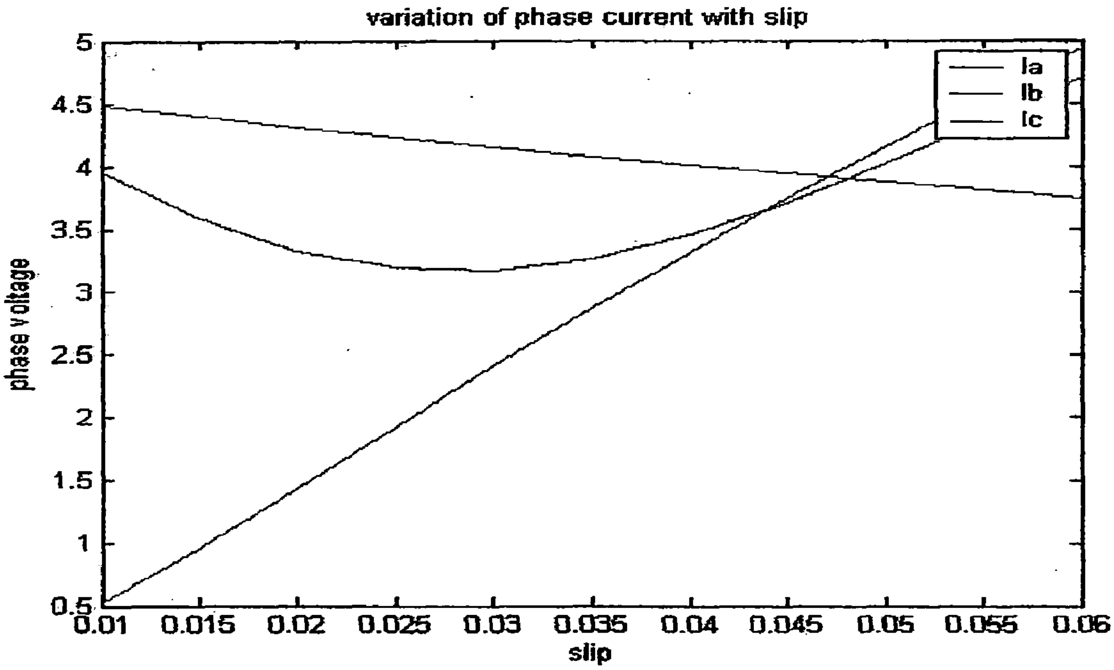



*Fig 3.4(c) Variation of phase current with slip using full load capacitances (Simulated Result)*

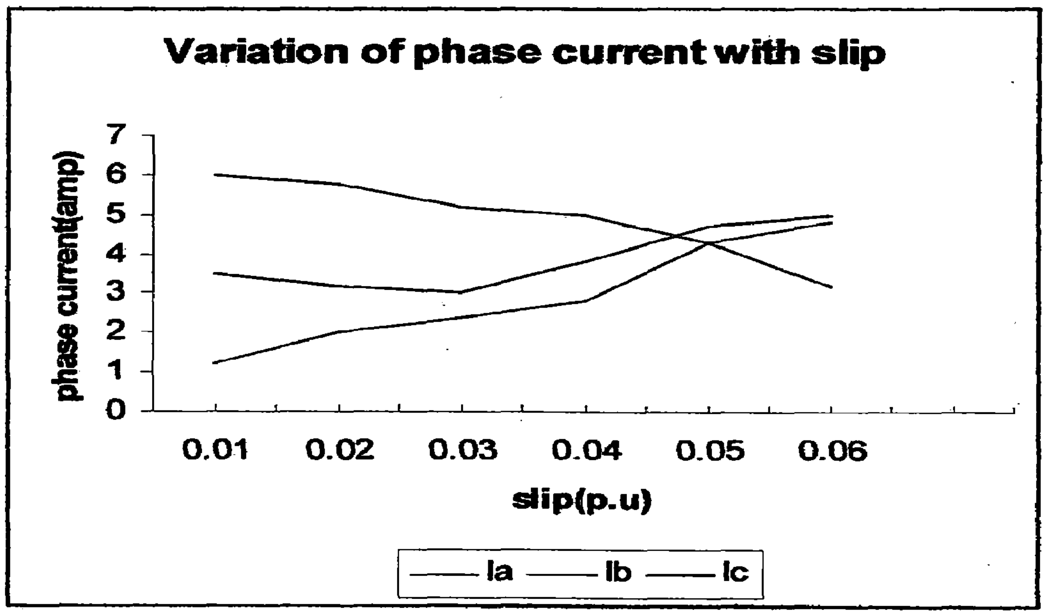



***Fig 3.4 (d) Phase currents Variation of three-phase induction motor with the smith connection (Experimental Results)***

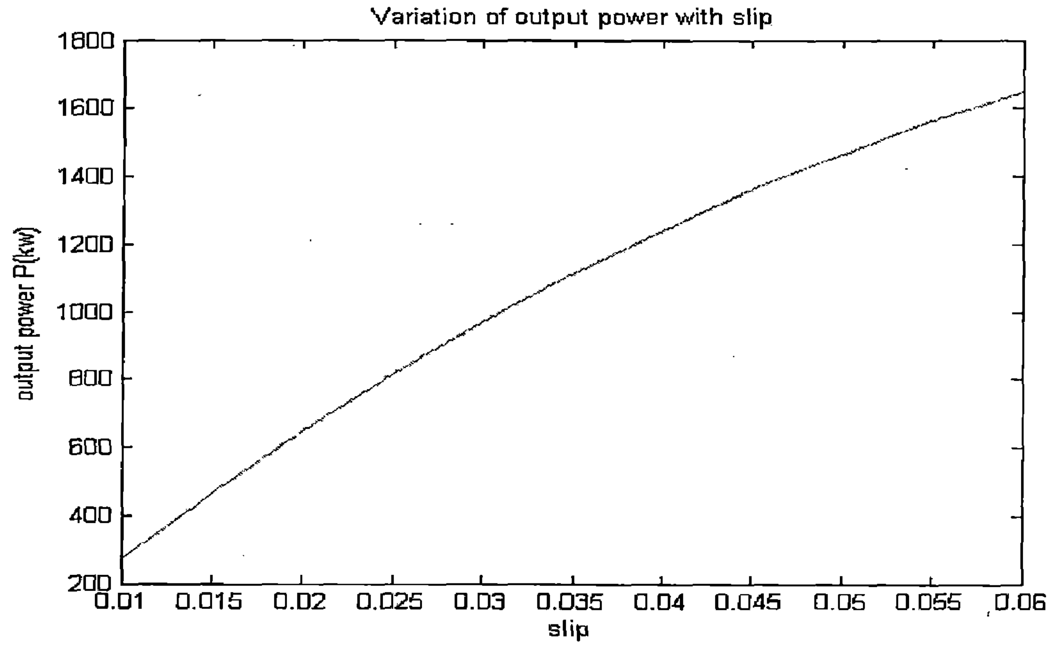



*Fig 3.4 (e) Variation of output power with slip for smith connected IM*

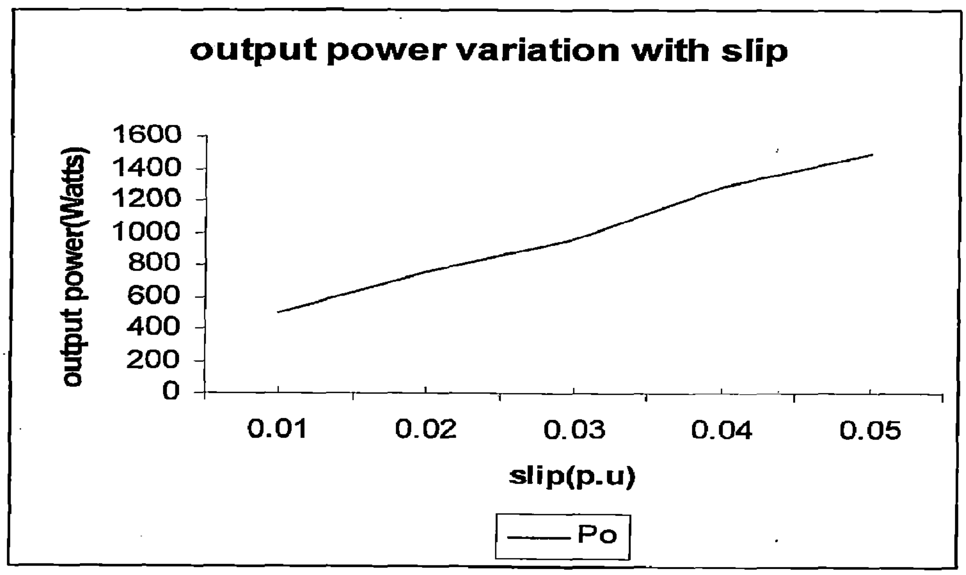



*Fig 3.4(f) Output power variation with slip using full load capacitances (Experimental results)*

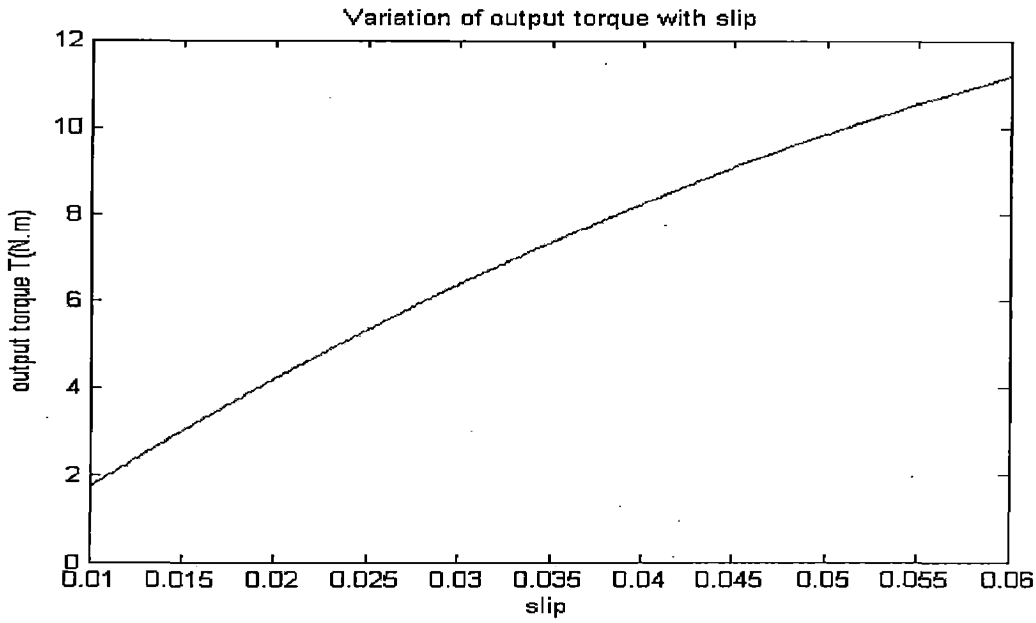



*Fig 3.4(g) Variation of output torque with slip for smith connected IM*

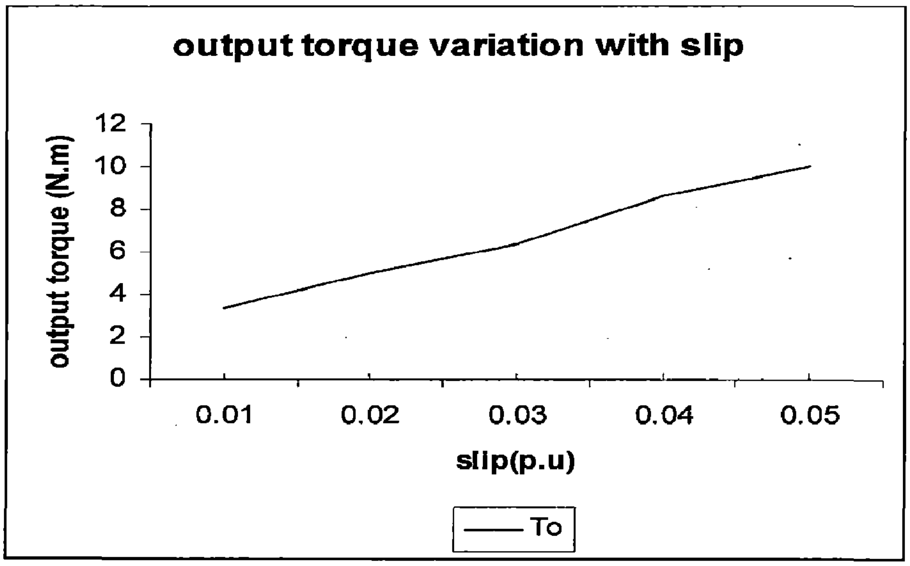



*Fig 3.4(h) Output torque variation with slip using full load capacitances (Experimental Results)*

## 3.3.2 Capacitor For Light Load: -

The circuit of fig 3.3 (a) can be used for light load. The constraint to be satisfied is that the no load voltage on the DL winding 3-12 not exceeds a preselected limit. We have chosen 15% overvoltage as the limiting constraint at no load. The capacitances in Table-3.3 give the balance operation in no load condition.

Table-3.3 Capacitor Microfarad for No Load

| Capacitors across winding | Experimental value of capacitors( Microfarad) | Calculated value of capacitors (Microfarad) |
|---|---|---|
| $C_{10\text{-}12}$ ($C_1$) | 16.25 | 18.3 |
| $C_{2\text{-}12}$ ($C_2$) | 4 | 1.5 |
| $C_{1\text{-}10}$ ($C_3$) | 8 | 3 |

Table-3.4: Voltage and current in phase winding at no load condition

| $V_A$ | $V_B$ | $V_C$ | $I_A$ | $I_B$ | $I_C$ |
|---|---|---|---|---|---|
| 139 V | 130V | 142 V | 0.21A | 0.188 A | 0.116A |

With the capacitors of table-3.3, as the shaft power increases, the DL voltage decreases, and the LL current increases. At 67.5% shaft power the LL current reaches rated value. Therefore this capacitance can be used for all shaft loads between no load and 67% load.

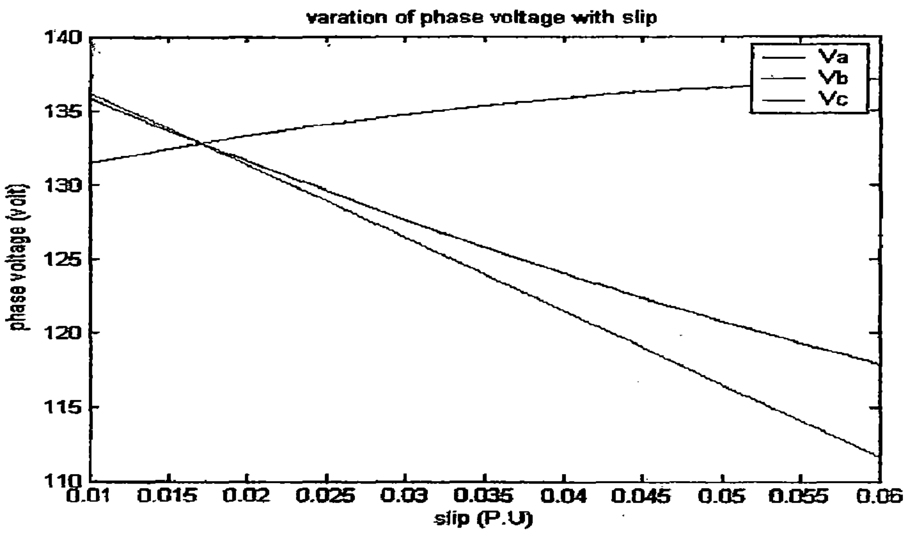



*Fig 3.5(a) Variation of phase voltage with slip using no load capacitances (simulated)*

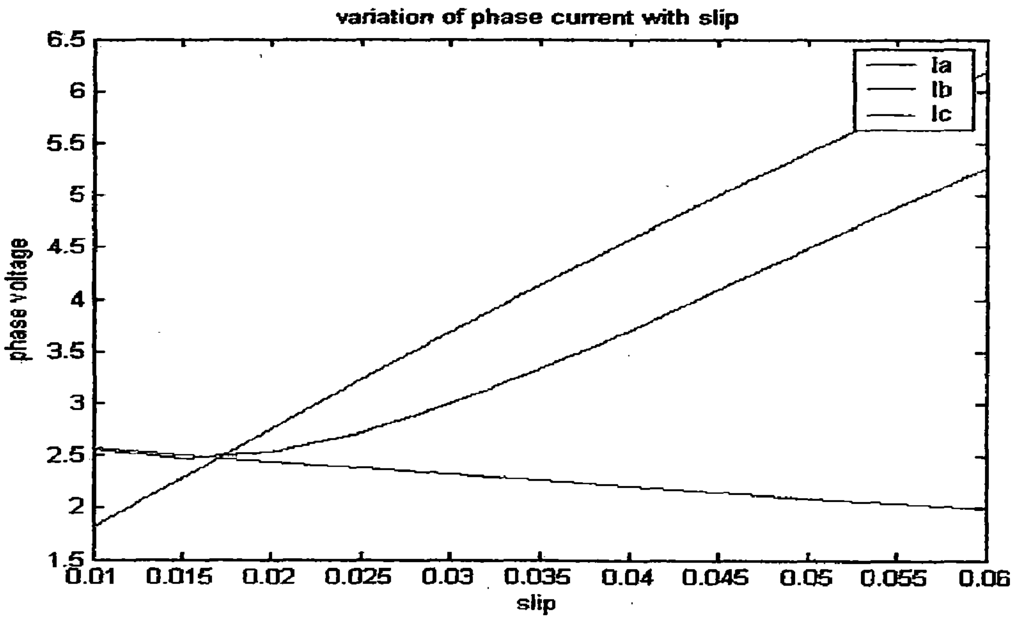



*Fig 3.5(b) Variation of phase current with slip using no load capacitances (simulated)*

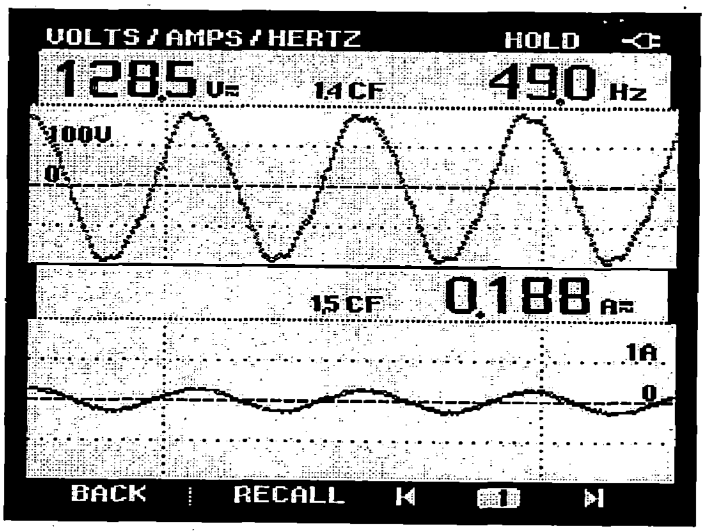



*Fig 3.5(d) Waveform of phase voltage and current across winding B with L-mode capacitances*

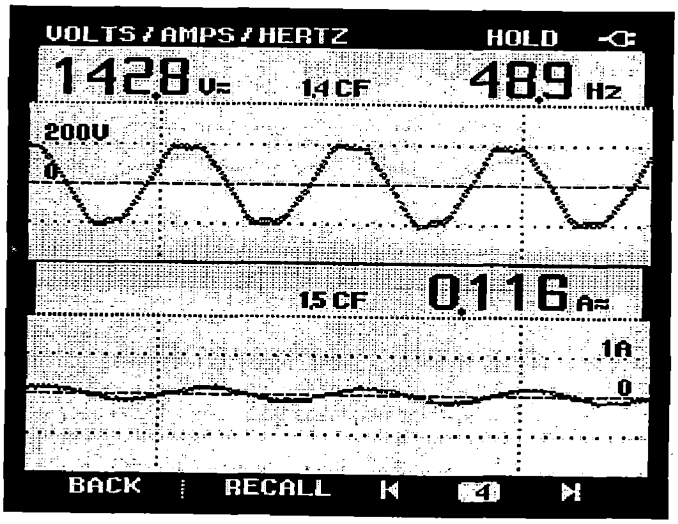



*Fig 3.5(e) Waveform of phase voltage and current across winding C with L-mode capacitances*

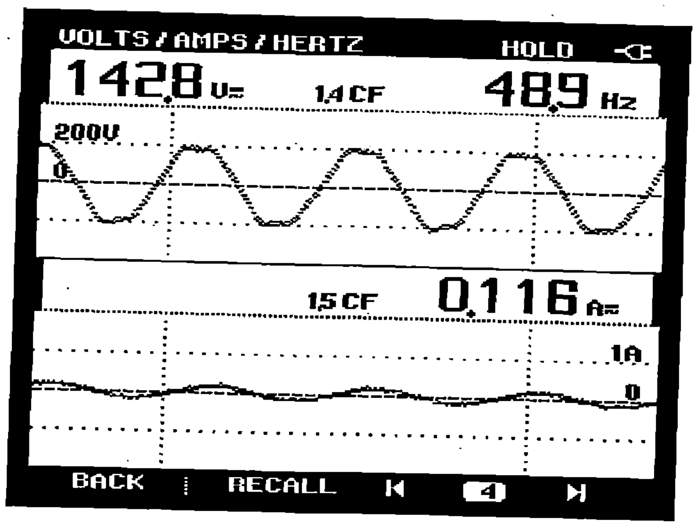



*Fig 3.5(e) Waveform of phase voltage and current across winding C with L-mode capacitances*

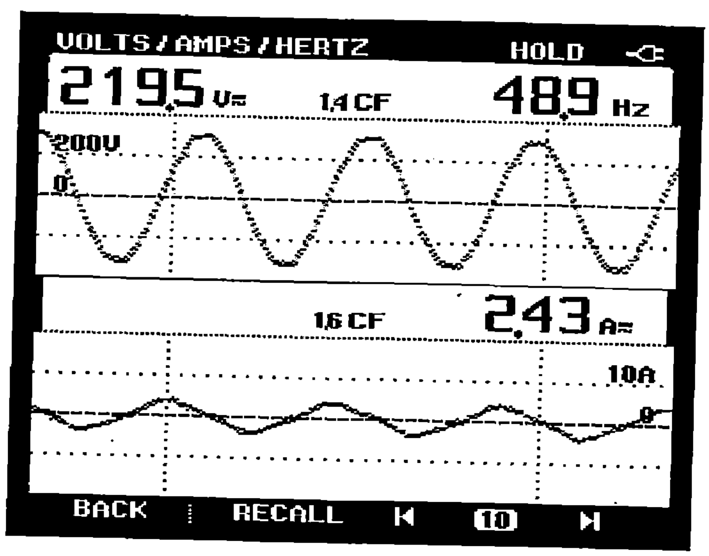



*Fig 3.5 (f) Waveform of input voltage and current with L-mode capacitances*

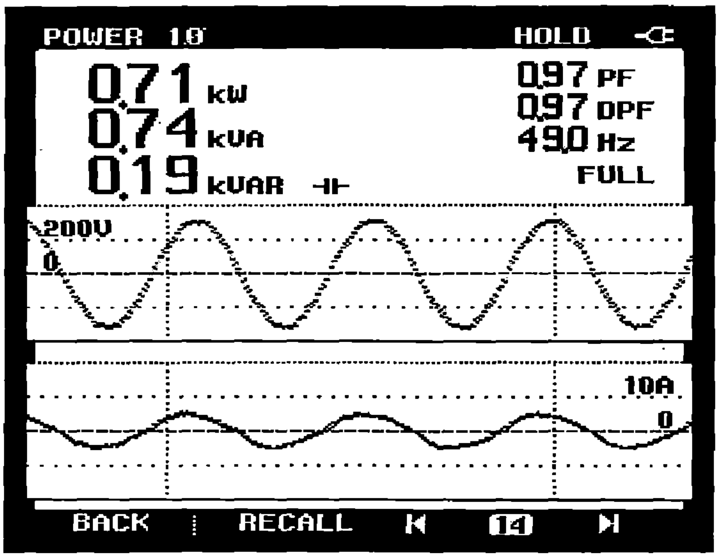



Fig 3.5(g) Input power and power factor

## 3.3.3 Capacitors For Medium Load: -

Capacitors in table-3.3 can be used for all shaft loads between no load and 67% load. But motor is unbalanced, for balanced operation at intermediate load different set of capacitance required. The capacitance in Table-3.5 gives the balance operation in Medium load condition. Fig 3.6 (a) and (b) shows the voltage and current variation at medium load.

Table-3.5 Capacitor Microfarad for Medium Load

| Capacitors across winding | Experimental value of capacitors( Microfarad) | Calculated value of capacitors (Microfarad) |
|---|---|---|
| $C_{10\text{-}12}$ ($C_1$) | 10.5 | 13.3 |
| $C_{2\text{-}12}$ ($C_2$) | 14 | 9.5 |
| $C_{1\text{-}10}$ ($C_3$) | 28 | 19 |

Table-3.6 Voltage and current in phase winding at Medium load condition

| $V_A$ | $V_B$ | $V_C$ | $I_A$ | $I_B$ | $I_C$ |
|---|---|---|---|---|---|
| 138 V | 142V | 154 V | 2.8A | 3.2 A | 3.6 A |

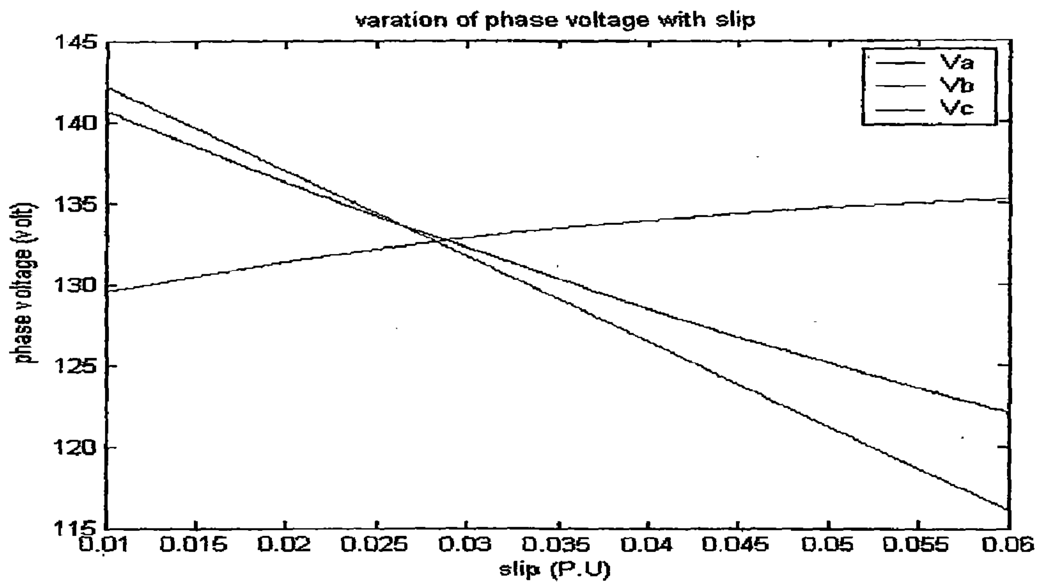



*Fig 3.5(h) Variation of phase voltage with slip using medium load capacitances (Simulated Result)*

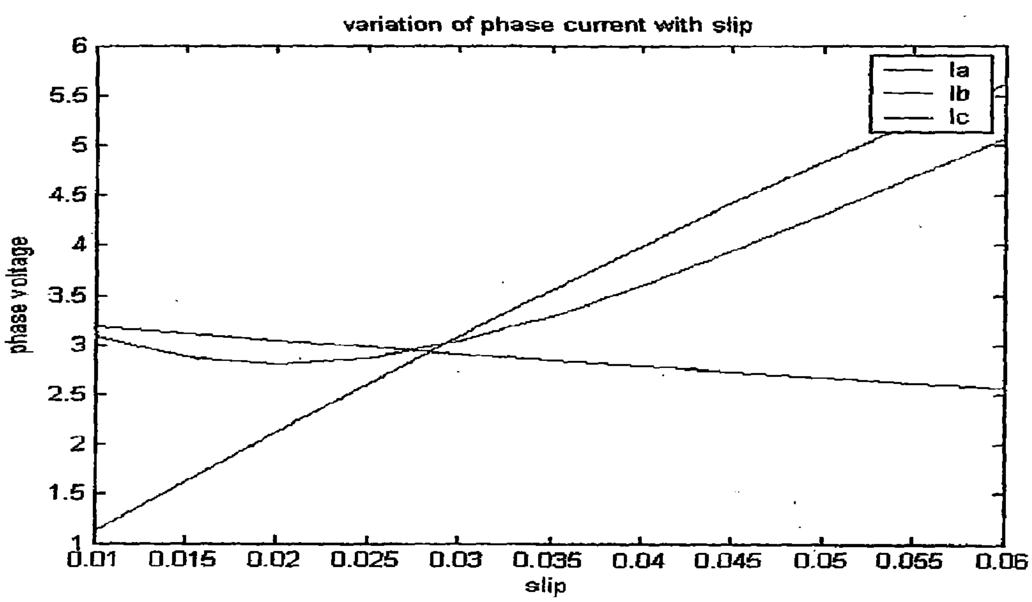



*Fig 3.5 (I) Variation of phase current with slip using medium load capacitances (Simulated Results)*

# CHAPTER-4

# HARDWARE DEPELOPMENT

## 4.1 Introduction

The smith connection is a special winding connection that enables a three-phase motor to operate with high efficiency on a single-phase supply system. In previous chapter the theoretical and experimental studies showed that perfect phase balance could be achieved at a given speed by using appropriate values of capacitances in the circuit, but phase imbalance would result when the rotor speed or load was changed. To ensure satisfactory machine performance over a wide range, the concept of multimode operation was proposed. The method involves the selection of different capacitance values that result in minimum phase imbalance at different rotor speeds. The theoretical analysis and experimental result presented in reveal the following facts:

1) For a given set of capacitances, the phase voltages and phase currents will change when the rotor speed changes. The A-phase voltage $V_A$ decreases with increase in rotor speed, whereas B-phase voltage $V_B$ and C-phase voltage $V_C$ both increase.
2) Input current I Varies almost linearly with the rotor speed.

The above observations suggest that instead of the rotor speed signal, the input current I may be exploited for controlling the switching of capacitances for multi-mode operation of induction motor. An advantage of this approach is that an expensive speed sensor need not be used. Fig 4.1 shows the logic for switching the capacitances for multi-mode operation, and fig 4.2 shows the linearly variation of input current with load.

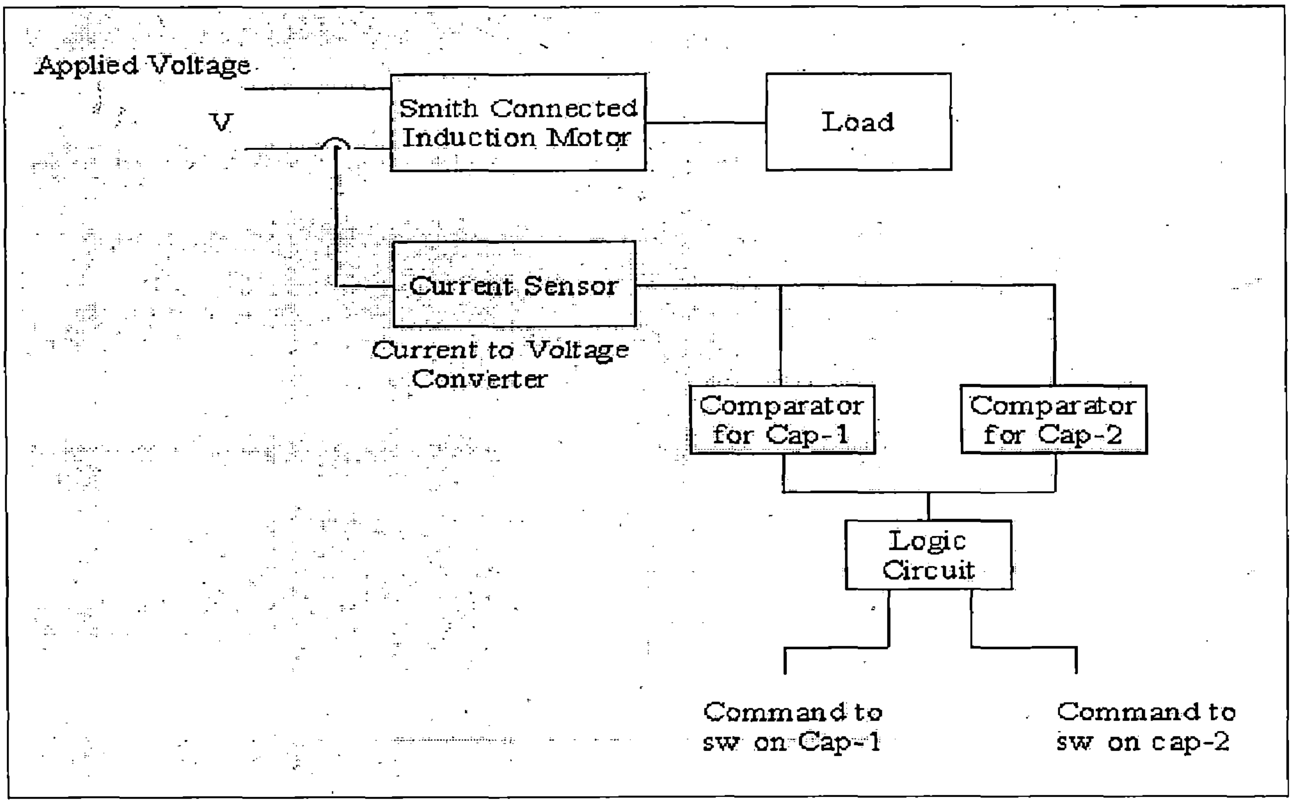



*Fig4.1 logical Diagram for Capacitances Switching*

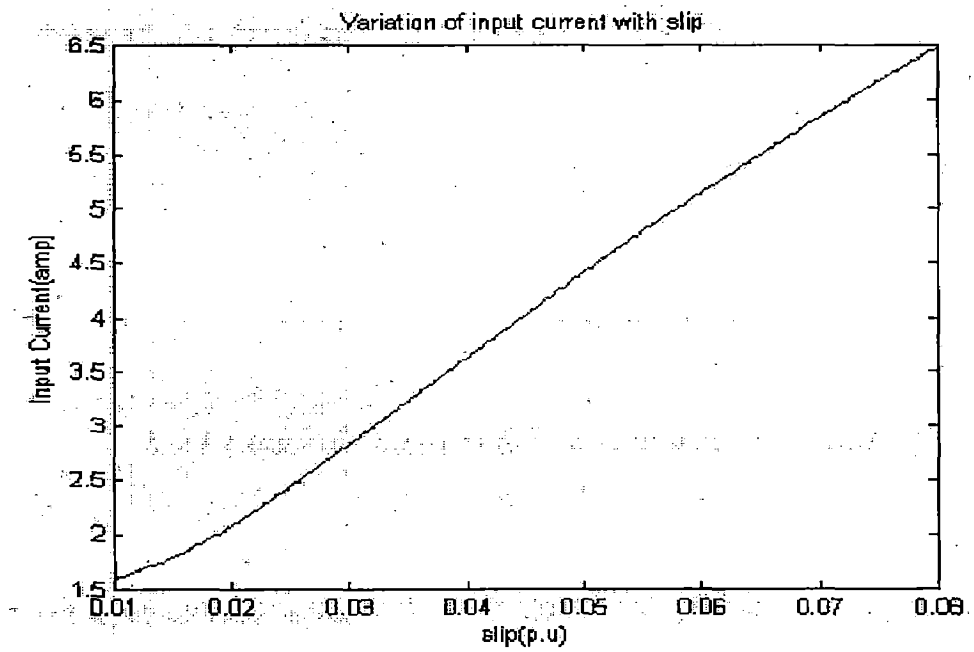



*Fig 4.2 Variation of Input Current*

## 4.2 Control Scheme:-

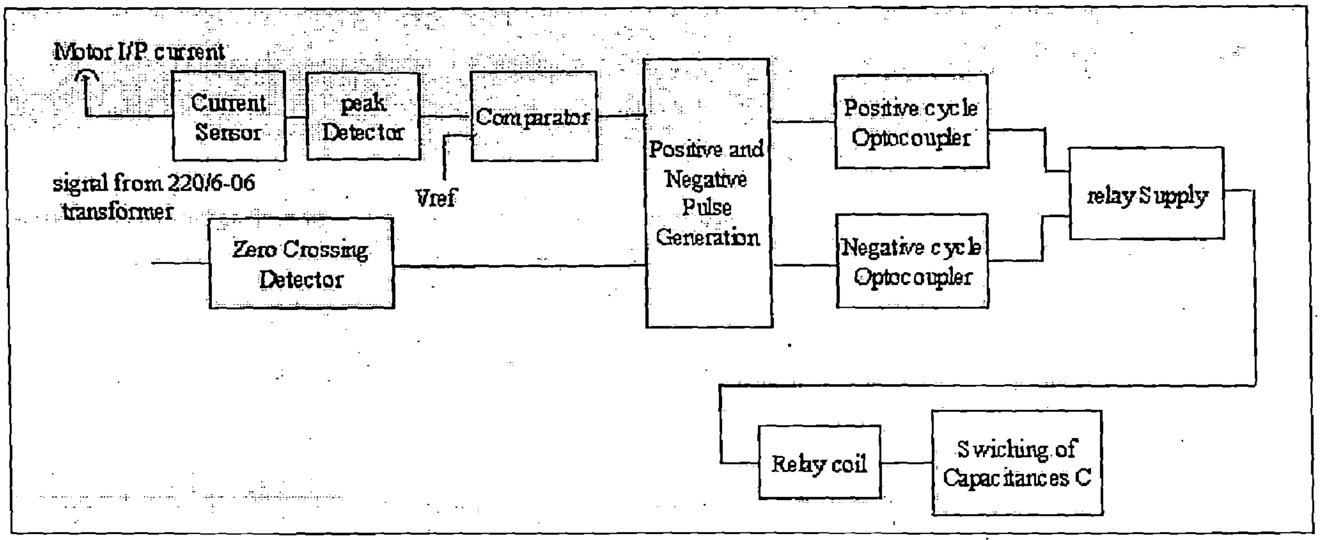



*Fig 4.3 Schematic diagram of proposed controller based mode selection system*

Control scheme is composed of two parts:

- Control circuit
- Power circuit

1) Control circuit:-

Control circuit used for generates the control pulses, these pulses used for controlling the switching of capacitances at different load condition. The control circuit is consist of current sensor, comparator, peak detector and zero crossing detector with using 'AND' gate and 'NOT' gate to generate pulses which replica to each other. The proposed scheme uses input current signal as a feedback to estimate the load on motor. This current is sense by a hall effect current sensor, the output current sense is converted into voltage signal so that it gives correct replica of load current. This voltage is compare in two comparator circuit, one is for capacitor set-1 and other is for capacitor set-2. If load goes beyond 67%, its corresponding input current is 2.8 ampere that is equivalent to 2.8V of calibrated current sensor circuit, these calibrate voltage compare by comparator circuit-1 which is set to reference voltage such that when the voltage is more than 2.8 V it gives the pulse, these pulse fed to the circuit which generate the two pulses, for positive and negative cycle of supply. These control pulses shown in fig 4.4(b).these two pulses given to the voltage regulator circuit as a gate pulse through opto-coupler. When input current is 2.8 A or above capacitance-1 is switched on. Similar circuit as fig 4.4(a) used to switching the capacitance-2, comparator-2 is set to give the output pulses when the load on motor increase to 80%. Output pulses for comparator-2 are shown in fig 4.4(c). Fig 4.4 shows the firing pulses when both capacitor are switch ON.

2) Power Circuit:-

Power circuit is consisting of voltage regulator. In voltage regulator the two thyristor connected in antiparaller, one thyristor conduct for positive half cycle, and other thyristor conduct for negative half cycle. Thyristor is conduct when gate pulse is applied. As Shown in fig 4.4(a) contactor (220 ac) connected to 220 V supply through voltage regulator. When the motor input current (it depend on the load) reach to preset value ,the comparator generate the pulses, these pulses applied to thyristor Th1 and Th2, thyristor is turn on and contactor-1 is energized so that capacitor-1 gets connected to motor circuit.

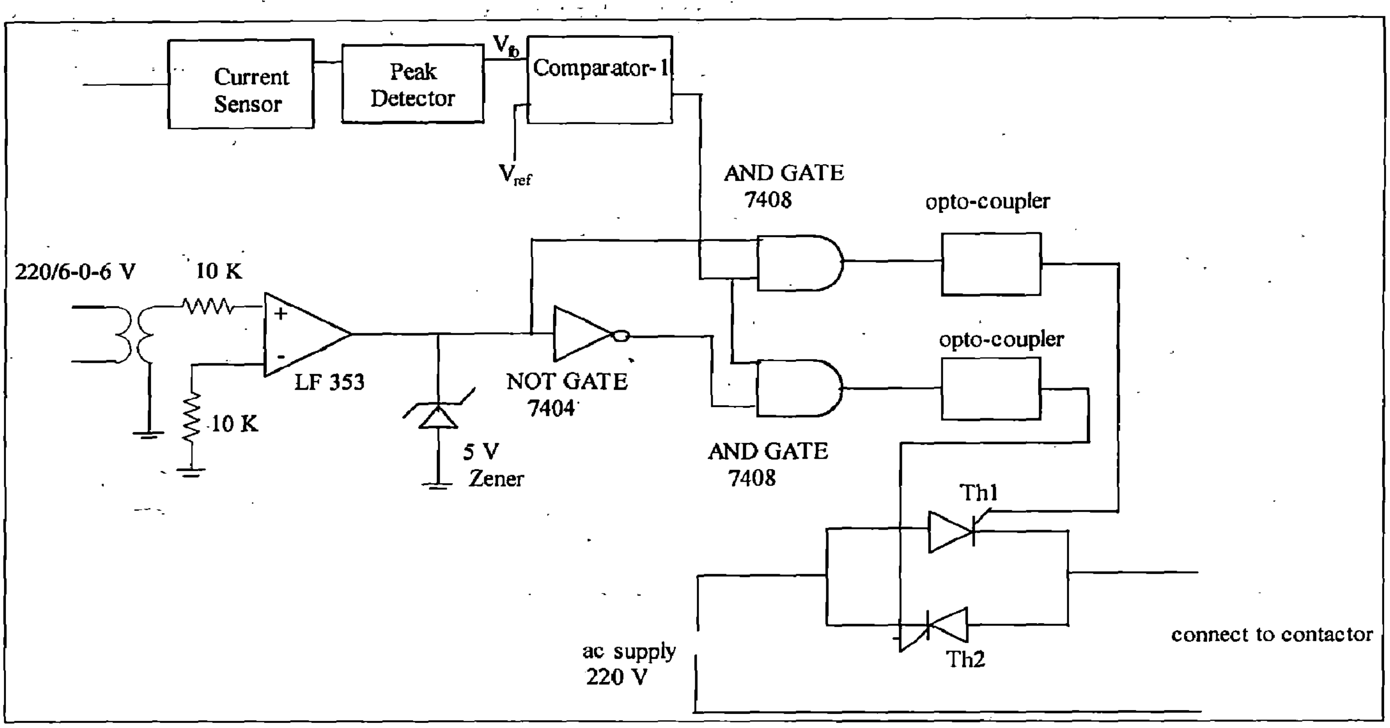



*Fig 4.4(a) logical diagram for switching capacitor-1*

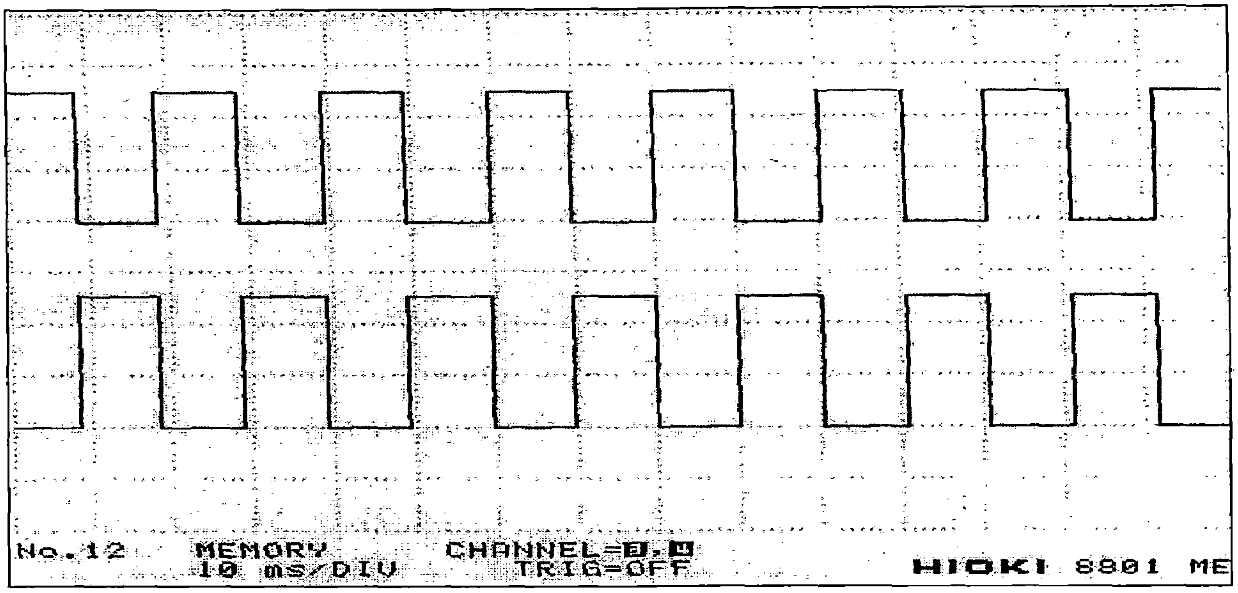



*Fig 4.4 (b) Output pulses when comparator-1 is switched on*

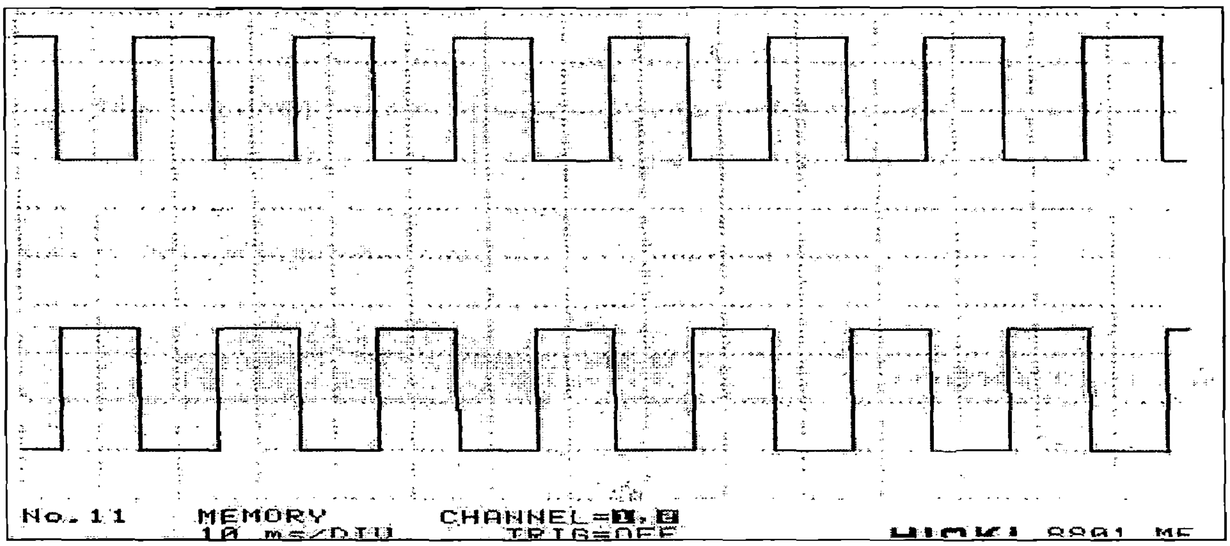



*Fig 4.4 (c) Output pulses when comparator-2 is switched on*

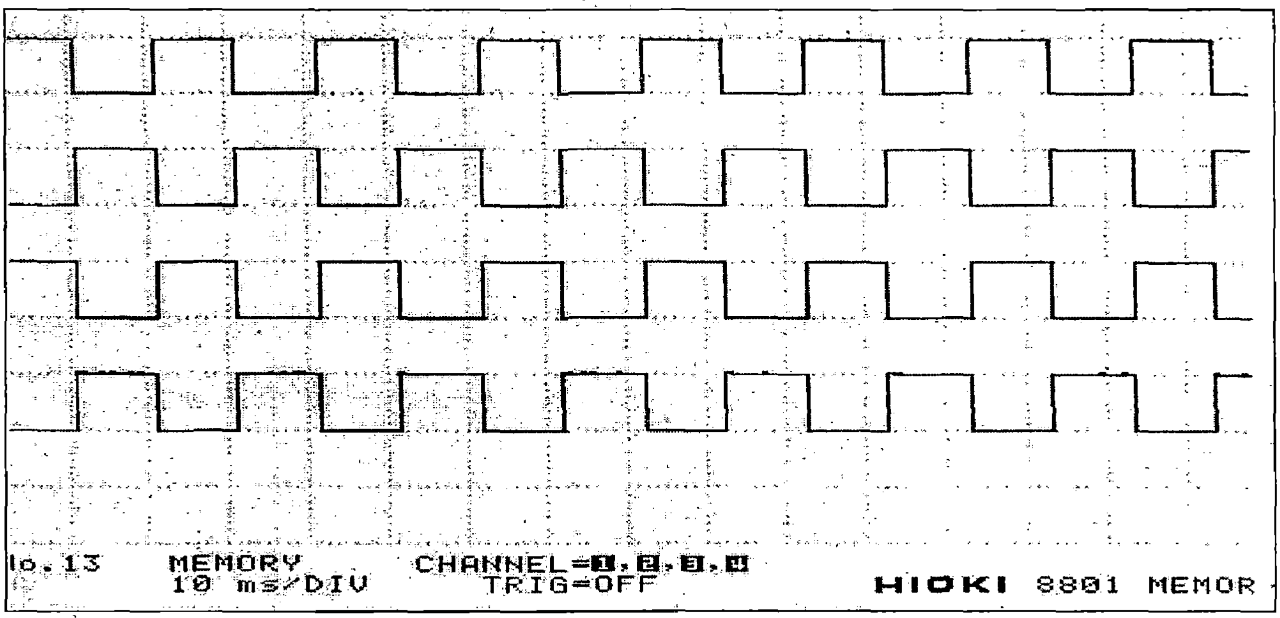



*Fig 4.4(d) Output pulses when both comparators are switched on*

## 4.3 Control Circuit

### 4.3 (a) Current Sensing Circuit

Closed loop Hall Effect current transformers use the ampere turn compensation method to enable measurement of current from dc to high frequency with the ability to follow rapidly changing level or wave shapes. The application of primary current (Ip) causes a change in the flux of the air gap. This in turn produces a change in output from the hall element away from the steady state condition. This output is amplified to produce a current ($I_s$),which is passed trough a secondary winding causing a magnetizing force to oppose that of the primary current, thereby reducing the air gap flux. The secondary current is increased until the flux is reduced to zero. At this point the hall element output will return to steady state condition and the ampere turn product of secondary circuit will match that of the primary. The current that passes through the secondary winding is the output current. The transformation ratio is calculated by the standard current transformation equation:

$$N_pI_p=N_sI_s$$

Where, $N_p$= Primary turns; Ip= Primary current

$N_s$= Secondary turns; Is= Secondary current

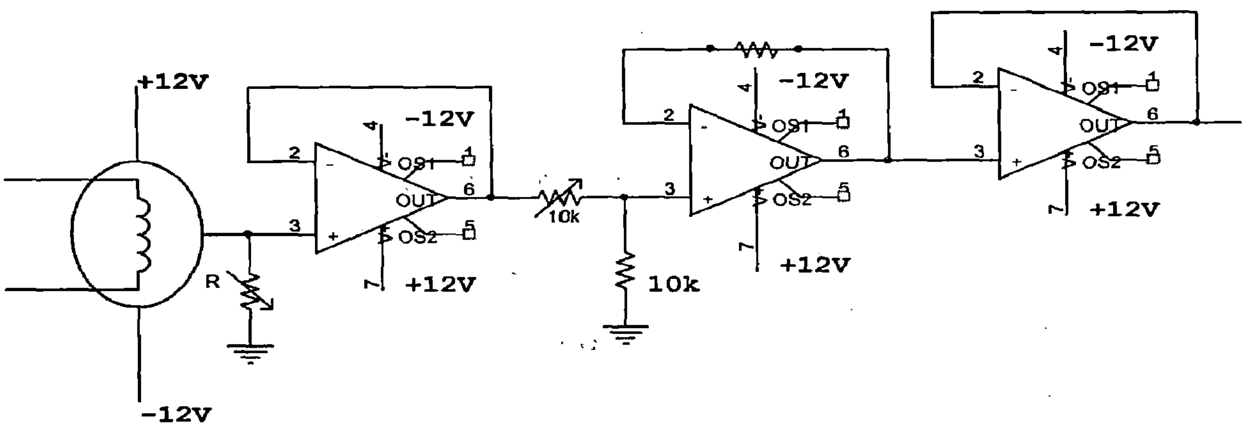



*Fig 4.5 Hall-effect Current sensor*

A 10KΩ resistor is used in the negative feed back path of the OP-AMP for gain adjustment so as to obtain a voltage of 1 volt corresponding to 1 Amp (DC current). The current carrying conductors are passed in the reverse direction in the current sensor in order to obtain right polarity current at the output of the inverting amplifier. Same circuit is used for measuring other currents ($I_b$, $I_c$).

## 4.3 (b) Pulse Amplification And Isolation Circuit

Pulse amplification and isolation circuit is shown in fig 3.3 shown below.

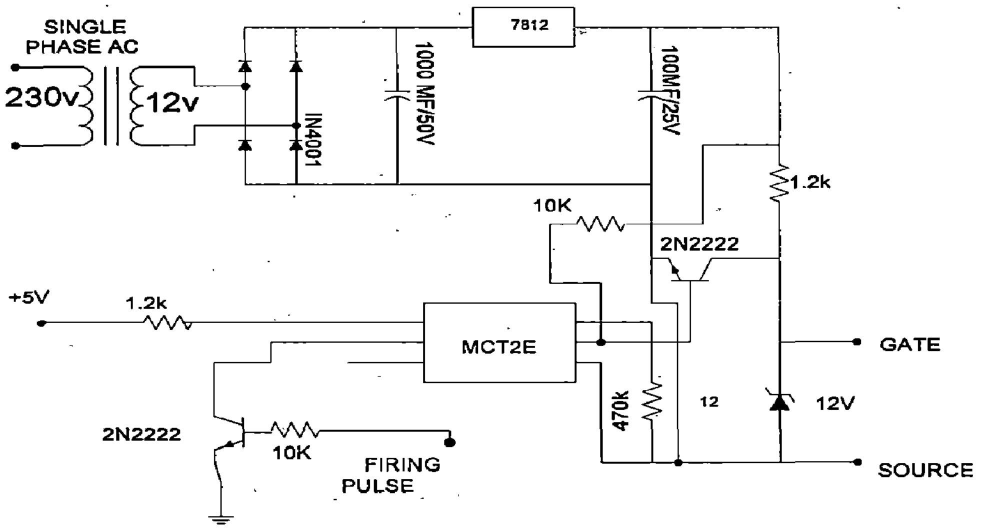
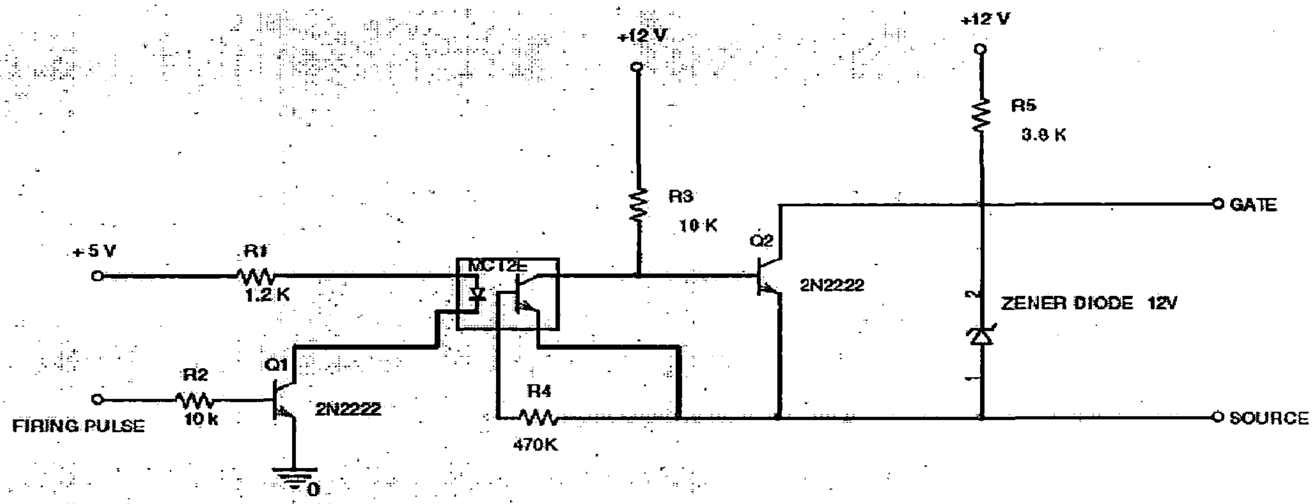


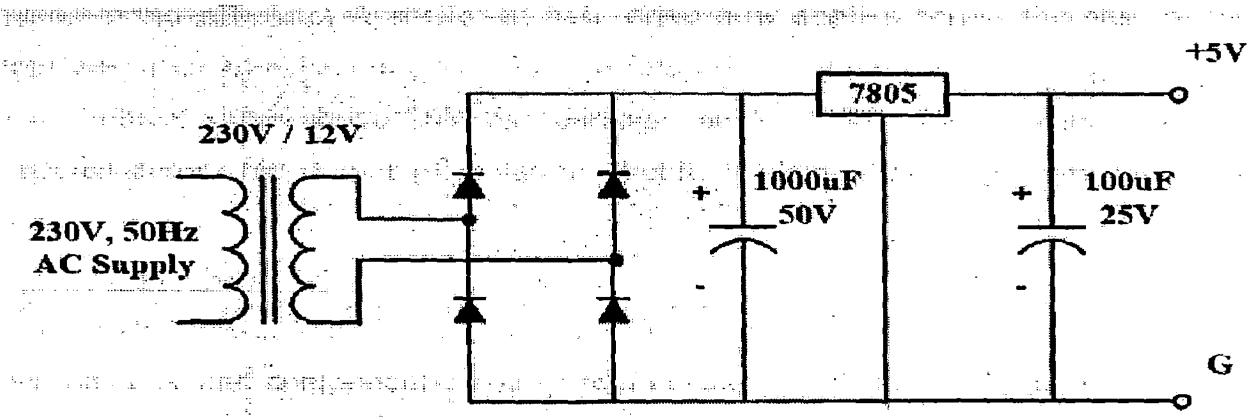

*Fig 4.6 Pulse amplification and isolation circuit*

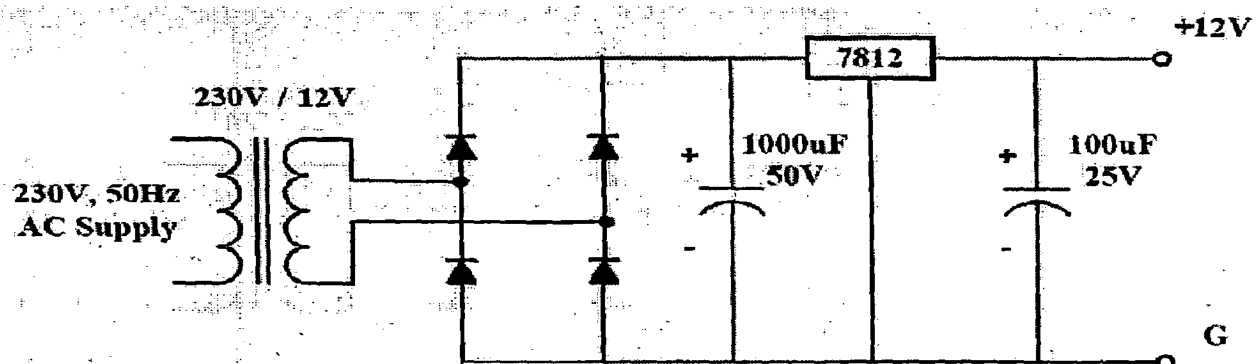


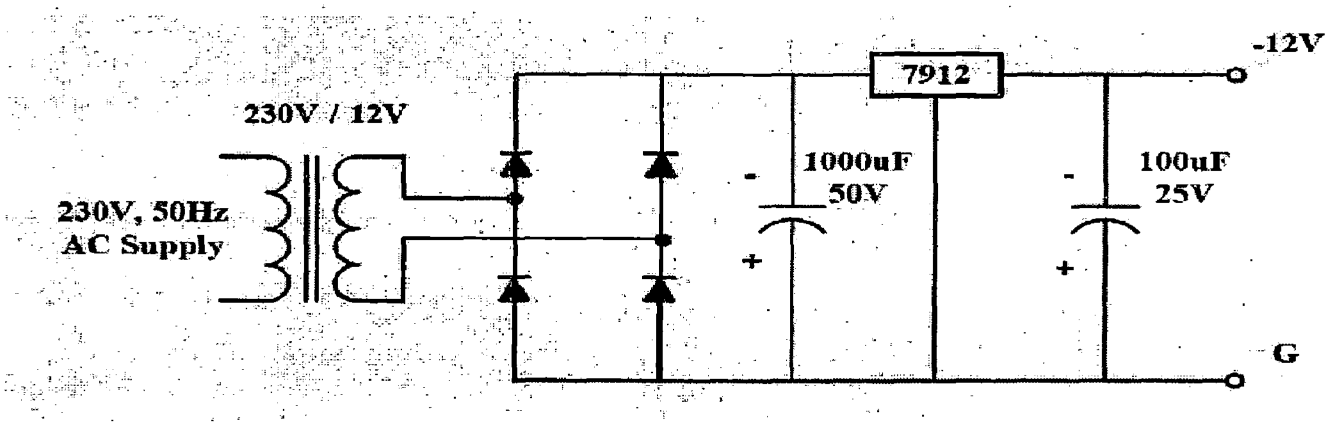

The opto-coupler MCT2E provides necessary isolation between the low voltage circuit and high voltage circuit. The pulse amplification is provided by the output amplifier transistor 2N2222. When the input gating pulse is at +5 volt level, the transistor saturates, the LED conducts and the light emitted by it falls on the base of phototransistor thus forming its base drive. The output transistor thus receives no base drive and therefore remains in cutoff state and a +12 volt pulse (amplified) appears across its collector terminals. When the input gating pulse is low the input switching transistor goes into the cutoff state and LED remains off thus emitting no lights and therefore a phototransistor of the opto-coupler receives no base drive and, therefore remains in cut-off state. A sufficient base drive now applies across the base of the output amplifier transistor it goes into the saturation state and output becomes low. Since slightest spike above 20V can damage the MOSFET, a 12V zener diode is connected across the output of isolation circuit. It clamps the triggering voltage at 12V.

## 4.3 (c) Power Supplies

DC regulated power supplies (±12V and +5V) are required for providing the biasing to various ICs, and components. The system development has in-built power supplies for this purpose. The circuit diagram for various DC regulated power supplies are shown in fig and fig below.






As shown the single phase AC voltage is stepped down and rectified using diode bridge rectifier. A capacitor of 1000 µf ,50V is connected at the output of the bridge rectifier for smoothing out the ripples in the rectified DC voltage of each supply .IC voltage regulated chips ,7812 7912,7805 are used for obtaining the dc-regulated voltages . A capacitor of 0.1µf, 50V is connected at the output of the IC voltage regulator of each supply for obtaining the constant, ripple free DC voltage.

| DC voltage | IC regulator |
|---|---|
| +5V | 7805 |
| +12V | 7812 |
| -12V | 7912 |

## 4.3(d) Peak Detector:-

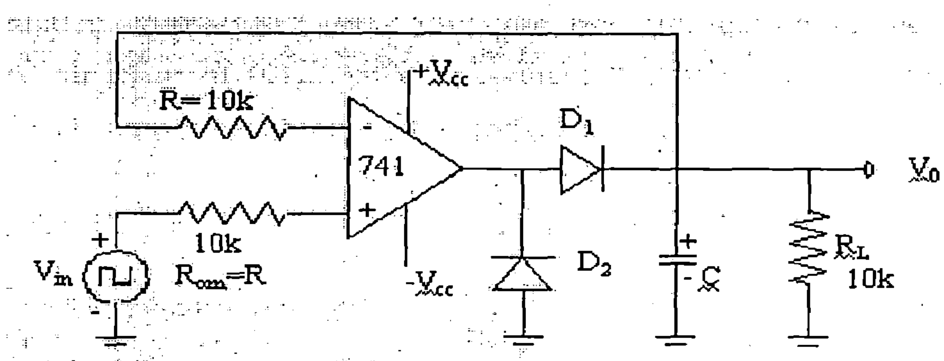



*Fig4.7 (a) Peak Detector Circuit*

Fig 4.7(a) shows a peak detector that measure the positive peak value of the square wave input during the positive half cycle of $V_{in}$. The output of the positive peak value $V_p$ of the input voltage $V_{in}$. Thus when $D_1$ is forward biased the op-amp operates as a voltage follower. On the other hand, during the negative half cycle voltage across C is retained. The only discharge path for C is through $R_L$. Since the input bias current IB is negligible. For proper operation of the circuit charging time constant ($CR_d$) and discharging time constant ($CR_L$) must satisfy the following condition.

$$CR_d <= T/10$$

Rd = Resistance of forward bias diode, 100Ω typically

T= time period of the input waveform

Resister R is used to protect the op-amp against the excessive discharging current especially when the power supply is switched off. Diode D2 conducts during the negative half cycle of Vin and hence prevents the op-amp from going into negative saturation.

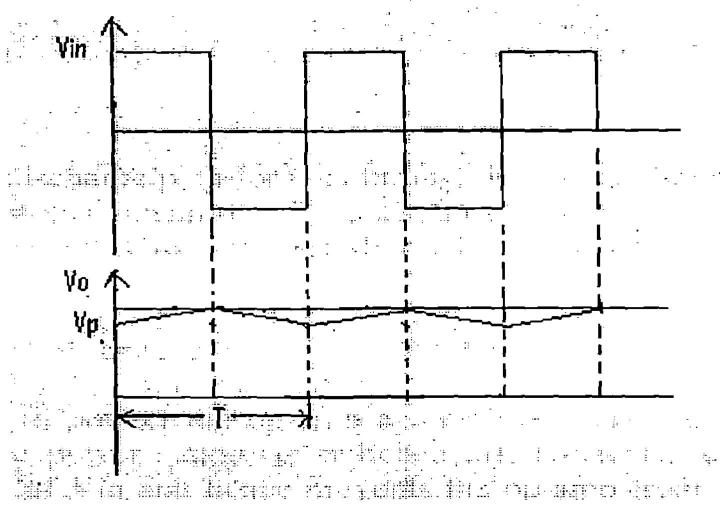



*Fig 4.7 (b) Input and Output Waveform*

**4.3(e)Comparator:-**

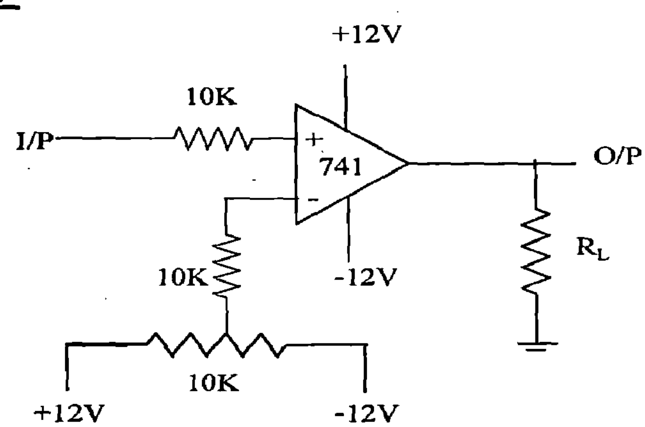



*Fig 4.8(a) Noninverting Comparator Circuit*

A comparator is a circuit which compares a signal voltage applied at one input of an op-amp with a known reference voltage at the other input. It is basically an open-loop op-amp with output + $V_{sat}$ and $-V_{sat}$ (=$V_c$). The circuit of fig 4.8 (a) is called a non-inverting comparator. A fixed reference voltage Vref is applied to (-) input and a time varying signal Vi is applied to (+) input. The output voltage is at $-V_{sat}$ for $V_i < V_{ref}$. And V0 goes to the $+V_{sat}$ for $V_i > V_{ref}$. The output waveform for a sinusoidal input signal applied to the (+) input is shown in fig. 4.8(b) for positive and negative $V_{ref}$ respectively. In practical circuit Vref is obtained by using a 10k potentiometer which forms a voltage divider with the supply voltages V+ and V- with the wiper connected to (-) input terminal as shown in fig 4.8(a). Thus a Vref of desired amplitude and polarity can be obtained by simply adjusting the 10k potentiometer.

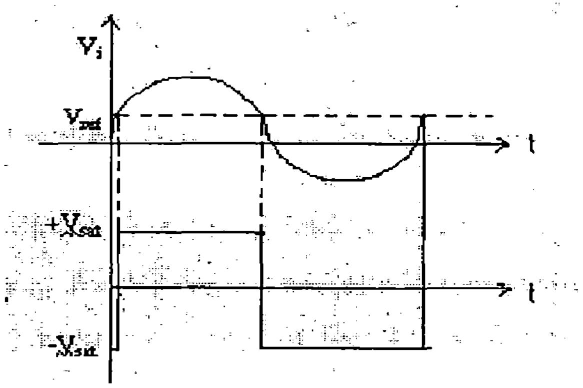



*Fig.4.8(b) Output Waveform of Noninverting Comparator*

## 4.3 (f) Zero Crossing Detector:-

The basic comparators can be used as a zero crossing detector provided that Vref is set to zero. A noinverting zero-crossing detector is shown in fig. 4.9 (a) and output waveform for a sinusoidal input signal is shown in fig 4.9 (b).

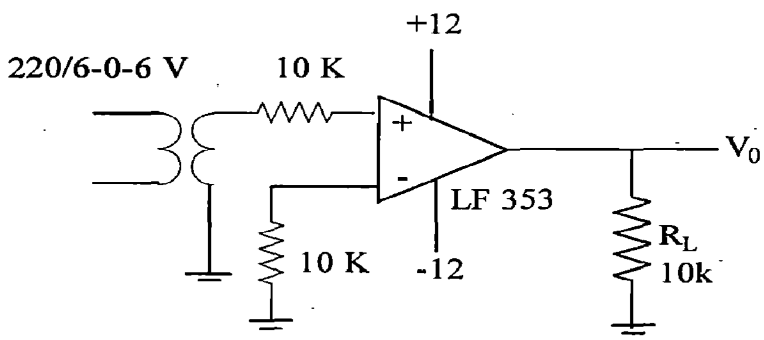



*Fig 4.9 (a) Zero Crossing detector*

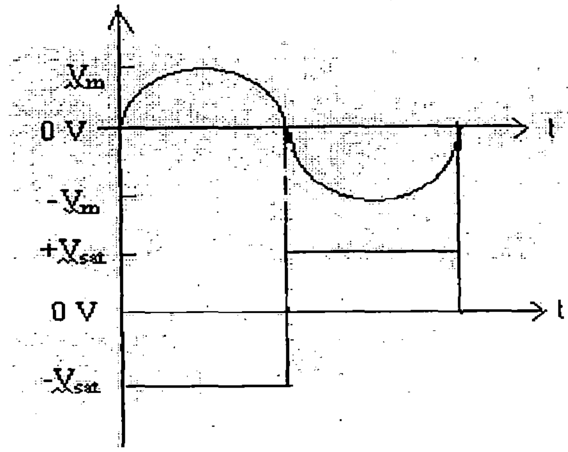



*Fig 4.9 (b) Input and Output Waveform*

## 4.4 Practical Implementation

Test performed on a 50 Hz, 4-pole, 415-V, 4.2-A experimental machine gave the sets of capacitances for phase balance as shown in table-4.4. Based on these results, the capacitor switching arrangement shown in fig. 4.10. Table-4.5 shows how the six switches S1 to S6 should be controlled in order to give the capacitance values in table-4.4.

Table-4.4 Capacitances for phase balance in experimental machine

| Mode | $C_1$ (μF) | $C_2$ (μF) | $C_3$ (μF) | Rotor speed at Balance (r/min) |
|---|---|---|---|---|
| L | 18.3 | 1.5 | 3 | 1480 |
| M | 13.3 | 9.5 | 19 | 1455 |
| H | 8.5 | 20.5 | 41 | 1430 |

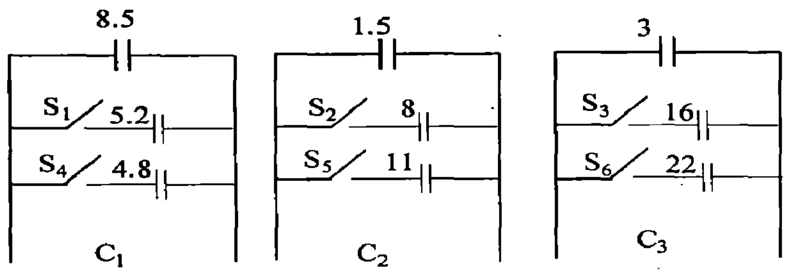



*Fig 4.10 Capacitor switching arrangement of single-phase induction motor with the smith connection*

Table-4.5

Switch control for phase balancing capacitances

| Mode | C1 | C2 | C3 |
|---|---|---|---|
| L | S1 closed<br>S4 closed | S2 open<br>S5 open | S3 open<br>S6 open |
| M | S1 open<br>S4 closed | S2 closed<br>S5 open | S3 closed<br>S6 open |
| H | S1 open<br>S4 open | S2 closed<br>S5 closed | S3 closed<br>S6 closed |

In our hardware circuit used two relay contactor; each relay contactor consists of 1-NC and 2-NO contact. The connection of contactor such that NC of contactor-1 and contactor-2 are switch S1 and S4 which are normally closed. 2-NO contact of contactor-1 is switched S2 and S3 and 2-NO contact of contactor-2 is S5 and S6.

At light load S1 and S4 is closed and other contact switch S2, S3, S5 and S6 is open. At medium load (M mode) relay contactor-1 is operated, now its NO become NC and NC become NO. Since Switch S1 open and switch S2, S3 is closed. At high load (H-mode) both contactor is on, now S1, S2 is open and S2, S3, S5 and S6 is closed.

CHAPTER 5

# APPLICATION AND LIMITATION

Until now we have shown different aspect of smith connection in case of motor. With economical consideration also this scheme proves beneficial. In this chapter we will discuss different application of motor.

## 5.1 Motor Application:-

In remote and ruler area where only a single phase supply is available standard three phase supply can be used in place of single phase supply. It operates at constant or full power. These include swimming pool pump, barn ventilators, hot-air furnace fans, kitchen and bath ventilation fans, dish washing machines, oil pumps for oil blower, and root cellar storage fans. For these applications three constant-valve running capacitors and a single starting capacitor are sufficient to drive a high-efficiency three phase motor from a single phase public utility. In some application of single phase motors the load is variable and the motor should operate with low loss at both one third power and at full power some of this applications are air compressor , grinder shop tools, irrigation pumps, planner table saws, lathes, pipe threading machines air conditions not hermetically sealed and garbage disposer. For these variable load applications, a different set of running capacitors permits high efficiency operation at partial load of three phase motor supplied from a single phase public utility

## 5.2 LIMITATION OF SCHEME:-

There are following limitations of smith connection in motor.

1. Power factor of the induction motor is limited in rage of $\pi/6$ to $\pi/3$.Beyond this rang inductor would be required for getting phase balanced that may cause magneti saturation at early stage.
2. Slip should not be less than 1.5% because below $C_2$ would be zero.
3. Minimum limit of slip is also decided by over voltage of the windings. As sli] decrease $V_A$ and $V_C$ increases while $V_B$ remain constant.
4. Also for lower value of slip overcurrent occur in phase C i.e. become overrated.

# CHAPTER 6

# CONCLUSION AND FUTURE SCOPE

## CONCLUSION:-

This dissertation has demonstrated the single-phase operation of a three-phase induction motor with the smith connection.

Smith connection has been analyzed using method of symmetrical components for computing the value of capacitances to gives perfect phase balance in the motoring operation on different load speed. The resulting input power factor is deduced using a phasor diagram approach. The input power factor very close to unity when the motor is balanced at full load current. The effect of capacitor on the input power factor of motor with the variation of load is shown.

Software programme for simulation of different characteristic like shaft torque, output power and efficiency has been developed and has shown effect of load variation on these characteristics. Since only capacitances are used for phase balancing, the smith connection is economical method for achieving high efficiency in a three-phase induction motor when operating on a single-phase supply.

Controller based multi-mode operation of a three-phase induction motor with the smith connection has been presented. The control system and mode switching strategy have been described. Very satisfactory motor performance has been obtained on a small laboratory induction machine.

An advantage of this approach is that an expensive speed sensor need not be used.

## FUTURE SCOPE:-

Proposed scheme gives the solution of all the problems which it is implemented but still there is lots of work has been done. Some area where future work can be done as follows:

1) The controller can be design digitally with the help of PLC controller, in which PLC take current sensor signal as analog input and after scaling it PLC generates 'ON' Command for particular capacitor.
2) To reduce the circuit complexity and to improve the system reliability, digital approach based on the microcontroller technology. A microcontroller may be viewed as a compact manufactured on a single chip. The built-in input/output

(I/O) and memory systems enable the chip to be interfaced with the hardware system to be controlled. The input current or C-phase voltage (Vc varies almost linearly with rotor speed) is to a signal conditioning circuit which consists of a two-winding step-down transformer, a diode rectifier and a sample-and-hold circuit. the sampled d.c. signal is next input to an analog-to-digital converter(ADC). The digital control signal is input to an 8052 microcontroller which functions as a voltage comparator and a mode selector. The output from the microcontroller is then used to drive a relay/contactor circuit the effect capacitor switching.

# APPENDIX-A

## SPECIFICATION OF INDUCTION MACHINE

The Experimental Induction Machine has following particular:

3.7 KW (5 HP), 415V, star connected, 4 pole, 50 Hz, squirrel-cage type.

| | |
|---|---|
| Stator leakage impedance | $= (3.4+j5.16)\ \Omega$ |
| Rotor leakage impedance | $= (3.26+j5.16)\ \Omega$ |
| Magnetizing Reactance | $= 104\Omega$ |
| Core loss resistance | $= 1024\ \Omega$ |
| Friction and Windage loss | = 157Watts |
| Stray load loss | = 1.8% of output power |
| Full load current | = ~~42~~ 7.4 amp. |

**$I_2 = I_3$**

Since in fig 1 at pseudo neutral point N current is zero.

Therefore.

$$I_A + I_B + I_1 + I_3 = 0 \qquad (1)$$

Also for the balance condition, sum of phase current at any point should be Zero.

i.e. $$I_A + I_B + I_C = 0 \qquad (2)$$

also $$I_C = I_1 + I_2 \qquad (3)$$

From eq. (1) and (3)

$$I_A + I_B + I_C - I_2 + I_3 = 0 \qquad (4)$$

Now substituting value in eq. (4) from eq. (2)

$$0 - I_2 + I_3 = 0$$

Or $I_2 = I_3$

**$V_2 = 2V_A$**

Since in fig 1

$$V_2 = V_A - V_B - V_C \qquad (1)$$

Also for balance circuit condition of voltage sum of phases voltage must be zero

i.e. $$V_A + V_B + V_C = 0 \qquad (2)$$

From eq. (2) $V_A = -(V_B + V_C)$

Substituting value in (1)

$$V_2 = V_A - (-V_A) \quad \text{or}$$

$$V_2 = 2\,V_A$$

---

**$Y_3 = 2Y_2$**

Since in fig 1 at pseudo neutral point N current is zero.

Therefore.

$$I_A + I_B + I_1 + I_3 = 0 \qquad (1)$$

Also for the balance condition, sum of phase current at any point should be Zero.

i.e. $$I_A + I_B + I_C = 0 \qquad (2)$$

also $$I_C = I_1 + I_2 \qquad (3)$$

From eq. (1) and (3)

$$I_A + I_B + I_C - I_2 + I_3 = 0 \qquad (4)$$

Now substituting value in eq. (4) from eq. (2)

$$0 - I_2 + I_3 = 0$$

$$I_2 = I_3 \qquad (5)$$

From fig 1

$$I_2 = V_2.Y_2 = (V_A - V_B - V_C)\,Y_2 \qquad (6)$$

Also for balance circuit condition of voltage sum of phases voltage must be zero

i.e. $$V_A + V_B + V_C = 0$$

$$V_A = -(\,V_B + V_C) \qquad (7)$$

Now substituting value in eq. (6) from eq. (7)

$$I_2 = (V_A + V_A).Y_2$$

$$I_2 = 2.V_A.Y_2 \qquad (8)$$

But $$I_3 = V_A.Y_3 \qquad (9)$$

From eq. (5)

$$I_2 = I_3$$

Substituting the value of I2 and I3 from eq (8) or (9)

$$2.V_A.Y_2 = V_A.Y_3$$ Or

$$Y_3 = 2.Y_2$$

# APPENDIX- B

Symmetrical components:

Any three coplanar vectors $V_A$, $V_B$, $V_C$ can be expressed in term of three new vectors $V_0$, Vp, Vn by three simultaneous linear equation with constant coefficient.

$$\begin{vmatrix} V_A \\ V_B \\ V_C \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix} \begin{vmatrix} V_0 \\ V_p \\ V_n \end{vmatrix}$$

Each of the original vectors (i.e. phase voltage) is replaced by set of three positive, negative and zero sequence voltages.

$$(3)^* \quad \begin{vmatrix} V_A \\ V_B \\ V_C \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix} \begin{vmatrix} V_0 \\ V_p \\ V_n \end{vmatrix}$$

1) Positive sequence component which has three vector of equal magnitude but displaced in phase form each other by $120^0$ and has the same phase sequence as the original vector.
2) Negative sequence component, which has three vectors of equal magnitude but displaced in phase from each other by $120^0$ and has the opposite phase sequence as the original vector.
3) Zero sequence component, which has three vector of equal magnitude and are in phase with each other.

# APPENDIX- C

$Vp = [ V / -a (1-a)]. \{a^2 Yn - 2 Y_2 - (1-a^2)Y_1 \} / \{3Y_1 + 2Y_2 + Yp + Yn \}$

$Vn = [ V / -a (1-a)]. \{2Y_2 + (1-a)Y_1 - aYp \} / \{3Y_1 + 2Y_2 + Yp + Yn \}$

---

Using symmetrical component

For Voltage

$V_A = ( V_0 + V_P + Vn )$ (1)

$V_B = ( V_0 + a^2.V_P + a. Vn)$ (2)

$V_C = ( V_0 + a.V_P + a^2. Vn)$ (3)

For current

$I_A = ( I_0 + I_P + In )$ (4)

$I_B = ( I_0 + a^2.I_P + a.In)$ (5)

$I_C = ( I_0 + a.I_P + a^2.In)$ (6)

From fig 1

$V = V_A - V_B$ (7)

$I_C = I_1 + I_2$ (8)

$I_1 = (V_A - V_C).Y_1$ (9)

$I_2 = ( V_A - V_B - V_C ).Y_2$ (10)

Substituting value of $V_A$ and $V_B$ in eq (7) from eq. (1) and (2)

$V = [ (1-a^2)Vp + (1-a)Vn ]$ (11)

From eq. (9) and (10)

$I_1 = [(1-a).Vp + (1-a).Vn].Y_1$ (12)

$I_2 = [(1-a^2-a).Vp + (1-a-a^2).Vn].Y_2$ (13)

From eq. (8)

$a.Vp.Yp + a^2.Vn.Yn = [(1-a).Y_1 + (1-a^2-a).Y_2].Vp+[(1-a)Y_1+(1-a-a^2)Y_2].Vn$

$[(1-a).Y_1+(1-a^2-a).Y_2-aYp].Vp+[(1-a).Y_1+(1-a-a^2).Y_2-a^2.Yn].Vn = 0$ (14)

From eq. (14)

$$Vp = \frac{-[(1\text{-}a).Y_1 + (1\text{-}a\text{-}a^2).Y_2 - a^2.Yn].Vn}{[\ (1\text{-}a).Y_1 + (1\text{-}a^2\text{-}a).Y_2 - a.Yp]} \qquad (15)$$

Substituting the value of Vp in eq (11) and solve it find the value of Vn is

$$Vn = [\ V / \text{-}a\ (1\text{-}a)].\ \{2Y_2 + (1\text{-}a)Y_1 - aYp\ \} / \{3Y_1 + 2Y_2 + Yp + Yn\ \} \qquad (16)$$

From eq. (16) put the value of Vn in eq (15) can be find out the value of Vp

$$Vp = [\ V / \text{-}a\ (1\text{-}a)].\ \{a^2\ Yn - 2\ Y_2 - (1\text{-}a^2)Y_1\ \} / \{3Y_1 + 2Y_2 + Yp + Yn\ \}$$

# APPENDIX-D

TABLE:

Sucepetance to give perfect phase balance in three phase induction motor

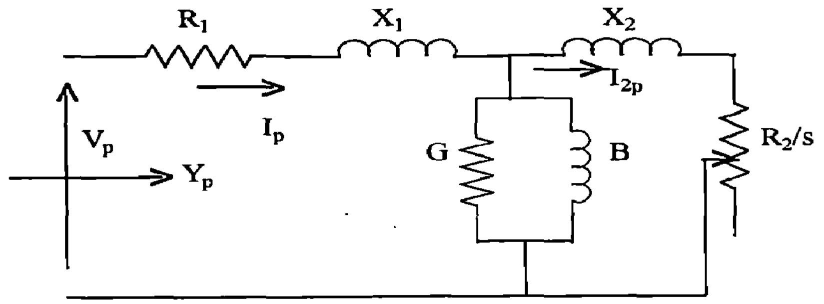
| Value of $\varphi_p$ | $Y_1$ | $Y_2$ | $Y_3$ |
|---|---|---|---|
| $\varphi_p < \pi /3$ | Capacitive | Inductive | Inductive |
| $\varphi_p = \pi /3$ | Capacitive | Zero | Zero |
| $\pi /3 < \varphi_p < \pi /6$ | Capacitive | Capacitive | Capacitive |
| $\varphi_p = \pi /6$ | Zero | Capacitive | Capacitive |
| $\varphi_p > \pi /6$ | Inductive | Capacitive | Capacitive |

# APPENDIX-E

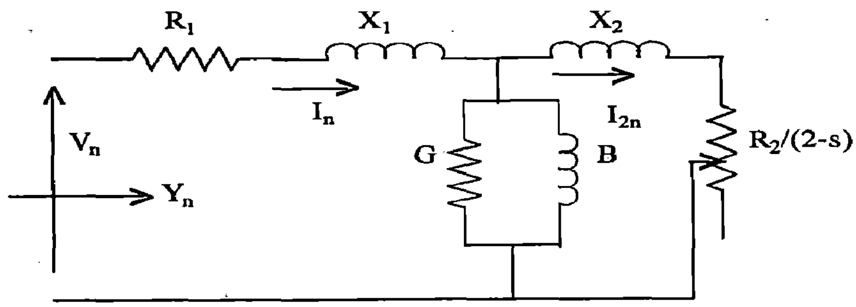
Three phase induction motor with asymmetrical winding connection (smith connection):-

A general performance analysis of a three-phase induction motor can be carried out using the method of symmetrical components. The positive, negative and zero sequence voltage can be determined.

The positive and negative-sequence equivalent circuit can then be used to compute the sequence currents $I_p$ and $I_n$. the machine performance, such as phase voltages, line currents, electromagnetic torque, power factor and efficiency can be obtained.




Positive sequence equivalent circuit




Negative sequence equivalent circuit

Zero sequence voltage and current are absent in a three-phase induction motor with the smith connection. $V_p$ and $V_n$ can be calculated (Appendix-C) so compute the sequence current $I_p$ and $I_n$.

Phase voltage and current can be calculated by using symmetrical component equation. (1) & (2)

$$\begin{vmatrix} V_A \\ V_B \\ V_C \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix} \begin{vmatrix} V_0 \\ V_p \\ V_n \end{vmatrix} \qquad (1)$$

$$\begin{vmatrix} I_A \\ I_B \\ I_C \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix} \begin{vmatrix} I_0 \\ I_p \\ I_n \end{vmatrix} \qquad (2)$$

For calculating the output power, shaft torque and efficiency using following equation.

$$P_f = (I_{2p})^2 . R_2/s \qquad (3)$$

$$P_b = (I_{2n})^2 . R_2/(2-s) \qquad (4)$$

$P_f$- Air gap power due to forward field

$P_b$- Air gap power due to backward field

$$P = P_f - P_b \qquad (5)$$

P- Total air gap power

Tb- backward-field torque

$$T_b = P_b/w_s \qquad (6)$$

$T_f$- forward field torque

$$T_f = P_f/w_s \qquad (7)$$

$$T = T_f - T_b \qquad (8)$$

Internal developed power Pm

$$Pm = (1-s).P \qquad (9)$$

$$\text{Shaft torque} = Pm - (\text{Rotational losses}) / (1-s)\ w_s \qquad (10)$$

$$\text{Efficiency} = \text{Shaft power} / \text{Input power} \qquad (11)$$

# APPENDIX-E1

```
% CALCULATION OF CAPACITANCES FOR PERFACT PHASE BALANCING
% IN CASE OF INDUCTION MOTOR WITH SMITH CONNECTION.
%--------------------------------------------------------------------
%Given Parameters are of induction motor in ohm.
%r is stand for rotor,s stand for stator.
Rr=3.26;
Rs=3.4;
Xr=5.16;
Xs=5.16;
Xm=104;
%Xm is magnatizing reactance (ohm)
Rc=1024;
%Rc is Core Loss Resistance(ohm)
Vs=complex(230,0);
%Vs is applied line voltage(volts)
fwloss=110;
%fw is friction loss in watt.
f=50;
ws=1500;
%ws is synchronous speed of motor.
j=sqrt(-1);
i=0;
for s=0.01:0.005:0.08
   i=i+1;
%W=2*pi*1500*(1-s)/60
W=2*pi*ws*(1-s)/60;
%W is rotor speed of motor
Zm=(Rc*j*Xm)/(Rc+j*Xm);
%Zm is parallel resultant of Rc and Xm
Zs=complex(Rs,Xs);
%Zs is stator impedance(ohm)
```

```
Zr=complex(Rr/s,Xr);
%Zr is rotor impedance(ohm)
Zp=((Zr*Zm)/(Zr+Zm)+Zs);
% positive sequence impedance of motor
Yp=1/Zp;
phy(i)=angle(Zp);
% positive sequence phase angle of motor
Y1=(2*Yp*sin(phy(i)-(pi/6)))/sqrt(3);
Y2=(Yp*sin(pi/3-phy(i)));
%Y1 And Y2 are admittance of balancing capacitance
S(i)=s;
C1(i)=abs((Y1)/(2*pi*f));
C2(i)=abs((Y2)/(2*pi*f));
C3=2*C2;
%C1,C2,C3 are balancing capacitors of scheme.
end

%CACULATION OF CAPACITOR USED IN SCHEME.
%---------------------------------------------
plot(S,C1,'r-',S,C2,'g-');
legend('C1','C2');
xlabel('slip(p.u)');
ylabel('capacitance(farad)');
title('Variation of capacitances C1 and C2 with slip');
%---------------------------------------------
```

# APPENDIX-E2

```
% PROGRAM FOR VARIATION OF PHASE CURRENT AND VOLTAGE WITH
SLIP IN CASE OF
% INDUCTION MOTOR WITH SMITH CONNECTION USING FULL LOAD
% CAPACITOR
%==================================================================
============
%given parameters are of induction motor in ohm.
%r is stand for rotor,s stand for stator.
clear all
clc
Rr=3.26;
Rs=3.4;
Xr=5.16;
Xs=5.16;
Xm=104;
%Xm is magnetising reactance(ohm)
Rc=1045;
% Rc is Core Loss Resistance(ohm)
Vs=complex(220,0);
Ws=1500;
% Ws is synchronous speed of motor.
j=sqrt(-1);
%Vs applied line voltage
f=50;
a=exp(j*2*pi/3);
%a=-0.5+j*0.866;
i=0;
for s=0.01:0.005:0.06
  i=i+1;
  Zm=(Rc*j*Xm)/(Rc+j*Xm);
  % Zm magnetizing impedance of induction motor
  Zs=complex(Rs,Xs);
  % Zs is stator impedance
  Zr1=complex(Rr/s,Xr);
  % Zr1 is positive sequance rotor impedance(ohm)
  Zr2=complex(Rr/(2-s),Xr);
  % Zr2 is negative sequence rotor impedance(ohm)
  Zp=((Zr1*Zm)/(Zr1+Zm))+Zs;
  %Zp is positive sequance impedance(ohm)
  Yp=1/Zp;
  Zn=((Zr2*Zm)/(Zr2+Zm))+Zs;
  %Zn is negative sequance impedance(ohm)
  Yn=1/Zn;
  phy(i)=angle(Zp);
  % positive sequence phase angle of motor
  C1=8.4*10^(-6);
  C2=20.5*10^(-6);
```

```
   Y1=j*C1*(2*pi*f);
   Y2=j*C2*(2*pi*f);
   %Y1 and Y2 is capacitive admmitance
   %Vp(i)=(sqrt(3)*Vs)*((a^2*Yn)-(2*Y2)-(1-a^2)*Y1)/-(a*(1-
a)*((3*Y1)+(2*Y2)+(Yp+Yn)));
   Z1=((a^2)*Yn)-(2*Y2)-(1-(a^2))*Y1;
   Z2=(3*Y1)+(2*Y2)+(Yp+Yn);
   Z3=Vs/sqrt(3)*(-a)*(1-a);
   Vp(i)=(Z1/Z2)*Z3;
   %Vp positive phase sequance voltage
   %Vn(i)=(sqrt(3)*Vs)*((2*Y2)+(1-a)*Y1-(a*Yp))/-(a*(1-
a)*((3*Y1)+(2*Y2)+(Yp+Yn)));
   Z4=(2*Y2)+(1-a)*Y1-(a*Yp);
   Vn(i)=(Z4/Z2)*Z3;
   %Vn negative phase sequance voltage
   Ip(i)=Vp(i)/Zp;
   In(i)=Vn(i)/Zn;
   % Ip and In is positive and negative sequance current
   Ia(i)=abs(Ip(i)+In(i));
   Ib(i)=abs((a^2)*Ip(i)+a*In(i));
   Ic(i)=abs(a*Ip(i)+(a^2)*In(i));
   % Ia, Ib and Ic is phase current
   Va(i)=abs(Vp(i)+Vn(i))/sqrt(3);
   Vb(i)=abs((a^2)*Vp(i)+a*Vn(i))/sqrt(3);
   Vc(i)=abs(a*Vp(i)+((a^2)*Vn(i)))/sqrt(3);
   % Va, Vb and Vc is phase voltge
   I2=abs(Va(i)-Vb(i)-Vc(i))*Y2;
   % I2 is current in capacitor C2
   I(i)=abs(I2-Ib(i));
   % I is input current
   S(i)=s;
   V1(i)=sqrt(3)*Vc(i);
   V2(i)=2*Va(i);
   V3(i)=Va(i);
   Vn(i)=abs((Z4/Z2)*Z3)
   % V1,V2 and V3 capacitor voltage

end

% PLOTING OF PHASE VOLTAGE VARIATION WITH SLIP
%------------------------------------------------
figure(1)
plot(S,Va,'b-',S,Vb,'r-',S,Vc,'g-')
xlabel('slip (P.U)');
ylabel('phase voltage (volt)');
title('varation of phase voltage with slip');
legend('Va','Vb','Vc');

% PLOTING OF PHASE CURRENT WITH SLIP
%----------------------------------------------
```

```
figure(2)
plot(S,Ia,'r-',S,Ib,'b-',S,Ic,'g-');
xlabel('slip');
ylabel('phase voltage');
title('variation of phase current with slip');
legend('Ia','Ib','Ic');

% PLOTING OF INPUT CURRENT WITH SLIP
%---------------------------------------------
figure(3)
plot(S,I,'r-');
xlabel('slip(p.u)');
ylabel('Input Current(amp)');
title('Variation of input current with slip');

% PLOTING OF CAPACITIVE VOLTAGE VARIATION WITH SLIP
%---------------------------------------------
figure(4)
plot(S,V1,'r-',S,V2,'b-',S,V3,'g-');
xlabel('slip(p.u)');
ylabel('voltage across capacitance C1,C2 and C3');
title('variation of capacitance voltage across C1,C2 and C3 with slip');
legend('V1','V2','V3');

% PLOTING OF NEGATIVE SEQUANCE VOLTAGE VARIATION WITH SLIP
%----------------------------------------------------
figure(5)
plot(S,Vn,'g-');
xlabel('slip(p.u)');
ylabel('Negative sequance voltage (Vn)');
title('variation of negative sequance voltage with slip');
%----------------------------------------------------
```

```
% EFFECT OF LOAD VARIATION ON OUTPUT-TORQUE,POWER OUTPUT
% AND EFFICIENCY IN CASE OF SMITH CONNECTED IM
%==============================================================
%given parameters are of induction motor in ohm.
%r is stand for rotor,s stand for stator.
clear all
clc
Rr=3.26;
Rs=3.4;
Xr=5.16;
Xs=5.16;
Xm=104;
%Xm is magnetisind reactance(ohm)
Rc=1024
% Rc is Core Loss Resistance(ohm)
Vs=complex(230,0);
%Vs applied line voltage
f=50;
Ws=1500;
% Ws is synchronous speed of motor.
fwloss=110;
%fw is friction loss in watt.
strayloss=1.8*37;
j=sqrt(-1);
a=exp(j*2*pi/3);
%a=-0.5+j*0.866;
i=0;
for s=0.01:0.005:0.06
   i=i+1;
   Zm=(Rc*j*Xm)/(Rc+j*Xm);
   % Zm magnetizing impedance of induction motor
   Zs=complex(Rs,Xs);
   % Zs is stator impedance
   Zr1=complex(Rr/s,Xr);
   % Zr1 is positive sequance rotor impedance
   Zr2=complex(Rr/(2-s),Xr);
   % Zr2 is negative sequence rotor impedance
   Zp=((Zr1*Zm)/(Zr1+Zm))+Zs;
   %Zp is positive sequance impedance
   Yp=1/Zp;
   Zn=((Zr2*Zm)/(Zr2+Zm))+Zs;
   %Zn is negative sequance impedance
   Yn=1/Zn;
   phy(i)=angle(Zp);
  %Y1 and Y2 is capacitive admmitance
   C1=1*10^(-6);
   C2=18.6*10^(-6);
```

```
  Y1=j*C1*(2*pi*f);
  Y2=j*C2*(2*pi*f);
  %Vp(i)=(sqrt(3)*Vs)*((a^2*Yn)-(2*Y2)-(1-a^2)*Y1)/-(a*(1-
a)*((3*Y1)+(2*Y2)+(Yp+Yn)));
  Z1=((a^2)*Yn)-(2*Y2)-(1-(a^2))*Y1;
  Z2=(3*Y1)+(2*Y2)+(Yp+Yn);
  Z3=Vs/(-a)*(1-a);
  Vp(i)=(Z1/Z2)*Z3;
  %Vp positive phase sequance voltage
  %Vn(i)=(sqrt(3)*Vs)*((2*Y2)+(1-a)*Y1-(a*Yp))/-(a*(1-
a)*((3*Y1)+(2*Y2)+(Yp+Yn)));
  Z4=(2*Y2)+(1-a)*Y1-(a*Yp);
  Vn(i)=(Z4/Z2)*Z3;
  % Vn is nagetive sequance voltage
  Ip=Vp(i)/Zp;
  % Ip is positive sequance current
  In=Vn(i)/Zn;
  % In is nagetive sequance current
  Ip2=Ip*(Zm/(Zm+Zr1));
  In2=In*(Zm/(Zm+Zr2));
  w=2*pi*1500*(1-s)/60;
  %w is rotor speed
  Pgf=((Ip2)^2)*Rr/s;
  % Pgf forward air gap power
  Pbf=((In2)^2)*Rr/(2-s);
  % Pbf is backward air gap power
  Pt=abs(Pgf-Pbf);
  % Pt is total power developed
  Pm=((1-s)*Pt);
  % Pm is mechanical power developed in rotor
  Psh(i)=(Pm-fwloss-strayloss);
  % Psh is shaft power
  Tsh(i)=Psh(i)/w;
  % Tsh is shaft torque
   S(i)=s;
  Va=(Vp(i)+Vn(i))/sqrt(3);
  Vb=(a^2*Vp(i)+a*Vn(i))/sqrt(3);
  Vc=(a*Vp(i)+a^2*Vn(i))/sqrt(3);
  % Va,Vb and Vc is phase voltage
  I2=(Va-Vb-Vc)*Y2;
  % I2 is current in capacitor C2
  Ib=(a^2*Ip+a*In)/sqrt(3);
  % Ib is current in phase B
  I(i)=abs(I2-Ib);
  % I is input current
  Pin(i)=Pt+(I(i))^2*Rs;
  % Pin is input power
  Effi(i)=Psh(i)/Pin(i);
  %Effi is efficiency of motor
end
```

```
%CALCULATION OF SHAFT TORQUE VARIATION WITH LOAD.
%-------------------------------------------
figure(1)
plot(S,Tsh,'r-');
Xlabel('slip');
ylabel('output torque T(N.m)');
title('Variation of output torque with slip');
%CACULATION OF SHAFT POWER VARIATION WITH LOAD.
%-------------------------------------------
figure(2)
plot(S,Psh,'g-');
xlabel('slip');
ylabel('output power P(kw)');
title('Variation of output power with slip');
%-------------------------------------------
%CALCULATION OF EFFICIENCY VARIATION WITH LOAD.

figure(3)
plot(S,Effi);
xlabel('slip');
ylabel('Efficiency(p.u)');
title('Variation of Efficiency with slip');
%----------------------------------------
```

# APPENDIX-E4

```
%EFFACT OF LOAD VARIATION ON OUTPUT-TORQUE, POWER AND
EFFICIENCY WITH SLIP
% THREE PHASE INDUCTION MOTOR CNNECTED TO 220 V SUPPLY
%=========================================================
%GIVEN PARAMETERS ARE OF INDUCTION MOTOR IN OHM
%r is stand for rotor,s stand for stator.
Rr=3.26;
Rs=3.4;
Xr=5.16;
Xs=5.16;
Xm=104;
% Xm is magnetizing reactance (ohm)
Rc=1024;
%Rc is core loss resistance(ohm)
Vs=complex(220,0);
% Vs is applied line voltage (volt).
fwloss=110;
% fw is friction loss in watt.
strayloss=1.8*37;
% stray load loss is taken 1.8% of output power.
i=0;
for s=0.01:0.005:0.07
   i=i+1;
   w=2*pi*1500*(1-s)/60;
   %w is rotor speed
   Zm=(Rc*i*Xm)/(Rc+i*Xm);
   % Zm is parallel reasultant of Rc and Xm.
   Zs=complex(Rs,Xs);
   % Zs is stator impedance(ohm)
   Zr=complex(Rr/s,Xr);
   % Zr is rotor impedance(ohm)
```

```
  Is=Vs*(Zr+Zm)/(Zr*Zm+Zr*Zs+Zs*Zm);
  E2=Vs-Is*Zs;
  % E2 voltage across rotor
  Ir=E2/Zr;
  % Is is stator current and Ir is rotor current.
  Pin(i)=3*real(Vs*Is);
  % power input to motor
  Zeq=Vs/Is;
  phi_p(i)=angle (Zeq);
  % phase angle of motor
  PFin(i)=Pin(i)/(3*abs(Vs)*abs(Is));
  PF_angle(i)=acos(PFin(i));
  Pm=3*(abs(Ir))^2*Rr*(1-s)/s;
  %Pm is internal mechanical power
  Psh(i)=(Pm-fwloss-strayloss);
  Tsh(i)=Psh(i)/w;
  % Psh is power available at shaft Tsh is available torque on shaft.
  S(i)=s;
  Effi(i)=Psh(i)/Pin(i);
  % Effi is efficiency of motor
end
% CALCULATION OF SHAFT TORQUE VARIATION WITH LOAD.
%------------------------------------------------
figure(1)
plot(S,Tsh,'r-');
Xlabel('slip');
ylabel('output torque T(N.m)');
title('Variation of output torque with slip');

% CACULATION OF SHAFT POWER VARIATION WITH LOAD.
%------------------------------------------------
figure(2)
plot(S,Psh);
xlabel('slip');
```

```
ylabel('output power P(w)');
title('Variation of output power with slip');

% CALCULATION OF EFFICIENCY VARIATION WITH LOAD.
%-----------------------------------------------
figure(3)
plot(S,Effi);
xlabel('slip');
ylabel('Efficiency(p.u)');
title('Variation of Efficiency with slip');
```

```
% VARIATION OF INPUT POWER FACTOR ANGLE WITH INMPEDENCE
% ANGLE OR (POWER FACTOR ANGLE)
%----------------------------------------------------
% Given Motor Parameter
clear all
clc
Rc=1024;
Xm=104;
% Rc is motor core loss Resistance(ohm)
% Xm is magnetising resistance
Rs=3.4;
Xs=5.16;
Zs=Rs+i*Xs;
%Zs is stator impedance
Rr=3.26;
Xr=5.16;
%Zr=Rr+i*Xr;
%Zr= is rotor impedance
Ws=1500;
s=.01;
j=1;
while(s<=1)
   Zr=(Rr/s)+i*Xr;
   Zm=(Rc*i*Xm)/(Rc+i*Xm);
%Zm is magnetizing impedance
Zp=((Zr*Zm)/(Zr+Zm))+Zs;
Yp=1/Zp;
% Zp is positive sequence impedance and Yp is its admittance.
phi_p(j,1)=(angle(Zp));
% Phase angle of positive sequence impedance (impedance angle).
gama(j,1)=asin(sin(2*(pi/3-phi_p(j,1)))/sqrt(1+8*(sin(pi/3-phi_p(j,1)))^2));
alpha(j,1)=gama(j,1)-phi_p(j,1)+pi/6;
%alpha is input power factor phase angle.
pf1(j,1)=cos(alpha(j,1));
S(j,1)=s;
s=s+.005;
j=j+1;
end
%Plote for input power factor with impedance angle.
%-----------------------------------------------
plot(phi_p*180/pi,alpha*180/pi,'r-');
axis([30 60 -30 30]);
xlabel('power factor angle (rad)');
ylabel('input power factor angle (rad)');
title('Variation of input power with power factor angle');
%-----------------------------------------------
```

# REFERENCE


1. T.F.chan and Loi Lei Lai "Single-Phase Operation Of a Three-Phase Induction Motor With Smith Connection" IEEE Transaction on Energy Conversion Vol. 18, No. 12 December 2000
2. O.J.M.Smith "High-Efficiency Single-Phase Motor" "IEEE Transaction on Energy Conversion. VOL.7. NO.3, pp. 560-569, September 1992.
3. J.E.Brown and C.S. Jha "The Starting of a Three-Phase Induction Motor Connected to a Single-Phase Supply System" Proc. of IEE, Vol. 106A, pp.183-190, 1959.
4. Otto J.M.Smith "Large Low Cost Single-Phase Semihex™ Motor" IEEE Transaction on Energy Conversion VOL. 14 NO. 4 pp.1353-1358 December 1999.
5. C.E. Tindall and W. Monteith, "Balance Operation of Three-Phase Induction Motor Connected to Single-Phase Supplies" Proc of IEE Vol. 123. NO.6 pp. 517-522 June 1976.
6. J.E.Brown and O.I. Butler "A General Method Of Analysis of Three-Phase Induction Motors With Asymmetrical Primary Connections" Proc. of IEE, Vol. 100A, Pt. II, pp.25-34, 1953.
7. O.J.Smith, "High-Efficiency Large Single-Phase Adapters and Motors" IEEE Power Engineering Review, Vol.18, No.12, pp.58-59, December 1998.
8. M.A. Badr, A. I. Alolah and M .A. Abdel-halim "A Capacitor Start Three-Phase Induction Motor" IEEE Transaction on Energy Conversion, Vol. 10, No. 4, December 1995.
9. Otto J.M. Smith "Three-Phase Motor Control" U.S. patent No 5, 300, 870, issued 5 April 1994.
10. Otto J.M. Smith "Three-Phase Motor Operated from a Single Power and Phase Converter" U.S. Patent No. 5, 545, 965, issued 13 August 1996.
11. Otto J.M. Smith "Three-Phase Induction Motor with Single-Phase Power supply" U.S. Patent No. 4, 792, 740 issued 20 December 1988.
12. S.S.Murthy, O.P. Malik and A.K. Tandon "Analysis Of Self-Excited Induction Generator" IEEE PROC, VOl. EC-2 , NO.3 September 1987

13. T.F.Chanand Loi Lei Lai. "A Noval Single-Phase Regulated Self Excited Induction Generator Using a Three-Phase Machine" IEEE Transaction On Energy Conversion. VOL. 16 No.2 June 2001.
14. T.F.Chan and Loi Lei Lai. "Capacitor Requirement of Three-Phase Induction Generator Self Excited with a Single capacitor and Supplying a Single-Phase Load" IEEE Transaction on Energy Convention. VOL.17 NO. Mach 2002.
15. T.F. Chan and L.L. Lai "Single-Phase Operation of a Three-phase Induction Generator with the Smith Connection" IEEE Trasactions on Energy Conversion, Vol.17, No.1 March 2002.
16. Otto J.M.smith "Three-Phase Induction Generator for Single-Phase Line" IEEE Transaction on Energy Conversion. VOL.EC-2, No-3 September 1987
17. C.L.Wadhawa "Electrical Power System" New Age Publishers (p)-Ltd Second Edition May 1999.
18. Ashfaq Husain "Network and System" Khanna book Publishers co.(p) Ltd. August 2000.
19. Dr. P.S.Bihamara "Electrical Machinery" Khanna Publishers, fifth edition.
20. Dr. P.S.Bihamara "Generalized theory of Electrical Machinery" Khanna Publishers, fifth edition.

## FEATURES

- Output capability: standard
- $I_{CC}$ category: SSI

## GENERAL DESCRIPTION

The 74HC/HCT11 are high-speed Si-gate CMOS devices and are pin compatible with low power Schottky TTL (LSTTL). They are specified in compliance with JEDEC standard no. 7A. The 74HC/HCT11 provide the 3-input AND function.

## QUICK REFERENCE DATA

GND = 0 V; $T_{amb}$ = 25 °C; $t_r = t_f$ = 6 ns

| SYMBOL | PARAMETER | CONDITIONS | TYPICAL | | UNIT |
|---|---|---|---|---|---|
| | | | HC | HCT | |
| $t_{PHL}/ t_{PLH}$ | propagation delay nA, nB, nC to nY | $C_L$ = 15 pF; $V_{CC}$ = 5 V | 10 | 11 | ns |
| $C_I$ | input capacitance | | 3.5 | 3.5 | pF |
| $C_{PD}$ | power dissipation capacitance per gate | notes 1 and 2 | 18 | 20 | pF |

**Notes**

1. $C_{PD}$ is used to determine the dynamic power dissipation ($P_D$ in μW):

   $P_D = C_{PD} \times V_{CC}^2 \times f_i + \Sigma (C_L \times V_{CC}^2 \times f_o)$ where:

   $f_i$ = input frequency in MHz

   $f_o$ = output frequency in MHz

   $C_L$ = output load capacitance in pF

   $V_{CC}$ = supply voltage in V

   $\Sigma (C_L \times V_{CC}^2 \times f_o)$ = sum of outputs

2. For HC the condition is $V_I$ = GND to $V_{CC}$
   For HCT the condition is $V_I$ = GND to $V_{CC}$ − 1.5 V

## ORDERING INFORMATION

See *"74HC/HCT/HCU/HCMOS Logic Package Information"*.

# Triple 3-input AND gate 74HC/HCT11

## PIN DESCRIPTION

| PIN NO. | SYMBOL | NAME AND FUNCTION |
|---|---|---|
| 1, 3, 9 | 1A to 3A | data inputs |
| 2, 4, 10 | 1B to 3B | data inputs |
| 7 | GND | ground (0 V) |
| 12, 6, 8 | 1Y to 3Y | data outputs |
| 13, 5, 11 | 1C to 3C | data inputs |
| 14 | $V_{CC}$ | positive supply voltage |

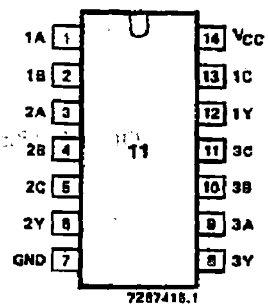



Fig.1 Pin configuration.

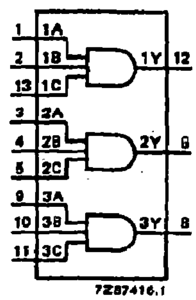



Fig.2 Logic symbol.

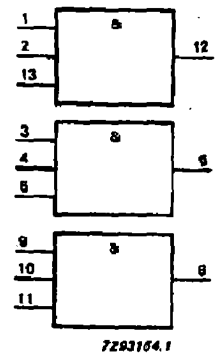



Fig.3 IEC logic symbol.

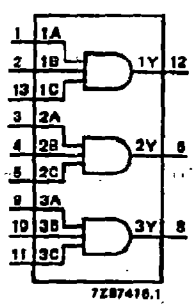



Fig.4 Functional diagram.

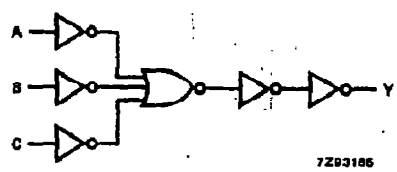



Fig.5 Logic diagram (one gate).

## FUNCTION TABLE

| INPUTS | | | OUTPUT |
|---|---|---|---|
| nA | nB | nC | nY |
| L | L | L | L |
| L | L | H | L |
| L | H | L | L |
| L | H | H | L |
| H | L | L | L |
| H | L | H | L |
| H | H | L | L |
| H | H | H | H |

**Notes**

1. H = HIGH voltage level
   L = LOW voltage level

## DC CHARACTERISTICS FOR 74HC

For the DC characteristics see *"74HC/HCT/HCU/HCMOS Logic Family Specifications"*.

Output capability: standard
$I_{CC}$ category: SSI

## AC CHARACTERISTICS FOR 74HC

GND = 0 V; $t_r = t_f = 6$ ns; $C_L = 50$ pF

| SYMBOL | PARAMETER | $T_{amb}$ (°C) | | | | | | | UNIT | TEST CONDITIONS | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 74HC | | | | | | | | $V_{CC}$ (V) | WAVEFORMS |
| | | +25 | | | −40 to +85 | | −40 to +125 | | | | |
| | | min. | typ. | max. | min. | max. | min. | max. | | | |
| $t_{PHL}$/ $t_{PLH}$ | propagation delay nA, nB, nC to nY | | 32 | 100 | | 125 | | 150 | ns | 2.0 | Fig.6 |
| | | | 12 | 20 | | 25 | | 30 | | 4.5 | |
| | | | 10 | 17 | | 21 | | 26 | | 6.0 | |
| $t_{THL}$/ $t_{TLH}$ | output transition times | | 19 | 75 | | 95 | | 110 | ns | 2.0 | Fig.6 |
| | | | 7 | 15 | | 19 | | 22 | | 4.5 | |
| | | | 6 | 13 | | 16 | | 19 | | 6.0 | |

### DC CHARACTERISTICS FOR 74HCT

For the DC characteristics see *"74HC/HCT/HCU/HCMOS Logic Family Specifications"*.

Output capability: standard
$I_{CC}$ category: SSI

**Note to HCT types**

The value of additional quiescent supply current ($\Delta I_{CC}$) for a unit load of 1 is given in the family specifications. To determine $\Delta I_{CC}$ per input, multiply this value by the unit load coefficient shown in the table below.

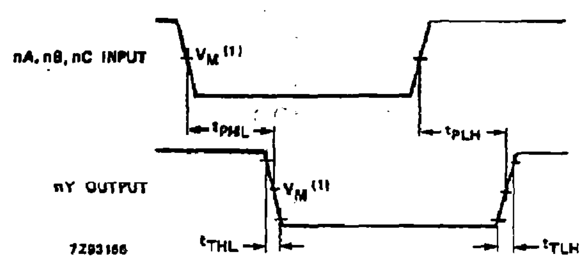
| INPUT | UNIT LOAD COEFFICIENT |
|---|---|
| nA, nB, nC | 1.00 |

### AC CHARACTERISTICS FOR 74HCT

GND = 0 V; $t_r = t_f = 6$ ns; $C_L = 50$ pF

| SYMBOL | PARAMETER | $T_{amb}$ (°C) | | | | | | | UNIT | TEST CONDITIONS | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 74HCT | | | | | | | | $V_{CC}$ (V) | WAVEFORMS |
| | | +25 | | | −40 to +85 | | −40 to +125 | | | | |
| | | min. | typ. | max. | min. | max. | min. | max. | | | |
| $t_{PHL}$/ $t_{PLH}$ | propagation delay nA, nB, nC to nY | | 16 | 24 | | 30 | | 36 | ns | 4.5 | Fig.6 |
| $t_{THL}$/ $t_{TLH}$ | output transition times | | 7 | 15 | | 19 | | 22 | ns | 4.5 | Fig.6 |

### AC WAVEFORMS




(1) HC : $V_M = 50\%$; $V_I$ = GND to $V_{CC}$
HCT: $V_M = 1.3$ V; $V_I$ = GND to 3 V.

Fig.6 Waveforms showing the input (nA, nB, nC) to output (nY) propagation delays and the output transition times.

### PACKAGE OUTLINES

See *"74HC/HCT/HCU/HCMOS Logic Package Outlines"*.