BRAKING OF ASYMMETRICAL TWO-PHASE INDUCTION MOTOR

A Dissertation
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MASTER OF ENGINEERING
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(ELECTRICAL ENGINEERING)

By

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CERTIFICATE

Certified that the dissertation entitled "Braking of Asymmetrical Two-Phase Induction Motor", which is being submitted by Shri Har Mohan Rai in partial fulfilment for the award of the degree of Master of Engineering in Advance Electrical Machines of University of Roorkee is a record of students own work carried out by him under our supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is to certify further that he has worked for a period of seven months from Jan. 1965 to Aug. 1965 for preparing this dissertation for Master of Engineering degree at the University.

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C O N T E N T S

Detailed Contents are given at the beggining of each chapter.

where are these?

SYNOPSIS

The importance of Electrical Machines braking an Electrical Machine is well known. Depending on the individual requirements various circuits are given for Braking of Induction Motors.

This dissertation mainly deals with the A.C. braking of a two-phase induction motor, having two windings in space quadrature with different number of turns. The analysis is based on the Symmetrical Component Theory.

This ispreceded by a brief review of schemes suggested from time to time.

S Y M B O L S

V_1 Positive-sequence right angle component of voltage

V_2 Negative-Sequence right angle component of voltage

I_1 Positive-sequence right angle component of current.

I_2 Negative-sequence right angle component of current

$Y_1=G_1+jB_1$ Positive -sequence right angle component of admittance

$Y_2=G_2+jB_2$ Negative-sequence right angle component of admittance

$Y_m=G_m+jB_m$ External admittance in 'm' winding as viewed from 'm' winding.

$Y_a=G_a+jB_a$ External admittance in 'a' winding as viewed from 'm' winding.

$aV=(a_1+ja_2)V$ Voltage applied to 'm' winding

$bV = (b_1+jb_2)V$ Voltage applied to 'a' winding

I_m Current in 'm' winding.

I_a Current in 'a' winding.

k Turns ratio . ?

V_m Voltage inducted in 'm' winding.

V_a Voltage inducted in 'a' winding

R_{1_2} Forward circuit right angle component of equivalent rotor resistence offered to I_1

R_{2_2} Backward circuit right angle component of equivalent rotor resistance offered to I_2

r_1+jX_1 Stator admittance as viewed from 'm' winding.

r_2+jX_2 Rotor admittance as viewed from 'm' winding.

Other symbols are explained in the text wherever used.

CHAPTER I

INTRODUCTION

No. CONTENTS

INTRODUCTION

1.1 GENERAL

Deceleration of electrical machines to a lower speed is a normal requirement in their various applications. In some cases speed reversal is desired. Deceleration can be effected either by friction brakes or electric braking

A friction brake consists of a brake shoe with friction lining , pressed on to a drum fixed on to the machine shaft. The system converts the kinetic energy of the rotating masses into heat energy at the drum. The control is achieved by adjusting the pressure of the brake and the machine can be brought to standstill.

Electrical braking has distinct advantages of a smooth shockless operation and quick speed reversal over friction brakes.

1.2. ELECTRIC BRAKING OF 3-Ø MOTORS

The following methods are usually employed to bring the three phase induction motors to standstill.

1. d.c. braking - Stator is disconnected from a.c. supply and connected to d.c. source.

ii. a.c. braking - a. Plug reversing.

b. Regenerative braking.

c. Introduction of capacitors in stator winding.

d. Unbalance operation.

1.3. ELECTRIC BRAKING OF SINGLE PHASE AND TWO PHASE MOTORS

The braking schemes for these motors can also be classified as

i. D.C. braking.

ii. A.C. braking.

D.C. Braking:

Siskind[1] has described in detail a circuit for braking single phase motor using rectifiers to convert a.c. to d.c. A similar patent circuit is given in Soviet Inventions [2].

A.C. BRAKING:

Dawson[3] has given a circuit in which the capacitor is connected accross a single phase capacitor start motor leads just before the a.c. supply to the motor is interrupted by a"make before break" relay.

A plugging circuit using two contact centrifugal switch, a voltage relay and a resistance is given by Veinott[4].

The possibility of reversing single phase squirrel cage motor in a fraction of cycle, simply by reversing supply voltage at the motor terminals is explored by Das Gupta[5].

For two phase asynchronous motors, single phase braking circuits are investigated by Richer[6].

Single phase brakes made by short circuiting the auxiliary winding on itself or through a capacitor is investigated by Trickey[7].

A plugging circuit for capacitor motor is analysed by Sreenivasan[8].

1.4. SCOPE OF THIS WORK

Suhr[9] demonstrated that the theory of symmetrical components can be used to predict the performance of single phase motors with great ease.

In the present work general circuit is considered for braking. The general equations deduced have large number of variables and as all the variables combined together becomes unmanagable, the analysis has been simplified by imposing restrictions on some variables and by making suitable assumptions.

The general circuit with large number of possible braking circuits. Each circuit is investigated for braking performances.

The theoretical results obtained are confirmed experimentally and practical circuits are suggested to achieve braking for each scheme investigated.

CHAPTER 2

SYMMETRICAL COMPONENTS

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SYMMETRICAL COMPONENTS

2.1. SYMMETRICAL COMPONENT THEORY

Fortescue[10] has stated " A System of n-vectors or quantities may be resolved, when n is prime into n different symmetrical groups or systems, one of which consists of n equal vectors and the remaining (n-1) system consists of n equi-spaced vector which with the first mentioned groups of equal vectors forms n equal number of symmetrical n-phase systems. When n is unprimed, some of the n-phase systems degenerate into repititions of systems having numbers of phases corresponding to the factors of n".

It has further shown that the internal characteristic behaviour of the rotating machines for each of these components systems can be readily expressed in terms of the simple fields which they represent.

2.2. SYMMETRICAL COMPONENTS OF FOUR PHASES SYSTEM

If $1, a, a^2 \ldots\ldots a^{n-1}$ are n roots of the equation $x^{n-1} = 0$, then a symmetrical polyphase system of n- phases may be represented by

$$E_{r1} = a^{r-1} E_{11} \qquad \ldots(2.1)$$

Since a vector has two degree of freedom so other system may be obtained by taking

$$E_{r2} = a^{r-1} E_{12} \qquad \ldots(2.2)$$

Where r can have any value between 1 to n

$$\text{Since } 1 + a + a^2 + \ldots\ldots + a^{n-1} = 0$$

the sum of all the vectors of a symmetrical polyphase system are zero.

If E_1, E_2 .....E_n be a system of n Vectors, the following holds good.

$$E_r = \left[\frac{E_1 + E_2 + \ldots + E_n}{n}\right] + a^{-(r-1)}\left[\frac{E_1 + aE_2 + \ldots + a^{n-1}E_n}{n}\right]$$

$$+ \ldots\ldots\ldots\ldots\ldots$$

$$+ a^{-(r-1)(r-1)}\left[\frac{E_1 + a^{r-1} E_2 + \ldots\ldots\ldots + a^{(r-1)(n-1)} E_n}{n}\right] \qquad \ldots(2.3)$$

Equation 2.1, states that a system of n vectors or quantities may be represented when n different symmetrical systems or groups, one of which consists of n equal vectors

$$\frac{E_1 + E_2 + \ldots\ldots\ldots + E_n}{n}$$

and the remaining (n-1) systems consists of n equi-spaced vectors which with first forms n equal number of symmetrical n - phase systems.

Considering the equation 2.3. for a four phase system by substituting $n = 4$

$$E_1 = \frac{E_1 + E_2 + E_3 + E_4}{4} + \frac{E_1 + aE_2 + a^2E_3 + a^3E_4}{4} + \frac{E_1 + a^2E_2 + a^4E_3 + a^6E_4}{4} + \frac{E_1 + a^3E_2 + a^6E_3 + a^9E_4}{4} \quad ....(2.4)$$

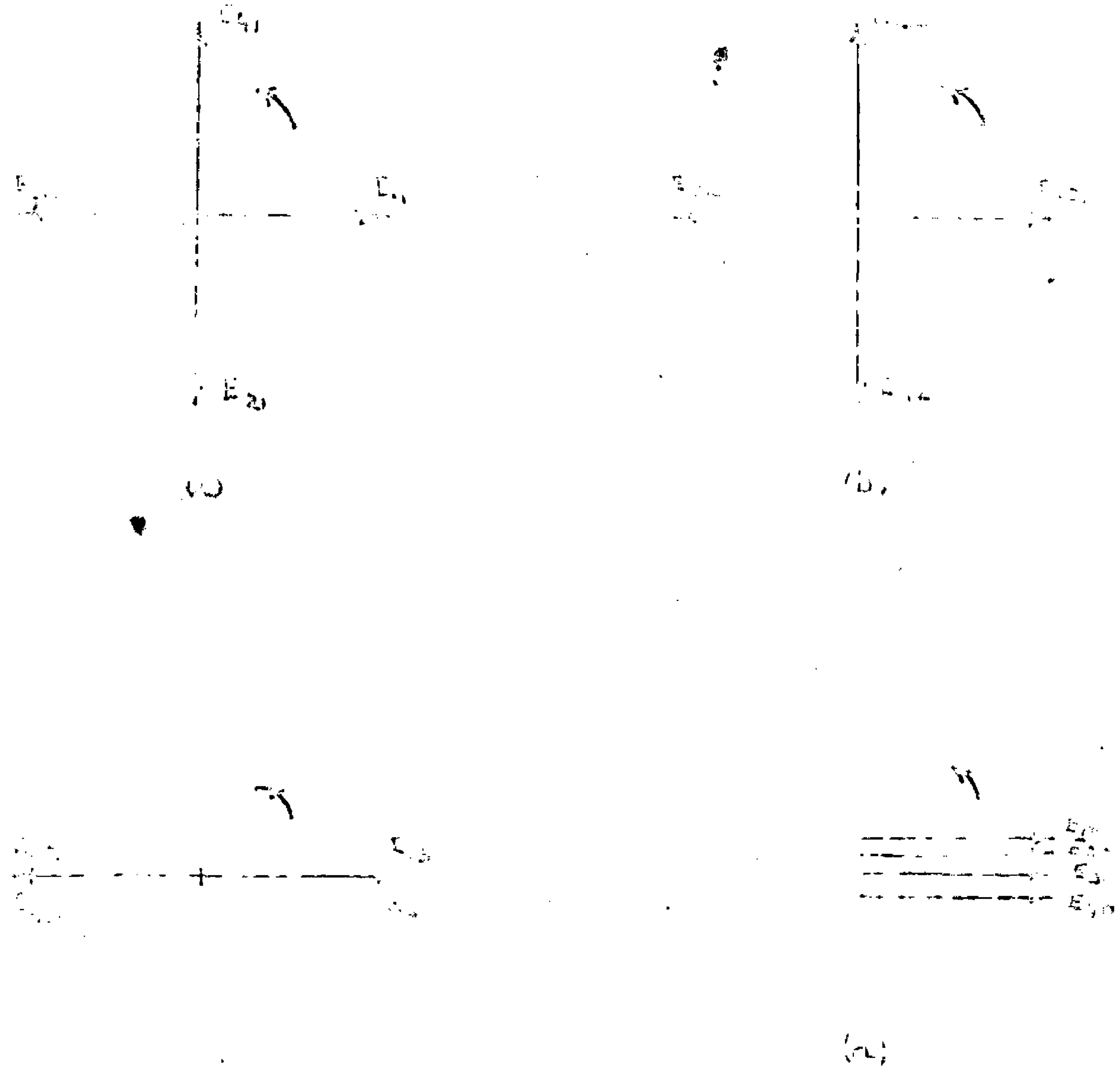
Since $a^4 = 1$ for a four phase system so

$$E_1 = \frac{E_1 + E_2 + E_3 + E_4}{4} + \frac{E_1 + aE_2 + a^2E_3 + a^3E_4}{4} + \frac{E_1 + a^2E_2 + E_3 + a^2E_4}{4} + \frac{E_1 + a^3E_2 + a^2E_3 + aE_4}{4} \quad ...(2.5)$$

Similar equations may be obtained for other three vectors of four phase system. The equation 2.5 states that any four vectors E_1, E_2, E_3, E_4 may be resolved into system of four equal vectors,

$$E_{10},\ E_{10},\ E_{10},\ E_{10}$$

and three symmetrical four phase system including



[illegible] COMPONENTS OF A [illegible] SYSTEM

[illegible]

repititive system (n = 4 is unprime).

$$E_{11} \quad , \quad aE_{11} , \quad a^2E_{11} , \quad a^3 E_{11}$$

$$E_{12} \quad , \quad aE_{12} , \quad a^2E_{12} , \quad a^3 E_{12}$$

$$E_{13} \quad , \quad a^2E_{13} , \quad E_{13} \quad , \quad a^2E_{13}$$ ..(Repetitive factor)

The system of symmetrical system is shown in Fig. 2.1.

The characteristic operator for four phase system can be deduced from n phase system by substituting n = 4 in the characteristics operator equation

$$a = \epsilon^{\frac{j2\pi}{n}} = \epsilon^{\frac{j2\pi}{4}} = 1 \angle 90^{o}$$

2.3 APPLICATION OF SYMMETRICAL COMPONENT THEORY TO TWO PHASE CIRCUITS

In a two phase machine, sometime known as quarter phase machine, the voltage generated are equal in magnitude , but 90^o apart in phase .

E_A and E_B are the generated voltages in phase A and B . They are equal in magnitude E_B lags E_A by 90^o these two vectors form an asymmetrical set of vectors due

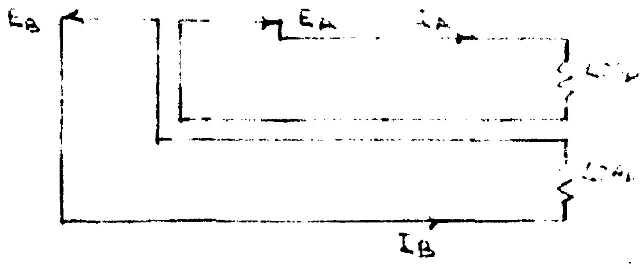


FIG 2.2 [illegible]

to their unequal phase displacement. For a symmetrical set of two vectors the phase displacement should be 180° and 0° . The two phase system being an unsymmetrical system can not be represented by a time changing one even under balance operation. There are several ways of replacing such a system of vectors. Application of individual depends on the nature of the problem. The following are the different ways (11).

1 Positive-and negative - sequence right angle components.

2 Positive - and zero - sequence symmetrical components.

3. Phase currents and voltages not replaced by components.

POSITIVE-AND NEGATIVE-SEQUENCE RIGHT ANGLE COMPONENTS

The two phase system, according to it, can be considered as a special case of four phase system in which two vectors E_A and E_B are

$$\left.\begin{aligned} E_A &= E_1 - E_3 \\ E_B &= E_2 - E_4 \end{aligned}\right\} \qquad \ldots(2.6)$$

This shows that the set of vectors 3 and 4 of symmetrical four phase system disappears to give rise to two set of vectors as shown in Fig. 2.3

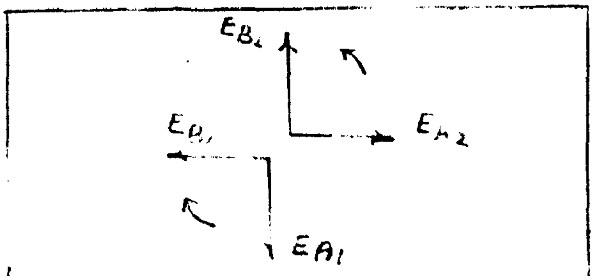


FIG 2.3 POSITIVE & NEGATIVE SEQUENCE COMPONENT

The vectors of each set are equal in magnitude and displaced from each other by 90°. They are called positive - and negative - sequence right angle components, due to their 90° phase displacement. This is distinct from single phase two vectors which are displaced from each other by 180°.

The phase voltage E_A and E_B are expressed in terms of the above components of phase A and B by the equations

$$\left.\begin{aligned} E_A &= E_{A1} + E_{A2} \\ E_B &= -jE_{A1} + jE_{A2} \end{aligned}\right\} \qquad \ldots(2.7)$$

Solving these to get

$$E_{A1} = \tfrac{1}{2}(E_A + jE_B)$$
$$E_{A2} = \tfrac{1}{2}(E_A - jE_B) \qquad \ldots(2.8)$$

Similarly for currents

$$I_A = I_{A1} + I_{A2}$$
$$I_B = -j\,I_{A1} + j\,I_{A2} \qquad \ldots(2.9)$$

$$I_{A1} = \tfrac{1}{2}(I_A + j\,I_B)$$
$$I_{A2} = \tfrac{1}{2}(I_A - jI_B) \qquad ..(2.10)$$

2.4. APPLICATION OF SYMMETRICAL COMPONENT THEORY TO INDUCTION MOTOR WITH FIELDS OF BOTH SEQUENCES

When a current flows in the rotor of the induction motor, a torque is produced. The torque in magnitude equals the square of the current magnitude multiplied by the effective rotor resistance offered to that current. In symmetrical component theory the rotor current has two components, the positive - sequence component and the negative sequence component.

If I_1, I_2 are the two current components, referred to main winding on the stator and R_{1_2} and R_{2_2}

are the effective resistanceoffered by the rotor to positive - and negative sequence currents respectively (values referred to stator).

The two torque components are

i) Torque due to positive - sequence current

$$= T_1 = [I_1]^2 R_{1_2} \qquad \ldots(2.11)$$

ii) Torque due to negative - sequence current

$$T_2 = [I_2]^2 R_{2_2} \qquad \ldots(2.12)$$

The two torques are due to currents of opposite phase sequence. The torques are therefore opposite in direction and the net torque T is given by the difference of the two

$$T = |I_1|^2 R_{1_2} - |I_2|^2 R_{2_2} \qquad \ldots(2.13)$$

When T is positive, it is assumed that this torque give forward rotation to the rotor and is hereafter called Driving Torque.

When T is negative, it is assumed that this torque give backward rotation to the rotor and is termed Braking Torque.

CHAPTER 3

GENERAL ANALYSIS OF ASYMMETRICAL TWO PHASE MACHINES

GENERAL ANALYSIS OF ASYMMETRICAL TWO-PHASE INDUCTION MOTORS

3.1. GENERAL

The two-phase induction motor has two windings denoted 'm' and 'a' in space quadrature, as represented in Fig. 3.1.

A symmetrical two phase motor has identical windings for the two phases. The two windings are fed from a two phase supply. An asymmetrical two phase induction motor has different number of turns in the two windings. (The supply source may or may not have 90° phase -displacement) when the motor is connected to the supply source, the voltages V_m and V_a are induced in the 'm' and 'a' windings respectively. I_m and I_a are the currents flowing in the 'm' and 'a' windings.

Therefore from equations 2.7 to 2.10, the two phase symmetrical components of voltages and currents can be obtained.

$$\left.\begin{aligned} V_m &= V_1 + V_2 \\ V_a &= jV_1 - j\,V_2 \end{aligned}\right\} \qquad \ldots(3.1)$$

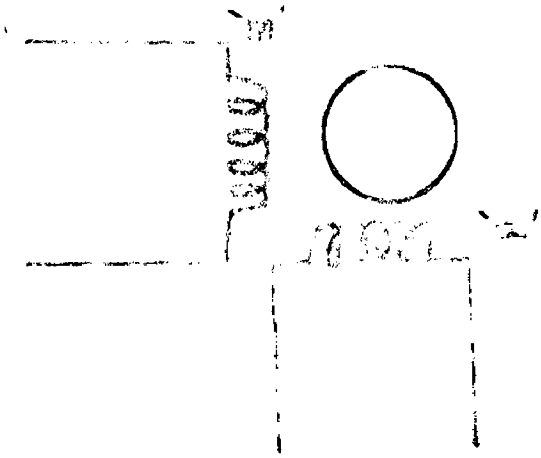


Fig 3·1. Representation of Two Phase Induction Motor

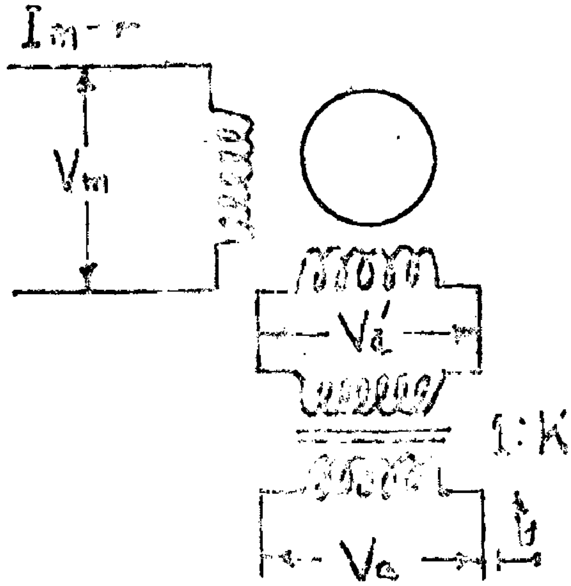


Fig 3·2 Asymmetrical Two Phase Induction Motor

$$\left.\begin{aligned} I_m &= I_1 + I_2 \\ I_a &= jI_1 - jI_2 \end{aligned}\right] \qquad \ldots(3.2)$$

Where V_1 and V_2 are positive and negative - sequence right angle compontnes of voltage, and I_1 and I_2 are positive - and negative sequence right angle components of current.

When the windings have different number of turns the effective turns ratio k, is defined as :

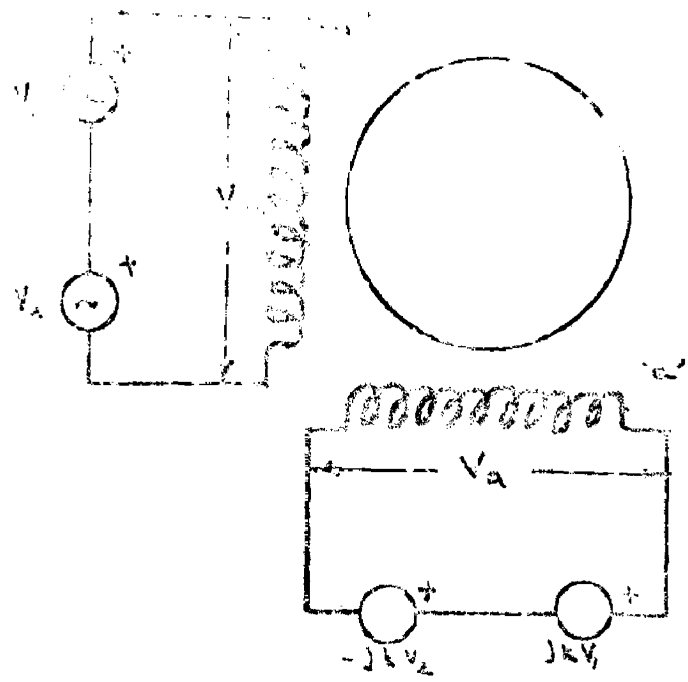
$$k = \frac{\text{Effective number of turns of 'a' winding}}{\text{Effective number of turns of 'm' winding.}}$$

This ratio can be determined either experimentally or from the design data (Appendix 6.1).

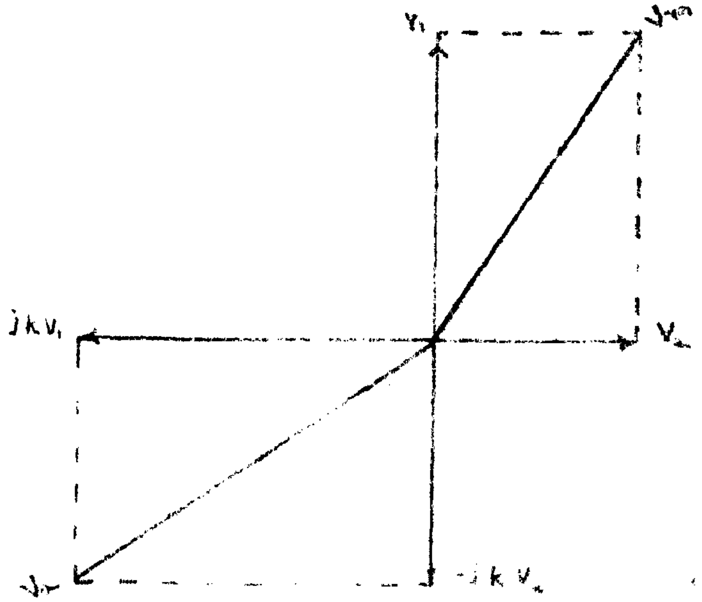
In order to simulate a symmetrical two phase motor the winding 'a' may be replaced by an equivalent winding having same number of turns as 'm' along with a transformer of voltage ratio k, as shown in Fig. 3.2.

This modifies equations 3.1 and 3.2. to give for the asymmetrical case

$$\left.\begin{aligned} V_m &= V_1 + V_2 \\ V_a &= jk\,(V_1 + V_2) \end{aligned}\right] \qquad \ldots(3.3)$$



(a)



(b)

FIG 3.3 (a) DIAGRAMATIC REPRESENTATION OF TWO PHASE INDUCTION MOTOR

(b) PHASOR DIAGRAM FOR (a).

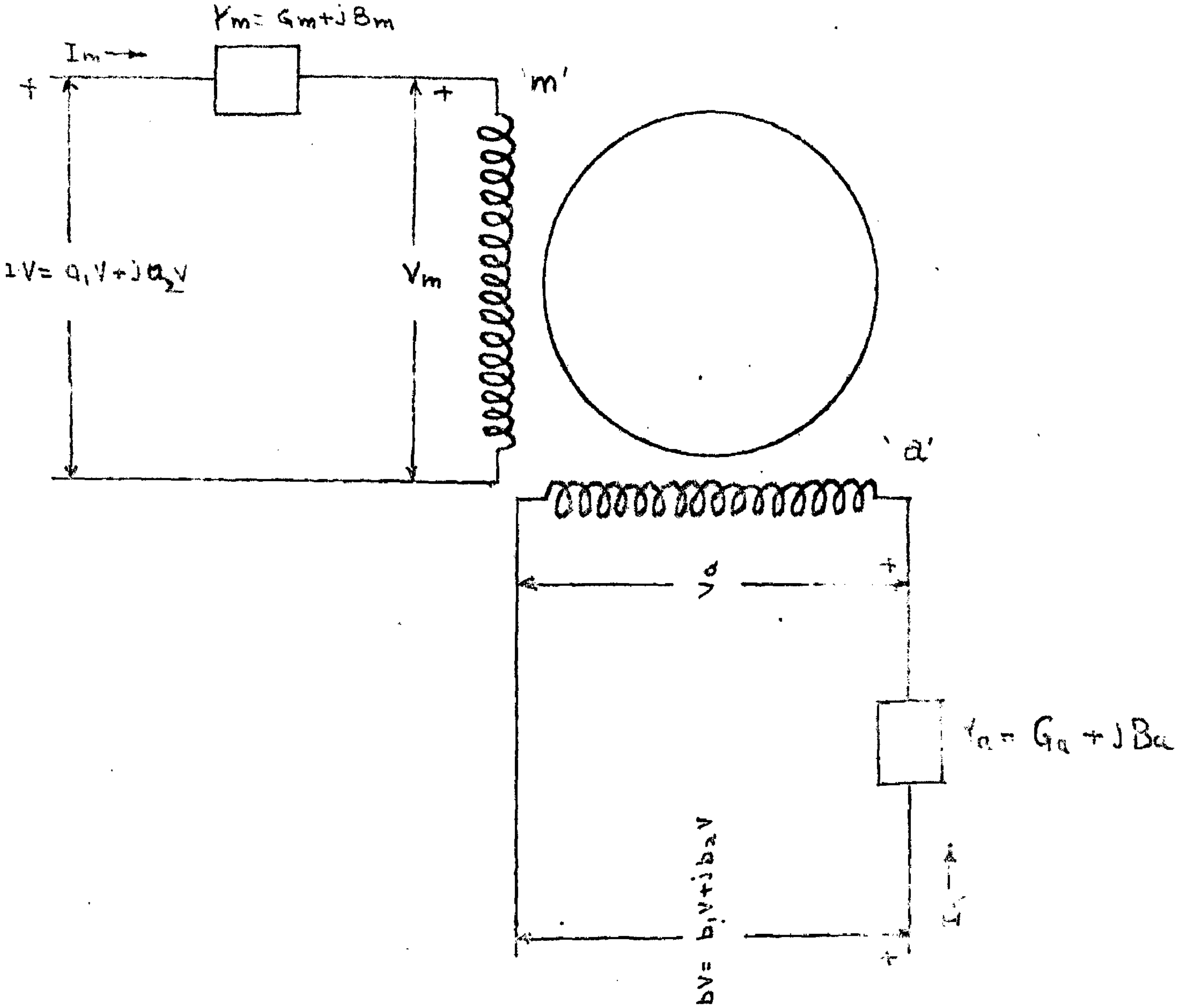


FIG 3.4 GENERAL CIRCUIT FOR BRAKING

$$\left.\begin{aligned} I_m &= I_1 + I_2 \\ I_a &= j\,(I_1 - I_2)\,/\,k \end{aligned}\right\} \qquad \ldots(3.4)$$

Diagramatically these equations can be represented as shown in Fig. 3.3.

3.2. THE ORITICAL ANALYSIS

In Fig. 3.4. a voltage aV is applied to the 'm' winding in series with an impedence element of admittance Y_m and a voltage bV is applied to the 'a' winding in series with an another element of admittance Y_a.

With these voltages applied, I_m and I_a are the currents flowing in the two windings.

The Kirchhoff's law equations for Fig. 3.4 can be written as

$$aV - \frac{I_m}{Y_m} - V_m = 0 \qquad \ldots(3.5)$$

$$bV - \frac{I_a}{Y_a} - V_a = 0 \qquad \ldots(3.6)$$

Equations 3.3 and 3.4. give

$$V_m = V_1 + V_2$$

$$V_a = jk\,(V_1 - V_2)$$

V_1

$$I_m = I_1 + I_2 = V_2Y_1 + V_2Y_2$$

$$I_a = j(I_1 - I_2)/k = j(V_1Y_1 - V_2Y_2)/k$$

Where Y_1 and Y_2 are the input admittances of the machine for the positive - and negative - sequence two phase system respectively.

Equation 3.5 and 3.6 reduce to

$$aV - \left(\frac{V_1Y_1 - V_2Y_2}{Y_m} \right) - (V_1 + V_2) = 0 \quad \ldots(3.7)$$

$$bV - \left(\frac{V_1Y_1 - V_2Y_2}{Y_a} \right) - jk(V_1 - V_2) = 0 \quad \ldots.(3.8)$$

These equations can be solved for V_1 and V_2 to give

$$V_1 = V \left[\frac{Y(ak^2Y_a + aY_2 + jkbY_a) - jbkY_2Y_a}{(Y_m + Y_1)(Y_2 + k^2Y_a) + (Y_m + Y_2)(Y_1 + k^2Y_a)} \right] .(3.9)$$

$$V_2 = V \left[\frac{Y(ak^2Y_a + aY_1 + jkbY_a) + jbY_1Y_a k}{(Y_m + Y_1)(Y_2 + k^2Y_a) + (Y_a + Y_2)(Y_1 + k^2Y_a)} \right] .(3.10)$$

Equations 3.9 and 3.10 pertain to a generalized two phase motor, in which the two windings placed in space quadrature may have a turns ratio other than unity. The

Voltages applied may be unbalanced two phase voltages, and different impedance elements may be connected in series with either or both of the two windings. All normal and abnormal modes of operation of two phase and single phase induction motors are particular cases of this generalized scheme, e.g. if Y_m = oc and Y_a = 0 the scheme represents an ordinary single phase induction motor operation.

3.3. EQUIVALENT CIRCUIT

The equivalent circuit of a two phase induction motor under unbalanced conditions can be shown as in Fig. 3.5[12]

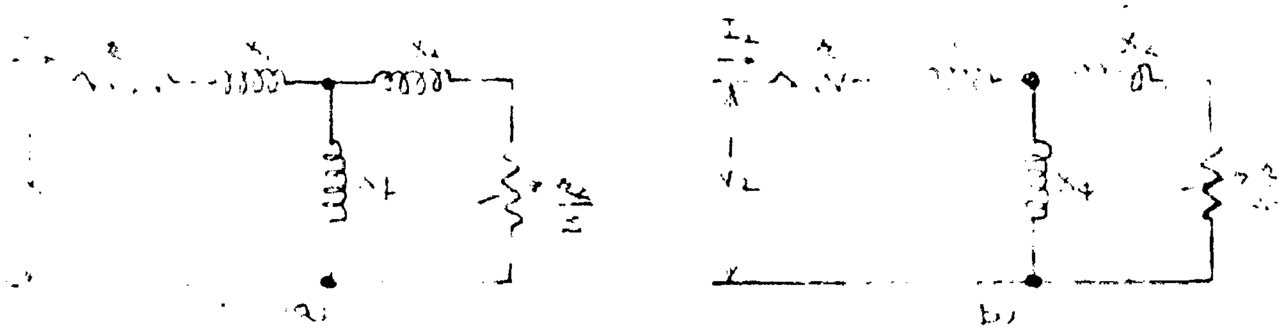


FIG 3.5 (a) POSITIVE-SEQUENCE EQUIVALENT CIRCUIT
(b) NEGATIVE-SEQUENCE EQUIVALENT CIRCUIT

When V_1, the positive sequence right angle component of voltage is applied to the two phase induction motor, I_1

the positive sequence right angle component of current flow at a phase angle difference of β_1 with the applied voltage V_1

$$Y_1 = \frac{I_1}{V_1}$$

$$= \frac{1}{R_1 + j X_1} \quad .....(3.11)$$

$$\text{i.e.} \quad R_1 = \frac{\cos \beta_1}{|Y_1|} \quad .....(3.12)$$

Where β_1 is the phase angle of current I_1

$$\text{and} \quad R_{1_2} = R_1 - r_1$$

$$= \left[\frac{\cos \beta_1}{|Y_1|} - r_1 \right] \quad .....(3.13)$$

$$\text{Similarly} \quad Y_2 = \frac{I_2}{V_2}$$

$$= \frac{1}{R_2 + j X_2} \quad ....(3.14)$$

$$\text{and} \quad R_2 = \frac{\cos \beta_2}{|Y_2|}$$

Where β_2 is the phase angle of current I_2

$$\text{and} \quad R_{2_2} = R_2 - r_1 = \left[\frac{\cos \beta_2}{|Y_2|} - r_1 \right] \quad ...(3.15)$$

VARIATION OF ADMITTANCE WITH SLIP

From the equivalent circuit of Fig. 3.5 the input admittances can be written as :

$$Y_1 = \frac{1}{(r_1 + j X_1) + \frac{(r_2/s + j X_2) jX\rho}{\frac{r_2}{s} + j(X_2 + X\rho)}} \quad ..(3.16)$$

$$Y_1 = \frac{1}{(r_1 + jX_1) + \frac{\left(\frac{r_2}{2-s} + jX_2\right) jX\rho}{\frac{r_2}{2-s} + j(X_2 + X\rho)}}$$

.....(3.17)

It is seen from equations 3.16 and 3.17 that the input admittances are functions of slip and they also vary with slip variation. Y_1 and Y_2 are experimentally obtained for various values of slip and curves plotted. The values of these admittances at a particular speed may be read off from these curves (Appendix 6.2).

3.4. CONDITION FOR TORQUE REVERSAL

Equations 3.9 and 3.10 can be written as

$$I_1 = V_1 Y_1$$

$$= V Y_1 \left[\frac{Y_m\,(ak^2 Y_a + aY_2 - jkbY_a) - jbkY_2 Y_a}{(Y_m+Y_1)(Y_2+k^2Y_a)+(Y_m+Y_2)(Y_1+k^2Y_a)} \right] \quad ..(3.18)$$

$$I_2 = V_2 Y_2$$

$$= V Y_2 \left[\frac{Y_m(ak^2Y_a+aY_1+jkbY_a)+jbkY_1Y_a}{(Y_m+Y_1)(Y_2+k^2Y_a) + (Y_m+Y_2)(Y_1+k^2Y_a)} \right]$$

$$....(3.19)$$

The torques in two directions are given by

$$T_1 = 2\left(\frac{\cos \beta_1}{|Y_1|} - r_1\right) V^2 \,|Y_1|^2 \left[\left| \frac{Y_m(ak^2 Y_a+aY_2-jbkY_a)-jkbY_2Y_a}{(Y_m+Y_1)\,(Y_2+k^2Y_a)+(Y_m+Y_2)\,(Y_1+k^2Y_a)} \right|^2 \right]$$

$$....(3.20)$$

$$T = 2\left[\frac{V}{\left|(Y_m + Y_1)(Y_2 + k^2 Y_a) + (Y_m + Y_2)(Y_1 + k^2 Y_a)\right|}\right]^2 \times$$

$$\left[\left(\frac{\text{Cos }\beta_1}{|Y_1|} - r_1\right)|Y_1|^2\left(\left|Y_m(ak^2 Y_a + aY_2 - jbkY_a) - jkbY_2Y_a\right|\right)^2 -\right.$$

$$\left.\left(\frac{\text{Cos }\beta_2}{|Y_2|} - r_1\right)|Y_m|^2\left(\left|Y_m(ak^2 Y_a + aY_1 + jbkY_a) + jkbY_1Y_a\right|\right)^2\right]$$

....(3.22)

For braking the net torques T should be negative and the following condition must be satisfied:

$$\left(\frac{\text{Cos }\beta_1}{|Y_1|} - r_1\right)|Y_1|^2\left[\left|Y_m(ak^2Y_a + aY_2 - jbkY_a) - jkbY_2Y_a\right|\right]^2$$

$$-\left(\frac{\text{Cos }\beta_2}{|Y_2|} - r_1\right)|Y_2|^2\left[\left|Y_m(ak^2Y_a + aY_1 + jbkY_a) + jkbY_1Y_a\right|\right]^2$$

$$< 0 \qquad ....(3.23)$$

The limiting condition of equation 3.23

$$\left(\frac{\text{Cos }\beta_1}{|Y_1|} - r_1\right)|Y_1|^2\left[\left|Y_m(ak^2Y_a + aY_a - jbkY_a) - jbkY_2Y_a\right|\right]^2$$

$$-\left(\frac{\text{Cos}\beta_2}{|Y_2|} - r_1\right)|Y_2|^2\left[\left|Y_m(ak^2Y_a + aY_1 + jbkY_a) + jbkY_1Y_a\right|\right]^2$$

$$= 0 \qquad ....(3.24)$$

Equation 3.24 is a quadratic equation. The solution of equation 3.24 renders the required braking range. (Appendix 3). As this equation contains so many variable parameters, it is not convinient to deduce the result in terms of all the variables involved. In the analysis, therefore, some assumptions of keeping some variables constant are necessary.

3.5. CURRENT AND VOLTAGES DURING BRAKING

Current in the 'm' winding $= I_m$ is given by the equation,

$$I_m = I_1 + I_2$$

$$= \frac{V\left[ak^2 Y_a Y_m (Y_1 + Y_2) + 2aY_1Y_2 Y_m + jbkY_aY_m(Y_2 - Y_1)\right]}{(Y_m + Y_1)(Y_2 + k^2 Y_a) + (Y_m + Y_2)(Y_1 + k^2 Y_a)}$$

...(3.25)

Similarly I_a the current in 'a' winding is given by equation

$$I_a = j\,(I_1 - I_2)/k$$

$$= \frac{j}{k}\,\frac{V\left[ak^2 Y_aY_m(Y_1 - Y_2) - jbkY_aY_m(Y_1 + Y_2)\right]}{\left[(Y_m + Y_1)(Y_2 + k^2 Y_a) + (Y_m + Y_2)(Y_1 + k^2 Y_a)\right]}$$

...(3.26)

Hence by proper substitution the two current may be calculated to establish the current variation during braking.

The voltages accross Y_m is given by

$$V_{m\,(ext)} = \frac{I_m}{Y_m}$$

$$= \frac{V\left[ak^2Y_a(Y_1+Y_2)+2a\,Y_1Y_2+jbkY_a(Y_2-Y_1)\right]}{(Y_m+Y_1)(Y_2+k^2Y_a)+(Y_m+Y_2)(Y_1+k^2Y_a)}$$

...(3.27)

Similarly the voltage accross the external admittance in the 'a' circuit

$$V_{a(ext)} = \frac{I_a}{Y_a}$$

$$= \frac{j}{k}\left\{\frac{V\left[ak^2Y_m(Y_1-Y_2)-jbkY_m(Y_1+Y_2)\right]}{(Y_m+Y_1)(Y_2+k^2Y_a)+(Y_m+Y_2)(Y_1+k^2Y_a)}\right]$$

...(3.28)

Voltage across 'm' winding V_m From equation 3.5

$$V_m = aV - \frac{I_m}{Y_m}$$

$$= V\left[a-\frac{ak^2Y_a(Y_1+Y_2)+2aY_1Y_2+jbkY_a(Y_2-Y_1)}{(Y_m+Y_1)(Y_2+k^2Y_a)+(Y_m+Y_2)(Y_1+k^2Y_a)}\right]$$

....(3.29)

Similarly V_a = Voltage accross 'a' winding from equation 3.6 is

$$V_a = bV - V_{a(ext)}$$

$$= V\left[b - \frac{1}{k} \times \frac{ak^2 Y_m(Y_1 - Y_2) - jbk\, Y_m(Y_1 + Y_2)}{(Y_m + Y_1)(Y_2 + k^2 Y_a) + (Y_m + Y_2)(Y_1 + k^2 Y_a)} \right]$$

....(3.30)

These voltage equations are necessary to establish the voltage rating of externally introduced impedences and also for the safety of the insulation of the winding.

CHAPTER FOUR

4.1. 'C' VARYING ROTOR CONNECTED THROUGH A CAPACITOR

The Scheme in principle is shown in Fig. 4.1.

Substituting the constants in equation 3.9 and 3.10, the positive and negative sequence voltages are obtained as

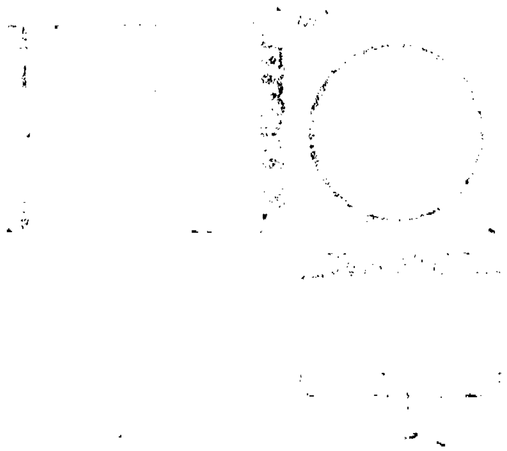
$$V_1 = V \left[\frac{Y_2 + j K^2 D_c}{Y_1 + Y_2 + 2j K^2 D_c} \right] \qquad \ldots\ldots (4.1)$$

$$V_2 = V \left[\frac{Y_1 + j K^2 D_c}{Y_1 + Y_2 + 2j^2 K D_c} \right] \qquad \ldots\ldots (4.2)$$

The torque - slip curves for 1/4 h.p. induction motor (details given in 6.1 & 6.2), for various values of D_c have been calculated and are shown in Figs. 4.3, & 4.4.

EQUIVALENT CIRCUIT

Equations 4.1 and 4.2 give the equivalent circuit of Fig. 4.2. By inspection of Fig. 42, it can be shown that when the value of $K^2 D_c$ increases from 0, both the positive - and negative sequence admittances become less and less. At $K^2 D_c$ = 1.72 (the value of the positive sequence inductive susceptance of the machine at the particular value of the slip), the



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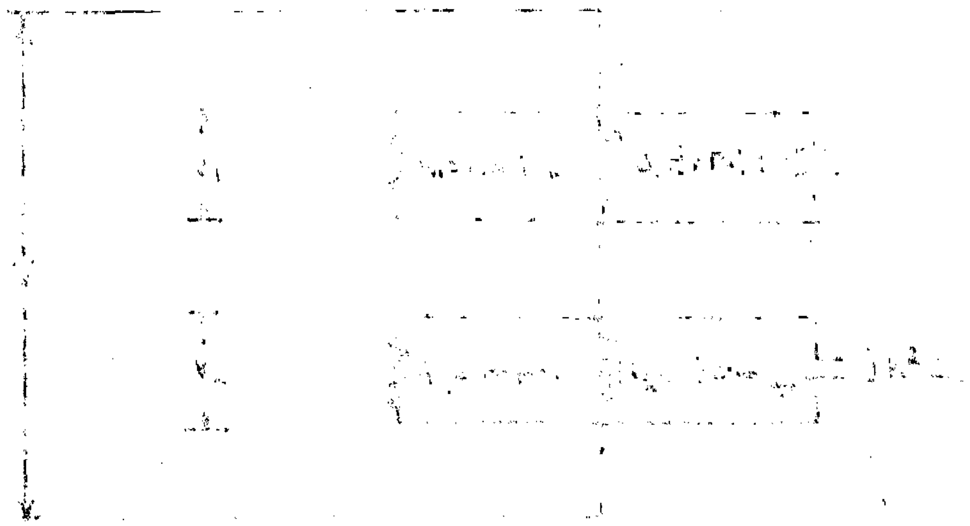

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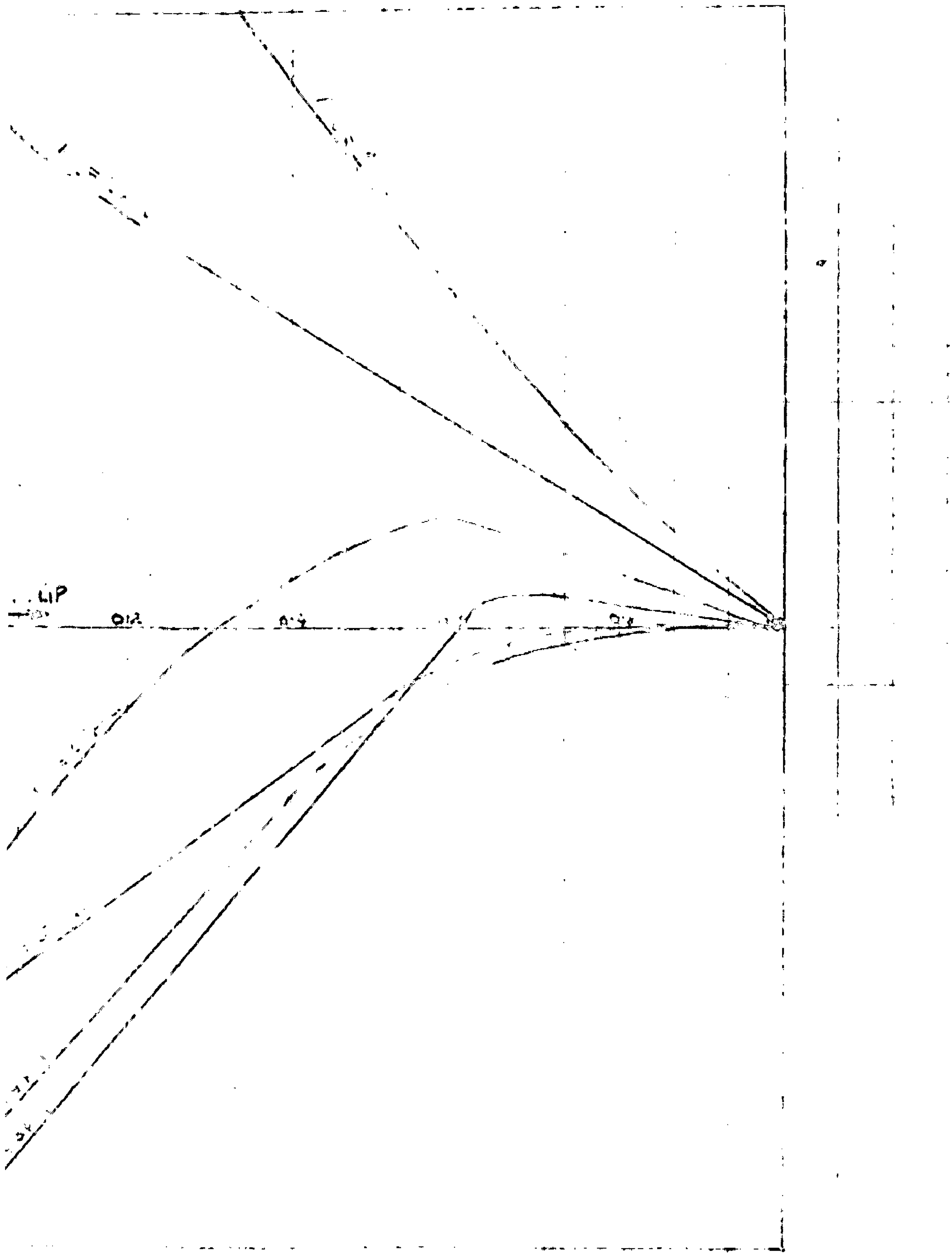
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positive sequence admittance become conductive. It gives minimum value of the negative - sequence voltage (Since the voltages divide in the inverse ratios) and hence the negative sequence torque. This results in the maximum driving torque.

Further if the value of $K^2 B_a$ is increased, the negative sequence torque increases and the positive sequence torque decreases. At $k^2 B_a = 3.16$ (The value of the negative - sequence inductive susceptance at the particular value of the slip), the positive - sequence torque is minimum giving thereby maximum backward torque.

Between $k^2 B_2 = 1.72$ p.u. to 3.16 p.u. for a certain value of $k^2 B_a$ the positive and negative sequence torques are equal, giving net torque as zero. This point gives the starting point for machine to brake.

When the value of $k^2 B_a$ is increased beyond 3.16p.u both positive and negative sequence torque increase. The positive sequence torque increases to give less braking torque. The nature of variation is shown in Fig. 4.4. The above explanation holds true for all values of slip.

In Fig. 4.3, for the value of $B_a = 2.5$ and $B_a = 3$, it is seen that the curve crosses over from negative side to positive side. This is on account of the fact that when $k^2 B_a$ is kept constant, for various values of slip B_1 (positive sequence inductive susceptance of the machine)

increases and B_2 (negative - sequence inductive susceptance of the machine) decreases as standstill is approached. So a point reaches when the two torques equals, giving net zero torque shown by points A andB . Beyond this the driving torque increases and ultimately at standstill it becomes zero.

INFERENCES:

1. Braking is possible with this scheme. The machine can be brought to standstill, by suitable selection of capacitors. For completely stopping the ½ ~~xxx~~ h.p motor considered the value of B_a should be more than 3 p.u.

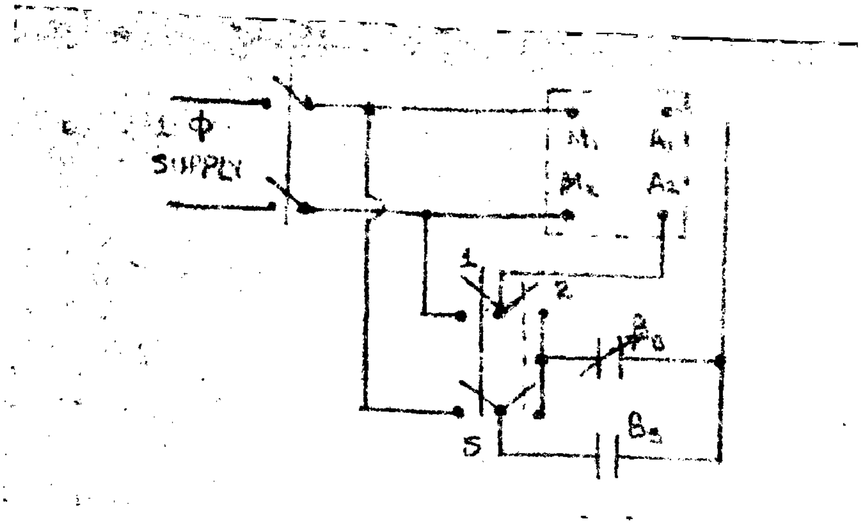
2. The motor cannot be reversed by this scheme, as at zero speed the net torque for all values of B_a is zero.

3. The capacitor required for braking is usually greater than the capacitor required for starting (compare with Fig. 4.17)

4. The scheme can be successfully employed for capacitor start and run motor.

REQUIREMENTS FOR BRAKING

For such a braking scheme to be useful a circuit has to be designed for the 'a' winding, whereby the following steps can be performed:



B_S :- Capacitor for Starting.

B_B :- Additional Capacitor For Braking.

Switch S in position 1 for Starting.

Switch S open for Running.

Switch S in position 2 for Braking.

Fig. 4.5 BRAKING CIRCUIT WITH 'a' WINDING SHORT CIRCUITED THROUGH A CAPACITOR.

i. The value of the starting capacitor changed to the value of the capacitor required for braking.

ii. 'a' winding is short circuited by the capacitor of (i).

Fig. 4.5 shows a circuit suggested to achieve the above operation for braking a motor.

EXPERIMENTAL VERIFICATION:

Experiments were performed on a ½ h.p. Induction Motor (details given in 6.1 and 6.2) and the following results were obtained.

i. For values of B_a more than 3.32 p.u. the motor can be brought to standstill.

ii. For values of B_a , between 2.4 p.u. and 3.32 p.u. there is speed reduction. The machine cannot be brought to standstill as at low speed the braking torque is insufficient.

iii. For values of B_a less than 2.4 p.u. there is no braking.

These points are in close concurrence with figs 4.3. and 4.4.

4.2. MODIFICATION OF SCHEME 1

In this modification a conductance G_a is connected in parallel with capacitor of braking scheme 1 as shown in Fig. 4.6.

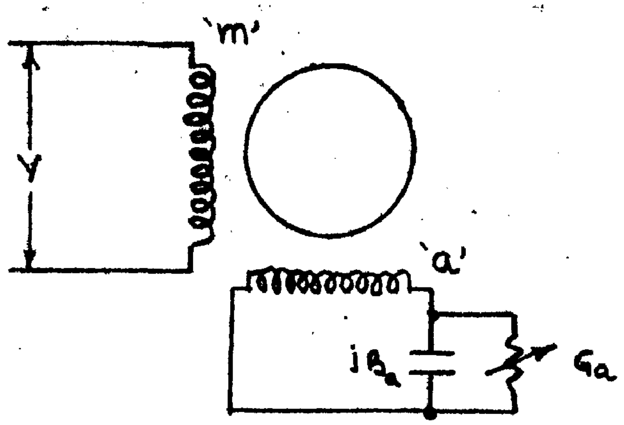


Fig. 4.6. Braking Scheme having 'a' Winding Short Circuited Through a Capacitor and a Resistor in parallel.

The positive- and negative-sequence voltages are :

$$V_1 = V \left[\frac{(G_2 + K^2 G_a) + j(K^2 B_a + B_2)}{(G_1 + G_2 + 2K^2 G_a) + j(2K^2 B_a + B_1 + B_2)} \right] \qquad ....(4.3)$$

$$V_2 = V \left[\frac{(G_1 + K^2 G_a) + j(K^2 B_a + B_1)}{(G_1 + G_2 + 2K^2 G_a) + j(2K^2 B_a + B_1 + B_2)} \right] \qquad ......(4.4)$$

The torques for various values of G_a and B_a are calculated. The curves are plotted in Fig. 4.7. The curves show that as G_a is increased, the torque (at a fixed slip) changes from negative value to positive values.

When the value of G_a is increased a stage comes when the effect of capacitor B_a is nullified and conductance predominates to give dominating positive sequence torque. Then the motor have no braking action.

INFERENCES

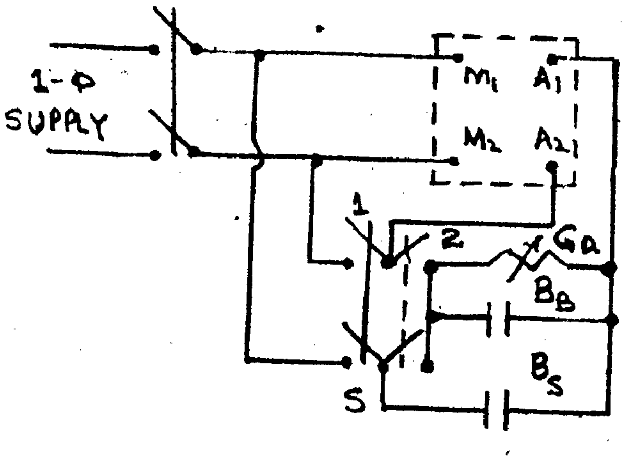
The introduction of resistance although results in overall poor braking performance but this scheme enables a continuous control on the braking torque. Such a braking scheme may prove useful when a slower rate of dissipation of braking energy is desired.

CIRCUIT WITH SUSCEPTANCE IN PARALLEL WITH CAPACITOR OF BRAKING SCHEME 1.

The effect of introduction of capacitance is to give increased value of B_a by the corresponding amount The inductance gives substraction from B_a The effect is similar to the braking scheme 1 with variable capacitor.

REQUIREMENTS FOR BRAKING:

The circuit for 'a' winding is to be designed to perform following operations simultaneously.



B_S :- Capacitor for Starting.

B_B :- Additional Suitable Capacitor for Braking.

G_a :- Resistance to Control Braking.

Switch S in position 1 for Starting.

Switch S open for Running.

Switch S in position 2 for Braking.

Fig. 4.8 BRAKING CIRCUIT WITH 'a' WINDING SHORT CIRCUITED THROUGH AN ADMITANCE.

i. To change the starting capacitor value to more suitable value for braking.

ii. To connect a resistance in parallel with the braking capacitor.

iii. To short circuit the 'a' winding through the resistor capacitor combination.

A circuit suitable for the above operations is suggested in Fig. 4.8.

EXPERIMENTAL VERIFICATION

The circuit was set up as shown in Fig. 4.8 The conductance was varied to observe poor braking action The braking became ineffective beyond the values of G_a = 1.03 p.u. for ½ h.p. motor with capacitor 3.6 p.u.

4.3. SECOND MODIFICATION OF BRAKING SCHEME NO. 1

When an external admittance is introduced in 'm' winding, the scheme is shown in Fig. 4.9

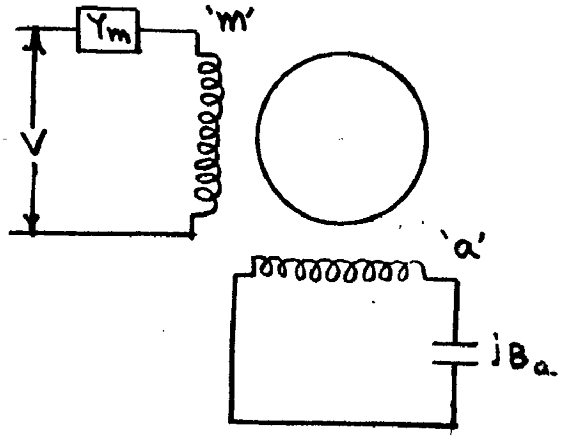


Fig. 4.9. INTRODUCTION OF Y_m IN BRAKING SCHEME I

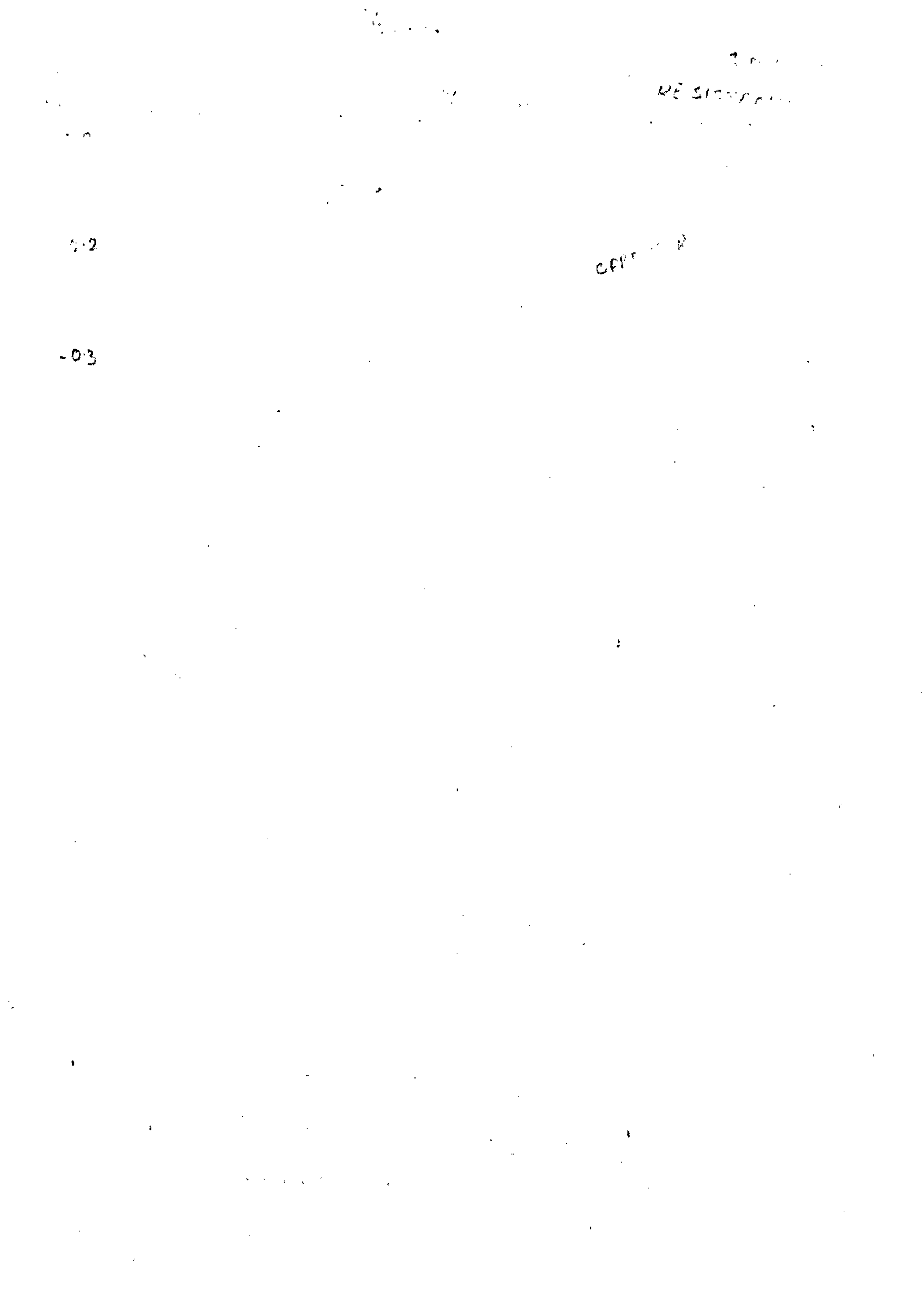
The positive and negative sewugnce voltages are

$$V_1 = V \left[\frac{Y_m (Y + jk^2 B_a)}{(Y_m + Y_1)(Y_2 + jk^2 B_a) + (Y_m + Y_2)(Y_1 + jk^2 B_a)} \right] \quad \ldots(4.5)$$

$$V_2 = V \left[\frac{Y_m (Y_1 + jk^2 B_a)}{(Y_m + Y_1)(Y_2 + jk^2 B) + (Y_m + Y_2)(Y_1 + jk^2 B)} \right] \quad \ldots(4.6)$$

The voltage ratio from above equations is

$$\frac{V_1}{V_2} = \frac{Y_2 + jk^2 B_a}{Y_1 + j k^2 B_a} \quad \ldots\ldots(4.7)$$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The ratio is same as obtained from equations (4.1) and (4.2) . This shows that Y_m only effects the braking torque performance when braking is achieved otherwise, but in itself cannot give a braking action on the motor.

WHEN $Y_m = G_m$ (Conductance)

The equations (4.5) and (4.6) becomes

$$V_1 = V \frac{G_m \left[G_2 + j\,(k^2 B_a + B_2) \right]}{\left[(G_m+G_1)+jB_1\right]\left[G_2+j(k^2 B_a+B_2)\right] + \left[(G_m+G_2)+jB_2\right]\left[G_1+j(k^2 B \;+B \;)\right]}$$

....(4.8)

$$V_1 = V \frac{G_m \left[G_1 + j\,(k^2 B_a + B_1) \right]}{\left[(G_m+G_1++jB_1)\right]\left[G_2+j(k^2 B_a+B_2)\right] + \left[(G \;+G \;)+jB\right]\left[G \;+j(k^2 B_a+B_1)\right]}$$

...(4.9)

The torque as a function of G_m for a fixed value of B_a is calculated and plotted in Fig. 4.10 . Curve shows that the braking torque performance is reduced.

WHEN $Y_m = jB_m$ (Susceptance)

The equations (4.5) and (4.6) becomes

$$V_1 = V \frac{jB_m\left[G_2 + j(k^2B_a + B_2)\right]}{\left[G_1+j(B_m+B_1)\right]\left[G_2+j(k^2B_a+B_2)\right] + \left[G_2+j(B_m+B_2)\right]\left[G_1+j(k^2B_a+B_1)\right]} \quad \ldots(4.10)$$

$$V_2 = V \frac{jB_m\left[G_1 + j(k^2B_a+B_2)\right]}{\left[G_1+j(B_m+B_1)\right]\left[G_2+j(k^2B_a+B_2)\right] + \left[G_2+j(B_m+B_2)\right] \times \left[G_1+j(k^2B_a+B_1)\right]} \quad \ldots(4.11)$$

(i) <u>WHEN B_m is negative (Inductance)</u>

$\left[G_1+j(B_m+B_1)\right]$ & $\left[G_2+j(B_m+B_2)\right]$ become

$\left[(G_1-j(B_m+B_1)\right]$ & $\left[G_2-j(B_m+B_2)\right]$ since B_1 & B_2 have always negative neumerical values. The nature of the equations (4.10) and (4.11) becomes same as equations (4.8) and (4.9) with the difference, there the conductance is increased and here susceptance is increased. The net result is thus similar and it is confirmed by Fig. 4.10.

(ii) <u>WHEN B_m is POSITIVE (CAPACITANCE)</u>

$\left[G_1+j(B_m+B_1)\right]$ & $\left[G_2+j(B_m+B_2)\right]$ becomes

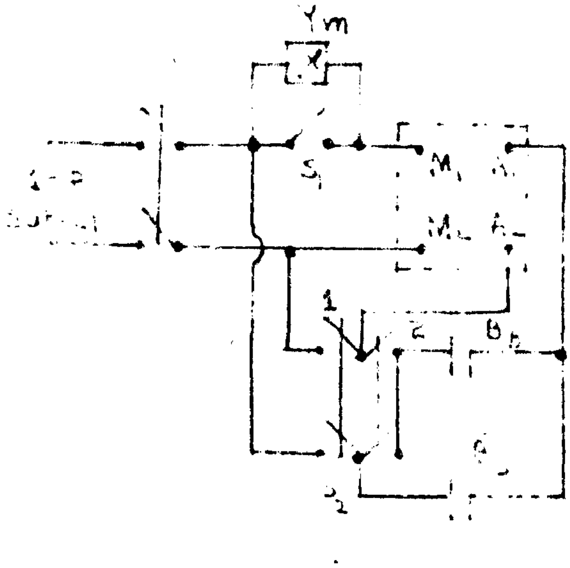
$\left[G_1 + j\ (B_m - B_1)\right]$ & $\left[G_2 + j\ (B_m - B_2)\right]$. This when compared with corresponding terms in (i) , it is seen that the numerical values will be less as compared to corresponding terms in (i) for same numerical values of B_m . This give the denominator of equations (4.10) and (4.11) lesser values as compared to (i). Thus torques are larger in this case as compared to (i) .

The torques for zero slip of ½ h.p. motor under study is calculated and plotted in (4.10) and (4.11) . Curves shows capacitor improves and in-ductance give poor braking torque performance.

EQUIVALENT CIRCUIT:

Opening the circuit at points A in 4.9 , the motor circuit can be split in two parts. Beyond A the circuit is similar to Fig. 4.1. This verifies the conclusion arrived at earlier that Y_m can only influence the braking performance when braking is achieved otherwise but in itself cannot give any braking action. Hence the equivalent circuit is similar to Fig. 4.2. for the part beyond A in Fig. 4.9 by replacing V by V_m , Where V_m is given by

$$V_m = \vec{V} + \frac{\vec{I_m}}{\vec{Y_m}}$$



B_S :- Capacitor for Starting.

B_B :- Additional Capacitor for Braking.

$Y_m = G_m + jB_m$:- External Admittance in 'm' winding .

For Starting:- Switch 'S_1' Close and 'S_2' in 1 position.

For Running:- Switch 'S_1' Close and 'S_2' open.

For Braking:- Switch 'S_1' Open and 'S_2' in positon 2.

Fig. 4.12 BRAKING CIRCUIT WITH AN EXTERNAL ADMITTANCE IN 'm' WINDING AND 'a' WINDING SHORT CIRCUITED THROUGH A CAPACITOR.

INFERENCE

The introduction of resistance and inductance in series with the 'm' winding of braking scheme give poor braking torque performance.

The introduction of capacitance in series with 'm' winding improves braking torque performance. So this scheme can be used effectively similar to scheme 1 it cannot give reverse rotation.

The circuit of fig. 4.2 may be used to achieve the switching needed and to verify this modification experimentally.

4.4. BRAKING SCHEME 2.

VOLTAGE INJECTED TO 'a' WINDING IN SERIES WITH A CAPACITOR

The scheme is shown in Fig. 4.14 with $b_1 = 1$, the scheme represent a single phase capacitor run motor.

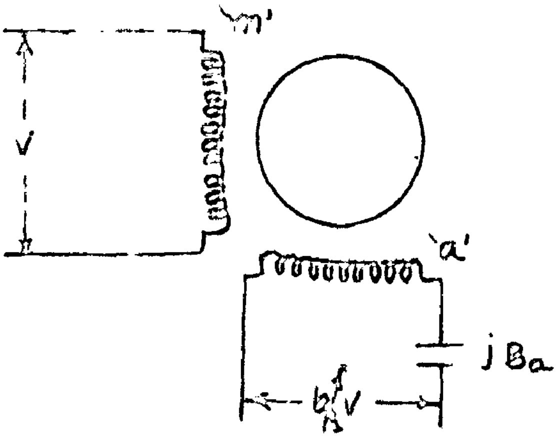
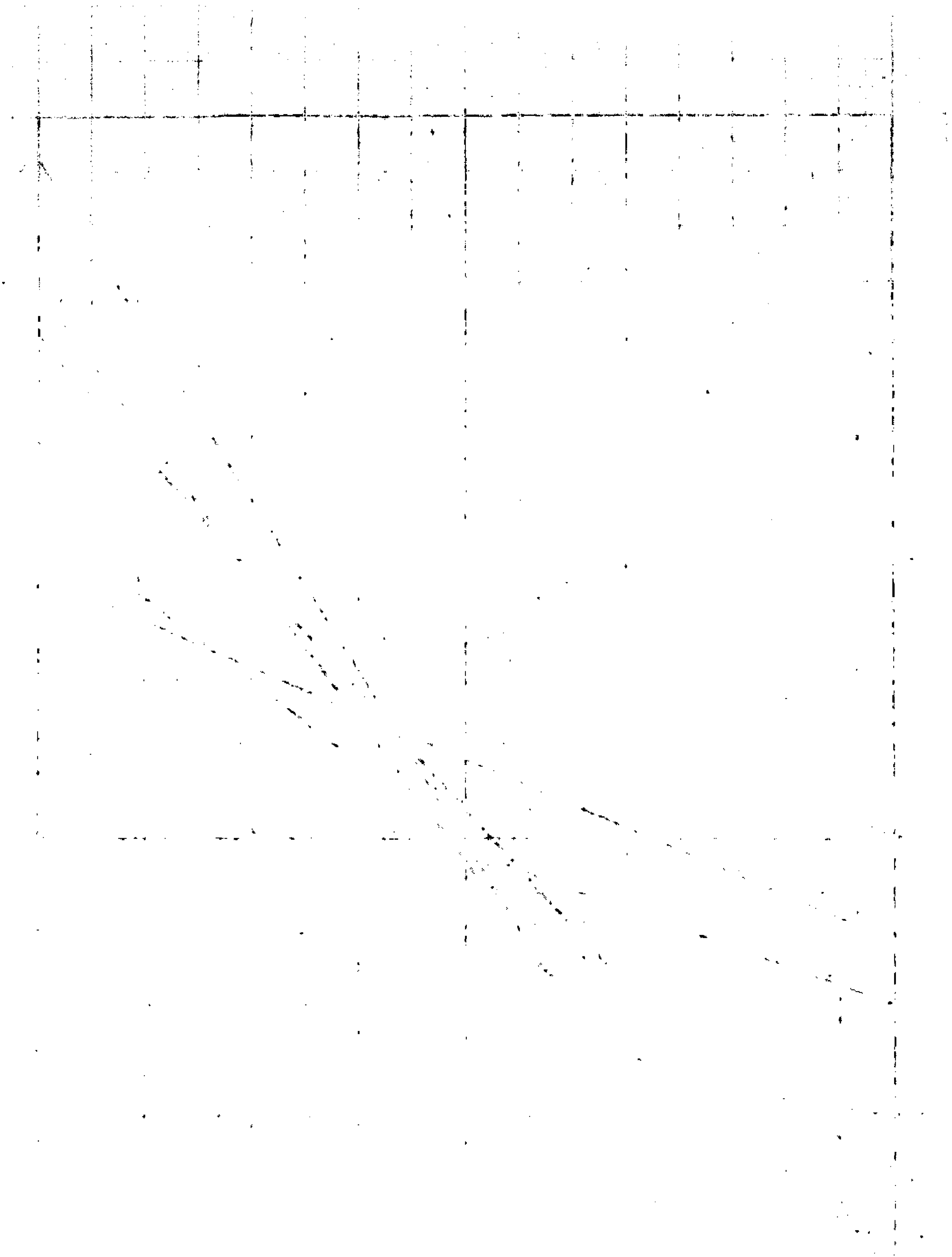


Fig. 4.14 CIRCUIT WITH A CAPACITOR AND A VOLTAGE SOURCE IN 'A' WINDING

The positive - and negative sequence voltages are given as

$$V_1 = V \left[\frac{(G_2 + K b_1 B_a) + j(B_2 + K^2 B_a)}{(G_1 + G_2) + j(B_1 + B_2 + 2K^2 B_a)} \right] \quad \ldots (4.12)$$

$$V_2 = V \left[\frac{(G_1 + K b_1 B_a) + j(B_1 + K^2 B_a)}{(G_1 + G_2) + j(B_1 + B_2 + 2K^2 B_a)} \right] \quad \ldots (4.13)$$

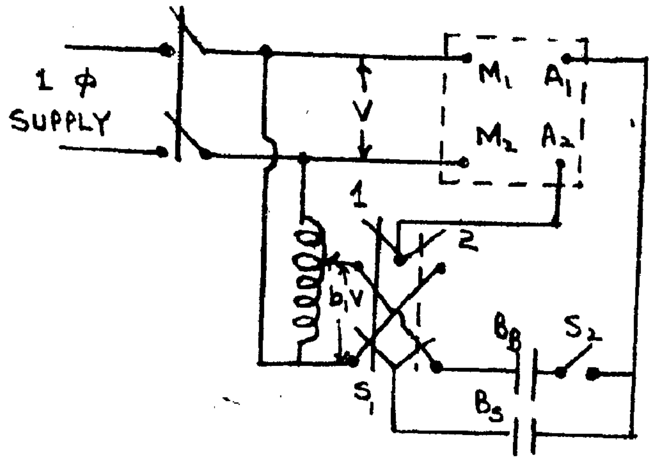


Inspection of equations (4.12) and (4.13) show that with positive values given to b_1 the positive-sequence voltage increases and negative - sequence decreases, giving corresponding increase in driving torque. When b_1 is given negative values, thenegative sequence torque increases and positive sequence torque decreases resulting in braking torque. This leads to idea of braking by plugging or plug reversing. The torque Vs b_1 curves for various values of B_a (for ¼ h.p. motor under study) are calculated and plotted in Fig. 4.15 for the zero slip. The curves confirm the above statement.

Fig. 4.15 shows that at a fixed value of voltage, when the value of B_a increases from 0 , the torque increases upto a certain value of B_a and then falls. It is also noted that the value of B_a which give maximum driving torque for a particular value of b_1 gives maximum braking torque for the same value of b_1 , but with winding terminals reversed. So the same capacitor can be effectively used for driving and braking of themotor.

INFERENCE

The variation of voltage applied to a winding results in a variation of the net torques . Thus a voltage in phase opposition to that of 'm' winding has to be applied to a winding to obtain a negative torque. This method has the advantage that it can be used not only to bring the motor to standstill, but also to reverse it. The scheme is also useful for capacitor start and capacitor run motors.



B_S :- Capacitor for Starting.

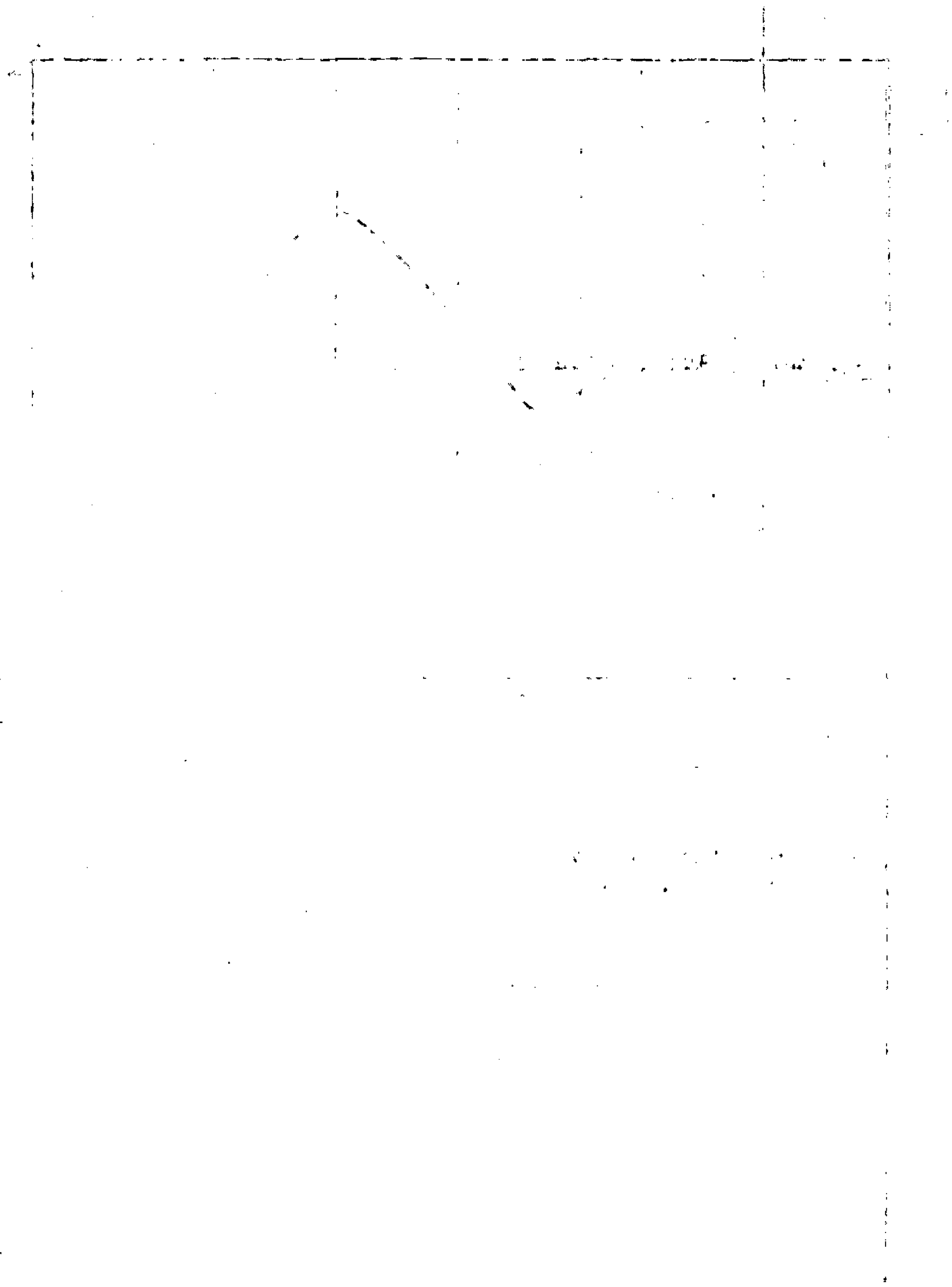
B_B :- Additional Capacitor for Braking.

For Starting:- Switch S_1 in position 1 and S_2 open.

For Running:- Switch S_1 open.

For Braking:- Switch S_1 in position 1 or 2 and S_2 close

Fig. 4.16 BRAKING CIRCUIT WITH 'a' WINDING HAVING A CAPACITOR AND A VARIABLE VOLTAGE.



The above was experimentally verified also.

REQUIREMENTS FOR BRAKING

The circuit shown in Fig. 4.16 can perform the requirements of this braking scheme, viz the voltage applied to the 'a' winding is changed through an autotransformer, and the voltage applied can be reversed through a changeover switch.

USE OF STARTING CAPACITOR FOR BRAKING AS IN SCHEME 2

To evaluate the usefulness of the starting capacitor in the braking scheme of 2 , the following curves w-ere drawn.

i. Starting torque ofthe motor as a function of E_a (This is shown in curve A of Fig. 4.17).

ii. A voltage equal and opposite to that applied to the 'm' winding is considered to be applied to 'a' winding with the motor initially assumed to be running at synchronous speed. The braking torque is calculated for various values of E_a and plot is shown in curve B in Fig. 4.17.

A comparision of curves A, B shows that the capacitor value which gives maximum torque at starting, also gives maximum torque in the reverse direction when the motor is plugged from synchronous speed.

Therefore in capacitor start motors, the starting capacitor can be usefully exploited for braking also.

4.5. MODIFICATION OF SCHEME 2

In scheme 2 when R_a = oo the positive and negative - sequence voltages are

$$V_1 = V \left(\frac{k - bj}{2 k} \right) \qquad ..(4.14)$$

$$V_2 = V \left(\frac{k + jb}{2 k} \right) \qquad ..(4.15)$$

The above equations show that V_1 and V_2 have some magnitude . The net torque T is given by

$$T = \frac{V^2}{4} \left(1 + \frac{b^2}{k^2} \right) \left(|Y_1|^2 R - |Y_2|^2 R_{2_2} \right) \qquad ..(4.16)$$

This equation when referred to 6.4 it give no change of sign and thus no braking is possible. By thism method it is possible to control torque (and speed) and hence can be used for it.

The fall in speed by varying the value of b_1 can be obtained experimentally and for no load. For $\frac{1}{4}$ h.p. motor (under study) a curve showing the speed Vs b_1 is shown in Fig. 4.18.

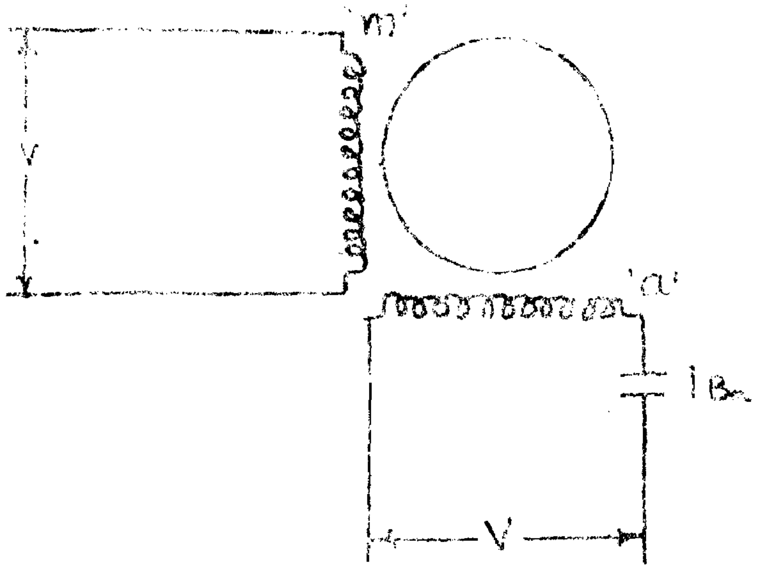


FIG 4.19 STARTING CIRCUIT FOR CAPACITOR MOTOR

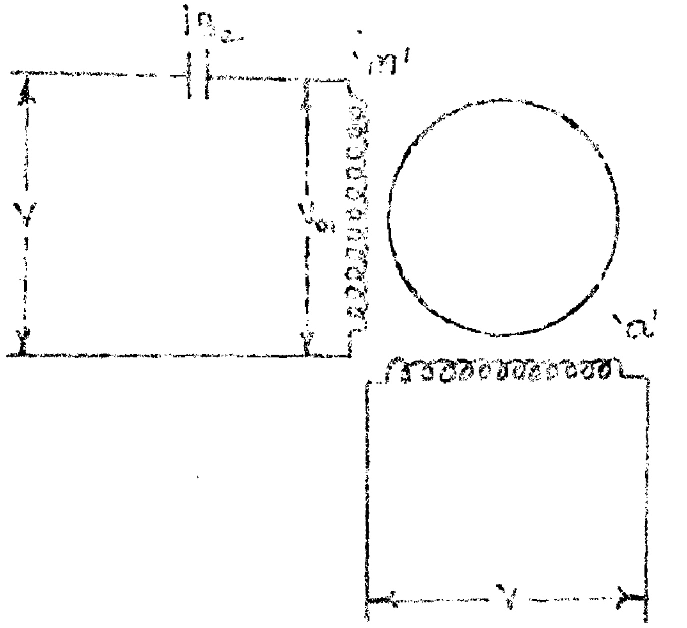


FIG 4.20 PLUGGING CIRCUIT FOR CAPACITOR MOTOR

4.6. BRAKING SCHEME 3 PLUGGING

In this scheme, the capacitor normally in 'a' winding is changed to 'm' winding and the braking performance is obtained. (8)

Normal circuit for starting is shown in Fig. 4.19

The positive-and negative - sequence voltages are

$$V_1 = V \left[\frac{Y_2 + (jk^2 + k) B_a}{Y_1 + Y_2 + 2j k^2 B_a} \right] \quad ..(4.17)$$

$$V_2 = V \left[\frac{Y_1 + (jk^2 - k) B_a}{Y_1 + Y_2 + 2jk^2 B_a} \right] \quad ..(4.18)$$

When plugging takes place the circuit is shown in Fig. 4.20.

The positive-and negative - sequence voltages becomes

$$V_1' = \frac{V}{k} \left[\frac{- jY_2 + B_a (jk + 1)}{Y_1 + Y_2 + 2 j B_a} \right] \quad ..(4.19)$$

$$V_2' = \frac{V}{k} \left[\frac{jY_1 + B (jk - 1)}{Y_1 + Y_2 + 2jB_a} \right] \quad ..(4.20)$$

Simplifying the equations (4.17) and (4.20) to

get

get

$$\left|\frac{V_1}{V_2}\right|^2 = \frac{(kB_a + G_2)^2 + (k^2B_a + B_2)^2}{(kB_a - G_1)^2 + (k^2B_a + B_1)^2} \qquad ..(4.21)$$

$$\left|\frac{V_1'}{V_2'}\right|^2 = \frac{(kB_a - G_2)^2 + (B_a + B_2)^2}{(kB_a + G_1)^2 + (B_a + B_1)^2} \qquad ..(4.22)$$

The inspection of equations (4.21) and (4.22) show

$$\left|\frac{V_1}{V_2}\right|^2 > \left|\frac{V_1'}{V_2'}\right|^2 \qquad ..(4.23)$$

This shows that the negative sequence torque increases to give braking operation.

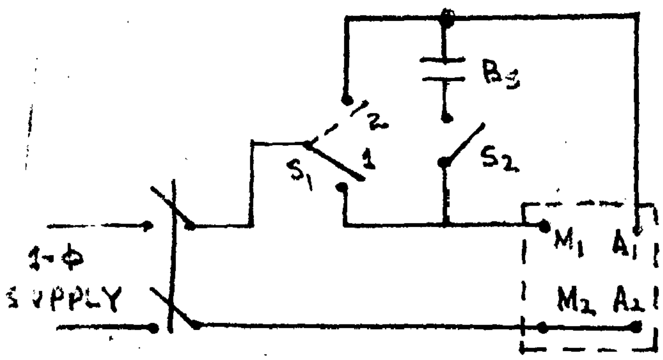
At unity slip the input admittances of the machine are equal

(Say $Y_1 = Y_2 = Y_3$ & $R_{1_2} = R_{2_2} = R$)

For $k = 1$ the net torque under two conditions are

$$T = \frac{V^2 |Y|^2 R}{(G)^2 + (B_a + B)^2} \left[B_a\, G\right] \qquad ..(4.24)$$

$$T' = \frac{V^2 |Y|^2 R}{(G)^2 + (B_a + B)^2} \left[-B_a\, G\right] \qquad ..(4.25)$$



B_S :- Capacitor For Starting.

For Starting:- Switch S_1 in position 1 and S_2 close.

For Running:- Switch S_1 in position 1 and S_2 open.

For Braking:- Switch S_1 in position 2 and S_2 close.

Fig. 4.21 PLUGGING CIRCUIT.

This shows that with circuit of Fig. 4.19 and 4.20 the two torques obtained oppose each other. Hence the two circuit give opposite rotation at the start. Further, the circuit of Fig. 4.20 give torque at zero speed, so the reversal is possible.

INFERENCE

i. The scheme can give speed reversals.

ii. The capacitor at the start can be used for torque reversal.

iii. The scheme is equally useful for capacitor start + run motors.

The circuit is so designed to disconnect the capacitor from 'a' winding and connecting it to 'm' winding. Then supply is given to both windings. The arrangement is to be made to disconnect the supply at the instant of zero speed.

The desired circuit is given in Fig. 4.21.

4.7. BRAKING SCHEME 4 - BRAKING WITH TWO PHASE SUPPLY

In this scheme the possibility of braking a 2-phase motor by supplying a two phase voltage (the phase voltages are in (quadrature) are explored. The circuit is shown in Fig. 4.22.

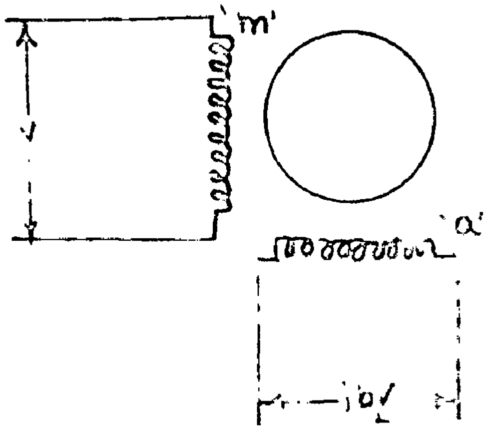


Fig. 4.22. TWO PHASE OPERATION.

The positive and negative - sequence component of voltages are $V_1 = \frac{V}{2}(1 + b/k)$ ..(4.26)

$V_2 = V(1 - b/k)/2$ ..(4.27)

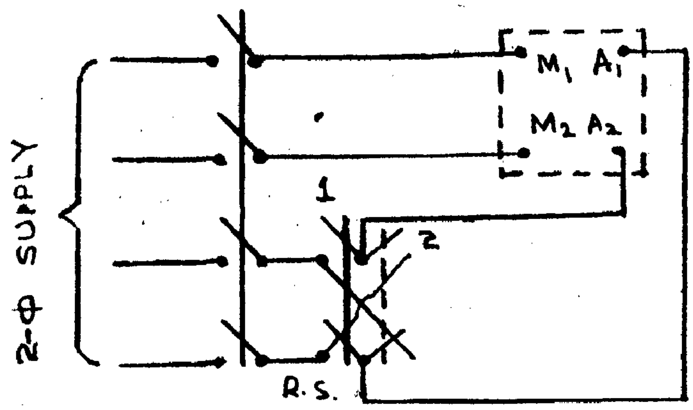
For all positive values of b, $V_1 > V_2$

Thus the positive - sequence torque is greater than negative sequence torque. $V_2 > V_1$ with negative values of b, giving thereby braking action.

REVERSAL.

The torque reversal is obtained by reversing the connections of one of the winding. To obtain zero speed the supply is to be disconnected at the instant of zero speed. It was verified experimentally.

Fig. 4.23 gives a scheme for braking & reversal of a two phase induction motor.



Reversing Switch R.S. in position 1 for Starting and Running.

Reversing Switch R.S. in position 2 for Plugging.

Fig. 4.23 BRAKING CIRCUIT WITH TWO PHASE SUPPLY.

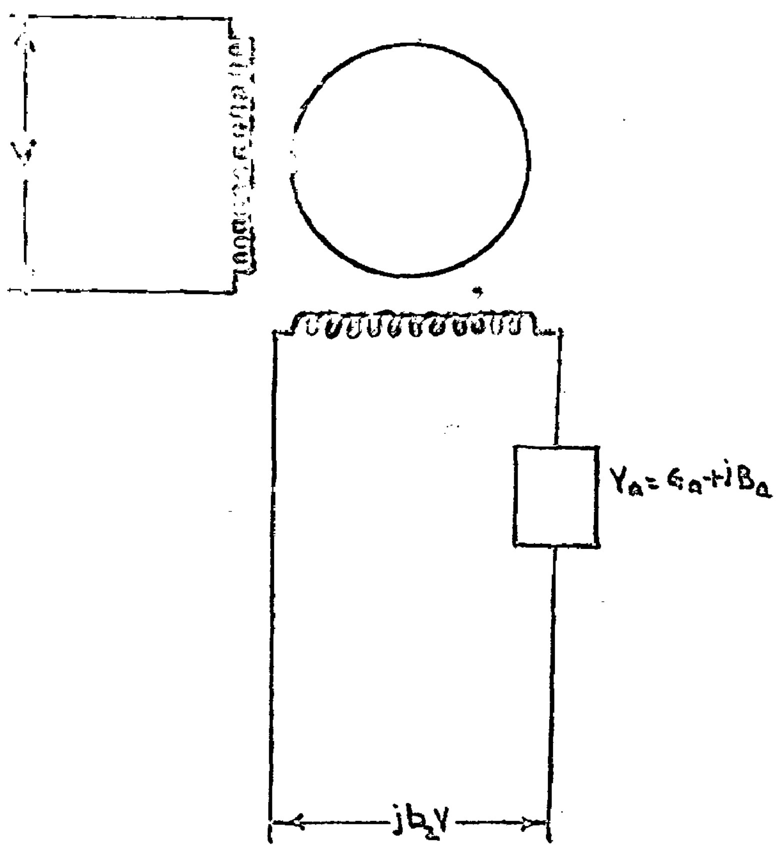


FIG 4·24 CIRCUIT WITH TWO-PHASE OPERATION AND ADMITTANCE IN 'a' WINDING

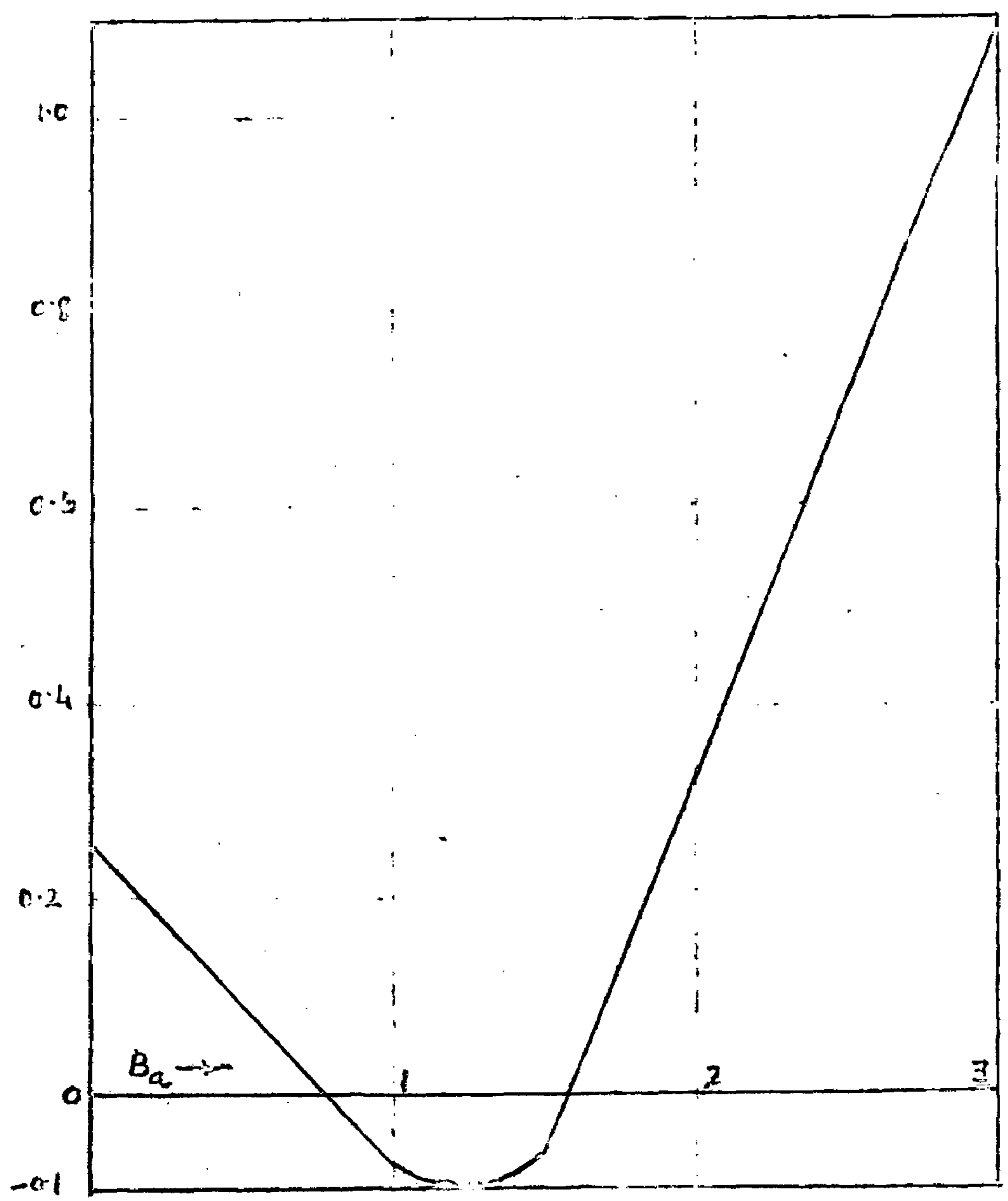


FIG 4·25 TORQUE VS B_a CHARACTERISTICS FOR FIG 4·24 AT ZERO SLIP OF 1/2 h.p. MOTOR UNDER STUDY

4.8. BRAKING SCHEME 5

The possibility of braking by introduction of an admittance in any of the two winding and two phase supply is expl-ored. The circuit is shown in Fig. 4.24.

Fig. 4.27 CIRCUIT FOR TWO PHASE OPERATION WITH ADMITTANCE IN STATOR WINDING

The positive and negative sequence voltages for Fig. 4.24 (a~~s~~ are)

$$V_1 = V \left[\frac{Y_2 + Y_a (k^2 + b_2 k)}{Y_1 + Y_2 + 2k^2 Y_a} \right] \quad .. (4.28)$$

$$V_2 = V \left[\frac{Y_1 + Y_a (k^2 - b_2 k)}{Y_1 + Y_2 + 2k^2 Y_a} \right] \quad ..(4.29)$$

Simplyfying the above equations by $b_2 = k = 1$ to set

$$V_1 = \frac{Y_1 + 2Y_a}{Y_1 + Y_2 + 2 Y_a} \quad ..(4.30)$$

$$V_2 = \frac{Y_1}{Y_1 + Y_2 + 2Y_a} \quad ..(4.31)$$

With $Y_a = G_a$ (conductance)

With $Y_a = G_a$ (conductance)

The voltage components are

$$V_1 = \frac{(G_2 + 2\,G_a) - j\,B_2}{(G_1 + G_2 + 2G_a) - j\,(B_1 + B_2)} \qquad ..(4.32)$$

$$V_2 = \frac{G_1 + j\,B_1}{(G_1 + G_2 + 2G_a) - j\,(B_1 + B_2)} \qquad ..(4.33)$$

The equations show that $V_1 > V_2$ (Ref. to Fig. 6.1, $G_2 > G_1$ & $B_2 > B_1$). Thus positive sequence torque is increased by introduction of conductance so no braking action is obtained.

When $Y_a = -j\,B_a$ (Inductance)

The voltage components are

$$V_1 = \frac{G_2 - j\,(B_2 + B_a)}{(G_1 + G_2) - j\,(B_1 + B_2 + 2\,B_a)} \qquad ..(4.34)$$

$$V_2 = \frac{G_1 - j\,B_1}{(G_1 + G_2) - j(B_1 + B_2 + 2B_a)} \qquad ..(4.35)$$

Again $V_1 > V_2$ to give no braking action with introduction of inductance.

When $Y_a = jB_a$ (Capacitance)

The voltage components are

$$V_1 = \frac{G_2 - j\,(B_2 - 2\,B_a)}{(G_1 + G_2) - j\,(B_1 + B_2 - 2B_a)} \qquad \ldots(4.36)$$

$$V_2 = \frac{G_1 - j\,B_1}{(G_1 + G_2) - j\,(B_1 + B_2 - 2B_a)} \qquad \ldots(4.37)$$

The above equations show that for certain values of B_a, V_2 can be made greater than V_1. Thus braking action is obtained by introduction of capacitance.

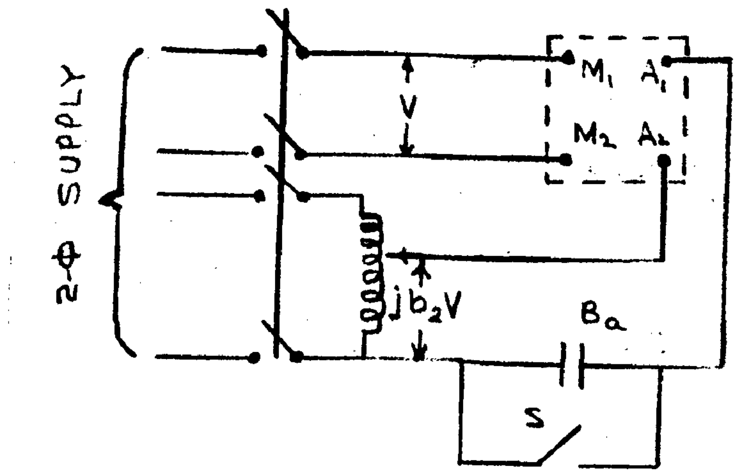
The analysis is given for the limiting case $b_2 = k = 1$ for simplifying the discussion and it hold true for other positive values of b_2.

If $b_2 = 1$ and the $\frac{1}{2}$ h.p. motor under study, the curve is plotted in Fig. 4.25 for various values of B_a and zero slip.

By inspection of the equations 4.28 and 4.29 for negative value of b_2 the $V_2 > V_1$ to give braking action.

INFERENCES:

1. If a capacitor is connected in series with the 'a' winding the net torque developed & its direction



B_a :- Capacitor in 'a' winding.

Switch S open for Starting and Running.

Switch S close for Braking andSpeed Reversal.

Fig. 4.26 CIRCUIT WITH TWO PHASE SUPPLY AND A CAPACITOR IN 'a' WINDING.

depend on the value of the capacitor. Proper choice of capacitor make the net torque negative. The maximum value of the net torque in the reverse direction is, however, much less then the torque obtained in the forward direction.

ii. The reversal is achieved by reversing the supply to one of the windings.

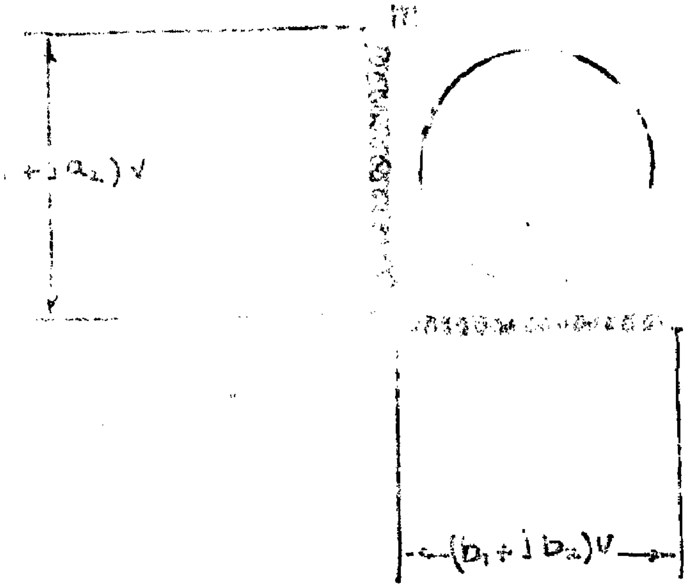
iii. The introduction of inductance and resistance does not help braking.

The circuit shown in Fig. 4.26 may be used for braking employing this 5 scheme.

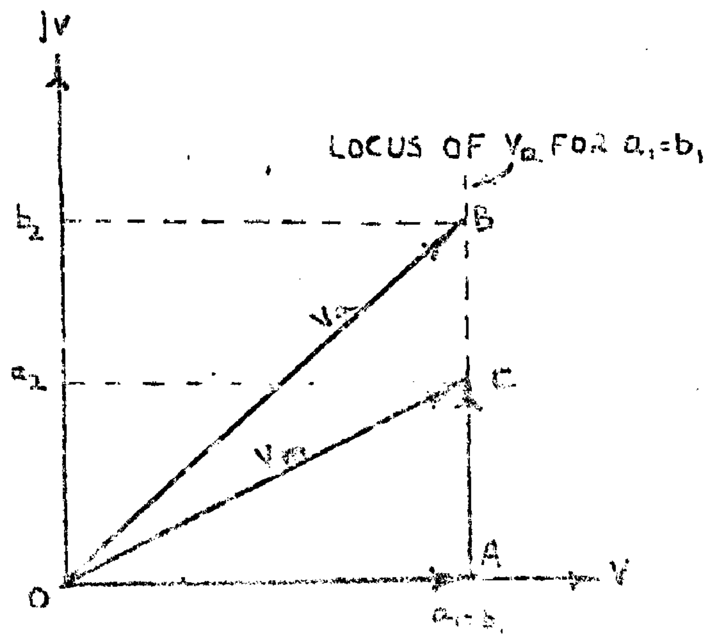
EXPERIMENTAL VERIFICATION

For a fixed value of capacitor in Circuit of Fig. 4.26 the machine reversed on closing the switch S. As the voltage to 'a' winding is increased the reversal was quicker.

Then with fixed value of voltage to 'a' winding the capacitance was varied to obtain the speed reversal in a certain range.



4·28 BRAKING CIRCUIT WITH UNBALANCE SUPPLY



4·29 VOLTAGE PHASOR DIAGRAM FOR TWO-PHASE MACHINE WITH UNBALANCE SUPPLY

4.9 BRAKING SCHEME 6 - BRAKING WITH TWO PHASE UNBALANCED SUPPLY

In this scheme the possibility of braking a two phase motor by supplying unbalanced voltages (of variable magnitude & adjustable phase difference) is explored. The circuit used for analysis is shown in Fig. 4.28.

The positive and negative sequence components of the voltages are :

$$V_1 = \frac{V}{2} \left[\left(a_1 + \frac{b_2}{k} \right) + j \left(a_2 - \frac{b_1}{k} \right) \right] \quad \ldots(4.38)$$

$$V_2 = \frac{V}{2} \left[\left(a_1 - \frac{b_2}{k} \right) + j \left(a_2 + \frac{b_1}{k} \right) \right] \quad \ldots(4.39)$$

By suitable adjustment of variables , a_1, a_2, b_1 & b_2 the positive-and negative-sequence components of the voltage and the corresponding torques can be varied. So suitable variation give braking or driving action may be attained as desired.

If a_1 is kept equal to b_1 , by varying only a_2 and b_2 the relative phase angle of the voltages applied to the two phases can be changed (ref. to Fig. 4.29)

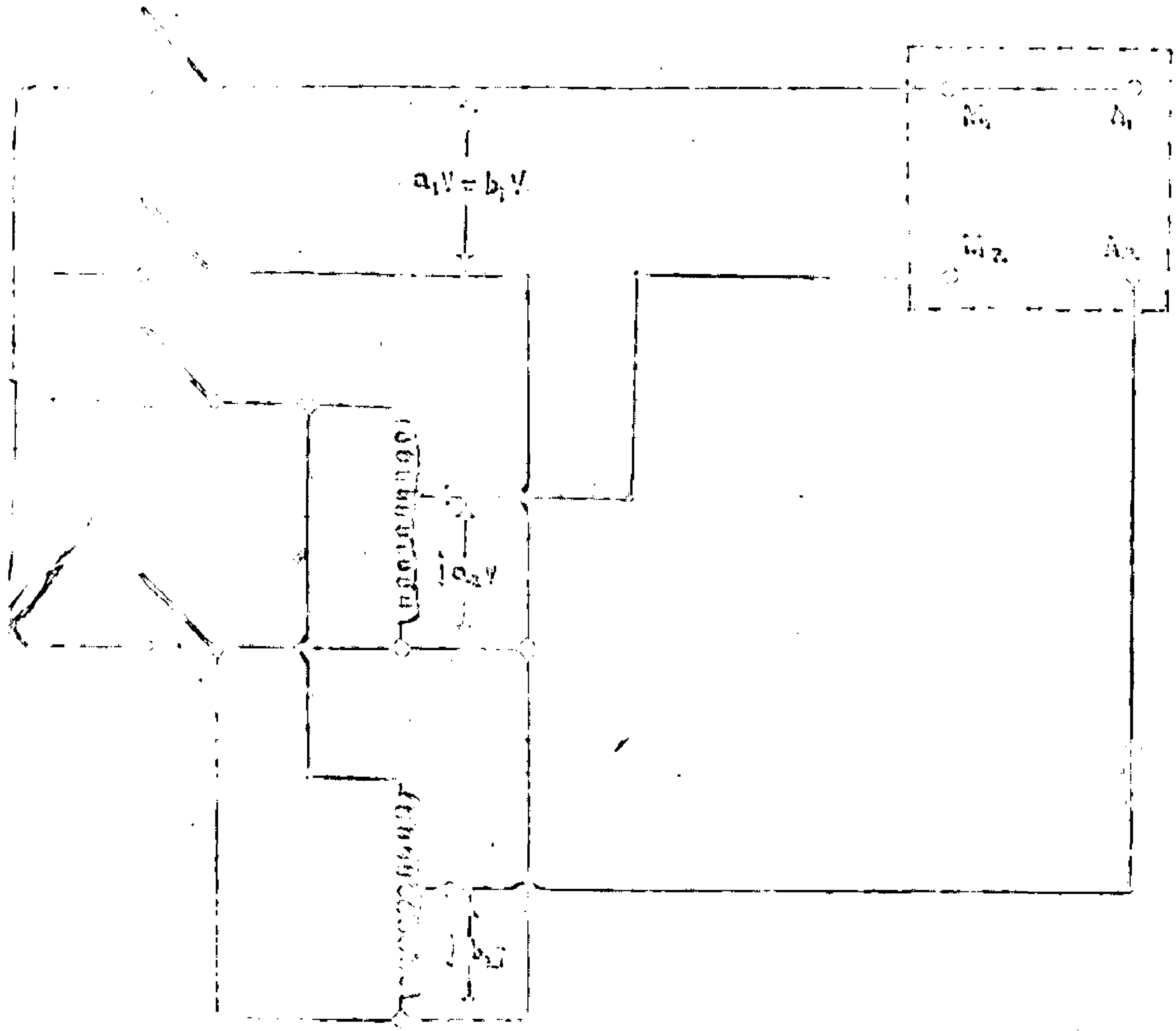


FIG. [illegible] CIRCUIT FOR MACHINE OPERATION WITH UNBALANCE SUPPLY.

INFERENCE:

For normal forward running, the two voltages are adjusted in phase quadrature, i.e. $a_2 = 0$; and their magnitudes are so adjusted that $b_2 / a_1 = k$
For reversal a number of operations are possible e.g. a_2 may be increased suitable, a_1 reduced to zero and simultaneously b_2 reduced to Zero and b_1 increased suitably.

EXPERIMENTAL VERIFICATION

The experimental circuit was set up as shown in Fig. 4.31. The circuit is for $a_1 = b_1$ and a_1 and b_2 are variable. By keeping a_2 constant the speed reversal was obtained by varying b_2 . Then b_2 was kept constant and speed reversal obtained by varying a_2 .

CHAPTER 5

CONCLUSIONS

CONCLUSION

THE CIRCUITS INVESTIGATED ARE COMPARED IN THE FOLLOWING TABULAR FORM

5.	Two phase supply & admittance in any one of the two windings.	Braking and reversal is obtained by short circuiting the capacitor . Put in any of the two windings. It is also obtained by reversing the supply terminals to one of the two windings.	Can be used only where 2 pha supply is available & the motor is required to stop or reverse only once.
6	Unbalanced supply	Braking and reversal is obtained by varying the voltage of one of the auto-transformer at a time.	Where two phase supply is available and cost is of not much importance.

CHAPTER 6

APPENDIX

CONCLUSION

THE CIRCUITS INVESTIGATED ARE COMPARED IN THE FOLLOWING TABULAR FORM

Scheme	INFERENCE	APPLICABILITY
1. 'a' Winding short circuit through a capacitor.	a. The value of the capacitor for braking is larger then that required for starting. b. Braking torque performance can be improved by introduction of capacitor in 'm' winding The control is affected by additional admittance in any or both windings.	a. When speed reversal is not required. b. Where the centrifugal switch is disconnected. c. In the capacitor run motor having the arrangement to disconnect 'a' winding from 'm' winding.
2. Supply to 'a' winding through a capacitor.	a. Same capacitor can be used for both starting and braking. b. Braking and reversal is achieved by reversing terminals of any one of the two windings. c. Braking torque performance can be affected by voltage control.	a. Where speed reversal is reqd. b. Where the centrifugal switch is disconnected. c. In the capacitor run motor having the arrangement to disconnect 'a' winding from 'm winding.
3. Plugging circuit	a. Same capacitor can be used for both starting and braking. b. Braking and reversal is obtained by changing the capacitor from one winding to the other.	Extremely useful for capacitor motor.
4. Two phase supply	Braking and reversal is obtained by reversing the supply to one of the two phases.	Where 2 phase supply is available and the machine have 2 windings in space quadratur
5. Two phase supply & admittance in any one of the two windings.	Braking and reversal is obtained by short circuiting the capacitor . put in any of the two windings. It is also obtained by reversing the supply terminals to one of the two windings.	Can be used only where 2 phas supply is available & the motor is required to stop or reverse only once.
6 Unbalanced supply	Braking and reversal is obtained by varying the voltage of one of the auto-transformer at a time.	Where two phase supply is available and cost is of not much importance.

APPENDIX

6.1. TURNS RATIO

Turns ratio as defined in 3.1 may be determined either experimentally or theoretically.

EXPERIMENTALLY:

The motor is started and the supply at rated voltage E_m is given to 'm' winding only. The open circuit voltage E_a accross 'a' winding is measured. The motor is again started and voltage E'_a, which is roughly 18% more than the rated is applied accross 'a' winding only. The open circuit voltage E'_m accross 'm' winding is measured. (4)

Turns Ratio k is given by

$$k = \sqrt{\frac{E_a \times E'_a}{E_m \times E'_m}}$$

For $\frac{1}{4}$ h.p. , 7.2 Amps, 110 volts, 50 cys, 1.1 induction motor

$$k = 1.14$$

For $\frac{1}{4}$ h.p. , 3 Amps, 110 volts, 50 c/s 1-ϕ , Induction motor

$$k = 1.12 .$$

THEORETICAL

From design data a unit emf is assumed per turn, andit is multiplied by the distribution factor of the winding and then added to get total emf . Turns ratio k is given by

$$k = \frac{\text{Total emf of 'a' winding}}{\text{Total emf of 'm' winding}}$$

For $\frac{1}{4}$ h.p. Induction motor (under consideration)

$$k = 1.10$$

6.2. MEASUREMENT OF POSITIVE AND NEGATIVE SEQUENCE INPUT ADMITANCES

The machine is coupled to a d.c. motor, so that the machine speed can be easily controlled. Then a two phase balanced reduced voltage is fed to 'm' and 'a' windings. The voltage of 'a' winding is k times that of 'm' winding magnitude to give equal voltage per turn. The power W, current I and voltage V in the 'm' winding are measured for various speed of the machine in both forward and backward directions. For a check W', I' and V' for 'a' winding are also recorded. The relation between the two should be

$W = W'$, $I = kI'$, $V = V'/k$

The induction machine is run on two phase supply to ascertain the positive direction of the machine field, which gives clue to positive sequence components. Opposite direction gives negative sequence components.

The d.c. resistance of 'm' winding at standstill is measured by voltmeter, ammeter and battery. By suitable constant the effective resistance r_1 is obtained. Then

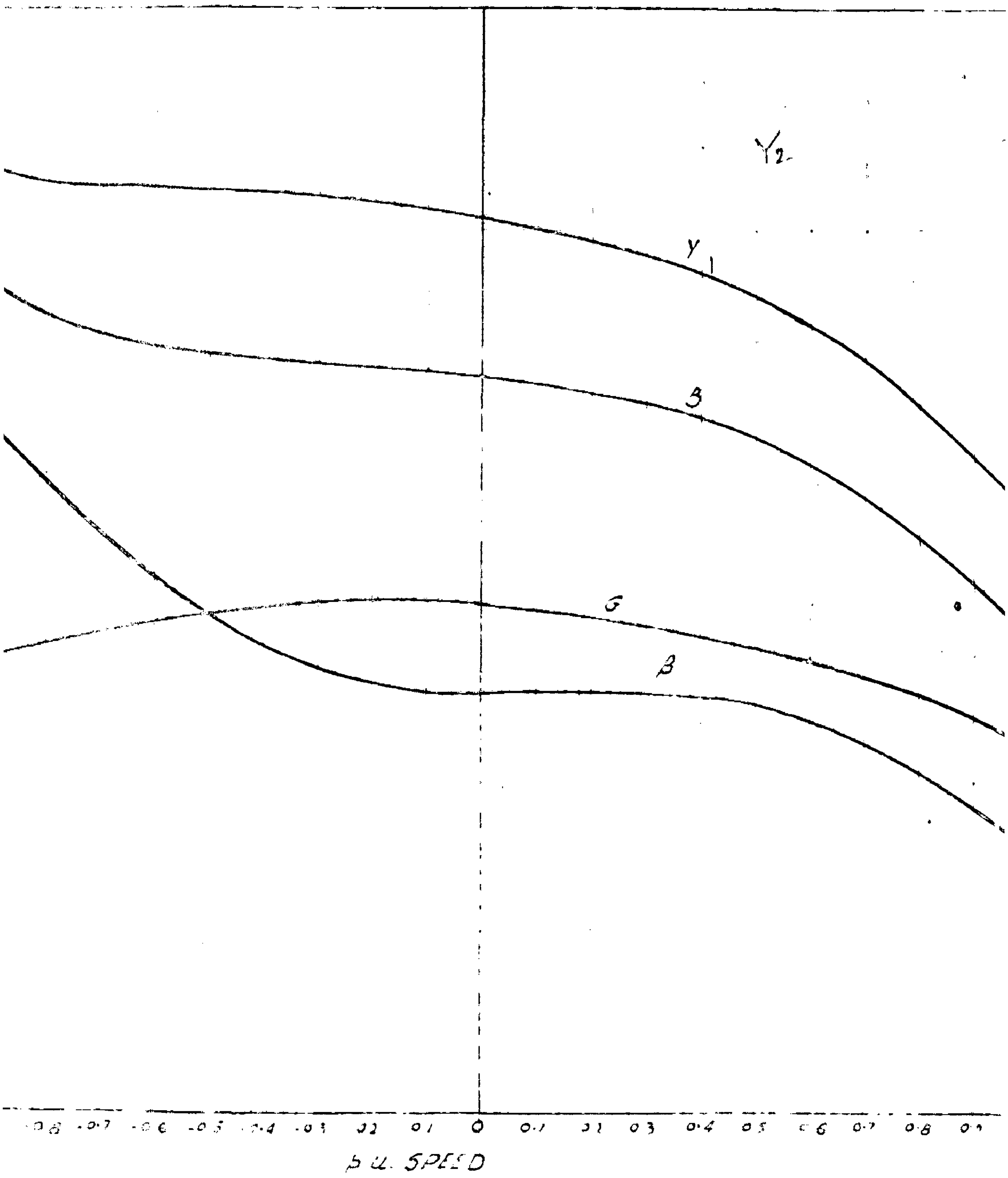
Admittance $Y = I/V$, Impedance angle $\beta = \cos^{-1}(W/IV)$

Susceptance $B = -Y \sin\beta$, Conductance $G = Y \cos\beta$

Total resistance $= \cos\beta / Y$,

Effective rotor resistance $= (\cos\beta / Y) - r_1$

The various values for ½ h.p. Induction motor are plotted in Fig. 6.1. to 6.3.



[illegible] OF 1/2 H.P. INDUCTION MOTOR

6.3. DETERMINATION OF RANGE FROM THE QUADRATIC EQUATION

The general quadratic equation may be written as

$$ax^2 + bx + c = y \qquad \ldots(6.1)$$

for $y = 0$, the quadratic equation 6.1, becomes;

$$ax^2 + bx + c = 0 \qquad \ldots(6.2)$$

Equation 6.2. has two roots, say x_1 and x_2

$$x_1 = -b/2a - \sqrt{\frac{b^2}{4a^2} - \frac{c}{a}} \qquad \ldots(6.3)$$

$$x_2 = -b/2a + \sqrt{\frac{b^2}{4a^2} - \frac{c}{a}} \qquad \ldots(6.4)$$

Let $-b/2a = A$

$$\sqrt{\frac{b^2}{4a^2} - \frac{c}{a}} = B$$

Where B is a real positive quantity, operator j values, are not considered here

Then roots x_1 and x_2 will be

$$\left.\begin{aligned} x_1 &= A - B \\ x_2 &= A + B \end{aligned}\right\} \qquad \ldots(6.5)$$

By inspection, it can be proved that

$$x_1 < x_2$$

The quadratic equation 6.1 may be rewritten as

$$y = a\left[\left(x + \frac{b}{2a}\right)^2 - \left(\frac{b^2}{4a^2} - \frac{c}{a}\right)\right]$$

$$= a\left[(x - A)^2 - B^2\right] \qquad \ldots(6.6)$$

Substituting

$$x = x_1 + h$$

$$= A - B + h \qquad \ldots(6.7)$$

Where h is any real quantity, positive or negative.

The quadratic equation 6.6. becomes

$$y = a\left[(-B + h)^2 - B^2\right]$$

$$= a\ (h^2 - 2Bh) \qquad \ldots.(6.8)$$

Considering the equation 6.8 for various values of h,

For $h < 0$, y will bemultiple of +a

For $h = 0$, y will be zero

For $0 < h < 2B$, y will be multiple of -a

for $h = 2B$, y will be zero

for $h > 2B$, y will be multiple of +a

This shows that for $0 < h < 2B$ or $x < x < x_2$ the value of y have the negative sign to that of a . For

$x < x_1$ and $x > x_2$, the value of y have the same sign as that of a. Hence to determine the characteristic nature of y, the values of roots x_1 and x_2 predict the range.

—

6.4. TO EVALUATE THE VALUE OF $|Y_1|^2 R_{1_2} - |Y_2|^2 R_{2_2}$

From the symmetrical component theory if V is the applied voltage to the positive sequence circuit then torque due to positive sequence current is

$$T_1 = V^2 |Y_1|^2 R_{1_2}$$

Similarly T_2 due to negative sequence current is

$$T_2 = V^2 |Y_2|^2 R_{2_2}$$

$$\text{Net torque } T = V^2 \left[|Y_1|^2 R_{1_2} - |Y_2|^2 R_{2_2} \right] \qquad ..(6.7)$$

Neglecting voltage drop in the stator and assuming a voltage V at rotor the net torque becomes:

$$T = V^2 \left[\frac{s\, r_2}{(r_2)^2 + (s^2 X_2)^2} - \frac{(2-s)\, r_2}{(r_2)^2 + (2-s)^2 X_2} \right] \qquad ..(6.8)$$

Comparing above equation to get

$$|Y_1|^2 R_{1_2} - |Y_1|^2 R_{2_2} = \frac{s r_2}{(r_2)^2 + (s X_2)^2} - \frac{(2-s) r_2}{(r_2)^2 + (2-s)^2 X_2^2}$$

i. If r_2 is negligible as compares to X_2 then

$$|Y_1|^2 R_{1_2} - |Y_2|^2 R_{2_2}$$

$$\simeq \frac{r_2}{sX_2^2} - \frac{r_2}{(2-s)\,X_2{}^2}$$

as s varies from 0 to 1

r_2 / sX_2 is always larger than $r_2/(2-s)X_2$

Giving thereby $|Y_1|^2 R_{1_2}$ always greater then

$|Y_2|^2 R_{2_2}$

ii. If X_2 is negligible as compared to r_2 then

$$|Y_1|^2 R_{1_2} - |Y_2|^2 R_{2_2}$$

$$\simeq \frac{s}{r_2} - \frac{2-s}{r_2}$$

As s varies from 0 to 1 s/r_2 is always less then $2-s / r_2$, giving thereby $|Y_1|^2 R_{1_2}$ always less then $|Y_2|^2 R_{1_2}$. Hence useful for braking in modified scheme 2.

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