BEHAVIOR OF CAPACITOR- RUN SINGLE - PHASE INDUCTION MOTORS DRIVEN FROM A VARIABLE FREQUENCY SUPPLY

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ABSTRACT: The capacitor - run single - phase induction motor is preferred than the other types of single - phase induction motors, due to lower current , higher efficiency and power factor. Speed control of these motors can be achieved through a wide range by the variable frequency controller .Frequency variation needs a voltage variation by the same ratio (V/F = constant) during the constant torque region. If the capacitor is kept constant , the maximum torque will be decreased by the frequency decreasing.

The main object of this work is to keep the maximum torque and thus full load torque, at higher values through the frequency decreasing. The capacitance value should be increased, by frequency decreasing, to a value which keeps the winding current at its rated value and the motor performance analysis is also achieved.

The computed and the measured performance characteristics are compared and found to be in a good agreement .

1.INTRODUCTION

The single - phase induction motor is widely used in many light duty applications such as compressors, pumps, air conditioners and other pieces of equipment that must start at load, where three-phase power is not readily available . The single- phase induction motor, like its three- phase counterpart , is a single speed device when operated from a fixed - frequency supply.

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When three - phase induction motor is supplied from a variable frequency source , the magnetizing current is normally held constant by helding the ratio of the terminal voltage to frequency constant (V/F=constant). At very low frequencies, the stator reactance drop must be compensated. Therefore, the three-phase induction motor torque-slip curves are identical in the low-frequency operation. Rated torque can be obtained from near synchronous speed all the way down to essentially zero speed by helding the level of magnetizing current.

The single-phase induction motor does not behave like three-phase induction motor in variable- frequency operation . Instead, the available torque is found to diminish substantially as the frequency reduced , even in the low power ranges a variable-frequency drives have not been applied to single-phase induction motors for a number of reasons: starting problems , low-speed operating characteristics (especially near the centrifugal switch operating point) [1,2,3].

The goal of this paper is to study the behavior of the capacitor - run single- phase induction motor in running conditions when supplied from a variable-frequency power supply to give an approximately constant maximum and output torque . The function of the capacitor is to realize another phase from the supply source to feed a second , auxiliary winding so that the motor can operate as a two- phase machines . For this purpose, the capacitor size must be carefully determined according to the impedance of auxiliary winding . Unfortunately , the auxiliary circuit impedance is increased at low - frequency yields to decreasing of the output torque of the motor. To increase the torque at low frequency, the auxiliary circuit capacitance must be increased to a value constrained by motor currents in auxiliary and main windings.

2.EQUIVALENT CIRCUIT

The theoretical analysis of the capacitor-run single-phase induction motor is obtained, based on the rotating field theory using the method of symmetrical component. Based on [4,5,6] the equivalent circuit and the motor performance equation are derived for nonsymetrical two phase motor. The motor consisting of the main phase winding A and the auxiliary phase winding B with an external impedance Z_p` (run-capacitor) connected as shown in Fig.(1-a).The two windings A and B have different number of turns, N_A and N_B, and different electrical impedance parameters, R_A, X_{Al} and R_B, X_{Bl}, respectively .. As usually done, one can transform one of the windings into a new fictitious winding having the number of turns of that of the other winding. Here, the new transformed auxiliary winding will have N_A turns, and its parameters will be calculated according to the transformation ratio

$$K_{AB} = (N_B * K_{WB} / N_A * K_{WA}) \qquad (1)$$

as follows,

$$R_B` = R_B / K_{AB}^2 \text{ , } X_{Bl}` = X_{Bl} / K_{AB}^2 \text{ , } Z_P`` = Z_P` / K_{AB}^2 \qquad (2)$$

and,

$$V_B` = V_B / K_{AB} \text{ , } I_B` = I_B * K_{AB} \qquad (3)$$

In order to arrive at a "symmetrical" motor, the difference in the impedance's of both windings will be included in the external impedance. Thus its value becomes ;

$$Z_P` = (Z_p / K_{AB}^2) + (R_B` - R_A) + j(X_{Bl}` - X_{Al}) \qquad (4)$$

The schematic of the "symmetrical" motor is given in Fig(1-b). Note that the rotor is not affected by this transformation .

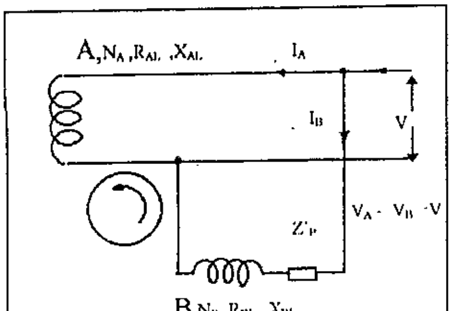

Fig.(1-a) Connection diagram of nonsymetrical two-phase motor

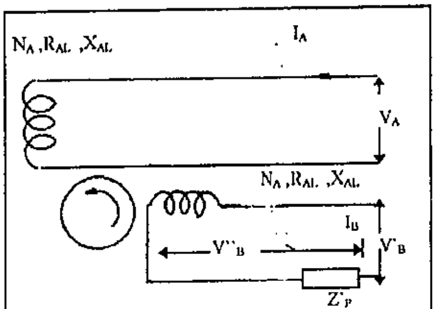

Fig.(1-b) "symmetrical" two- phase motor

The voltage equations of the machine can now be obtained in terms of symmetrical components. For the main - phase one can write;

$$V = V_A = V_{Af} + V_{Ab} \qquad (5\text{-a})$$

and for auxiliary phase;

$$V_B = V_{Bf} + V_{Bb} = jV_{Af} - jV_{Ab} \qquad (5\text{-b})$$

The terminal voltages expressed in terms of currents and impedance's then become;

$$V_A = Z_f I_{Af} + Z_b I_{Ab} \qquad (6\text{-a})$$

and,

$$V_B = V_B + Z_P I_B = V_B + Z_P I_{Bf} + Z_P I_{Bb} \qquad (6\text{-b})$$

where,

$$Z_f = R_A + jX_{Al} + Z'_{2f} \quad (7\text{-a})$$

and,

$$Z_b = R_A + jX_{Al} + Z'_{2b} \quad (7\text{-b})$$

The rotor impedance's Z'_{2f} and Z'_{2b} are defined as in [4,5] , which consist of the parallel connection of the impedance's of the magnetizing , and rotor branches.

If the symmetrical components for the currents are introduced

$$I'_{AF} = (I_A - jI_B)/2 \;,\; I_{Ab} = (I_A + jI_B)/2 \quad (8)$$

and noting that

$$I_{Bf} = jI_{Af} \;,\; I_{Bb} = -jI_{Ab} \quad (9)$$

one can define the current ratio of the main and auxiliary -phase winding as;

$$\gamma' = (I_{Ab}/I_{Af}) = -(I_{Bb}/I_{Bf})$$
$$= ((Z_P + Z_f(1 - (j / K_{AB})) /((Z_P + Zb (1 - j / K_{AB})) \quad (10)$$

using the Eqs. 7-10 for phase A, the equivalent circuit as a function of γ' can be drawn as shown in Fig.(2).

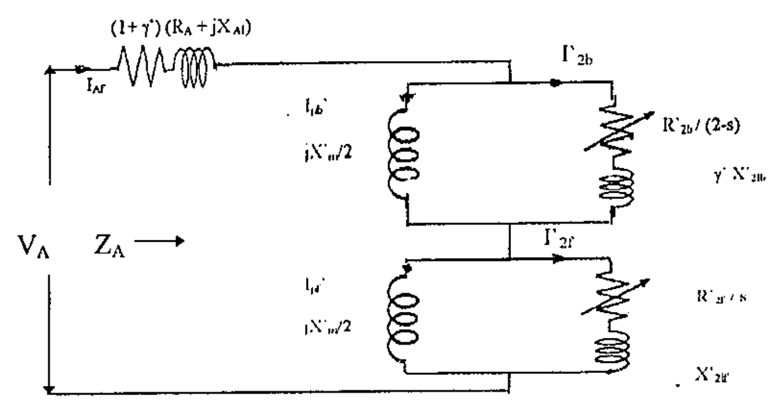

Fig. (2) Equivalent circuit of phase A

Therefore one obtains from Fig . (2) the total impedance of phase A :

$$Z_A = Z_{2f} + \gamma' Z_{2b} + (1+\gamma')(R_A + jX_{Al}) = Z_f + \gamma' Z_b \quad (11)$$

The forward and backward rotating components of phase A current are then;

$$I_{Af} = (V_A/Z_A),\ I_{Ab} = \gamma` I_{Af} \quad (12)$$

and the total current of phase A becomes

$$I_A = I_{Af} + I_{Bf} \quad (13)$$

For the currents of phase B are obtained correspondingly;

$$I_{Bf} = j(I_{Af}/ K_{AB}),\ I_{Bb} = j(I_{Ab}/K_{AB}),\ I_B = I_{Bf} + I_{Bb} \quad (14)$$

The terminal current is then

$$I = I_A + I_B \quad (15)$$

The power factor is obtained from;

$$\cos(\varphi) = \text{Real}(I) / [I] \quad (16)$$

Losses and efficiency:

The losses are the stator and rotor copper losses ,and the iron losses which

obtained expermintaly;

$$P_{losses} = P_{cuA} + P_{cuB} + P_{cu2} + P_i \quad (17)$$

where ;

$$P_{cuA} = I_A^2\ R_A',\ P_{cuB} = I_B^2 R_B \quad \text{, and} \quad (18)$$

$$P_{cu2} = 2\left((I`_{2f})^2 R`_{2f} + (I`_{2b})^2 R`_{2b}\right)$$

The $I`_{2f}$ and $I`_{2b}$ are obtained from the equivalent circuit as,

$$I`_{2f} = (Z_{2f} / ( R`_{2f} / s + j X`_{2f}))\ .I_{af} \text{, and}$$

$$I`_{2b} = (\gamma`(Z_{2b} / (R`_{2b} / (2-s) + j X`_{2b}))\ .\ I_{af}$$

From the above equations the efficiency and output torque can be obtained

while the input power can be obtained from:

$$Pi/p = V\, I \cos(\varphi) \quad (19)$$

3.Motor Behavior

From equations (1-19) , the motor characteristics are obtained as shown in Figs. (3-10). Figure. (3) shows the variation of output torque versus speed at rated capacitance of 18μF and with a constant ratio of voltage to frequency V/F in which frequency is decreased from 50 c/s to 15 c/s in a 5 c/s decrement. It shows that the maximum torque is decreased with decreasing of frequency . This Leeds to decrease the full load torque , due to the decreasing of auxiliary winding currents as a result of increasing auxiliary capacitor reactance at low frequency. Figures (4 - a,b,c) show the variations of the auxiliary winding , main winding and supply currents versus speed . These shows that the currents are decreased at low speed which tend to decreasing of the torque's as shown in Fig. (3) .

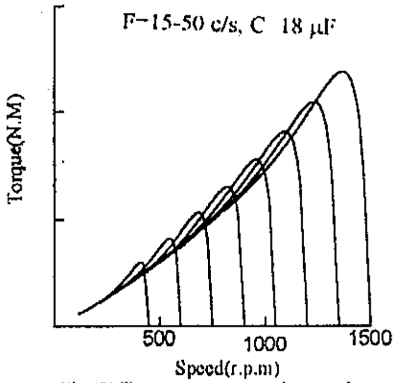

Fig.(3) Torque versus speed at rated capacitance value and constant V/F

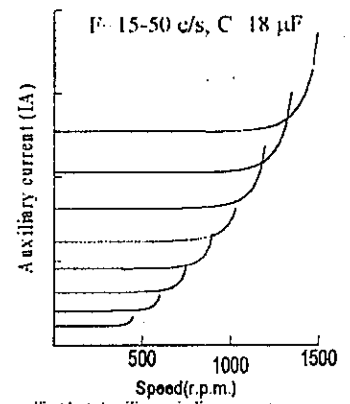

Fig.(4-a) Auxiliary winding current versus speed at rated capacitance value and constant V/F

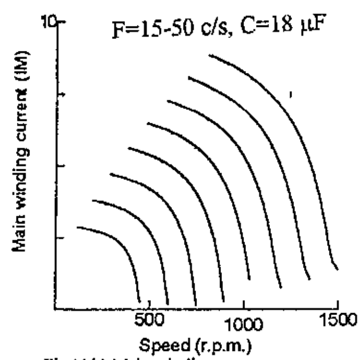

Fig.(4-b) Main winding current versus speed at rated capacitance value and constant V/F

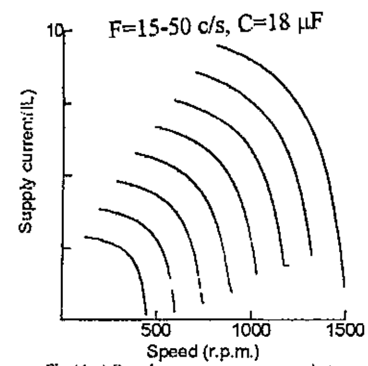

Fig.(4-c) Supply current versus speed at rated capacitance values and constant V/F

To improve the characteristics of the motor at low frequencies (to give a constant values of output torque , high efficiency and power factor) is achieved either by increasing the capacitor-run value which decrease the capacitor reactance or by increasing the constant value of V/F which conserve the field intensity value or both. By the trial and error method , a compromise choice between the suitable value of C and V/F value to give a maximum torque and full load torque is constrained by rated motor current at low frequency .

Figures (5) and (6) show the variation of the capacitor - run values and variation of V/F versus frequency. These two curves are used for obtaining the running motor characteristics as shown in Figs. (7-10) .

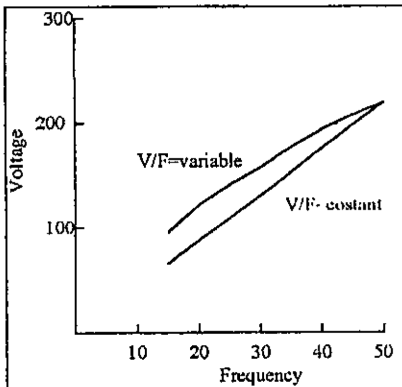

Fig.(5) Voltage versus frequency

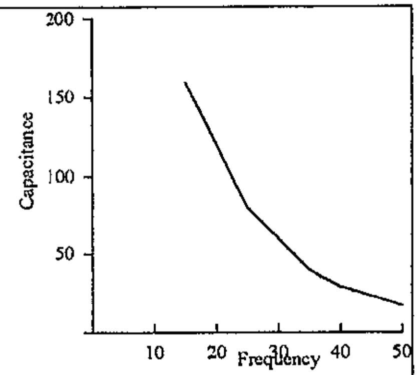

Fig.(6) Capacitance versus frequency

Figure (7) shows the variations of the out-put torque's versus speed at variable frequency. Increasing the capacitor-run values at low-frequencies and voltage supply above V/F constant the chosen values of capacitance and voltage are related to Figs.(5,6). It shows that the full load torque is approximately constant at rated value 50c/s and 0.05 slip .

Figures (8-a,b.c) show the variations of supply , main winding , auxiliary winding currents versus speed at variable frequency at the same conditions of the torque respectively . It show that the currents illustrated by a load line are approximately equal the rated value .

The variation of efficiency versus speed shown in Fig. (9) illustrates that efficiency is decreased slowly than that at full load . Also the variation of power factor versus speed shown in Fig.(10), it shows that the power factor is increased reaching the unity power factor at low frequency.

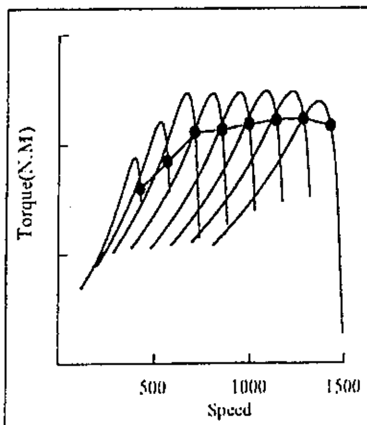

Fig.(7) Torque versus speed at variable frequency

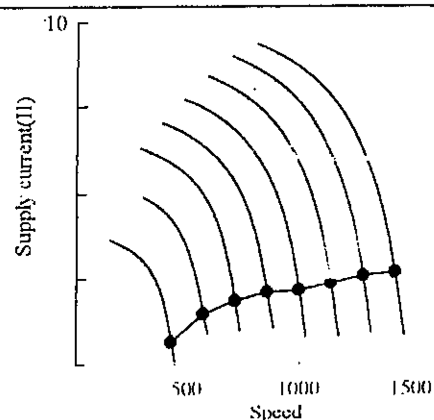

Fig.(8-a) Supply current versus speed at variable frequency

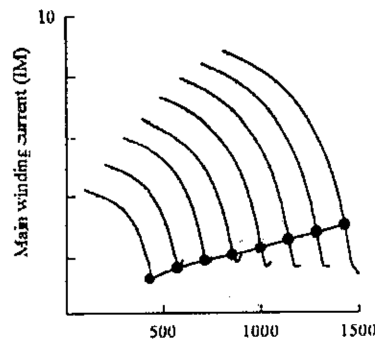

Fig.(8-b) Main winding curmt versus speed at variable frequency

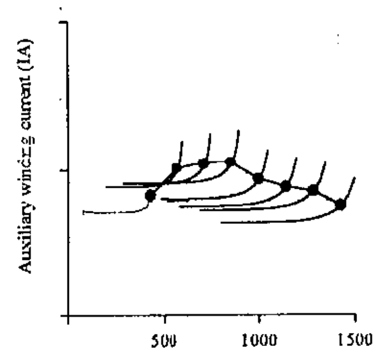

Fig.(8-c) Auxiliary winding current versus speed at variable frequency

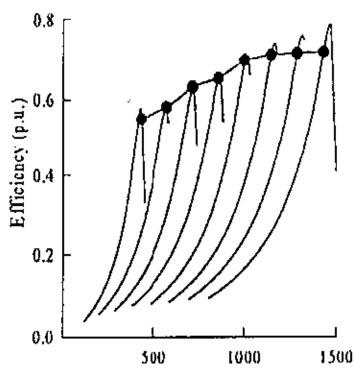

Fig.(9) Efficiency versus speed at variable frequency

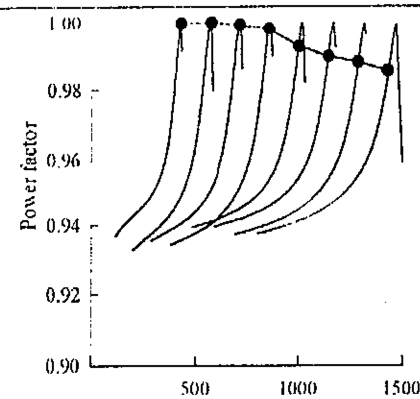

Fig.(10) Power factor versus speed at variable frequency

4. EXPERIMENTAL RESULTS

The 0.5 hp capacitor - run single - phase induction motor was tested at low - frequency from a variable frequency supply . The rotational , core, and other stray losses were carefully determined so that they could be combined with actual mechanical torque for comparisons to the electromagnetic torque data from the simulations . The test results of the motor compared with theoretical results at variable frequency and 0.05 slip are shown in table {1}, it shows a good agreement with each other.

Table {1}
Experimental and theoretical results at variable frequency and 0.05 slip

F	v	c	Torque		I(supply)		I (aux.)		I (main)		Eff.		P.F.	
			Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.	Exp.	Th.
50	220	18	4.1	4.327	4.35	4.167	1.55	1.500	3.15	3.012	0.68	0.714	0.935	0.985
45	207.9	24	4.2	4.454	4.3	4.091	1.8	1.703	2.9	2.780	0.67	0.711	0.938	0.988
40	193.6	30	4.2	4.432	4.1	3.906	1.85	1.760	2.7	2.555	0.67	0.706	0.939	0.989
35	177.1	40	4.15	4.365	3.9	3.739	1.9	1.869	2.4	2.308	0.66	0.693	0.94	0.992
30	158.4	60	4.05	4.261	3.8	3.690	2.2	2.111	2.2	2.088	0.659	0.649	0.948	0.998
25	143	80	4.0	4.218	3.65	3.482	2.1	2.093	1.9	1.896	0.597	0.629	0.949	0.999
20	118.8	120	3.5	3.702	3.3	3.173	2.1	2.030	1.7	1.637	0.55	0.58	0.95	0.999
15	95.7	160	3.05	3.195	2.6	2.519	1.7	1.647	1.3	1.251	0.52	0.55	0.96	0.999

5. CONCLUSIONS

In this paper an extensive study has been carried out in order to investigate the capability of a capacitor-run single-phase induction motor to be operated at low frequency with a full load torque. This study presented the chosen values of capacitance and voltage that had given a full load torque at low - frequency and improved power factor. Good agreement exists between the measured and simulated data. To overcome the effect of stator resistances at low frequencies, the voltage should be increased than the constantvalues of V/F.

6. REFERENCES

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عنـــوان البـــــحث

أداء المحرك التأثيري أحادى الوجه ذو مكثف البدء يعمل على منبع متغير التردد

د/ أحمـــد حســـانين مرســـى عبد المنعم المزين
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ملخـــص البحـــث

يعتبر المحرك التأثيري أحادى الوجه من المحركات شائعة الاستخدام في الأحمال الخفيفة وآلتي تبداء عموما مع وجود حمل وذلك مثل الأدوات المنزلية وطلمبات رفع المياه.......الخ. حيث تختلف المحركات أحادية الوجه عن المحركات ثلاثية الاوجة فى انه ينتج بداخلها مجال مغناطيسى نبضى بدلا من المجال المغناطيسى الدوار المتولد فى المحركات الثلاثية الاوجة. ولذلك وضعت مكثفات فى حالات البدء أو فى حالات التشغيل أو فى كليهما فى ملفات مساعدة وذلك لجعل هذه المحركات تعمل كمحركات ثنائية الأوجه متولدا بداخلها مجال مغناطيسى دوار له اتجاه دوران ثابت. فى هذا البحث أجريت دراسة نظرية مستفيضة على المحرك التأثيري أحادى الوجه ذو مكثف التشغيل يعمل على منبع متغير التردد وذلك للحصول على عزم الحمل الكامل عند الترددات المنخفضة مع المحافظة على قيم التيارات فى الملفات المختلفة عند القيم المقننة, وذلك أدى الى استنباط منحنيات لقيم المكثفات وكذلك الجهود اللازمة لتعويض الزيادة فى ممانعة الملف المساعد نتيجة لانخفاض التردد والزيادة فى هبوط الجهد فى مقاومة ملفى العضو الثابت. أجريت التجارب المعملية على المحرك عند الترددات المختلفة مع قيم المكثفات والجهود المناظرة للترددات وقد وجد تقارب كبير بين النتائج العملية والنظرية .