VARIABLE VOLTAGE - FREQUENCY CONTROL OF A SINGLE PHASE INDUCTION MOTOR DRIVEN BY SHEPWM INVERTER

Ali Hussein Abdul-Jabbar
Al-Mustansiriyah University
College of Engineering
Electrical Engineering Department

ABSTRACT

Single phase AC induction motors are one of the widely used motors in the world, yet relatively little woke has been done in the applications of power electronic converter to these motors to achieve variable speed operation. When variable speed is required, it is usually achieved either by using auto transformer or by switching between two or more fixed winding configurations. The motor is analyzed as an unbalanced two phase system to determine the torque that can be expected under variable frequency control.

The performance of capacitor-run single phase induction motor used in SHEPWM adjustable speed drives in the steady-state is investigated. The supply voltage-frequency law for the motor is selected in such a way as to insure a correct operation of the motor over the whole speed range.

السيطرة على مسوق محرك حثي أحادي الطور مغذى من عاكس يعمل بتقنية SHPWM باستخدام طريقة التردد و الجهد المتغيرين

الخلاصة

ألمحرك ألحثي أحادي الطور هو أحد المحركات الأكثر شيوعا في العالم. حتى الآن توجد أعمال قليلة نسبياً تم إنجازها حول تطبيقات محولات الكترونيات القدرة التي تغذي هذه المحركات لتحقيق عملية تغيير السرعة. عندما يكون المطلوب تغيير السرعة فأن ذلك يتم عادة أما باستخدام المحولة الذاتية أو بواسطة التحويل بين أثنين أو أكثر من التشكيلات الثابتة للملف. تم تحليل المحرك كمنظومة ثنائية الطور غير متزنة لحساب العزم الذي يمكن توقعه تحت سيطرة التردد المتغير.

تم التحقق من أداء المحرك ألحثي أحادي الطور ذو المتسعة الدائمية وعند الحالة المستقرة والمستخدم في مسوقات السرعة القابلة للتنظيم والتي تعمل بتضمين عرض النبضة بحذف التوافقيات الانتقائي. يتم اختيار قانون الفولتية- تردد للمحرك بطريقة ما ليضمن الاشتغال الصحيح للمحرك عبر المدى الكامل للسرعة.

INTRODUCTION

Single phase induction motors are one of the most widely used types of low power motors in the world, especially for domestic or commercial applications where a three-phase power supply is not available. These are inherently single and comparatively constant speed machines. In the case of applications requiring variable speed operation, a supply with variable frequency and voltage is needed. Variable frequency-voltage supplies can be available in the form of inverter [M.Ozdemir 1999, D.G.Holmes 1993].

However, speed modulation of a single-phase motor is usually achieved either by some electrical means, such as reducing supply voltage by auto-transformer, or by switching windings to change the number of motor poles for different operating condition as required.

Up to date only a few alternatives to variable frequency converters have been reported used to achieve variable speed single phase motor operation. One of these approaches uses a single phase converter to control the phase angle of the voltage applied to the motor auxiliary winding, while the main winding remains connected to the AC supply [E.R. Collins 1988]. Other work have proposed a continuous variable speed control of single phase motor, using a standard three phase voltage source inverter [M.Ozdemir 1999].

Voltage control is a simple method for changing the speed of capacitor-run motor shown in Fig.1, but it allows only a very limited speed range to be obtained. Nowadays the frequency control acts as an interesting alternative to voltage control [P.C.Sen 1997]. The capacitor-run motor seems to be one of the most appropriate actuators for variable speed drives [Twin City 2000]. In this paper frequency control in a range below the rated frequency is investigated. The current study provides a performance analysis of capacitor-run single phase induction motor fed from variable frequency variable voltage supply involved steady-state equivalent circuit of the machine.

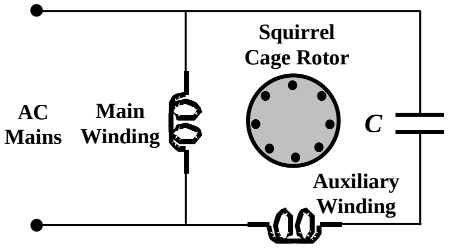


Fig. 1: Capacitor-run Single Phase Induction Motor

SINGLE PHASE INDUCTION MOTOR MODEL

Single winding single phase motors are most effectively analyzed using the Double Revolving Field Theory, which splits the oscillating single magnetic field produced by a current flowing through the winding into two contra-rotating magnetic fields, each of which can be analyzed using normal three phase rotating field theory. The equivalent circuit for a single winding motor under these conditions is shown in Fig.2 [D.G.Holmes 1993].

The rotor impedance referred to the stator has been separated into two halves, with one half influenced by the forward rotating field and the other influenced by the backward rotating field.

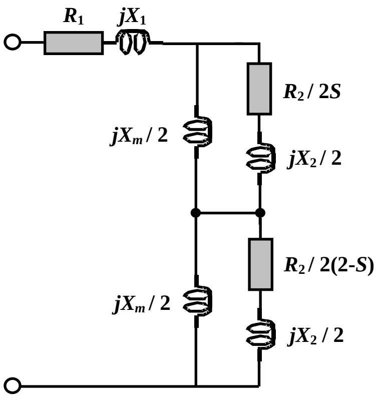


Fig. 2: Equivalent Circuit of Single Winding Single Phase Induction Motor

For a two winding motor, with the windings arranged in space quadrature on the stator, this analysis can be extended to develop a similar single phase equivalent circuit for each winding, with an additional speed voltage in each winding representing the voltage induced in the winding from the other winding's flux. The total equivalent circuit for this arrangement is shown in Fig.3, for two unbalanced windings with a turns ratio of "1:a_s" between the main and the auxiliary winding. Note that the parallel branches for each winding equivalent circuit have been converted into equivalent series impedances.

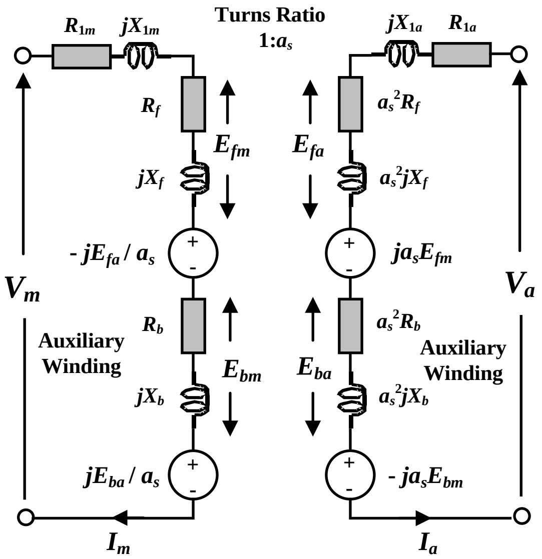


Fig. 3: Equivalent Circuit of Unbalanced Two Winding Induction Motor

The impedances for this equivalent circuit are defined as:
R_{1m}, X_{1m}= Main winding resistance and leakage reactance.
R_{1a}, X_{1a} = Auxiliary winding resistance and leakage reactance.
X_m = Main winding magnetizing reactance.
$a_s^2X_m$ = Auxiliary winding magnetizing reactance.
R_2, X_2 = Rotor resistance and leakage reactance referred to main winding.
$a_s^2R_2$, $a_s^2X_2$ = Rotor resistance and leakage reactance referred to auxiliary winding.
$1:a_s$ = Turns ratio between main and auxiliary winding.
No attempt has been made to include a core loss representation into the model.

Using these definitions, the series equivalent forward and backward impedances shown in Fig. 3 become:

$$R_f = \frac{X_m{}^2 R_2 / S}{(R_2/S)^2 + (X_2 + X_m)^2} \tag{1}$$

$$X_f = \frac{X_m\left[(R_2/S)^2 + X_2(X_2 + X_m)\right]}{(R_2/S)^2 + (X_2 + X_m)^2} \tag{2}$$

$$R_b = \frac{X_m{}^2 R_2 /(2-S)}{(R_2/(2-S))^2 + (X_2 + X_m)^2} \tag{3}$$

$$X_b = \frac{X_m\left[(R_2/(2-S))^2 + X_2(X_2 + X_m)\right]}{(R_2/(2-S))^2 + (X_2 + X_m)^2} \tag{4}$$

where S is the motor slip.
As shown in [D. G. Holmes 1993], the average motor torque developed using this model is given by:

$$T_{av} = \frac{1}{\omega_1}\begin{bmatrix} \left(I_m{}^2 + a_s{}^2 I_a{}^2\right)\left(R_f - R_b\right) \\ + 2a_s\left(I_m I_a \sin\varphi\right)\left(R_f + R_b\right) \end{bmatrix} \qquad (5)$$

, and the pulsating torque is:

$$T_{puls} = \frac{1}{\omega_1}\left\{ \begin{array}{l} \left[I_m{}^4 + (a_s I_a)^4 + 2(a_s I_m I_a)^2 \cos(2\varphi)\right] \\ *\left[(R_f - R_b)^2 + (X_f - X_b)^2\right] \end{array} \right\}^{1/2} \qquad (6)$$

where φ is the Phase angle between the main winding current I_m and auxiliary winding current I_a and ω_1 is the angular synchronous speed.

SPEED CONTROL OF INDUCTION MOTORS

There are really only two techniques by which the speed of an induction motor can be controlled. One is to vary the synchronous speed, and the other is to vary the slip of the motor for a given load. The synchronous speed (N_1) of an induction motor is given as:

$$N_1 = 60\, f_1 / P \qquad (7)$$

So only two ways in which N_1 can be varied: (i) by changing the electrical frequency (f_1) and (ii) by changing the number of poles ($2P$) on the machine. Slip control may be accomplished by varying either the rotor resistance or terminal voltage of the motor.
There are two major approaches to changing the number of poles: (i) the method of consequent poles, and (ii) multiple stator windings.
For the first method, the speeds will be in ratio of 2:1. With combining the two methods it is possible to build a four-speed induction motor only (could be accomplished for three phase induction motor only).
The speed may be controlled over limited voltage by varying line voltage. This method is sometimes used on small motors driving fans. The torque developed by the motor is proportional to the square of the applied voltage.
In the wound rotor induction motors, it is possible to change the shape of torque-speed curve by inserting extra resistances into the rotor circuit machine. The more popular speed control technique is by changing the line frequency [S.J. Chapmen 1999].

A. (*V/f*) Speed control Strategy

Nowadays the rotary-converter method is being supplanted on a wide scale by static converter methods in which performance and reliability of variable speed AC systems are improved.
If the electrical frequency applied to the stator of an induction motor is changed, the rate of rotation of its magnetic fields N_1 will change in direct proportion to the change in electric frequency, and the no-load point on the torque-speed characteristic curve will change with it. The synchronous speed of the motor at rated conditions is known as the base speed. By using variable frequency control, it is possible to adjust the speed either above or below the base speed. A properly designed variable-frequency

induction motor drive can be very flexible. It can control the speed of the motor over a range from as little as 5% of base speed up to about twice base speed. However it is important to maintain certain voltage and torque limits on the motor as the frequency is varied, to ensure safe operation.

When running at speed below the base speed of the motor, it is necessary to reduce the terminal voltage applied to the stator linearly with decreasing stator frequency. This process is called (derating). If it is not done, the steel in the core of the motor will saturate and excessive magnetization currents will flow in the machine.

The starting current drawn by an induction motor with a fixed frequency during direct-on-line start is normally about six times its rated value. This current can be reduced by reduction of supply voltage magnitude which leads to reducing the starting torque. However, when variable frequency is used it is possible to use a low starting frequency and voltage and then raise it as the motor accelerates to maintain constant air gap flux, and constant (V/f) [A. Jalil 1980].

The method of choice today for induction motor speed control is the solid-state variable-frequency induction motor drive. The output voltage and frequency control is achieved by using PWM techniques.

B. Choice of Voltage and Frequency Patterns

Some loads such as fans require little torque when starting (or running at low speeds) and have torques, which increases, as the square of the speed. Other loads might be harder to start, requiring more than the rated full-load torque of the motor just to get the load moving. This drive provides a variety of voltage-versus-frequency patterns, which can be selected by its load. Fig. 4.a shows the general-purpose pattern, and Fig.4.b shows fan torque pattern (with low starting torques) when the output voltage changes parabolically with changes in output frequency for speeds below base speed (f_1).

For any given frequency below the base frequency, the output voltage will be lower than it was with the general pattern, providing a slow, smooth start for low torque loads [S.J. Chapmen 1999] for this work the selected voltage values will increases by 10% for the low order frequency (5-15Hz) to improve the starting torque .

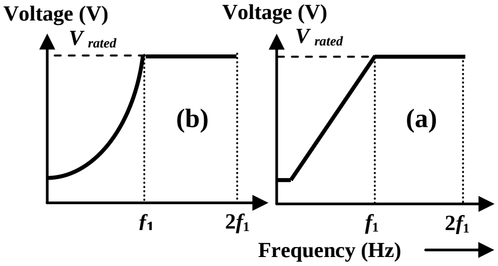


Fig. 4: Voltage versus Frequency Patterns: (a) General Purpose, (b) Fan Torque.

C. Speed Control of Capacitor-run Single Phase Induction Motor

Fractional horsepower single phase motors were estimated to constitute about 80 % of the motors used in the industrial and commercial sectors. Therefore, the intensive exists to improving the efficiency and power factor and harmonic contents of single phase motor applications [Y. Baghzouz 1988].

The capacitor-run single phase motor seems to be one of the most appropriate actuators for variable speed fractional-horse-power drives. Voltage control is a simple method for changing the capacitor-run motor speed. The supply voltage may be varied by an autotransformer, as in the past, or by semiconductor switching elements. However, voltage control of standard capacitor motors allows only a very limited speed range to be obtained.

Nowadays the development of less expensive electronic power devices makes frequency control an interesting alternative to voltage control. Recently some authors have proposed to change the speed of single phase motors using cycloconverters, or inverters. The most advantageous of this kind of control seems to be the possibility of obtaining satisfactory speed regulation with standard motors [Twin City 2000,U. Raghzouz 1988].

Adjustable speed is needed in various single phase motor drives. At speed lower than the rated value, the motor current increases considerably. The resulting heat dissipation, in addition to sufficient motor torque development, sets a lower limit to the operating speed range. It is well known that line power factor improvement and minimum current distortion can be achieved by using PWM inverters which have been successfully applied to adjustable-speed three phase induction motor drives where motor voltage and frequency are simultaneously controlled. It is feasible to apply the variable-voltage variable-frequency control strategy to a PWM inverter-fed single phase motor [Twin City 2000,U. Reghzouz 1988]. In this paper, frequency control in a range below rated frequency is investigated.

With the same number of pulses per cycle, the optimized Selective Harmonic Elimination PWM technique tends to produce currents of higher quality than do other PWM techniques [Jamal A. 2002]. In this paper, the feasibility of applying the variable-voltage variable-frequency control strategy to a HEPWM inverter-fed single-phase motor is studied.

torque-speed characteristic of a single phase motor will first be analyzed for the frequency range of interest, followed by a simulation of the drive in steady-state condition.

SIMULATION RESULTS

The operation of a single phase induction motor under the proposed variable-speed control strategy has been extensively tested in simulation using a four pole, 1275 rpm, 220V**,** 175W, capacitor-run single phase induction motor, and the applied voltage rose by 10% for the frequencies (5, 10 and 15) to improve the starting torque. The parameters of this motor are listed in the Table A.1 in the Appendix A.

Simulation of this motor was developed using the MATLAB program on a PC, using the model topology shown in Fig. 3, but with all reactance's replaced with equivalent inductance values, to allow the effects of the variable supply frequency to be investigated.

The performance of capacitor-run single phase induction motor used in adjustable speed drives is investigated by applying the optimal SHEPWM technique [Dariusz 2002] for two different values of switching angles (*sw*=3 and 7 or eliminating of the first two and six harmonics respectively). Fig. 5 shows the comparison of the motor performance at these two cases. It can be seen from the curves that the rated, starting and maximum motor currents with *sw*=7 are less than that with *sw*=3 for the most frequency range. It can be seen that decreasing of frequency causes decreasing of these currents, since the voltage decreases with frequency at the same time. It should be noted that for 5Hz; the starting and maximum torque to rated torque (T_s/Tr and T_m/Tr =9.5) with *sw*=7, while they are equal to (8.5 to 9) for *sw*=3. Therefore the torque ratios with *sw*=7 are larger than that with *sw*=3 by (11.2%) at the low frequency. So that the motor will start with higher starting torque with *sw*=7 than that with *sw*=3. From the same figure we can also see that the motor rated and maximum currents, losses, additional losses, input power, pulsating torque, and additional pulsating torque with *sw*=7 is less than that with *sw*=3.

Since the switching angles with *sw*=7 is higher than that with *sw*=3, therefore the switching losses will be higher with *sw*=7. The drive switching losses can be neglected with respect to the motor losses. As a result the overall efficiency (η) will be higher with *sw*=7 than that with *sw*=3. It can be seen from the Fig. (5) that the performance of the motor fed be SHPWM inverter with *sw*=7 is better than that with *sw*=3. In other word increasing the switching angles (or harmonics to be eliminated) in the output voltage of the inverter will improve the performance of the motor. As a result the 7-switching angles SHEPWM technique is more suitable to be used with the motor adjustable speed drive.

Table 1 illustrates the performance of the motor with different frequencies with *sw*=3 and 7 to get speed control of motor with smooth start.

Fig. 6 shows the performance curves of the proposed motor fed by 7-switching angles SHEPWM inverter adjustable speed drive. The figure shows that the maximum slip are equal to unity (standstill) at low frequency 5 Hz, and will decrease with increasing frequency, therefore the motor starts at maximum torque. In this case, the starting with frequency more than 5 Hz is suitable for speed control. As a result, the motor torques (starting and maximum) are very low at low frequencies and they increase with increasing frequency. It can be seen from the same figure that the starting and maximum to rated currents (I_s/I_r and $I_m/I_r \approx 1$) at lower frequency (5 Hz) and equal to (1.91 and 1.35 respectively) at (50 Hz). Therefore the starting current with f=5Hz, reduces by approximately (91%) of that with base frequency. Therefore the frequency 5Hz is suitable for smooth starting.

It can also be seen that the current ratios approximately (equal to 1.6) in the range of (5-15) Hz, which is more than the rated (due to voltage increasing) and that might cause heating the motor over the rated due to increases.

Studying the curves in Fig. 6 is very important for improving the performance of the proposed motor. As a result it is feasible to apply the variable-voltage-frequency control strategy to SHEPWM inverter fed single phase capacitor-run induction motor.

The mechanical and electrical characteristics of the proposed motor fed by 7-switching angles SHEPWM adjustable speed drive are shown in Fig.7. It can be seen from the mechanical characteristic, that the speed range for fixed load (Tc) will be limited to 50 Hz curve only, since this curve intersects the straight line Tc at the point Q_{50}, while the fan load line (T_L) will pass through all the operating points (>5Hz). As a result, the speed control of motors with fan load is more effective than with fixed load.

The electrical characteristic in Fig. 7 shows how the motor will be started smoothly at 5 Hz drawn 1.5A, and increases with frequency increase till it reach 2.355 at (50Hz). While the motor will drawn four to five times of its rated if starts directly with 50 Hz (220volt) main supply

At low frequency operation the torque reduced due to increasing the effect of the capacitor reactance which lead to torque reduction, increasing the applied voltage for low frequencies will cause starting torque increasing as well as the losses.

CONCLUSIONS

At speed lower than the rated speed the motor current increases considerably for constant voltage. The resulting heat dissipation, in addition to insufficient motor torque development, sets a lower limit to the operating speed.

The current study has shown that the variable-voltage variable-frequency method can be effectively applied to control the speed of a single phase induction motor through a SHEPWM inverter. Note that not only the motor performance is improved, but also the speed range is much wider.

Increasing the voltage for low frequencies is a good solution to improve the starting torque but might cause extra heating.

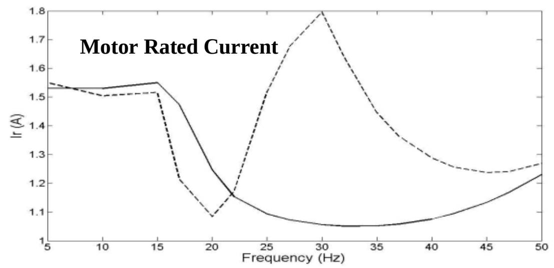
Smooth starting of the motor prevents the excessive current from occurring at starting time, which causes heat generation and may destroy the motor insulation and decrease the motor lifetime. As a result smooth starting improves the motor performance.

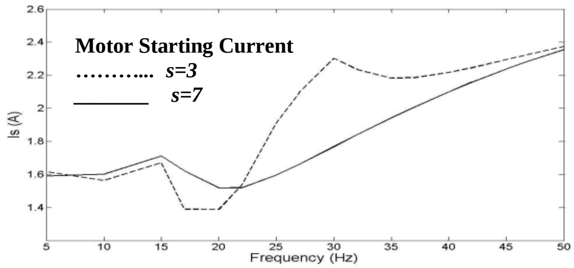
Single phase motor can only be effectively applied for adjustable-speed drives with fan-type loads for constant *(v/f)* but it can by effective for general purpose when starting torque improved.

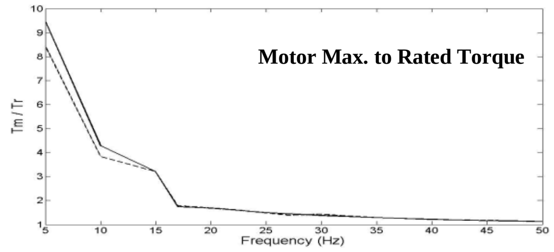
Increasing the switching in the output voltage of the inverter will improve the performance of the motor but increasing the switching losses

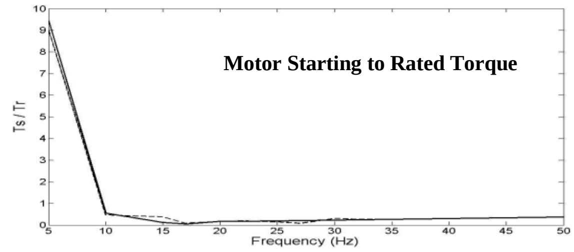
REFERENCES

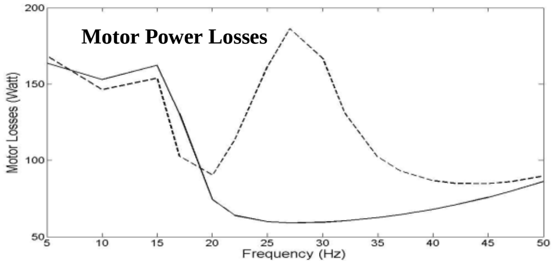
- A. Jalal. B. , 1980 **"Two-Phase Inverter Supplied Two-Phase Induction Motor"**, M.Sc. Thesis, Baghdad University.
- Dariusz Czarkowski, David V. Chudnovsky, Gregory V. Chudnovsky, and Ivan W. Selesnick, ,April 2002 "**Solving the Optimal PWM Problem for Single-Phase Inverters**," IEEE Trans. on Circuits and Sys., Vol.49, No.4, pp.465-475.
- D. G. Holmes, and A. Kotsopoulos, , October 1993 "**Variable speed control of single and two phase induction motors using a three phase voltage source inverter**," in IEEE/IAS Annual Meeting Conference Record, pp. 613-620.
- E.R. Collins Jr., H.B. Puttgen, W.E. Sayle, , 1988 "**Single Phase Induction Motor Adjustable Speed Drive: Direct Phase Angle Control of the Auxiliary Winding Supply**," 11, IEEE IAS-88, Pittsburgh, pp246-252.
- K.S. Krikor and Jamal A. Mohammed, 2002 "**PWM Strategies for Inverter-Fed Induction Motors - A Comparative Study**," University of Technology, Vo. 21, No. 11.
- M. Özdemir, S. ünter and B. Yurtseven, 1999 "**Modeling and Simulation of a Split Phase Induction Motor Fed by Single-Phase AC-AC Converter**," Inter. Journal for Eng. Modeling, Vol. 12, No. 1-4, pp. 17-23.
- P.C. Sen, 1997 "**Principles of Electric Machines and Power Electronics"**, 2nd Edition, John Wiley and Sons, Inc.
- S. J. Chapman, 1999 "**Electric Machinery Fundamental"**, 3rd Edition, McGraw-Hill, New York.
- Twin City Fan Companies, 2000 "**Speed Control for Fractional Horse Power Motors"**, Engineering Data, Ltd. ED-1000.
- U. Reggiani, C. Tassoniand G. Figalli, 1983 "**Analysis of an Inverter-Fed Single-Phase Induction Motor Drive**," IFAC Control in Power Electronic and Electric Drives, Lausanne, Switzerland.
- Y. Baghzouz, and O. T. Tan, 1988 "**PWM Inverter-fed Single-phase Induction Motor Drives**," Journal of Energy System, Vol. 8, No. 3.

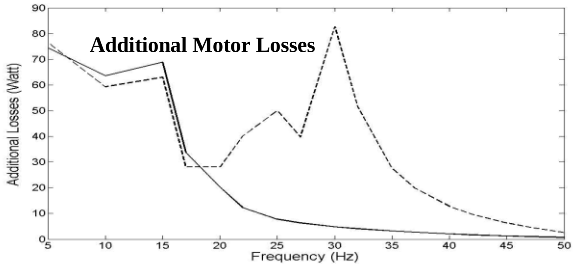

Motor Rated Current
Ir (A)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)

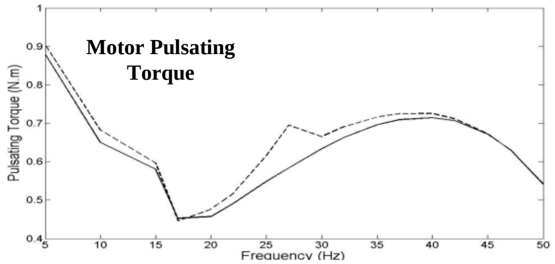

Motor Starting Current
………... s=3
_______ s=7
Is (A)
2.6
2.4
2.2
2
1.8
1.6
1.4
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)

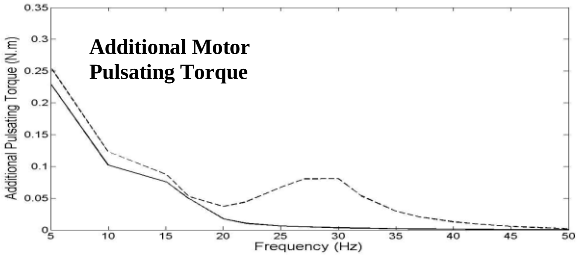

Motor Max. to Rated Torque
Tm / Tr
10
9
8
7
6
5
4
3
2
1
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)

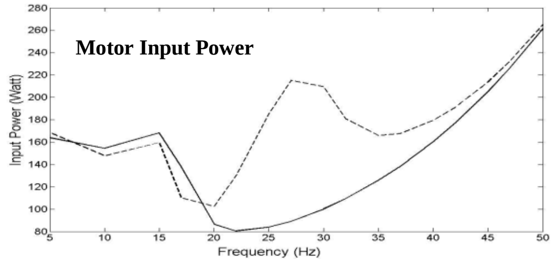

Motor Starting to Rated Torque
Ts / Tr
10
9
8
7
6
5
4
3
2
1
0
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)

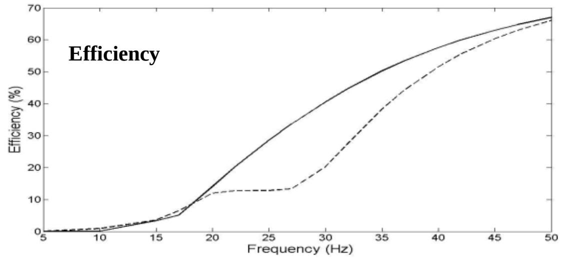

Motor Power Losses
Motor Losses (Watt)
200
150
100
50
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)

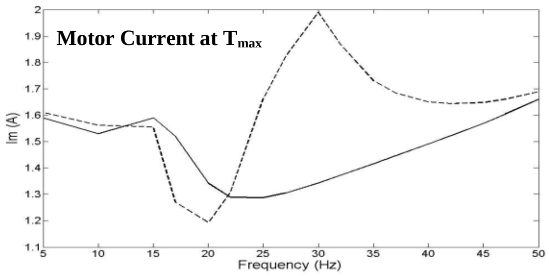

Additional Motor Losses
Additional Losses (Watt)
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)

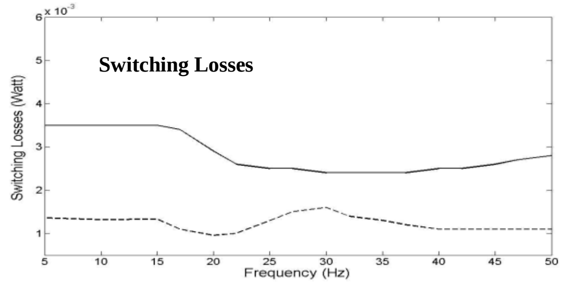

Motor Pulsating Torque
Pulsating Torque (N.m)
1
0.9
0.8
0.7
0.6
0.5
0.4
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)


Additional Motor Pulsating Torque
Additional Pulsating Torque (N.m)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)


Motor Input Power
Input Power (Watt)
280
260
240
220
200
180
160
140
120
100
80
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)


Efficiency
Efficiency (%)
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)


Motor Current at T_{max}
Im (A)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)


x 10^{-3}
Switching Losses
Switching Losses (Watt)
6
5
4
3
2
1
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)

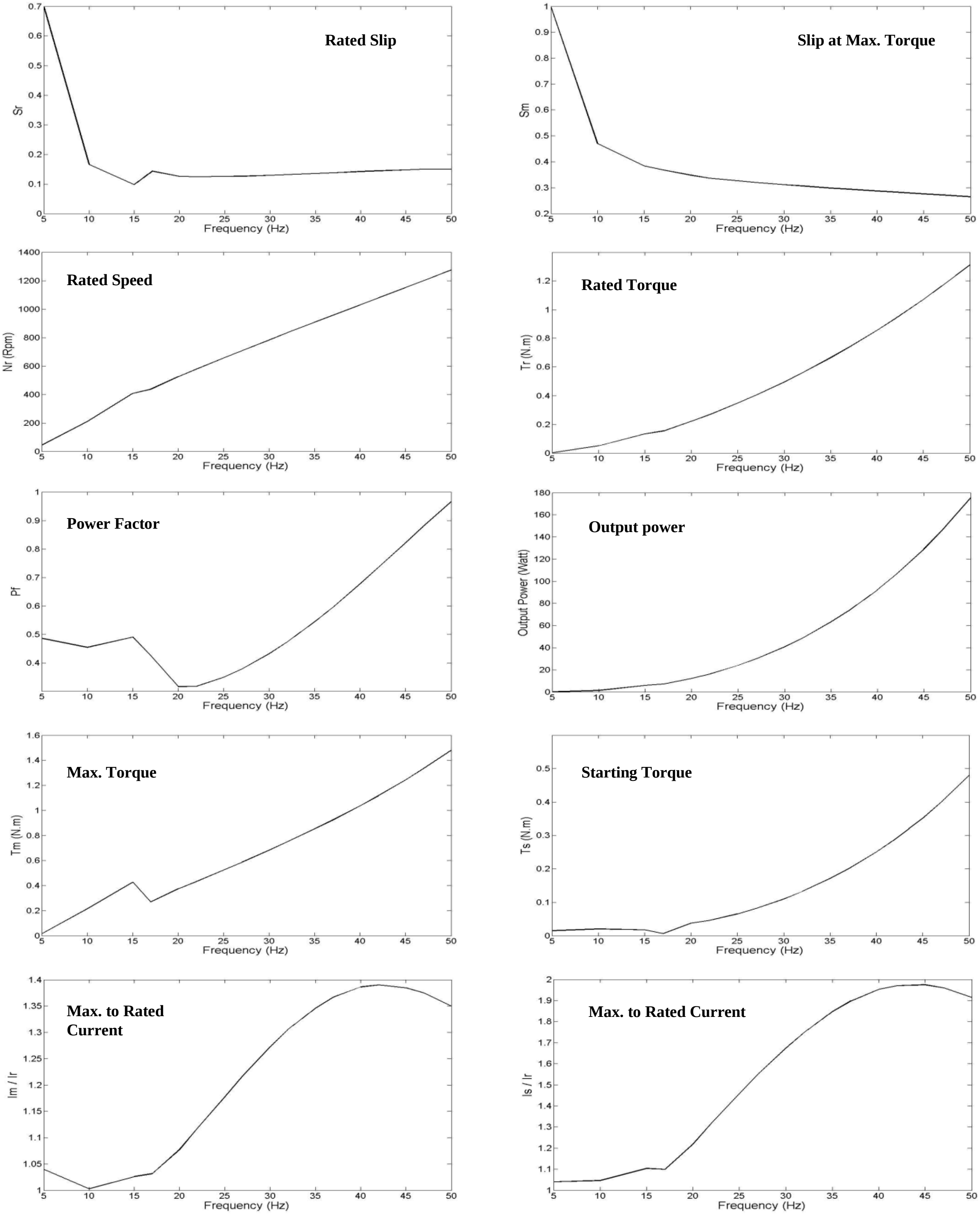


Fig. 6: the performance of the proposed motor fed by 7-Switching Angles SHEPWM Inverter Adjustable Speed Drive

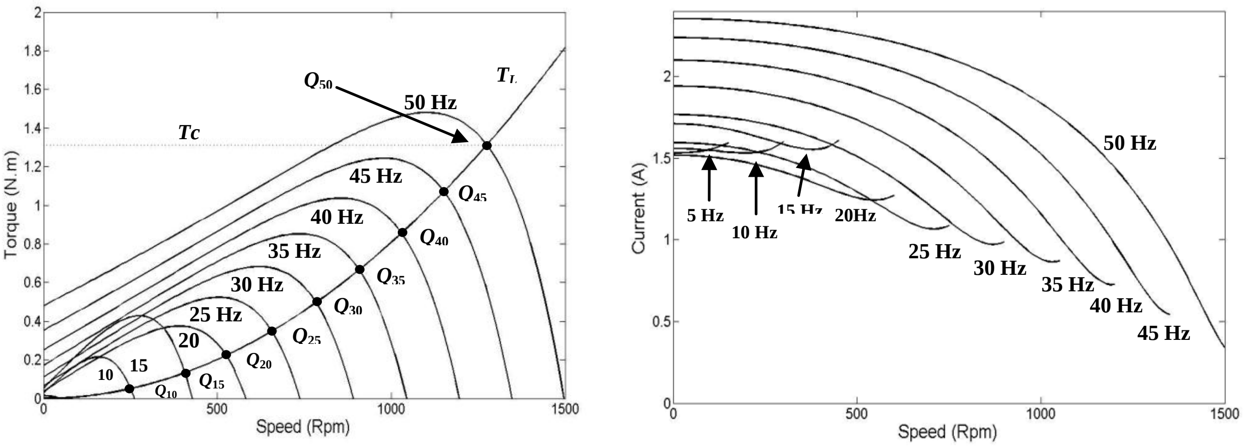


Fig. 7: Mechanical and Electrical Characteristics of the Proposed Motor Fed by 7-Sw. Angles SHEPWM Adjustable Speed Drive

Table 1: Motor Speed Control by Using Variable-Voltage, Variable-frequency Method Using SHPWM Technique

s		3						7					
***f* (Hz)**	**V_1 (V)**	***Nr* (Rpm)**	***Ir* (A)**	***Is* (A)**	***Tr* (N.m)**	***Ts* (N.m)**	**η (%)**	***Nr* (Rpm)**	***Ir* (A)**	***Is* (A)**	***Tr* (N.m)**	***Ts* (N.m)**	**η (%)**
5	24.2	45	1.55	1.56	1.66e-3	.015	4.6e-3	44	1.5	1.59	1.5e-3	.0147	2.5e-3
10	48.4	250	1.54	1.6	.056	.0215	.9	208	1.53	1.6	.05	.027	.8
15	72.6	406	1.51	1.67	.1334	.049	3.6	406	1.5	1.7	.1335	.0174	3.4
20	88	525	1.0837	1.3872	.2234	.0347	11.96	525	1.246	1.5178	.222	.0372	14.1
25	110	654	1.5185	1.9115	.3461	.0468	12.79	656	1.0932	1.5946	.3491	.065	28.62
30	132	796	1.7963	2.3013	.5095	.1506	20.29	784	1.0554	1.7666	.4953	.1098	40.59
35	154	910	1.4454	2.1826	.6681	.1771	38.39	908	1.0514	1.9407	.6642	.1709	50.25
40	176	1030	1.287	2.2156	.8574	.2519	51.57	1030	1.0751	2.0994	.8548	.2505	57.61
45	198	1152	1.2371	2.2933	1.0694	.3523	60.35	1151	1.1332	2.2374	1.0709	.352	63
50	220	1275	1.2692	2.3747	1.3122	.48	66.13	1275	1.2299	2.3539	1.312	.4799	67.04

Appendix (A)

Table A. 1: Parameters and Specifications of the Proposed Motor

Turn ratio	a_s	1.066	
Number of pole pair	P	2	
Main winding resistance	R_{1m}	33.5	Ω
Main winding leakage reactance	X_{1m}	27	Ω
Auxiliary winding resistance	R_{1a}	34.5	Ω
Auxiliary winding leakage reactance	X_{1a}	28	Ω
Rotor resistance	R_2	20	Ω
Rotor leakage reactance	X_2	12.5	Ω
Magnetization reactance	X_m	173	Ω
Rated supply voltage	V_1	220	V
Rated current	I	1.215	A
Total Power losses	ΣP	85	W
Output power	P_2	175	W
Efficiency	η	67.38	%
Power factor	P_f	0.9726	
Rated speed	N_r	1275	Rpm
Capacitance	C	6	μF