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Comparative Analysis of Steady State Characteristics of Three-Phase Induction Motor under different Speed Control Scheme

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ABSTRACT: Induction motors are the most widely used electrical motors due to their reliability, low cost and robustness. However, induction motors is a constant speed machine; hence it speed control is difficult. Electric drive system is increasingly required to meet the higher performance and reliability requirement of motors used in industrial applications. This work presents different speed controlmethod for three-phase induction motor The steady state equation were written directly from the dynamic equations of the motor based on Parks two-axis techniques. The equations were validated in MATLAB. Amongs the selected speed control methods, the constant voltage frequency (v/f) ratio scheme with peripherial intergral (PI) controller gave a competitive advantage over others. In this method of constant v/f ratio, by use of rectifier and pulse width modulation (PWM) inverter, the supply voltage as well as the supply frequency is varied such that the voltage and frequency ratio of the motor remains constant and the flux remains constant too. With reference speed of 1500 rpm at diiferent load, results shows that the maximum torque of the motor remains unchanged at different operating zone for various speeds and given load, the maximul torque being 2.2 Nm at steady state opration. The work was done using a three-phase, 4-pole 50Hz, 155 volts induction motor.

KEYWORDS: Steady-state characteristics, three-phase induction motor, speed control, maximum torque.

1. INTRODUCTION

The presence of three-phase induction motor is mainly seen in theinductries for the purpose of mechanical loads. This is because of the streght of induction motors compared to their cournterparts likes synchronous motor and direct current motors. This streght is dissipated in the squirrel rotor type induction motor which has toughness and minimal expense. One of the problems of induction motors is that it operates on a constant speed mode. It is difficult to vary the speed of the motor since its does not have some features like field windings where the current can be altered and hence, the speed is varied. So, under light load, the motor power factor is lagging; and under heavy load, the motor runs sluggishly (Naveed, 2012). Interestingly, the utilization of three-phase induction motors will keep on expanding because the machines are rocky in development, which gives them an intrinsically high dependability and strength,; and tey are cheap. The analysis of three-phase induction motors required a sound knowledge of their behavior and principal characteristics. From the electrical machine point of view, it is necessary to consider the relationship between the electromagnetic torque and speed, obtained an equivalent circuit of the machine representing the operations.

It is reported that different speed control measures have been proposed. These include the pole pair changing method, variable stator voltage method variable stator and rotor resistance method, both the constant voltage frequency ratio approach and the adjustable speed method. The drawback of this speed control approach for pole pair change is that it is used in low performance drives that typically require operation at two distinctly different operating speed (say, a washing machine; spinning is done at high speed, while normal washing cycle takes place at low speed) but where control accuracy is not an ineffective (Aspalli, et al 2014). Again, the universality of this approach is limited to situations where two distinct speed values, rather than constant speed variation, are required. Control the speed by pole pair changing necessitates a specially wound rotor and is typically discovered by mechanically reconnecting the stator from one pole couple number to the other (Aspalli et al 2014). The variable voltage method on its own is the simplest and least expensive for changing the stator voltage. This application is only suitable in drives that run for prolonged periods of time with very light loads. This is also replica for the variable frequency method because when frequency is varied, the rms value of the supply voltage also varies (Aspalli et al 2010). For variable stator and rotor resistance, it is revealed that increase in stator or rotor resistance can cause the motor to develop more jerks on startup, change the shape of the run-up speed and torque (Obuah & Inyenemi, 2018). For constant voltage frequency ratio, a wide speed control range with an induction machine can be realized only as the stator frequency is made constant with the supply voltage keeping the flux constant. It has been realized that the constant voltage frequency ratio is the most efficient method, however, this method is ineffective when it comes to accuracy (Aspalli et al 2014). A performance boost plan using a constant voltage frequency ratio (v/f) technique integrated with peripheral integral (PI) controller. It is believed that by making the voltage and frequency of the motor constant, a smoother and wider range of speed control can be covered. This can be implemented with pulse width modulation (PWM) inverter drive. The drive supplies variable voltage and frequency with the aid of a (PWM) technique and a PI controller.

Present day patterns and improvement of speed control techniques for the three-phase induction motor have likewise cultivate the expanded in the interest of induction motors in electrical drives broadly. (Aspalli et al 2010; Vabuderan et al, 2015, Zoheir, et al, 2016). This involves the use of search control methodss or artificial intelligence (AI) tools such as the artificial neural network (ANN), Nature Inspired Algorithms (NIA), and fuzzy logic. Fast convergence can be accomplished by these controllers. Nature Inspired Algorithms (NIA) are somewhat a more current expansion to class of population based stochastic search procedures based with respect to self-organizing collective processes in nature and human artifacts.

Marungsri et al, (2006) utilized artificial neural network (ANN) to improve efficiency of a three-phase induction motor. Complex loss model in d-q frame of the motor, including magnetic and warm deviations of its parameters is utilized to estimate losses. In light of this model, the neural network is trained to estimate the optimal rotor torque, speed and rotor resistance. They utilized the Levenberg-Marquardt learning algorithm; and the neural network was prepared with a disconnected plan. The neural controller comprises of three layers, three neurons in the input layer and the output layer is the current flux reference. Contribution of the proposed controller comprises of electromagnetic force, rotor resistor and speed of the motor.

Scarcely any different authors contrast the different flux optimization algorithm which further develops effectiveness at steady state in a vector-controlled induction motor drive. Yamazaki, (2012) designed a controller to create signal voltage and frequency references all the while. This strategy takes into account control of both the speed and effectiveness. Priya et al (2018) proposed a neuro-controller which changes the slip angular frequency adaptively of induction motor, for minimal loss activity in light of the deliberate input power. A Neuro-Fuzzy base on Line Efficiency Optimization is proposed. Mohscn et al, (2018) have proposed search in base on the "Rosenbrock" strategy, which decides the flux level that outcome in the base input power. When this ideal motion level has been utilized, this data is used to refresh the standard base of a fuzzy controller that assumes the part of a verifiable numerical model of the framework. At first, for any load condition, the standard base yields the rated flux. As the ideal focuses related with the standard working circumstances (given by the necessary rates and load torgue) are recognized by the search control, the standard base is continuously refreshed to such an extent that the fuzzy controller figures out how to display the ideal working circumstances for the whole force speed plane. As the machine parameters are dependent upon future developments during activity, the search control is kept dynamic to follow conceivable minor deviation of the ideal point, in this manner guaranteeing genuine ideal effectiveness activity.

Since power electronic frameworks and drives have complex non-direct construction with parameter vulnerability, fuzzy logic is very reasonable for power devices and motion control. Some reseachers such as Qu, (2012), Zoheir et al (2016), Akpama et al, (2015) used fuzzy logic for the sped control of induction motor. Qu, (2012) forinstance examined the fuzzy logic-based speed control of indirect field oriented controlled twofold star induction motor connected parallel with a single six-phase inverter supply. The paper presents a speed control of two double star induction motors working in parallel configuration with direct control utilizing a fuzzy logic controller with six-phase PMW based inverter fed from a DC source. Simulation was utilized to study performance of the proposed technique under load unsettling influences. The speed reaction with two control is thought about and its outcomes is introduced and analyzed.

Zoheir et al, (2016) on ther other hand, utilized fuzzy logic to decrement flux up to the drives settled down minimum input power. However, the torgue or force order changes, the efficiency optimization utilizing fuzzy deserted and the rated flux was established to get the best transient presentation. Feed forward torgue compensator used to decrease torque pulsation. Akpama et al, (2015) figured out that when the drive framework is in a steady state condition, the effectiveness improvement is empowered and the fuzzy search controller starts to search for the optimal flux. At the point when the load torgue or the command speed unexpectedly changes, the related flux operation is laid out. The low frequency pulsation torgue because of decrementation of rotor flux is compensated in a feed forward way.

Bambang, (2017) in his work proposed one step change of voltage, independent of load change. Be that as it may, they have proposed keeping away from too large decrease in voltage since it will bring about large slip which will lead to poor efficiency, high rotor heating and in any event, pulling out and motoring slowing down. Kouki et al, (2017) have proposed the search controller in the scalar control model by adaptively getting the stator voltage per hertz proportion utilize fuzzy logic controller. Contribution of the fluffy rationale regulator is the difference in input power and volt per hertz proportion. The result is the new difference in volt per hertz proportion.

It is clear that most of the techniques for power electronics and motion control of three-phase machine mentioned from existing literature such as the AI and Fuzzy logic are giving a satisfactory result for machine optimization and control. However, they are complex and sophisticated (Tan and Huo, 2015). Hence, a simpler approach which is the use of voltage frequency ratio PMW drive and PI is presented for the sake of analysis (Levi et al, 2006), (Fitzgerald et al 2002), Garcia et al, 1994). It is believed that this will still achieve a desirable result in an easier way.

2. METHOD

The work shall include simulation or validation of three-phase induction motor based on Park's d-q techniques. Simulation and validation are conducted using MATLAB software for controller design and implemented of the PI, and for testing of the controller to verify the correctness of the models. In this paper the following simplifying assumptions have been made: Core losses, Eddy current and hysteresis effects are negligible.

In a steady state operation, the derivative terms in the voltage equation are made zero (Krause and Thomas, 1965), (Krause et al, 2013), Yiqi and Ali, 2017). So, from equation (3.9) through (3.12), the steady state voltage equations of the machine are expressed as:

$$V_{qs} = \omega_r \lambda_{qs} + i_{qs} r_s \quad (1)$$

$$V_{ds} = \omega_r \lambda_{ds} - i_{ds} r_s \quad (2)$$

$$V_{qr} = (\omega_s - \omega_r)\lambda_{qr} - i_{qr} r_r \quad (3)$$

$$V_{dr} = (\omega_s - \omega_r)\lambda_{dr} + i_{dr} r_r \quad (4)$$

where

$$\begin{aligned} \lambda_{qs} &= (L_{ls} + L_m) i_{qs} + L_m i'_{qr} \\ &= L_{ls} i_{qs} + L_m i_{qs} + L_m i'_{qs} \\ &= L_{ls} i_{qs} + L_m (i_{qs} + i'_{qr}) \end{aligned} \quad (5)$$

$$\lambda_{ds} = L_{ls} i_{ds} + L_m \left(i_{ds} + i'_{dr}\right) \quad (6)$$

$$\begin{aligned} \lambda'_{qr} &= L_m i_{qs} + (L'_{lr} + L_m) i'_{qr} \\ &= L_m i_{qs} + L'_{lr}\, i'_{qr} + L_m i'_{qr} \\ &= L'_{lr}\, i'_{qr} + (i_{qs} + i'_{qr}) L_m \end{aligned} \quad (7)$$

$$\lambda'_{dr} = L_{ls} i'_{dr} + L_m \left(i_{ds} + i'_{dr}\right) \quad (8)$$

Now, treating only the q-axis stator voltage and substituting (5) into equation (1) yields:

$$\begin{aligned} V_{qs} &= r_s i_{qs} + j\omega_s \left[L_{ls} + L_m (i_{qs} + i'_{qr})\right] \\ &= r_s i_{qs} + j\omega_s L_{ls} + j\omega_s L_m (i_{qs} + i'_{qr}) \\ &= r_s i_{qs} + jX_{ls} i_{qs} + jX_m (i_{qs} + i'_{qr}) \end{aligned} \quad (9)$$

Also, treating only the q-axis rotor voltage and substituting (7) into equation (3) yields:

Also

$$\begin{aligned} V_{dr} &= r'_r\, i'_{qr} + js\lambda'_{qr}\,, \\ &= r_r' i'_{qr} + js\left[L_{qr}' + L_m (i_{qs} + i'_{qr})\right] \\ &= r_r' i'_{qr} + jsX_{lr} i'_{qr} + jsX_m (i_{qs} + i'_{qr}) \end{aligned} \quad (10)$$

where s is the slip.

If the q –axis is aligned with 'a' phase of the machine such that

$$V_{qs} = V_{as};\, i_{qs} = i_{as};\, V'_{qr} = V'_{ar} = V'_{ar};\, i'_{qr} = i'_{ar}$$

equation (9) becomes

$$V_{as} = r_s i_{as} + jX_{ls} i_{as} + jx_m (i_{as} + i'_{ar}) \quad (11)$$

while equation (10) becomes

$$V'_{ar} = r'_r\, i'_{ar} + jsX'_{lr}\, i_{as} + jsX_m (i'_{ar} + i_{as}) \quad (12)$$

In (12), dividing *by s, we have*

$$\frac{V_{ar}}{s} = \frac{r'_r}{s} i_{ar} + jX'_{ir}\, i_{as} + jX_m (i_{as} + i'_{ar}) \quad (13)$$

The per-phase steady state equivalent circuit of the three-phase induction motor can be seen in Figure 1.

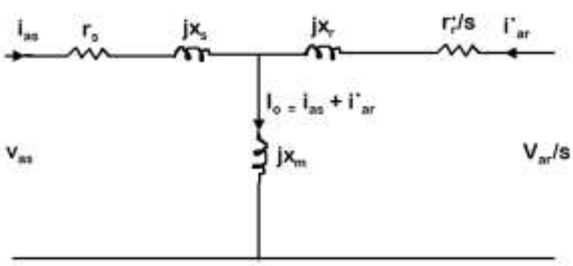

Figure 1. Per phase equivalent circuit of an induction motor

Using the per-phase equivalent circuit of the induction motor in Figure 1, if the stator power loss is given as $P_s = I_s^2 r_s$ and the rotor loss is expressed as $P_r = (I_r')^2 r_r'$; and they are neglected, the rotor current can be expressed as:

$$I_{ar} = \frac{V_{as}}{\sqrt{\left(r_s + \frac{r_r}{s}\right)^2 + j\left(X_s + X'_r\right)^2}} \quad (14)$$

Relating that to the stator input power; the air gap power can be given as:

$$P_{ag} = 3\left|I_{ar}\right|^2 \frac{r'_r}{s} \quad (15)$$

Substituting the value I_{ar} into the above equation, we have

$$P_{ag} = \frac{3V^2_{as}}{\sqrt{\left(r_s + \frac{r_r}{s}\right)^2 + j\left(X_s + X'_r\right)^2}} * \frac{r'_r}{s} \quad (16)$$

Mechanical torque develop is $T_m = \frac{P_{ag}}{\omega_s}$ (17)

Now, by substituting the value of P_{ag} into (3.38)

$$T_m = \frac{3}{\omega_s} \frac{V^2_{as}}{\sqrt{\left(r_s + \frac{r_r}{s}\right)^2 + j\left(X_s + X'_r\right)^2}} * \frac{r'_r}{s} \quad (18)$$

If we differentiate T_m with respect to s and equating to zero, the slip for maximum torque can be given as

$$s_{\max} = \pm \frac{r_r}{\sqrt{\left(r_s\right)^2 + j\left(X_s + X'_r\right)^2}} \quad (19)$$

Substituting (19) into (18) gives the value of maximum torque, thus

$$T_{\max} = 2\omega_s \frac{V^2_{as}}{\sqrt{\left(r_s\right)^2 + j\left(X_s + X'_r\right)^2} \pm r_s} \quad (20)$$

where

r_s is the stator resistance, r_r is the rotor winding resistance i_{qs} is the stator current in the q-axis, i_{ds} is the stator current in the d-axis, L_{qs} is the stator inductance in the q-axis, L_{ds} is the rotor inductance in the d-axis, i'_{qr} is the rotor current in the q-axis, i'_{dr} is the stator current in the d-axis, L'_{qr} is the rotor inductance in the q-axis, L'_{dr} is the rotor inductance in the d-axis L_m , is the stator-rotor mutual inductace, L_{ls} , and L'_{lr} are the stator and the rotor leakage inductance respectively, ω_s is the synchronous speed in rad/sec and ω_r is the rotor speed in rad/sec. X_s is the stator reactance and X_r is the rotor reactance.

3. RESULTS AND DISCUSSION

Using a typical machine parameter found in (Ichem et al, 2022), the detailed plot of the steady state characteristics of the torque speed relationship of the motor on variable resistor is shown in Figure 2. According to the graph, the maximum torque generated is unaffected by the rotor circuit impedance. Smaller amounts of resistance provide higher torque, and there is little to no speed control. The greatest torque may be achieved by using resistors with the proper value. This can be applied in situations when significant starting torque is necessary. The external resistance can be removed once the motor has started in order to provide high torque all through the acceleration range. The majority of the I^2R loss is dissipated through the external resistances since they are coupled, which limits the rise in rotor temperature during beginning. Again, maximum torque changes inversely as stand-still rotor resistor since the resistor was not changed. Finally, the opposition of the rotor determines the slip at which the peak power occurs.

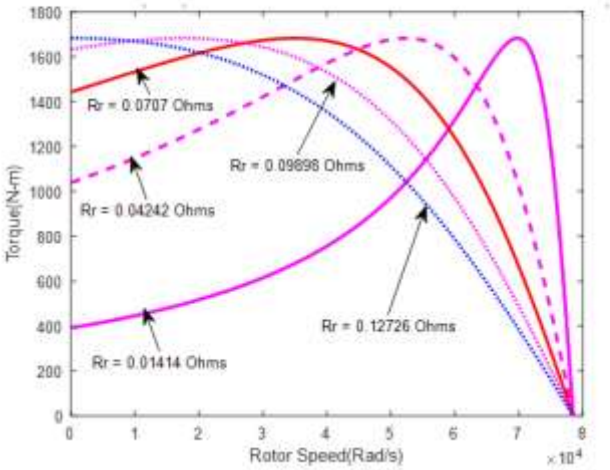

Figure 2. Steady state characteristics of the torque-speed relationship of the motor at different rotor resistance

The steady state characteristics of the torque-speed relationship of Figure 3 shows an illustration of the motor. The results show that as the supply voltage is reduced, the value of maximum torque correspondingly declines. This still takes place at the same slip as before, though. Additionally, both the beginning torque and total torque decrease. As a result, the equipment is hardly used, and there aren't many uses for this speed control technique. This will work effectively for loads that need relatively little initial torque but may need more torque as speed increases. Furthermore, the machine may start even at lower voltages since the lift force at zero speed is zero. With loads that have constant torque, this will not be achievable.

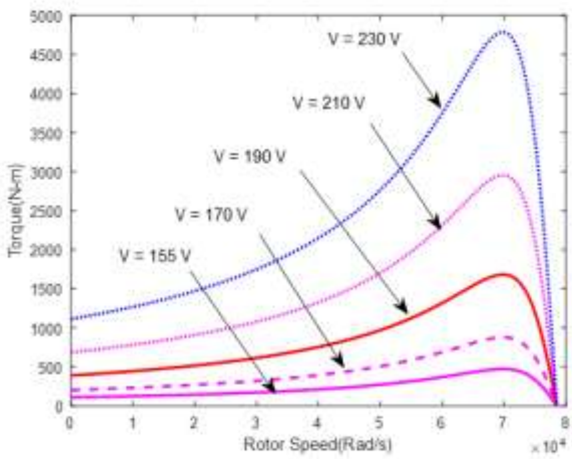

Figure 3. Steady state characteristics of the torque-speed relationship of the motor at different supply voltage

Figure 4 illustrate the steady state characteristics of the torque-speed relationship of the motor on constant voltage frequency ratio method without peripheral integral controller (PI). By concurrently altering the supply frequency so that the ratio v/f stays constant, the stator voltage may be changed while keeping the flux constant. As it can be seen; the variation of these tow electrical quantities does not yield a result where the rotor speed is uniform. So, when the load increases, the torque and speed are altered.

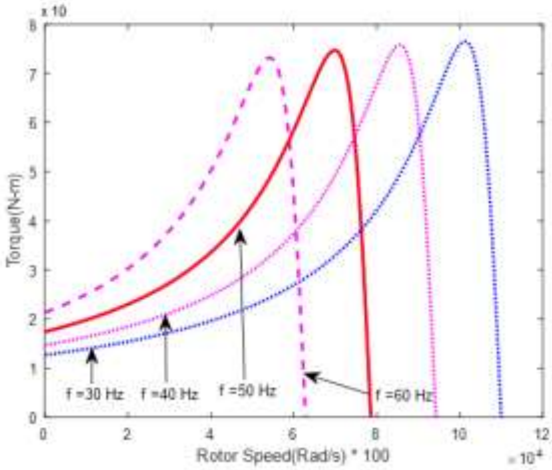

Figure 4. Steady state characteristics of the torque-speed relationship of the motor on constant voltage frequency ratio without pi controller (open loop)

The steady state plot of the motor speed control using constant v/f with PI is shown in Figure 5 through Figure 7 for 500 rpm, 750 rpm, and 1500 rpm rotor reference speed respectively. The nominal rotor speed is used as the reference speed for measuring and comparing the rotor's speed. It has been noted that more initial torque is produced prior to control. Additionally, the initial startig torque is regulated for all reference speed queueing system until it reaches its maximum, which is 2.3 N-m or above. The proportional controller processes the inaccuracy, and adjusts the supply frequency as a result. The motor speed may be changed using voltage source converters and constant current inverters. The voltage is also adjusted such that the v/f ratio is constant when the control system feeds the voltage source inverter. This maintains a consistent flux value across the speed range, which in turn guarantees a constant max torque. So, speed control is accomplished. At different loads, the ability to switch can be reached.

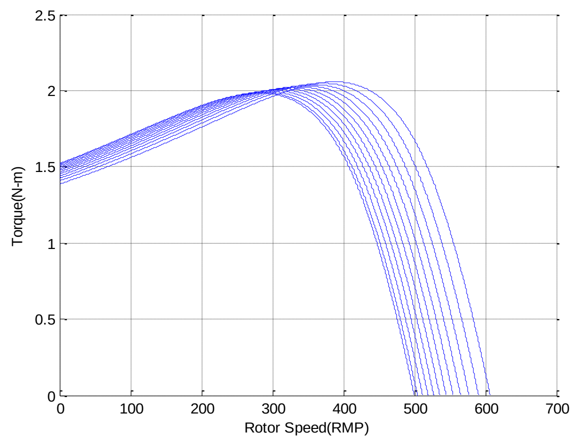

Figure 4.28. Steady state torque-speed characteristics of the induction motor on constant voltage-frequency ration with PI
(starting load torque =0, reference speed of 500 rpm)

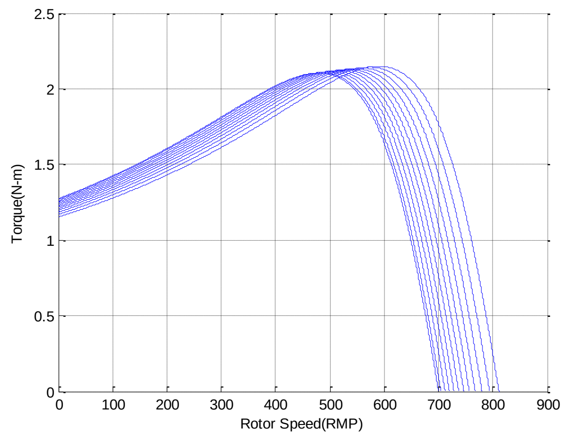

Figure 4.29. Steady state torque-speed characteristics of the induction motor on constant voltage-frequency ration with PI
(starting load torque = 0, reference speed of 750 rpm)

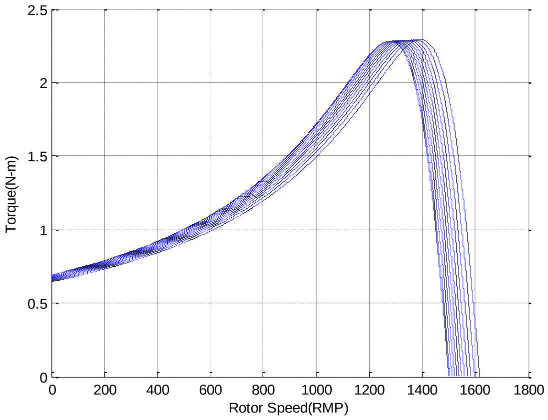

Figure 4.30. Steady state torque-speed characteristics of the induction motor on constant voltage-frequency ration with PI
(starting load torque = 0, reference speed of 1500 rpm)

4. CONCLUSIONS

This paper has completed carried out a comparative analysis of the steady state characteristic of three-phase induction motor under different speed control scheme. The machine uterlises Parks d-q model approach. The torque-speed characteristics for large and diverse motor speed controlling techniques, such as the rotor resistance control method and the variable supply voltage control method, were acquired and studied. The creation of MATLAB/Simulink programming codes allowed for these successes. To create the code, actual motor electrical specifications were used. The starting torque can be changed when variable rotor resistance control technique is used; and the maximum torque is unaltered. Therefore, the rotor resistance may be changed to even get the maximum torque at beginning for tasks needing strong starting torque. The maximum torque for the variable supply voltage control technique of speed control diminishes as the supply voltage rises, leaving the motor not fully uterlized. Due to this flaw, the variable stator voltage control approach cannot be employed to achieve good performance. When using constant v/f ratio control approaches, the supply voltage and supply frequency may be changed while the flux stays constant. As a result, multiple working zones may be obtained for different speeds and torques can be produced at constant flux. The motor is fully exploited when various synchronous speeds are reached with nearly the same load torque, and we also have a wide variety of speeds. The constant voltage frequency was arranged with a proportional integral controller.

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