# Speed Control of Wound Rotor Induction Motors by AC Regulator Based Optimum Voltage Control

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*Abstract*—**Wound-rotor induction motors are generally used for high torque and adjustable speed conditions. At lower speeds, either power is wasted in rotor resistances or power is pumped back from the rotor circuit to grid using different standard energy recovery methods. At low torque and low speed conditions, the power wastage in the rotor circuit becomes enormously high. Furthermore, if stator voltage control method is used it is effective for fan type loads only. For constant torque loads, the speed control range thus achieved is very limited. An efficient, low cost, simple speed control scheme is presented for wound rotor induction motors. Both stator voltage control and rotor resistance control methods are combined together and an optimum condition is found for voltage control. A thyristor based ac regulator used for stator voltage control, works efficiently at this condition . Then the rotor resistance is controlled for the adjustable speed requirements. A full speed control range has achieved i.e. about zero to the rated speed. The motor operates satisfactorily even at very low torque and low speed conditions.**

*Key words* : **speed control , ac regulator ,induction motor**

## I. INTRODUCTION

Both volts/hertz (V/f) and vector control based speed controllers available for induction motors are quite complex and costly. Moreover, for very high power applications (MW range), thyristor based controllers are preferred due to the limitations of MOSFET/ IGBT based high power controllers. Ac regulators are extensively used for soft starting, speed control and loss minimization[1]. Generally the schemes used do not provide all the above requirements. The method suggested provides all the advantages with a wide speed control range at good efficiency.

The stator voltage control method is suitable for fan type loads only. For a constant load torque requirement, the speed control range thus achieved is very limited as shown in Fig.1.Earlier voltage control method was employed to improve the efficiency of induction motors at the cost of speed [2,3]. Alternatively, slip-ring induction motors with rotor resistance control can be used but the efficiency of the controller becomes very poor for low load-torque and low speed requirements. To remove these drawbacks and to utilize the advantages of these schemes, a combination of ac phase angle control and rotor resistance control are used together.

## II. METHODOLOGY

In the proposed method a three phase ac regulator is used to reduce the input or stator voltage.It improves the efficiency of the motor at an optimum voltage condition. The optimum condition is found at which the torque requirement is met with a lower motor flux. The flux dependent core losses and magnetizing component of the stator losses are, therefore, reduced, while the rotor hence the stator current is not excessively increased. The power factor is also improved at this reduced stator voltage condition. A three-phase ac regulator is used for this purpose.

An external resistance is put in the rotor in conjunction with a diode bridge as shown in Fig.2. At the reduced voltage, motor draws minimum power from the supply for a given load condition. However, the speed also reduces slightly due to increased slip as shown in Fig.1.Now rotor resistance control is used to control the speed from about rated speed to zero.

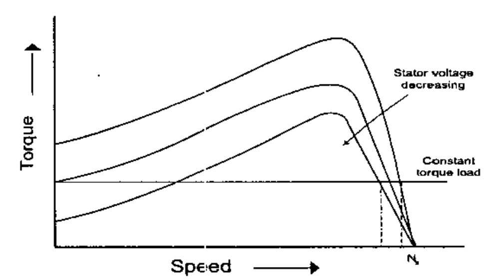



Fig.1 Speed –Toque characteristics of induction motor with variable supply voltage

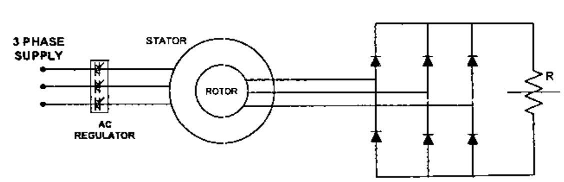
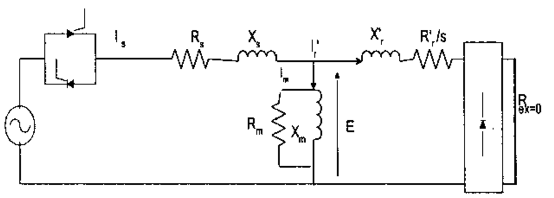



Fig.2 Wound rotor induction motor with rotor resistance and supply voltage control.

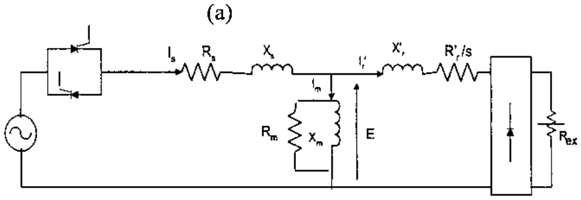
Figure.3 shows the equivalent circuit of the wound rotor induction motor where

$I_s$ = stator current,
$I_r'$ = rotor current referred to stator frequency,
$I_m$ = magnetizing component of current,
$R_s$ and $X_s$ = stator resistance and reactance,
$R_r'$ and $X_r'$ = rotor resistance and reactance referred to stator frequency,
$R_m$ and $X_m$ = iron loss resistance and magnetizing reactance,
s = slip,
E = rotor induced emf,
a = constant (0 < a < 1).

As the voltage is reduced the magnetizing component of current reduces thereby reducing core losses. However to maintain the magnitude of the air gap power(for constant load-torque),slip increases. Therefore rotor current hence stator current and the copper losses increase (Fig.4).The stator voltage is now reduced using the ac regulator and keeping external resistance in the rotor circuit zero (i.e. $R_{ex}$ = *0*) till minimum power is drawn by the load.



(a)



( b )

Fig. 3.Equivalent circuit of wound rotor induction motor with diode bridge in rotor circuit .(a)without external resistance, (b) with external resistance.

At low load torque the slip is close to zero and $R_r/s$ is large compared to $X_r$. This induced voltage in the rotor circuit can be taken in phase with the rotor current[4]. The magnetizing current phasor ($I_m$) lags behind the induced voltage (rotor current) by almost 90°. The resultant of both these currents, is the stator current which is drawn from the supply. As the voltage is reduced by a factor 'a' (0 < a < 1) the magnetizing current reduces in the same proportion. Thus the rotor current increases as it is inversely proportional to the applied voltage. An optimum voltage 'aV' can be calculated from this phasor diagram so that $I_s$ becomes minimum (Fig.4).

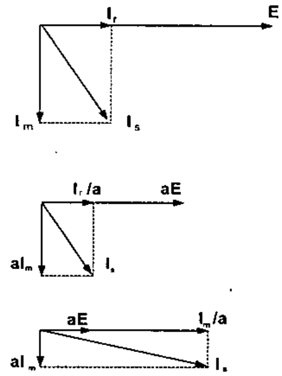


Fig.4 . Current relationships with decreasing supply voltage

The optimum reduced voltage is now applied to the motor for which it draws minimum power. The rotor resistance is now increased to control the speed of the motor.

A limiting condition in terms of low torque (rotor current) is found for which voltage reduction provides improvement in efficiency. Limiting condition is given by

$$|I_m| = |I_r'| \quad (1)$$

$$\bar{I}_s = \bar{I}_m + \bar{I}_r' \quad (2)$$

therefore, $$|I_s| = \sqrt{2}\,|I_m| \quad (3)$$

## III. RESULTS

A 3-phase, 50Hz, 2.2kW, 415, 6.6A, 950rpm motor is tested and its performance is compared with different controller arrangements. By implementing optimum voltage control a higher efficiency is observed even with conventional rotor resistance control method without chopper over whole speed range. Furthermore, a wide speed control range is achieved which is not obtained in conventional stator voltage control method for a constant load torque. Also, the power factor of the motor is improved with this scheme. Harmonic components of the current due to the ac phase control are also within a reasonable range (Fig.5). Results using conventional voltage and rotor resistance control are compared with the results of the scheme presented(Fig.6)

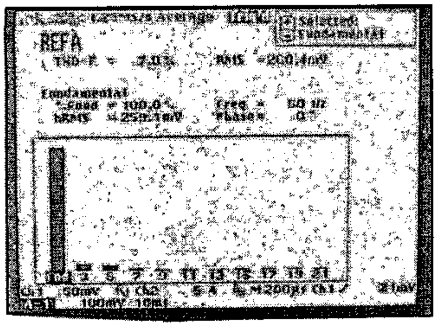
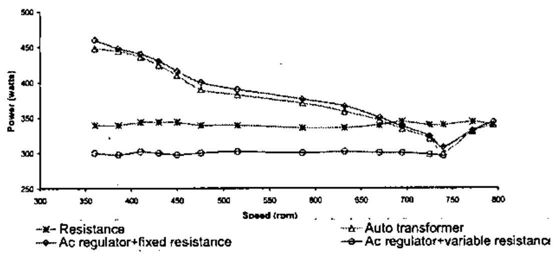
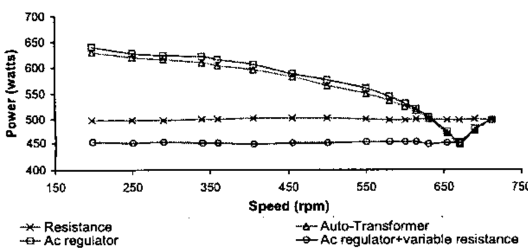


Fig.5. Harmonic content of output current waveform from ac regulator




(a)

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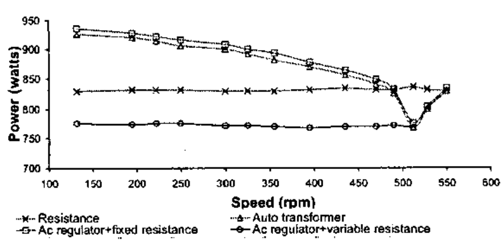


( c )

Fig.6.Comparison of Speed – Input power characteristics of a, 2.2 kW,415V,6.6A,950rpm, 50 Hz wound rotor induction motor (a) At 0.16 p.u torque, (b) At 0.25 p.u torque ,(c) at 0.33 p.u torque

## IV. DISCUSSION

It is evident from the Fig.6.that a wide speed range up to near the rated speed is achieved. It is observed that the power drawn from the supply remains the same throughout the operating range. Although losses take place in the rotor resistances but they are much less than conventional rotor resistance control methods. A slight reduction in the maximum speed also occurs due to the voltage is now reduced from rated to the optimum value.

At reduced voltages the torque capability also reduces but the optimum voltage at which the efficiency is maximum is much higher than the break down voltage. It is shown that the reduction in voltage for improvement in efficiency only helps in cases for which the magnitude of the load or rotor current is less than the magnetizing or no load current. For any torque drawing a rotor current more than the no load current, the voltage reduction does not provide any improvement in efficiency. However, it gives a sufficiently large torque range as no load current varies from 25% to 40% of full load current.

## V. CONCLUSION

Ac voltage controller and rotor resistance control provide stepless and flexible control of wound rotor induction motor by a low cost simple circuit. The same circuit can be used as a starter speed control and loss minimization. This is a cheap, simple and efficient method for speed control of induction motors even at low torque and low speed requirements. Thus, the same high power wound rotor motor can be operated efficiently even at low speed and low torque conditions. Rotor resistance control in conjunction with ac regulator is a cheap, robust, efficient drive, which provides a large starting torque. The proposed method is applicable only for the load-torque for which the magnitude of the rotor current magnitude is equal to or less than the magnitude of the magnetizing current. In other words this method is suitable only for loads drawing load current not more than $\sqrt{2}$ times the no-load current (magnetizing current). The power factor of the motor is also appreciably improved using this method.

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