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Effect of Capacitor Injection in the Rotor Winding of an Induction Machine

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ABSTRACT

This is the presentation of the effect of capacitor injection into the rotor circuit of an induction machine through the slip rings. It is shown that if capacitor (whose reactance is twice that of the inductive reactance of the rotor) is injected into the rotor circuit such that the effective reactance of the rotor is capacitive, there will be reversal of power flow. The slip of the machine will be positive, yet it will be operating as a generator.

Keywords: *Induction Generator, Capacitor Injection, Reversal of Power Flow*

1. INTRODUCTION

Induction machines are regarded as the workhorse of the electric power industry. This because it is being used in a wide variety of applications as a means of converting electrical power to mechanical work.

One distinguishing feature of an induction machine is that it is singly excited machine, although the machine is equipped with both field and armature winding [1]. It is only the field winding (Stator) that is connected to the a.c. source while current flow to the rotor by induction. This type of machine is called asynchronous machine since they run at a speed other the synchronous speed of the rotating field developed by the stator currents. Like other electrical machine, the asynchronous machine can operate as both motor and generator.

In operation as a generator, there are different modes in which the machine operates depending on the mode of excitation.

1.1 Self-Excited Induction Generator (SEIG)

In this mode the generator needs a reasonable amount of a reactive power which must be fed externally to establish the magnetic field required to convert the mechanical power from its shaft into electrical power [2]. This external reactive power source must remain permanently connected to the stator winding which is responsible for output voltage control [3,4]. In interconnected application, the synchronous grid supplies such reactive power while in stand-alone application; the reactive power must be supplied by the load itself or by a bank of capacitors connected across its terminals.

1.2 Doubly Fed Induction Generator (DFIG)

The doubly fed induction generator is a wound rotor machine where the rotor circuit is connected to an external variable voltage and frequency source via slip rings and the stator is connected to the grid network [5].

In either mode of operation of induction generator, either SEIG or DFIG, the motor runs at a super-synchronous speed. If the rotor circuit is made to be capacitive, the generator will be running at a speed below the synchronous speed.

2. ANALYSIS OF CURRENT LOCI OF ASYNCHRONOUS MACHINE

The rotor circuit voltage equation of an induction motor in phasor form can be written from its equivalent circuit of Figure 1 as:

$$E_2 = I_2\left(\frac{r_2}{s} + jx_2\right) \tag{1}$$

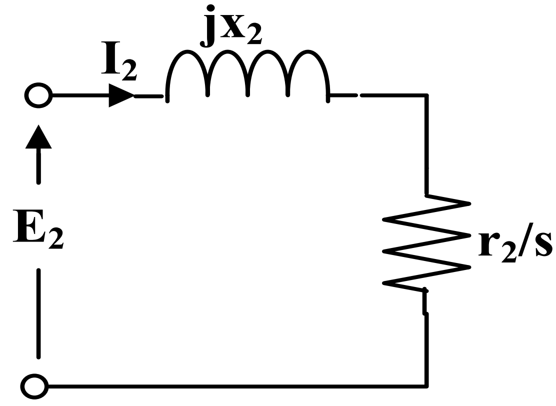

Figure 1: Rotor equivalent circuit of an induction motor

The per-phase rotor current at any slip s is given by

$$I_2 = \frac{E_2}{\sqrt{\left(\frac{r_2}{s}\right)^2 + x_2^{\ 2}}\ \tan^{-1}\left(\frac{sX_2}{r_2}\right)} \quad (2)$$

The rotor current I_2 lags the rotor voltage E_2 by an angle $\tan^{-1}\left(\frac{sX_2}{r_2}\right)$

The power input to the rotor which is the power transferred across the air-gap from the stator is given by:

$$P_g = E_2 I_2 \cos\varphi_2 \quad (3)$$

where $\varphi_2 = \tan^{-1}\left(\frac{sX_2}{r_2}\right)$

The power factor $\cos\varphi_2$ may be expressed as:

$$\cos\varphi_2 = \frac{\text{per phase rotor resistance}}{\text{per phase rotor impedance}} = \frac{r_2/s}{\sqrt{\left(r_2/s\right)^2 + x_2^{\ 2}}} \quad (4)$$

Therefore, (2.7) becomes:

$$P_g = E_2 I_2 \frac{r_2/s}{\sqrt{\left(r_2/s\right)^2 + x_2^{\ 2}}} = I_2^{\ 2}\, r_2/s \quad (5)$$

In order to obtain the rotor current locus, (1) can be rewritten as:

$$\frac{-jE_2}{x_2} = I_2 - jI_2\frac{r_2}{sx_2} \quad (6a)$$

It can be seen from equation 7 that E_2/x_2 is a constant current that lags behind E_2 by 90^o and it is also made up of two components: the current in the rotor circuit I_2 and a variable component $I_2\frac{r_2}{sx_2}$ lagging I_2 by 90^o as shown in Figure 2

From the geometry of the phasor diagram shown in Figure 2., where a right-angled triangle is formed over a constant diameter E_2/x_2, it can be seen that the phasor I_2 traces out a semicircle as $\frac{r_2}{sx_2}$ varies from 0 to ∞. If $\frac{r_2}{sx_2}$ takes negative values, implying s being traditionally negative (super synchronous speed of the rotor), equation (6a) modifies to:

$$\frac{-jE_2}{x_2} = I_2 + jI_2\frac{r_2}{sx_2} \quad (6b)$$

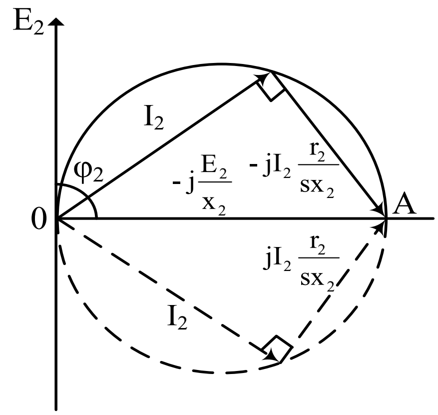

Figure 2: Current locus for inductive rotor circuit of induction machine

The phasor I_2 will trace out a semicircle below the OA co-ordinate, which is the negative slip region. The phasor I_2 will now lag the applied voltage by an angle greater than 90^o. This means negative power factor ($\cos\varphi_2$) or that electric power flows out of the machine from rotor to the stator resulting in generator operation $\left(P_g = -I_2^{\ 2}\, r_2/s\right)$, a reversal of power flow.

3. CAPACITOR INJECTION IN THE ROTOR CIRCUIT

Suppose capacitance is injected into the rotor circuit through the slip-rings, which results to the rotor equivalent circuit as shown in figure 3 and of magnitude twice that of the leakage reactance x_2 say, the overall reactance of the rotor circuit becomes $-jx_2$ even though s is positive. Equation 2.10a will now be modified to:

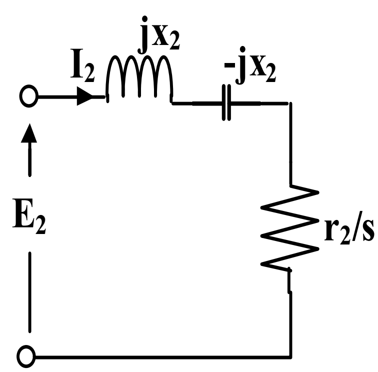

Figure 3: Rotor equivalent circuit of an induction motor with capacitor injected

$$\frac{jE_2}{x_2} = I_2 + jI_2 \frac{r_2}{sx_2} \qquad (6c)$$

From equation (2.6c), the locus of I_2 as s varies from zero to ∞ is as shown in Figure 4.

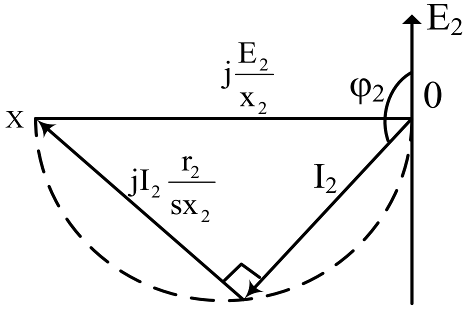

Figure 4: Current locus for the capacitive rotor circuit of induction machine

It can be seen from Figure 2.3 that the rotor current I_2 leads the applied voltage E_2 by $\varphi_2 > 90^o$. Consequently, the leading power factor $\cos\varphi_2$ is negative, which means that power flows out of the machine from the rotor to the stator resulting in generating operation $\left(P_g = -I_2{}^2 \frac{r_2'}{sx_2}\right)$. In summary, the generating operation can be obtained at rotor speeds below synchronous ($\omega<\omega_o$) by capacitive injection into the rotor circuit, such that the overall reactance of the rotor circuit becomes capacitive (i.e. injected capacitive reactance X_c is greater than the leakage reactance x_2).

If for instance, in DFIG, instead of connecting the rotor circuit to an external variable voltage and frequency source, a band capacitor which will be such that it will make the whole rotor circuit capacitive, is connected via slip ring, the generator will then be delivering electrical power at lesser speed which makes this machine useful in wind energy generation.

4. CONCLUSION

It can be seen from Figure 2.3 that the rotor current I_2 leads the applied voltage E_2 by $\varphi_2 > 90^o$. Consequently, the leading power factor $\cos\varphi_2$ is negative, which means that power flows out of the machine from the rotor to the stator resulting in generating operation $\left(P_g = -I_2{}^2 \frac{r_2'}{sx_2}\right)$. In summary, the generating operation can be obtained at rotor speeds below synchronous ($\omega<\omega_o$) by capacitive injection into the rotor circuit, such that the overall reactance of the rotor circuit becomes capacitive (i.e. injected capacitive reactance X_c is greater than the leakage reactance x_2).

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REFERENCES

[1] Linus U. Anih, Emeka S. Obe, Eugene O. Agbachi, *Analytic Synthesis of Hysteresis Motor,* Energy Conversion and Management 52 (2011), pg 391 – 396

[2] Simoes M. G. and Farre F. A.; *Renewable Energy System, Design and Analysis with Induction Generator,* CRC Press 2004

[3] M. Godoy Simoes, Sudipta Chakrabarty abd Robert Wood, *Induction Generator for small Wind Energy Systems*, IEE Power Electronics Society Newsletter, Third Quarter, 2006, pg 19-23

[4] Edward Muljadi, Jesus Sallan, Mariano Sanz and Charles P Butterfield, *Investigation of Self-Excited Induction Generators for for Wind Turbine Application,* Presented at the 1999 IEEE Industry Applications Society,Annual Meeting,Phoenix, Arizona,October 3-7*, 1999*

[5] Faret F. A. and Smoes M. G., *Integration of Alternative Sources of Energy*. Wiley-IEEE Press 2006