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Comparative Study of Induction Generator And Synchronous Generator Using D-Q Model

Vemireddi Tejeswara Rao

EEE Department, GITAM Institute of Technology,
GITAM Deemed University,
Visakhapatnam, India

Abstract

In wind power plants two types of generators are used either synchronous generator or induction generator. In this paper a comparative study of induction generator and synchronous generator using d-q model is carried, results are compared and furnished in this paper.

Keywords —d-q model, Induction generator, Synchronous generator, Space vector model, Rotor flux, Voltage equation

1. Introduction

In the recent times, the power needs are increasing day by day .To meet the demand, new ways of power generating techniques to be investigated. In wind power generation, synchronous generator and induction generators are used in present scenario. In this paper, a d-q modeling of synchronous generator and induction generator are modeled. And comparisons between the two generators have been tabulated.

2. Modeling of Induction Generators

A. Space Vector model:

To develop induction generator space-vector model, two assumptions are considered

(1)The induction generator structure is symmetrical and three-phase balanced

(2) The stator and rotor magnetic core is linear with negligible core losses.

It is generally composed of three sets of equations: voltage equations, flux linkage equations, and motion equation

The Stator and rotor voltage equations are

$$\begin{cases} \vec{v}_s = R_s \vec{i}_s + p\vec{\lambda}_s + j\omega\vec{\lambda}_s \\ \vec{v}_r = R_r \vec{i}_r + p\vec{\lambda}_r + j(\omega - \omega_r)\vec{\lambda}_r \end{cases}$$

where

$\vec{v}_s$, $\vec{v}_r$—stator and rotor voltage vectors (V)

$\vec{i}_s$, $\vec{i}_r$—stator and rotor current vectors (A)

$\vec{\lambda}_s$, $\vec{\lambda}_r$—stator and rotor flux-linkage vectors (Wb)

R_s, R_r—stator and rotor winding resistances (Λ)

ω—rotating speed of the arbitrary reference frame (rad/s)

ω_r—rotor electrical angular speed (rad/s)

p—derivative operator ($p = d/dt$).

The stator and rotor flux linkages λs and λr:

$$\begin{cases} \vec{\lambda}_s = (L_{ls} + L_m)\vec{i}_s + L_m \vec{i}_r = L_s \vec{i}_s + L_m \vec{i}_r \\ \vec{\lambda}_r = (L_{lr} + L_m)\vec{i}_r + L_m \vec{i}_s = L_r \vec{i}_r + L_m \vec{i}_s \end{cases}$$

where

$L_s = L_{ls} + L_m$—stator self-inductance (H)

$L_r = L_{lr} + L_m$—rotor self-inductance (H)

L_{ls}, L_{lr}—stator and rotor leakage inductances (H)

L_m—magnetizing inductance (H)

The last equation is the motion equation; this equation describes the dynamic behavior of the rotor mechanical speed in terms of mechanical and electromagnetic torque:

$$\begin{cases} J\dfrac{d\omega_m}{dt} = T_e - T_m \\ T_e = \dfrac{3P}{2}\mathrm{Re}\left(j\vec{\lambda}_s \vec{i}_s^{\,*}\right) = -\dfrac{3P}{2}\mathrm{Re}\left(j\vec{\lambda}_r \vec{i}_r^{\,*}\right) \end{cases}$$

where

J—moment of inertia of the rotor (kgm^2)

P—number of pole pairs

T_m—mechanical torque from the generator shaft (N · m)

T_e—electromagnetic torque (N · m)

ω_m—rotor mechanical speed, $\omega_m = \omega_r/P$ (rad/sec)

These equations develop the space-vector model and the equivalent circuit is shown below.

The generator model in arbitrary reference frame, with the arbitrary speed ω

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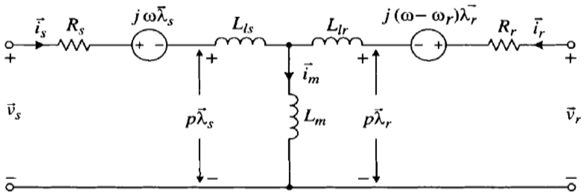
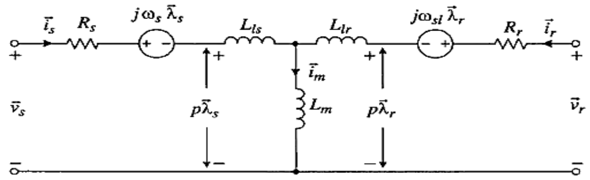


With regard to the direction of the current that flows into the stator, induction generator space vector model is build on the motor convention

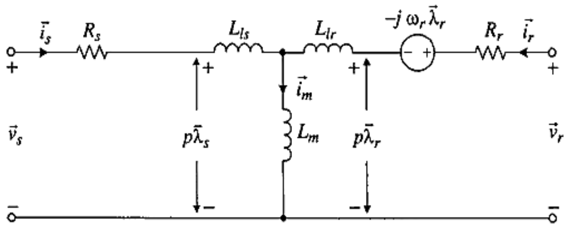
The above convention is unquestioned as most of the induction machines are used as motors, as there is no loss of generality the equations related to space vector model are used to model the induction machine as a motor or a generator.

B. d-q Model:

The d-q model of the induction generator is acquired by separating the space-vectors into their corresponding d-axis and q-axis components



(a) IG model in the synchronous frame



(b) IG model in the stationary frame

$$\begin{cases} \vec{v}_s = v_{ds} + j v_{qs}; \; \vec{i}_s = i_{ds} + j i_{qs}; \; \vec{\lambda}_s = \lambda_{ds} + j\lambda_{qs} \\ \vec{v}_r = v_{dr} + j v_{qr}; \; \vec{i}_r = i_{dr} + j i_{qr}; \; \vec{\lambda}_r = \lambda_{dr} + j\lambda_{qr} \end{cases}$$

Substituting and gathering real and imaginary components on the two sides of the equations, the d-axis and q-axis voltage equations are acquired

$$\begin{cases} v_{ds} = R_s i_{ds} + p\lambda_{ds} - \omega\lambda_{qs} \\ v_{qs} = R_s i_{qs} + p\lambda_{qs} + \omega\lambda_{ds} \\ v_{dr} = R_r i_{dr} + p\lambda_{dr} - (\omega - \omega_r)\lambda_{qr} \\ v_{qr} = R_r i_{qr} + p\lambda_{qr} + (\omega - \omega_r)\lambda_{dr} \end{cases}$$

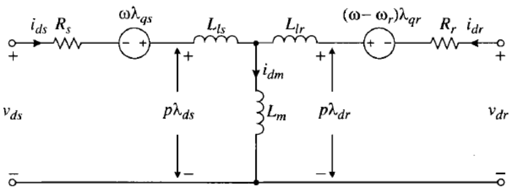
Similarly, the d-axis q-axis flux linkages are obtained

$$\begin{cases} \lambda_{ds} = (L_{ls} + L_m) i_{ds} + L_m i_{dr} = L_s i_{ds} + L_m i_{dr} \\ \lambda_{qs} = (L_{ls} + L_m) i_{qs} + L_m i_{qr} = L_s i_{qs} + L_m i_{qr} \\ \lambda_{dr} = (L_{lr} + L_m) i_{dr} + L_m i_{ds} = L_r i_{dr} + L_m i_{ds} \\ \lambda_{qr} = (L_{lr} + L_m) i_{qr} + L_m i_{qs} = L_r i_{qr} + L_m i_{qs} \end{cases}$$

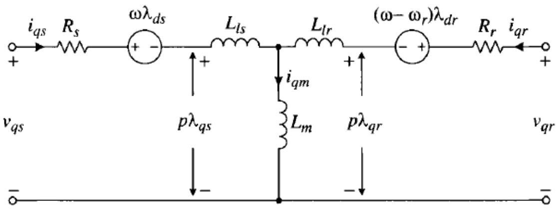
The electromagnetic torque T_e can be conveyed by d-q axis flux linkages and currents. Using mathematical operations, various equations for the torque can be attained. The most commonly used equations are given by

$$T_e = \begin{cases} \frac{3P}{2}(i_{qs}\lambda_{ds} - i_{ds}\lambda_{qs}) \\ \frac{3PL_m}{2}(i_{qs}i_{dr} - i_{ds}i_{qr}) \\ \frac{3PL_m}{2L_r}(i_{qs}\lambda_{dr} - i_{ds}\lambda_{qr}) \end{cases}$$

d-axis circuit:

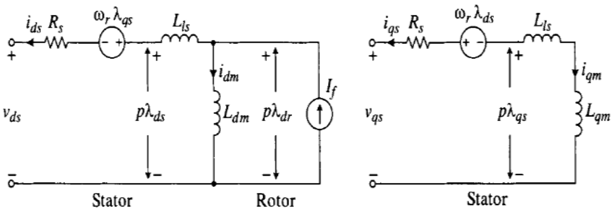


q-axis circuit:



3. Dynamic Model of Synchronous Generator

The Synchronous generator commonly modeled in the rotor field synchronous reference frame. The stator circuit of the d-q axis model is similar to the induction generator the speed of the arbitrary reference frame ω in the induction generator model is replaced with the rotor speed ω_r in the synchronous frame the magnetizing inductance Lm is replaced with the d-q axis magnetizing inductances Ldm and Lqm of the synchronous generator.



The equations of voltage for the synchronous generator are

$$v_{ds} = -R_s i_{ds} - \omega_r\lambda_{qs} + p\lambda_{ds}$$

$$v_{qs} = -R_s i_{qs} + \omega_r\lambda_{ds} + p\lambda_{qs}$$

λds, λqs ⟶ d-axis and q-axis stator flux linkages

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$$\lambda_{ds} = -L_{ls} i_{ds} + L_{dm}\left(I_f - i_{ds}\right) = -(L_{ls} + L_{dm}) i_{ds} + L_{dm} I_f = -L_d i_{ds} + \lambda_r$$

$$\lambda_{qs} = -(L_{ls} + L_{qm}) i_{qs} = -L_q i_{qs}$$

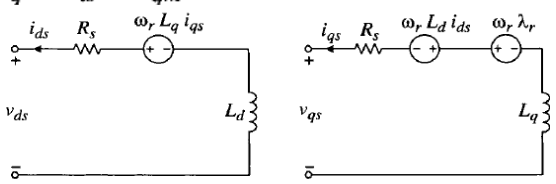
λr ⟶ rotor flux,

Ld, Lq ⟶ stator d-q axis self-inductances

$$\lambda_r = L_{dm} I_f$$

$$L_d = L_{ls} + L_{dm}$$

$$L_q = L_{ls} + L_{qm}$$

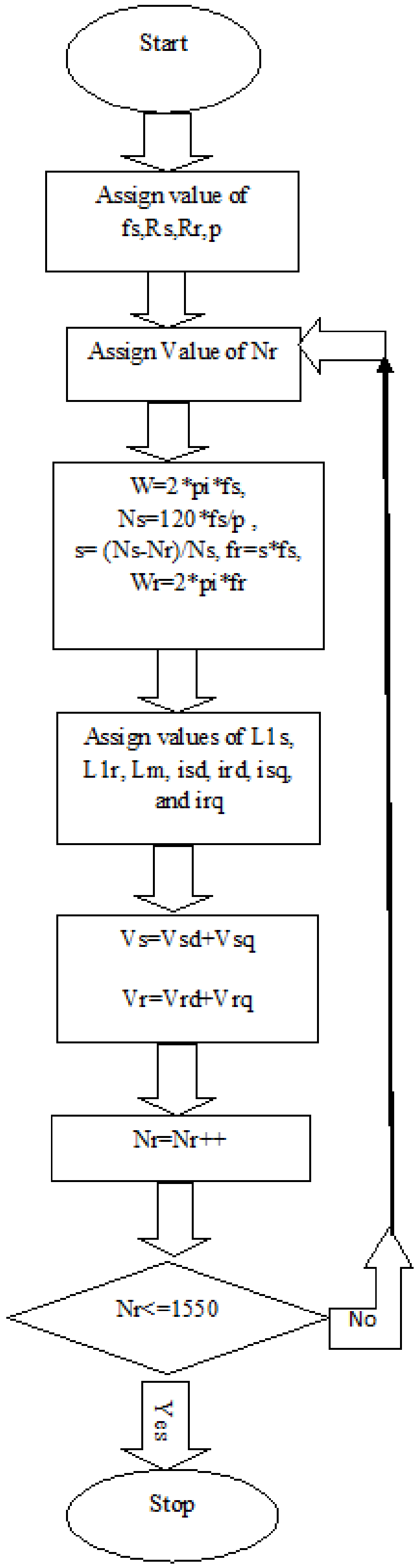


$$v_{ds} = -R_s i_{ds} + \omega_r L_q i_{qs} - L_d p i_{ds}$$

$$v_{qs} = -R_s i_{qs} - \omega_r L_d i_{ds} + \omega_r \lambda_r - L_q p i_{qs}$$

The Synchronous generator model is valid for permanent-magnet as well as for wound-rotor synchronous generator. For a given field current I_f in the wound-rotor synchronous generator, the rotor flux can be calculated by λr = Ldm I_f. Permanent magnets produce rotor flux λr in permanent magnet synchronous generator and the rated value of generator is picked up from the name plate details and generator specifications. This model is viable for salient pole synchronous generator as well as for non salient-pole synchronous generator. In a non salient generator, the d-q axis synchronous inductances, Ld and Lq are same .Where as they are different for a salient-pole generator.

4. Flow Chart For Induction Generator



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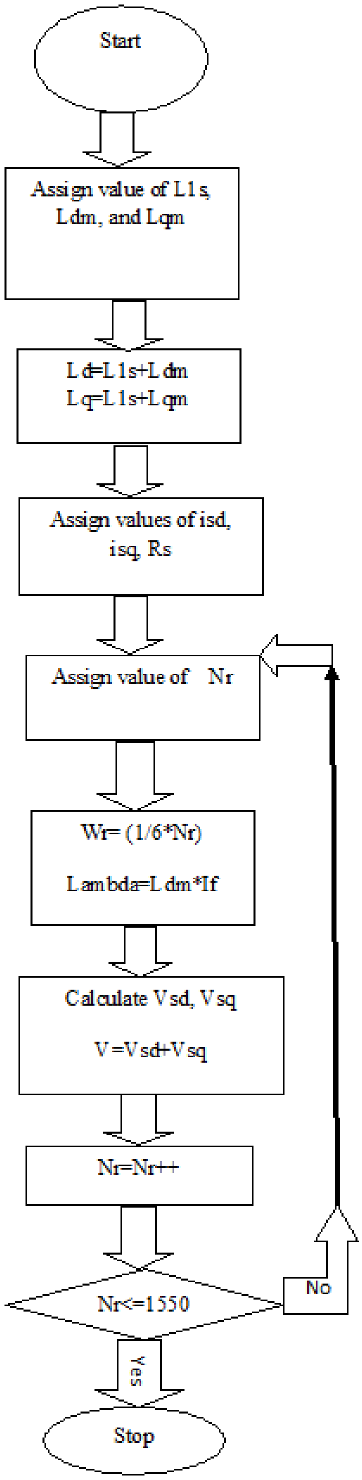
5. Flow Chart For Synchronus Generator



6. Result

Table: voltage comparison for different speeds

Speed	S.G(volts)	I.G(volts)
1500	2460	1057
1510	2476	1060
1520	2493	1063
1530	2509	1066
1540	2526	1069
1550	2542	1072

The Result in the form of graph

A. Induction Generator:

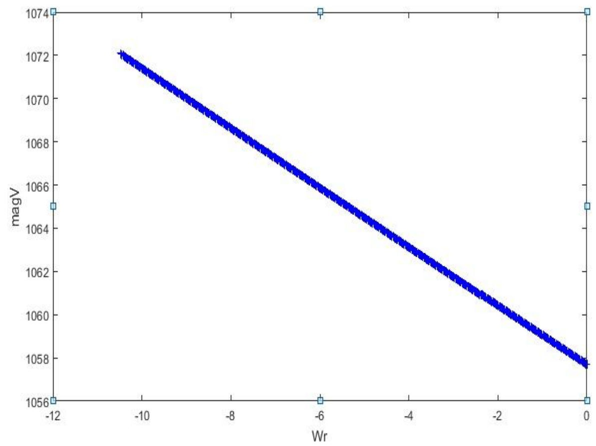


Fig: plot between Wr and magV

B. Synchronous Generator:

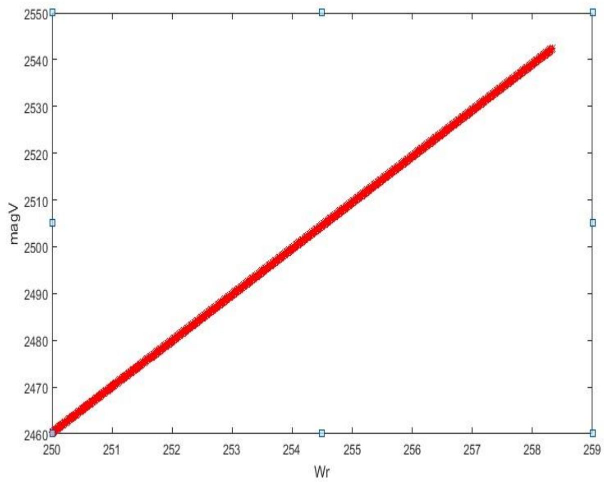


Fig: plot between Wr and magV

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7. Conclusion

In this paper, an algorithm is developed for the d-q model of the synchronous generator and induction generator. The results are compared and tabulated. From the results, it is concluded that synchronous generator is providing the better voltage profile compared with the induction generator. But induction generator is preferred in wind power generation because of its different speed ranges.

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