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The Self Excited Induction Generator with Observation Magnetizing Characteristic in the Air Gap

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ABSTRACT

This paper discusses The Self Excitated Induction Generator (SEIG) by approaching the induction machine, physically and mathematically which then transformed from three-phase frame abc to two-axis frame, direct-axis and quadratur-axis. Based on the reactive power demand of the induction machine, capacitor mounted on the stator of the induction machine then does the physical and mathematical approach of the system to obtain a space state model. Under known relationships, magnetization reactance and magnetizing current is not linear, so do mathematical approach to the magnetization reactance and magnetization current characteristic curve to obtain the magnetization reactance equation used in the calculation. Obtained state space model and the magnetic reactance equation is simulated by using Runge Kutta method of fourth order. The equations of reactance, is simulated by first using the polynomial equation and second using the exponent equation, and then to compare those result between the polynomial and exponent equations. The load voltage at d axis and q axis using the polynomial lags 640µs to the exponent equation. The polynomial voltage magnitude is less than 0.6068Volt from the exponent voltage magnitude.

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1. INTRODUCTION

The length of the air-gap has a significant influence on the characteristics of an electric machine, the air-gap length has to be increased considerably from the value obtained for a standard electric motor. The efficiency of motor is highly dependent on the rotor eddy current losses. Air gap flux of induction motors contains rich harmonics. A flux monitoring scheme can give reliable and accurate information about electrical machine conditions. Any change in air gap, winding, voltage, and current can be reflected in the harmonic spectra [7]. A minimum air gap flux linkage is required for the self-excitation and stable operation of an isolated induction generator feeding an impedance load. The minimum air gap flux linkage requirement is the value at which the derivative of the magnetizing inductance with respect to the air gap flux linkage is zero. This minimum air gap flux linkage determines the minimum or maximum load impedance and minimum excitation capacitance requirements. This result is demonstrated using single-phase and three-phase induction generators [1]. Connection of induction generators to large power systems to supply electric power can also be achieved when the rotor speed of an induction generator is greater than the synchronous speed of the air-gap revolving field [2]. The magnetization curve of the induction motor was identified and compared with the one obtained by the no-load test. The method sensitivity to the load torque and the transient inductance has also been considered. A very good accuracy of the magnetization curve estimation has been also obtained at bigger load torques [3]. Two modes of operation can be employed for an induction generator. One is through self-excitation and other is through external-excitation. In first mode, the induction generator takes its excitation from VAR generating units, generally realized in the form of capacitor banks [4], [6].

The asynchronous machine is machine, what it has the rotating rotor and rotating stator flux's are different. The asynchronous machine is known also as the induction machine, what it does as a generator needed. One of specialty the induction generator from the synchronous generator can operated above synchronous speed, whice known as Self-Excitation. In this condition, the generator will use the energy, that it is generated from rotor rotation for to generate stator flux and rotor flux using reactive power. The reactive power is given local bank capacitor, that it conected to the stator. With suitable capacitors connected across the terminals and with rotor driven in either direction by a prime mover, voltage builds up across the terminals of the generator due to self excitation phenomenon leaving the generator operating under magnetic saturation at some stable point. Such generator is known as self-excited induction generator (SEIG) [4]. Using the simulation will be done the mathematical approach for hope to achieve a describe about all SIEG responses, in dq axis.

2. METHODOLOGY

The three phase induction generator has some equation. The equation flux average $\bar{\phi}$ is the flux as time function $\lambda(t)$ [11].

The equations stator voltage:

$$v_{as} = i_{as}r_s + \frac{d\lambda_{as}}{dt} \quad (1)$$

$$v_{bs} = i_{bs}r_s + \frac{d\lambda_{bs}}{dt} \quad (2)$$

$$v_{cs} = i_{cs}r_s + \frac{d\lambda_{cs}}{dt} \quad (3)$$

The equations rotor voltage:

$$v_{ar} = i_{ar}r_r + \frac{d\lambda_{ar}}{dt} \quad (4)$$

$$v_{br} = i_{br}r_r + \frac{d\lambda_{br}}{dt} \quad (5)$$

$$v_{cr} = i_{cr}r_r + \frac{d\lambda_{cr}}{dt} \quad (6)$$

The stator and rotor turns flux are written as below:

$$\begin{bmatrix} \lambda_s^{abc} \\ \lambda_r^{abc} \end{bmatrix} = \begin{bmatrix} L_{ss}^{abc} & L_{sr}^{abc} \\ L_{rs}^{abc} & L_{rr}^{abc} \end{bmatrix} \begin{bmatrix} i_s^{abc} \\ i_r^{abc} \end{bmatrix} \quad (7)$$

$$\lambda_s^{abc} = (\lambda_{as}, \lambda_{bs}, \lambda_{cs})^T \quad (8)$$

$$\lambda_r^{abc} = (\lambda_{ar}, \lambda_{br}, \lambda_{cr})^T \quad (9)$$

The stator and rotor current are written as below:

$$i_s^{abc} = (i_{as}, i_{bs}, i_{cs})^T \quad (10)$$

$$i_r^{abc} = (i_{ar}, i_{br}, i_{cr})^T \quad (11)$$

The Inductance stator to stator:

$$L_{ss}^{abc} = \begin{bmatrix} L_{ls} + L_{ss} & L_{sm} & L_{sm} \\ L_{sm} & L_{ls} + L_{ss} & L_{sm} \\ L_{sm} & L_{sm} & L_{ls} + L_{ss} \end{bmatrix} \quad (12)$$

The Inductance rotor to rotor:

$$L_{rr}^{abc} = \begin{bmatrix} L_{lr} + L_{rr} & L_{rm} & L_{rm} \\ L_{rm} & L_{lr} + L_{rr} & L_{rm} \\ L_{rm} & L_{rm} & L_{lr} + L_{rr} \end{bmatrix} \quad (13)$$

The Inductance stator to rotor and rotor to stator:

$$L_{sr}^{abc} = \left[L_{rs}^{abc}\right]^{T} \quad (14)$$

$$L_{sr} = \begin{bmatrix} \cos\theta_r & \cos\left(\theta_r + \frac{2\pi}{3}\right) & \cos\left(\theta_r - \frac{2\pi}{3}\right) \\ \cos\left(\theta_r - \frac{2\pi}{3}\right) & \cos\theta_r & \cos\left(\theta_r + \frac{2\pi}{3}\right) \\ \cos\left(\theta_r + \frac{2\pi}{3}\right) & \cos\left(\theta_r - \frac{2\pi}{3}\right) & \cos\theta_r \end{bmatrix} \quad (15)$$

Where:

stator self inductance : $L_{ss} = N_s^2 P_g$ (1)

rotor self inductance : $L_{rr} = N_r^2 P_g$ (2)

stator mutual inductance : $L_{sm} = N_s^2 P_g \cos\left({2\pi}/{3}\right)$ (18)

rotor mutual inductance : $L_{rm} = N_r^2 P_g \cos\left({2\pi}/{3}\right)$ (19)

stator to rotor peak mutual inductance $L_{sr} = N_s N_r P_g$ (20)
N_s : stator total turns lilitan stator
N_r : rotor total turns
P_g : air gap permeability

The equation transformation from stator and rotor in $qd0$ axis is obtained from the Clark and Park transformation,

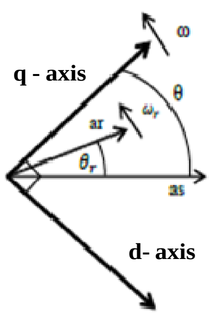


Figure 1. The “vector a-axis” at stator and rotor and dq axis [10]

$$[fd \quad fq \quad fo]^{T} = \left[T_{dq0}(\theta)\right][fa \quad fb \quad fc]^{T} \quad (21)$$

The equation of stator and rotor position θ:

$$\theta(t) = \int_0^t \omega(t)dt + \theta_s(0) \quad (22)$$

$$\theta_r(t) = \int_0^t \omega_r(t)dt + \theta_r(0) \quad (23)$$

The matric transformation in dq0 axis, is shown as below:

$$[T_{dq0}(\theta)] = {}^{2}/_{3}\begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{24}$$

And,

$$[T_{dq0}(\theta)]^{-1} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-\frac{2\pi}{3}) & \sin(\theta-\frac{2\pi}{3}) & 1 \\ \cos(\theta+\frac{2\pi}{3}) & \sin(\theta+\frac{2\pi}{3}) & 1 \end{bmatrix} \tag{25}$$

The stator and rotor voltage in dq0 axis is shown:

$$v_{qs} = \dot{\lambda}_{qs} + \omega_s\lambda_{ds} + r_s i_{qs} \tag{26}$$

$$v_{ds} = \dot{\lambda}_{ds} - \omega_s\lambda_{qs} + r_s i_{ds} \tag{27}$$

$$v_{0s} = \dot{\lambda}_{0s} + r_s i_{0s} \tag{28}$$

$$v_{qr} = \dot{\lambda}_{qr} + (\omega_s - \omega_r)\lambda_{dr} + r_r i_{qr} \tag{29}$$

$$v_{dr} = \dot{\lambda}_{dr} - (\omega_s - \omega_r)\lambda_{qr} + r_r i_{dr} \tag{30}$$

$$v_{0r} = \dot{\lambda}_{0r} + r_r i_{0r} \tag{31}$$

The flux equation in dq0 axis:

$$\begin{bmatrix} \lambda_{qs} \\ \lambda_{ds} \\ \lambda_{0s} \\ \lambda_{qr} \\ \lambda_{dr} \\ \lambda_{0r} \end{bmatrix} = \begin{bmatrix} L_{ls}+L_m & 0 & 0 & L_m & 0 & 0 \\ 0 & L_{ls}+L_m & 0 & 0 & L_m & 0 \\ 0 & 0 & L_{ls} & 0 & 0 & 0 \\ L_m & 0 & 0 & L_{lr}+L_m & 0 & 0 \\ 0 & L_m & 0 & 0 & L_{lr}+L_m & 0 \\ 0 & 0 & 0 & 0 & 0 & L_{lr} \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{0s} \\ i_{qr} \\ i_{dr} \\ i_{0r} \end{bmatrix} \tag{32}$$

The stator and rotor flux equations in dq0 axis:

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr} \tag{33}$$

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr} \tag{34}$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs} \tag{35}$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds} \tag{36}$$

Where:

$$L_s = (L_{ls} + L_m) \ \text{ and } L_r = (L_{lr} + L_m) \tag{37}$$

Analysis has been extended to identify effectiveness of the machine parameters to improve the operating performance of the generator. It is found that operating performance of the machine may be improved by proper design of stator and rotor parameters [4]. When an induction machine is driven by a prime mover, the residual magnetism in the rotor produces a small voltage that causes a capacitive current to flow. The resulting current provides feedback and further increases the voltage. It is eventually limited by the magnetic saturation in the rotor. Variable capacitance is required for self-excited induction generator [2]. The Self Excited Induction Generator (SEIG) using capacitors, is the induction generator as noload operation. This system is described as a three phase induction machine symetrically and conected to identic bank capacitor. The using model induction machine stationery, than to obtain equivalent circuit of the self excitated induction generator SEIG in d-axis, as Figure 2 as below [5]:

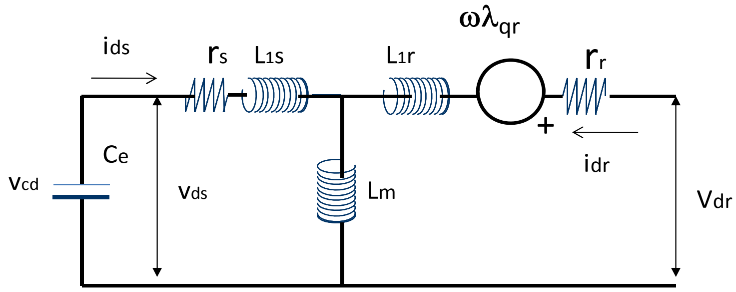


Figure 2. Stasionery circuit at d-axis with excited capacitor [5]

From the equivalent circuit as Figure 2, is obtained voltage equations in dq axis:

$$\begin{bmatrix} V_{ds} \\ V_{qs} \\ V_{dr} \\ V_{qr} \end{bmatrix} = \begin{bmatrix} r_s + L_s p + \frac{1}{pC_e} & 0 & L_m p & 0 \\ 0 & r_s + L_s p + \frac{1}{pC_e} & 0 & L_m p \\ L_m p & \omega L_m & r_r + L_r p & \omega L_r \\ -\omega L_m & L_m p & -\omega L_r & r_r + L_r p \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} \quad (38)$$

The three external elements that can change the voltage profile of SEIG are speed, terminal capacitance and the load impedance. By varying the elements, one at a time the performance characteristics of the squirrel-cage induction generator obtained. In most of SEIG applications, the rotational speed is rarely controllable. Therefore, the load seen by the generator or terminal capacitance has to be controlled [9]. The load RL series, is conected parallel with the bank capacitor.

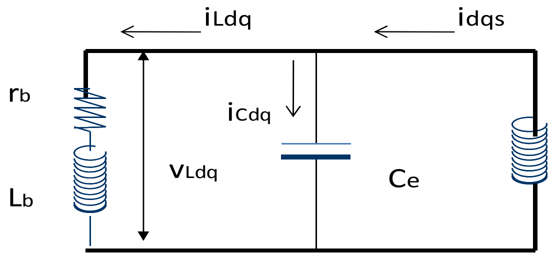


Figure 3. The SEIG RLC load [5]

$$i_{Cd} = C_e p \dot{V}_{Ld} = (r_b p C_e + L_b p^2 C_e) i_{Ld} \quad \text{and} \quad i_{Ld} = \frac{i_{ds}}{r_b p C_e + L_b p^2 C_e + 1} \quad (39)$$

Where:

$$i_{ds} = i_{Cd} + i_{Ld}\ , \quad \text{and } i_{ds} = (r_b p C_e + L_b p^2 C_e) i_{Ld} + i_{Ld}$$

$$V_{Ld} = (r_b + L_b p)\, i_{Ld} \quad \text{or} \quad V_{Ld} = \frac{r_b + pL_b}{r_b p C_e + L_b p^2 C_e + 1} i_{ds} \quad (40)$$

Using the the equivalent circuit for q-axis is obtained:

$$V_{Lq} = \frac{r_b + pL_b}{r_b p C_e + L_b p^2 C_e + 1} i_{qs} \quad (41)$$

The substitution voltage v_{cd} , v_{cq} and V_{Ld}, V_{Lq} to Equation (26)-(27) and (29)-(30), and then:

$$[v_{ds} \quad v_{qs} \quad v_{dr} \quad v_{qr}]^T = [Z]\,[i_{ds} \quad i_{qs} \quad i_{dr} \quad i_{qr}]^T \tag{42}$$

$$Z = \begin{bmatrix} r_s + pL_s + \frac{r_b + pL_b}{r_b p C_e + L_b p^2 C_e + 1} & 0 & pL_m & 0 \\ 0 & r_s + pL_s + \frac{r_b + pL_b}{r_b p C_e + L_b p^2 C_e + 1} & 0 & pL_m \\ pL_m & \omega L_m & r_r + pL_r & \omega L_r \\ -\omega L_m & pL_m & \omega L_{lr} & r_r + pL_r \end{bmatrix} \tag{43}$$

The Equation (33) until (36) is written in the state space model, as below:

$$[\dot{x}] = [A][x] + [B][u] \tag{44}$$

Where:

$$[B][u] = K \begin{bmatrix} -L_r & 0 & L_m & 0 \\ 0 & -L_r & 0 & L_m \\ L_m & 0 & -L_s & 0 \\ 0 & L_m & 0 & -L_s \end{bmatrix} \begin{bmatrix} v_{ds} \\ v_{qs} \\ v_{dr} \\ v_{qr} \end{bmatrix} \tag{45}$$

$$[x] = [i_{ds} \quad i_{qs} \quad i_{dr} \quad i_{qr} \quad V_{Ld} \quad V_{Lq} \quad i_{Ld} \quad i_{Lq}]^T \tag{46}$$

$$K = 1/\left(L_m{}^2 - L_s.L_r\right) \; : \tag{47}$$

$$A = K \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \tag{48}$$

$$A_{11} = \begin{bmatrix} r_s L_r & -\omega L_m{}^2 & -r_r L_m & -\omega L_m L_r \\ \omega L_m{}^2 & r_s L_r & \omega L_m L_r & -r_r L_m \\ -r_s L_m & \omega L_m L_s & r_r L_s & \omega L_r L_s \\ -\omega L_m L_s & -r_s L_m & -\omega L_r L_s & r_r L_s \end{bmatrix} \quad A_{12} = \begin{bmatrix} L_r & 0 & 0 & 0 \\ 0 & L_r & 0 & 0 \\ -L_m & 0 & 0 & 0 \\ 0 & -L_m & 0 & 0 \end{bmatrix}$$

$$A_{21} = \begin{bmatrix} 1/C_e K & 0 & 0 & 0 \\ 0 & 1/C_e K & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad A_{22} = \begin{bmatrix} 0 & 0 & -1/C_e K & 0 \\ 0 & 0 & 0 & -1/C_e K \\ 1/L_b K & 0 & 0 & 0 \\ 0 & 1/L_b K & 0 & 0 \end{bmatrix} \tag{49}$$

The reactance of inductance magnetizing Xm is determined using technical approach with the exponential equation as Equation (50):

$$X_m = \omega L_m = V_u / i_m = F.\left(K_1 e^{K_2 i_m{}^2} + K_3\right) \tag{50}$$

Using the equations of reactance, is done an algorithm of simulation the self excited induction generator using Runge Kutta method. First using the polynomial equation and second using the exponent equation.

Simulation using Linear Time-Variying State Model is used discrete computation runge kutta method of fourth order, in the state space equation as below [8]:

$$\dot{x}(t) = f(x, t) \tag{51}$$

$$x[(n-1)T] = x_T(n-1) \text{ and } x_T(n) \cong x(nT) \tag{52}$$

The sampling time T is *step interval*. The state space counting programme is using the function $f(x,t)$ for determine $\dot{x}(t) = f(x,t)$ along *x* and *t*. And then is determine every step as below:

For $x_T(n+1) \cong x((n+1)T)$ (53)

$$f(x,t) = [A(x(t))][x(t)] + [B(x(t))][u(t)] \quad (54)$$

And,

$$[A(nT)] = [A_T(n)] = [A_T(x_T(n))]$$
$$[B(nT)] = [B_T(n)] = [B_T(x_T(n))] \quad (55)$$

$$[A((n+1)T)] = [A_T(n+1)] = [A_T(x_T(n+1))]$$
$$[B((n+1)T)] = [B_T(n+1)] = [B_T(x_T(n+1))] \quad (56)$$

$$g_o \equiv f[(x_T(n))]$$
$$g_1 \equiv f\left[(x_T(n)) + g_o\left(\frac{T}{2}\right)\right]$$
$$g_2 \equiv f\left[(x_T(n)) + g_1\left(\frac{T}{2}\right)\right]$$
$$g_3 \equiv f[(x_T(n) + g_2 T)]$$
$$g_4 \equiv (g_o + 2g_1 + 2g_2 + g_3)/6 \quad (57)$$

Renew the state equation and time:

$$x_T(n+1) = x_T(n) + g_4 T \quad (58)$$

$$[A_T(n+1)] = [A_T(x_T(n+1))]$$
$$[B_T(n+1)] = [B_T(x_T(n+1))] \quad (59)$$

$$n = (n+1) \quad \text{and} \quad t = (n)T \quad (60)$$

$$x((n+1)T) = f(x_T(n), nT) \quad (61)$$

$$f(x_T(n), nT) = [A(x_T(n))][x_T(n)] + [B(x_T(n))][u(n)] \quad (62)$$

3. RESULTS AND ANALYSIS

The data of the self excited induction generator SEIG, three phase 380 volt, 50 hertz, 7.5 kW, and 4 poles [5].

Tabel 1. Data of Self Exitated Induction Generator [5]

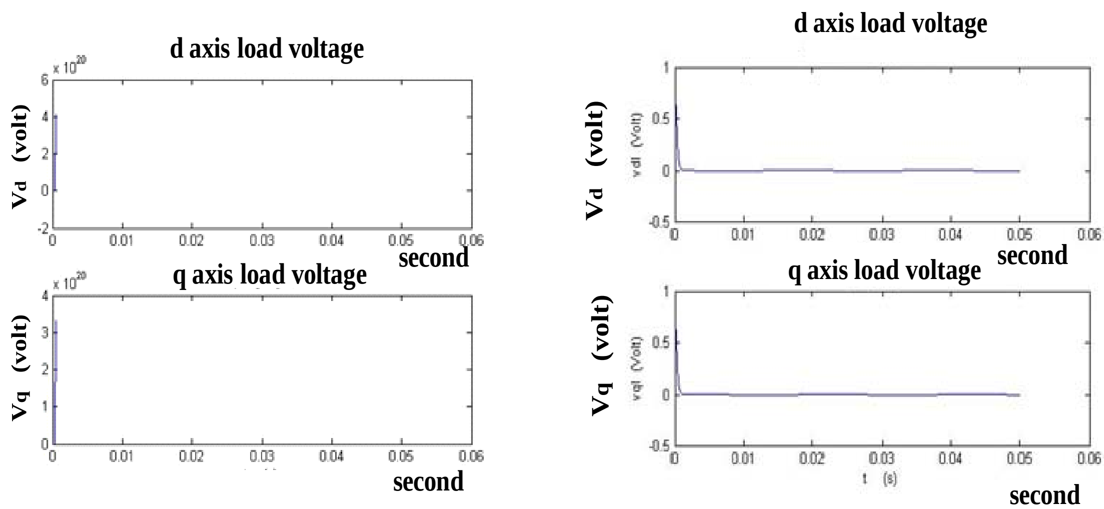
	magnitude	unit		magnitude	unit
r_s	1	Ohm	Ce	180	μF
L_s	1	mH	r_b	180	Ohm
r_r	0.77	Ohm	L_b	20	mH
Lr	1	mH	J	0.23	Kgm^2

3.1 Simulation using the Polynomial Equation

In this simulation is used the magnetizing inductance equation [5]:

$$L_m = 0.1407 + 0.0014 i_m - 0.0012 {i_m}^2 + 0.00005 {i_m}^3 \quad (63)$$

Using the parameter in Table 1, is done some of simulations using Equation (53) and sampling time 10^{-4} second. The load voltage response in dq axis is shown as Figure 4 as below:

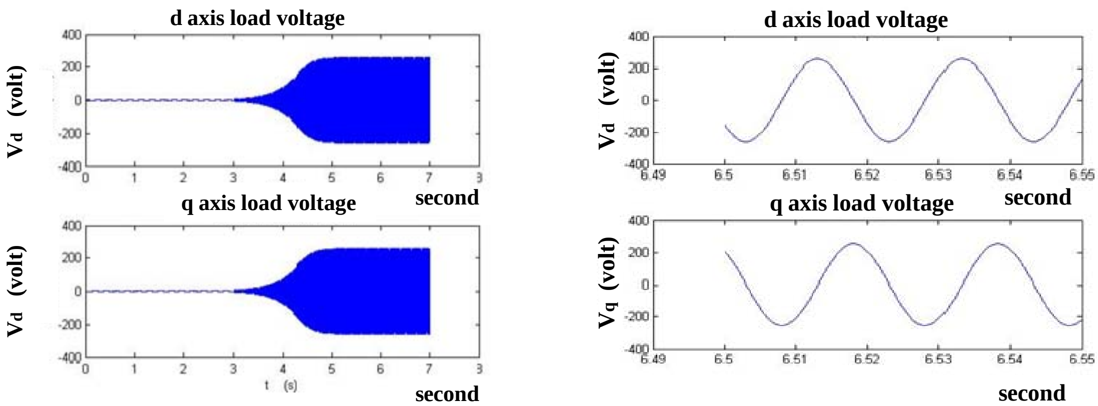


(a) (b)

Figure 4. Load voltage using (a) sampling time 10^{-4} second, (b) sampling time 10^{-5} second

In Figure 4(a) the load voltage, that it the simulation does not give good response and not occure of the excitation because the sampling time very high. The second simulation is used the sampling time reduce to become 10^{-5} second, and the result is shown in Figure 4(b). The accuracy choice of sampling time gives a best response.

After the excitation succeed, then using sampling time 10^{-5} second, is obtained the load voltage as Figure 5 as below:



(a) (b)

Figure 5. Load voltage at d axis and q axis (a) until 7 second. (b) time from 6.50 until 6.55 second

The load voltage rises begin at time is 3 second until 5 second and after that its is constant at voltage 240 volt, and the form of wave is pure the sine form with the frequency is 50 cycles per second, as the conclusion this method using polynomial equation gives the accuracy response. The magnetizing curve from polynomial equation is shown in Figure 6, as below:

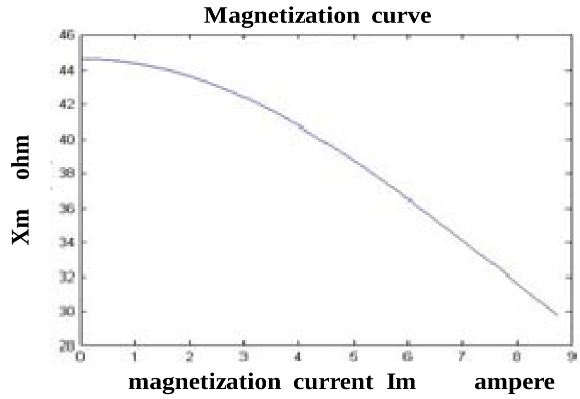


Figure 6. The magnetizing curve from polynomial equation

3.2. Simulation using the Exponent Equation

Base on using polinomial equation that it is iterrated by magnetizing current $\boldsymbol{i_m}$ in interval 0.01 ampere and then is determined the exponent equation using the programme "*constant Kij determine*", so that is obtained the curve as Figure 7, as below:

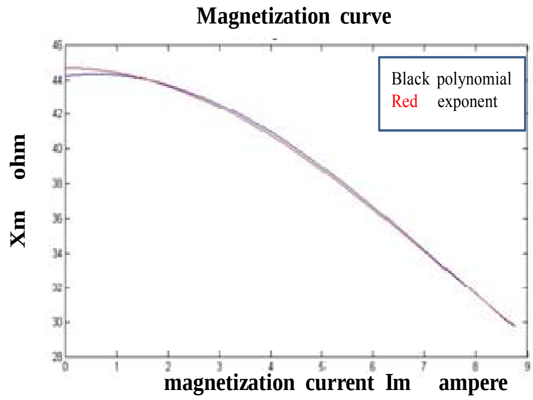


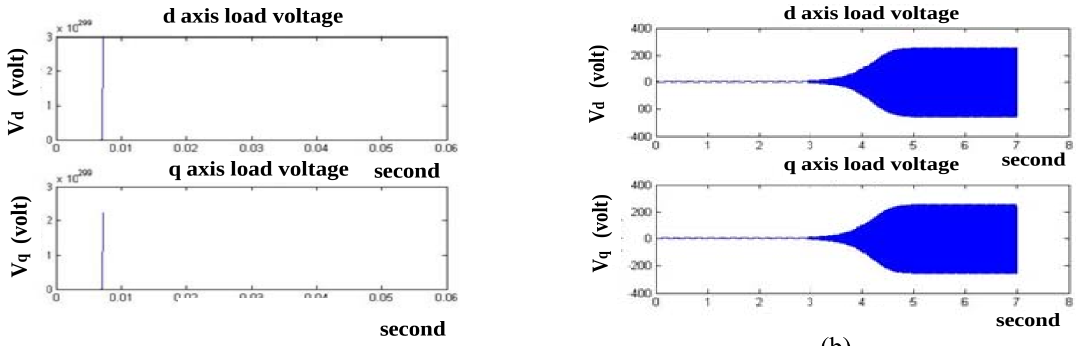
Figure 7. The polynomial equation using the exponent equation approach

Using the simulation and matlab programme is determined the constant K_1 = 0.1027 Ohm.second/radian , K_2 = -0.0081 1/ampere^2 and K_3= 0.0395 Ohm.second/radian. The magnetizing inductance curve L_m is shown in Figure 7 has exponent equation as Equation (64):

$$L_m = [0.1027 * (e^{-0.0081 * i_m * i_m})] + 0.0395 \quad (64)$$

Base on Figure 6, the magnetizing current starts from null ampere until 9 ampere. The constant value K_1, K_2 and K_3 is chosen, cause has a most precise value, that it nearst the polynomial equation until 9 ampere is shown as Figure 7. Using the data parameter motor and the exponent equation is done simulation , use the sampling time 10^{-4} second and the load voltage curve is shown as Figure 8(a). And then using the sampling time 10^{-5}second and do the simulation, is obtained the load voltage achieve the nominal voltage 240 volt, is shown as Figure 8(b):

The exponent equation of sinusoid load voltage at one periode is 20 milisecond, it means the frequency of sine wave is 50 cycles per second, and the peak load voltage achieves the nominal voltage 240 volt is shown in Figure 9. The result of simulation using the exponent equation is determine the magnetizing curve is shown as Figure 10.



(a) (b)

Figure 8. Load voltage using (a) sampling time 10^{-4} second, (b) sampling time 10^{-5}second

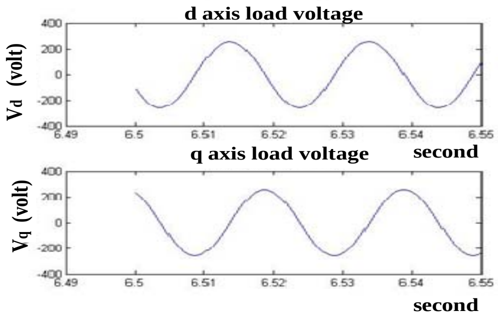


Figure 9. The load voltage at 6.50 until 6.55second

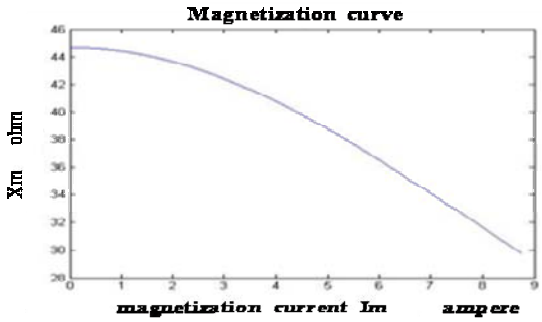
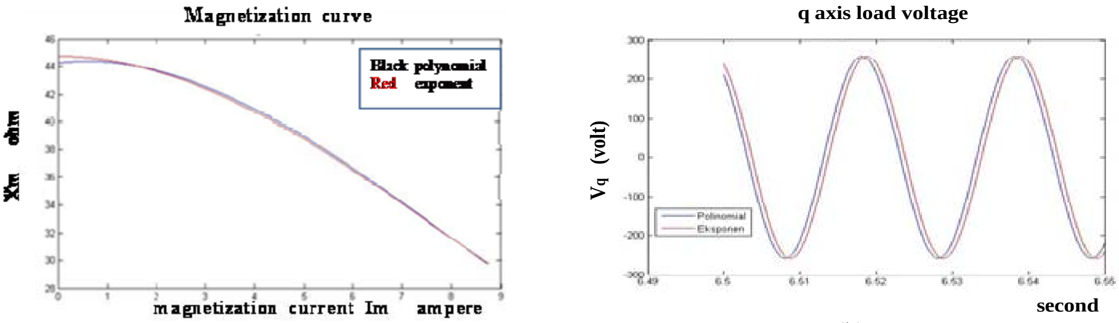


Figure 10. The magnetizing curve

3.3. Comparison Results Between The Polynomial And The Exponent Equations



(a) (b)

Figure 11. Comparison results using the polynomial and the exponent equation (a) the magnetism reactance Xm vs the magetizing current Im, (b) The loads voltage at q axis using the polynomial and the exponent equation

For to observe the difference between these results, is done to compare the data of it, that it are the magnetizing reactance *Xm* as function of and the magnetizing current i_m is shown as Figure 11(a). The second, to observe the difference results between the loads voltage using of both the equations. The load voltage at q-axis using the polynomial laggs 640 µs to the exponent equation and the polynomial voltage magnitude is less than 0.6068 volt from the exponent voltage magnitude. is shown as Figure 11(b).

4. CONCLUSION

The results have been determined for SEIG with using the iterration with sampling time , so much the smaller of sampling time, that the error value becomes very small. The accuracy choice of sampling time gives a best response. The phase to neutral output SEIG voltage for both equations achieves the nominal voltage and the form of waves are a sine wave. The comparison between the load voltages the polynomial and the exponent, the load voltage at using the polynomial laggs 640 µs to the exponent equation. The polynomial voltage magnitude is less than 0.6068 volt from the exponent voltage magnitude. The accuracy and exactness of magnetizing inductance equation L_m is very important, because these equations influence in determine of the equation in simulation depend on magnetizing current i_m. The accuracy of the magnetizing inductance L_m gives the output terminal voltage of SEIG is precision. The optimal distance of the air gap between stator and rotor, will be obtain the optimal magnetizing inductance. For the future this research can be expanded about noise in the air gap using the Wavelet Transform.

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