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MULTIPHASE INDUCTION GENERATOR (MODELING, ANALYSIS AND SIMULATION) AND POWER QUALITY

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ABSTRACT: In this research work the generator scheme presented in is based on the dual stator winding induction machine with displaced power and control three-phase winding having same number of poles and it deal with the double stator machine with extended rotor common to both stators. The analysis of steady-state performance is important for ensuring good quality power and assessing the suitability of the configuration for a particular application. Here complete modeling the Multi phase Induction Generator shown and so power quality improves.

1.INTRODUCTION:

The induction generator's ability to generate power at varying speed facilitates its application in various modes such as self-excited stand-alone (isolated) mode; in parallel with synchronous generator to supplement the local load, and in grid-connected mode. The research has been underway for the last three decades to investigate the various issues related to the use of induction generator as potential alternative to the synchronous generator to utilize the small hydro and wind energy to accomplish the future energy requirement, and to feed the power to remote locations and far flung areas, where extension of grid

is economically not feasible. This work, reviews the progress made in induction generator particularly, the self-excited induction generator (SEIG) research and development since its inception. Attempts are made to highlight the current and future issues involved in the development of multi phase induction generator technology for its large-scale future applications. The induction generator operation in the referred modes during steady-state and various transient conditions is important for the optimum utilization of its advantageous features. The analysis of steady-state performance is important for ensuring good quality power and assessing the suitability of the configuration for a particular application. In this work complete modeling the Multi phase Induction Generator and with the inclusion of series capacitors, voltage regulation profile of SEIG improves and to collect the output data of multiphase induction generator. To Simulate / Trained the data and saving the state in software. To mitigate the power quality such as voltage sag and swell using custom power devices are used.

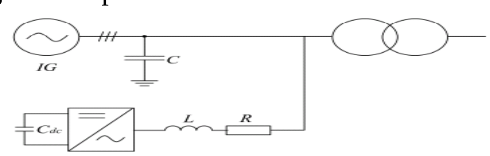

Figure 1. Single-line diagram of the induction generator with the shunt-connected capacitors and STATCOM.

A shunt-connected STATCOM may be used to regulate the voltage at the induction generator terminals. A STATCOM has been considered only during some phasor-type simulations. The STATCOM is represented as a Voltage Source Converter (VSC) with a capacitor on the dc link and it is connected to the generator terminals via a series RL filter, as shown in Figure 5. The control part of the STATCOM is implemented in a *dq* reference frame. The ac and dc voltage regulators are PI controllers. The current controller is a proportional-integral vector current controller (VCC). The series RL filter is directly implemented into the STATCOM model. The filter equations are implemented in the *dq* reference frame.

synchronous generators have been used for power generation but induction generators are increasingly being used and further researched these days because of their relative advantageous features over conventional synchronous generators. These features are brush less and rugged construction, low cast, maintenance and operational simplicity, self-protection against faults, good dynamic response, and capability to generate power at varying speed. The investigation spread over the

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last two decades indicate the technical and economic viability of using the number of phases higher than three in ac machine in general and induction machine in particular. With the growth of increasingly sophisticated design methods and increased importance of economic, environmental and several other factors, the multi-phase systems are being considered as one of the potential alternatives to conventional three-phase systems. With the use of higher phase in transmission, the interphase insulation requirement, spacing, conductor surface gradient and noise levels are reduced considerably. As a result, a multi-phase line with smaller dimensions can be used to transmit a larger amount of power covering entire range of transmission voltages. Because of the potential benefits resulting from the use of a phase order higher than three in transmission, some interest has also grown in the area of multi-phase machine. For machine drive applications, multi-phase system could potentially meet the demand for high power electric drive systems, which are both rugged and energy-efficient. A six-phase (split-phase) motor can be obtained by splitting the individual stator phase belts of a three phase motor into two equal halves with an angular separation of 30 electrical degrees between the two halves.

2.METHODOLOGY:

A. Modeling of Self-Excited Induction Generator:

A schematic representation of the stator and rotor windings for a two pole, six-phase induction machine is given in Fig.1. The six stator phases are divided into two wye-connected three-phase sets, labeled abc and xyz (called set I and II respectively), whose magnetic axes are displaced by an arbitrary angle cc. The windings of each three-phase set are uniformly distributed and have axes that are displaced 120^0 apart. Three-phase rotor windings Ar, Br, Cr are also sinusoidally distributed and have axes that are displaced by 120^0 apart. In developing the equations, which describe the behavior of a multi-phase machine, it is assumed that there is no physical fault propagation from one three-phase set to other three-phase set as neutral of both the stator winding sets are separate.

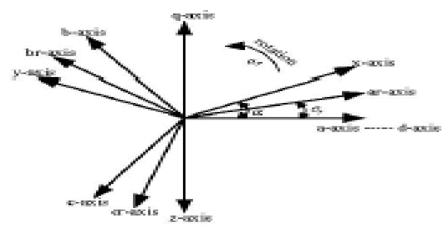

Fig. 2. A two-pole six-phase induction machine with α^0 and displacement between the two stator winding sets

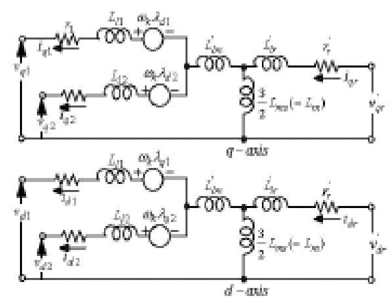

Fig. 3. The q- and d- axis equivalent circuit of a six-phase induction machine in arbitrary reference frame

The following voltage equations are written for a multiphase induction machine in arbitrary reference frame:

$V_{q1} = -r_1 i_{q1} + w_k \lambda_{d1} + p\lambda_{q1}$ ----(1.1)

$V_{d1} = -r_1 i_{d1} + w_k \lambda_{q1} + p\lambda_{d1}$ ----(1.2)

$V_{q2} = -r_2 i_{d1} + w_k \lambda_{d1} + p\lambda_{q1}$ -----(1.3)

$V_{d2} = -r_2 i_{d2} + w_k \lambda_{q2} + p\lambda_{d2}$ -----(1.4)

$0 = -r_r i_{qr} + (w_k - w_r)\lambda_{dr} + p\lambda_{qr}$ -----(1.5)

$0 = -r_r i_{dr} + (w_k - w_r)\lambda_{qr} + p\lambda_{dr}$

Where, w_k is the speed of the reference frame, p denotes differentiation w.r.t. time, w_r is the rotor speed, and all other symbols have their usual meaning. Here, rotor quantities are referred to stator. The expressions for stator and rotor flux linkages are:

$\lambda_{q1} = -L_{11} i_{q1} - L_{1m}(i_{q1} + i_{q2}) + L_m(-i_{q1} - i_{q2} + i_{qr})$

$\lambda_{d1} = -L_{11} i_{d1} - L_{1m}(i_{d1} + i_{d2}) + L_m(-i_{d1} - i_{d2} + i_{dr})$

$\lambda_{q2} = -L_{12} i_{q2} - L_{1m}(i_{q1} + i_{q2}) + L_m(-i_{q1} - i_{q2} + i_{qr})$

$\lambda_{d2} = -L_{1id2} - L_{1m}(i_{d1} + i_{d2}) + L_m(-i_{d1} - i_{d2} + i_{dr})$

$\lambda_{qr} = -L_{1r} i_{qr} + L_m(-i_{q1} - i_{q2} + i_{qr})$

$\lambda_{dr} = -L_{1r} i_{dr} + L_m(-i_{d1} - i_{q2} + i_{qr})$

$L'_{1m} = (N_1 / N_2) L_{1m}$

Where, N1 and N2 are the number of turns of the abc and xyz winding sets respectively, and

L_{lm} is the common mutual leakage inductance between the two sets of stator winding, Lm is the mutual inductance between stator and rotor. L_{lm} is given by:

$$L1m = L1ax \cos\alpha + L1ay \cos(\alpha + 2\pi/3) + L1az \cos(\alpha - 2\pi/3)$$

These equations suggest the equivalent circuit as shown in Fig. 2. The common mutual leakage inductance L_{lm} in Fig. 2 represents the fact that the two sets of stator windings occupy the same slots and are, therefore, mutually coupled by a component of leakage flux. This mutual leakage inductance, L_{lm} has an important effect on the harmonic coupling between the two stator winding sets and depends on the winding pitch and the displacement angle between the two stator winding sets. The basic reason for the effect of coil pitch on leakage reactance is that, with short pitch coils, some slots have conductors belonging to two different phases. The current in these phases are out of phase with each other, and therefore, the net slot current and leakage flux are less than for slots with currents belonging to same phase. The result is a reduction in reactance dependent on the fraction of slots having shared conductors and also on the phase angle between their currents. Standard test procedures [10] are available to determine the various machine parameters. In the above expressions, the prime quantities are referred to stator. As for as transient behavior is concerned, it has been found that neglecting the stator mutual leakage reactance X_{lm} has no noticeable effect except some changes in voltage harmonic distortion (VHD). Solving for the currents and back substituting these currents into the voltage equation and rewriting them as differential equations yields:

$$p\lambda_{q1} = [\, V_{q1} - w_k \lambda_{d1} - (r_1 / L)((L_{12} + L_{1m}')\lambda_{q1} - L_{1m}'\lambda_{q2} - L_{12}\lambda_{mq})]$$

$$p\lambda_{d1} = [\, V_{d1} - w_k \lambda_{q1} - (r_1 / L)((L_{12} + L_{1m}')\lambda_{d1} - L_{1m}'\lambda_{d2} - L_{12}\lambda_{md})]$$

$$p\lambda_{q2} = [\, V_{q2} - w_k \lambda_{d2} - (r_1 / L)((L_{11} + L_{1m}')\lambda_{q2} - L_{1m}'\lambda_{q1} - L_{11}\lambda_{mq})]$$

$$p\lambda_{d2} = [\, V_{d2} - w_k \lambda_{q2} - (r2 / L)((L_{11} + L_{1m}')\lambda_{d2} - L_{1m}'\lambda_{d1} - L_{11}\lambda_{md})]$$

$$p\lambda_{qr} = [-(w_{k-} w_{r)} \lambda_{dr} - (r_r/L_{1r}))(\lambda qr - \lambda_{mq})]$$

$$p\lambda_{dr} = [-(w_{k-} w_{r)} \lambda_{qr} - (r_r/L_{1r}))(\lambda_d r - \lambda_{mq})]$$

where,

$$\lambda mq = A\,[\,(L_{12}\lambda_{q1} + L_{11}\lambda_{q2}) / (L) + (\lambda_{qr} / L_{1r})$$

$$\lambda md = A\,[\,(L_{12}\lambda_{d1} + L_{11}\lambda_{d2}) / (L) + (\lambda_{dr} / L_{1r})$$

$$A = 1/[\,1/L_m) + (1/L_{1r}) + ((L_{11} + L_{12}) / L)\,]$$

$$L = [\,L_{11} L_{12} + L_{1m}'(L_{11} + L_{12})\,]$$

The torque and rotor dynamics equations can be expressed as:

$$T_{em} = (3/2)(P/2)(L_m/L_r)[\,i_{q1} + i_{q2})\lambda_{dr} - (i_{d1} + i_{d2})\lambda_{qr}\,]$$

$$(w_r / w_b) = (1/p)[\,(1/w_b)(P/2)(1/J)(T_{em} - T_{sh})$$

Where, T_{sh} is shaft torque (prime mover torque), P is number of poles, J is moment of inertia, w_b is the base speed (rad. /sec.), and $L_r = L_{1r} + L_m$

The magnetizing inductance Lm depends on the degree of saturation and it is non-linear function of the magnetizing current Im, which can be expressed by the following equation for the given test machine.

$$I_m = \sqrt{\,[(-i_{q1} - i_{q2} + i_{qr})^2 + (-i_{d1} - i_{d2} + i_{dr})^2}$$

$$L_m = a_1 + a_2 Im + a3\, Im^2 + a_4\, Im^3$$

Where a1, a2, a3, a4 are constants.

B. Modeling of Shunt excitation Capacitors:

The voltage current equations of the excitation capacitor can be transformed from the three-phase quantities into d-q axis ones by using Krause transformation [11,12] and are given by :

$$P\,V_{q1} = (i_{q1c} / C_{sh1}) - w_b V_{d1}$$

$$P\,V_{d1} = (i_{d1c} / C_{sh1}) + w_b V_{q1}$$

$$P\,V_{q2} = (i_{q2c} / C_{sh2}) - w_b V_{d1}$$

$$P\,Vd2 = (i_{d2c} / C_{sh1}) + w_b V_{q2}$$

Where, i_{qlc}, i_{dlc} and i_{q2c}, i_{d2c} are q- and d- axis components of currents flowing into the exciter capacitor, C_{shl} and C_{sh2} connected across the three-phase winding set I and II respectively.

C. Modeling of Series Capacitors:

The current through series capacitor C_{se1} and C_{se2} (in case of short shunt) connected in winding set I and II respectively is same as the load current. The load current along with series capacitance determine the voltage across series capacitor, and when transformed into d-q axis is given by

$$PV_{q1se} = i_{q1L} / C_{se1}$$

$$PV_{d1se} = i_{d1L} / C_{se1}$$

$$PV_{q2se} = i_{q2L} / C_{se2}$$

$PV_{d2se} = i_{d2L} / C_{se2}$

And the load terminal voltage is expressed as:

$V_{Lq1} = V_{q1} - V_{q1se}$

$V_{Ld1} = V_{d1} - V_{d1se}$

$V_{Lq2} = V_{q2} - V_{q2se}$

$V_{Ld2} = V_{d2} - V_{d2se}$

D. Modeling of Static Load:

If a resistive load is connected across the terminal of the generator, the load current (without series capacitor) can be given by:

$I_{d1L} = V_{d1} / R_1$, and $i_{q1L} = V_{q1} / R_1$

$I_{d2L} = V_{d2} / R_2$, and $I_{q2L} = V_{q2} / {}_{R2}$

Applying Kirchhoff's current law at capacitor terminals, the current flowing through the shunt capacitor will be given by

$I_{q1c} = i_{q1} - i_{q1L}$, and $i_{d1c} = i_{d1} - i_{d1L}$

$I_{q2c} = i_{q2} - i_{q2L}$, and $i_{d2c} = i_{d2} - i_{d2L}$

Hence, with pure resistive load the voltage equation can be modified as

$PV_{q1} = (i_{q1}/ C_{sh1}) - (V_{q1} / (R_1C_{sh1})) - w_b V_{d1}$

$PV_{d1} = (i_{d1}/ C_{sh1}) - (V_{d1} / (R_1C_{sh1})) + w_b V_{d1}$

$PV_{q2} = (i_{q2}/ C_{sh2}) - (V_{q2} / (R_2C_{sh2})) - w_b V_{d2}$

$PV_{d2} = (i_{d2}/ C_{sh2}) - (V_{d2} / (R_2C_{sh2})) + w_b V_{d2}$,

Where R_1 and R_2 are load resistances connected across the winding set I and II respectively.

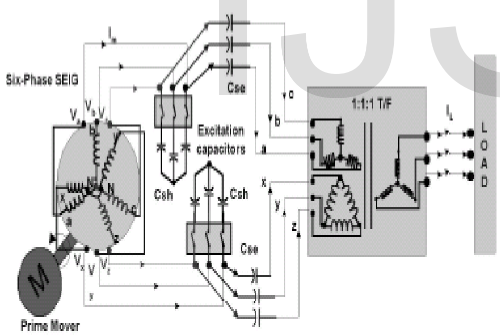

Fig.4 Schematic diagram of generator system employing a split wound six-phase SEIG.

E. ANALYTICAL RESPONSE OF SIX-PHASE SEIG:

The theoretical studies using MATLAB /SIMULINK have been carried out on a six-phase self-excited induction generator. In the study, the effect of cross saturation has been neglected [11].The transient performance under following operating conditions have been presented, (i) Voltage and current build-up of six-phase SEIG at no-load, (ii) Dynamic response under resistive loading without, and with series compensation, (iii) Dynamic response under R-L loading without, and with series compensation.

(i)Voltage Build-Up at No Load:

Fig. 5 shows in result the analytical waveform of voltage and current during no-load voltage build up for the two threephase winding sets. In the present study, the per phase value of the shunt excitation capacitance is selected as 90 uF. The steady state no-load voltage generated is about 250 V at rated speed of 1500 rpm. It is observed that the SEIG terminal voltage and current build-up from their initial value of few volts and few amperes to their steady state values. The rate of no-load voltage and current buildup depend upon the value of shunt excitation capacitance and the level of residual magnetism in the rotor circuit of the SEIG.

(ii)Transient Response of Sudden Switching of Resistive Load without Series Compensation:

Fig. 6 in results displays the simulated transient response of six phase SEIG terminal voltage and load current, while switching-in a resistive load of 200 ohm at t = 2 sec. On sudden application of the resistive load, the terminal voltage is reduced to 75 V. This decrease in terminal voltage also causes a decrease in excitation capacitor current, which further affects the voltage regulation of the generator. The poor voltage regulation of the SEIG is due to lack of reactive power that can be compensated through series capacitor connected in each line.

(iii)Transient Response of Sudden Switching of Resistive Load with Series Compensation:

The transient response of six-phase SEIG feeding a resistive load of 200 ohm, when series capacitors of 10 ,uF are connected in each line between load and SEIG as short shunt. When load is suddenly switched-on at t = 2 sec, the SEIG almost retains the no load voltage because of self regulating reactive power supplied by the series capacitors. As it is evident from Fig. 8, the voltage level before the switching of load is more than the no-load voltage since the series capacitors are assumed to be connected before the switching-in of the load. It is found that drop in SEIG terminal voltage becomes less susceptible to sudden loading conditions as a result of series compensation. The application of series

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capacitor results in an over-voltage across the generator terminals. A careful selection of the value of shunt and series capacitors may avoid the excessive voltage at SEIG terminals. The selection of series capacitance should be justified not only on the basis of full load voltage regulation but also from the view point of load voltage profile and maximum utilization of the machine as the generator.

(v)Transient Response of RL Load with Series Compensation:

Series capacitors of value 15uF each were connected in series with the generator terminals as short shunt scheme. The voltage and current responses are shown in Fig. 10. The load is switched on at t = 2 sec. It is observed that the SEIG retains the no-load voltage due to the reactive power supplied by the series capacitors. As shown in Fig. 10, the voltage before the switching of the RL load at t = 2 sec, is more than the no-load voltage. It is due to the fact that the series capacitors are assumed to be connected before the switching-in of the load. For a SEIG with constant speed, the speed of the rotating magnetic field lags behind the rotor speed. With the increase in the load of the SEIG, the magnitude of the negative slip increases. In this case, as the rotor speed is the input, the increase in slip is due to the decrease in the speed of the rotating magnetic field. Since generated voltage and frequency are proportional to the speed of rotating magnetic field, a decrease in the speed of rotating magnetic field will inevitably decreases the generated voltage and frequency.

3.RESULTS:

The **expected results** of this research are as given below:

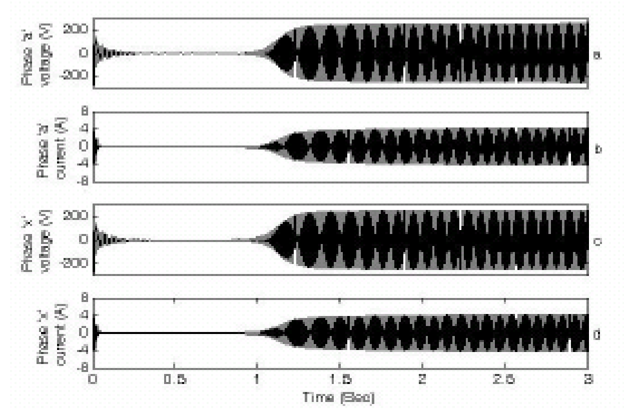

Fig. 5. Voltage and current build-up of six-phase SEIG at no load

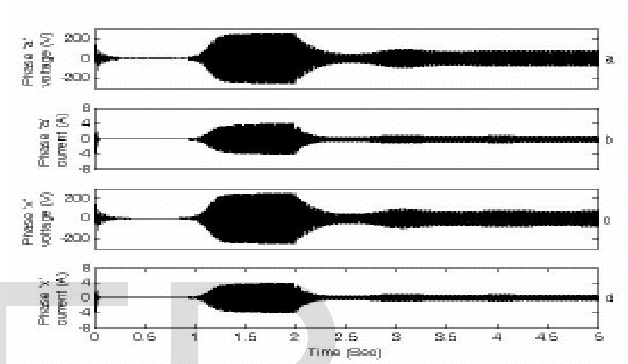

Fig.6 Transient performance of six-phase SEIG on switching of resistive load without series compensation

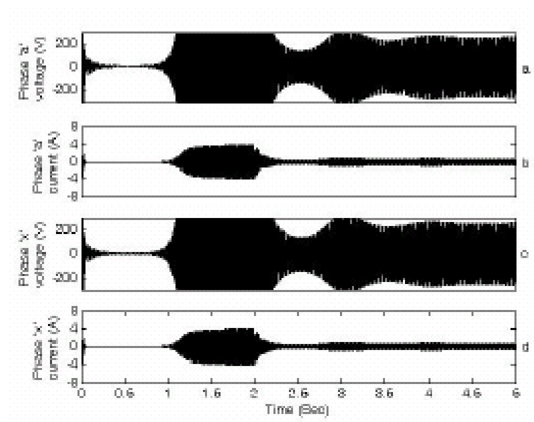

Fig. 7. Transient performance of six-phase SEIG on switching of resistive load with series compensation

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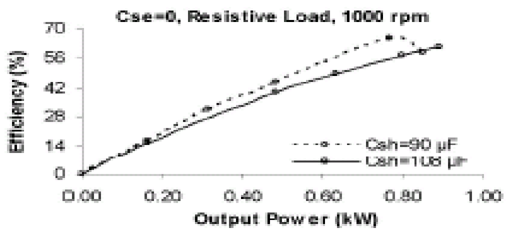

Fig. 8. Load Characteristics showing effects of shunt capacitances (C_{sh} = 90µF to 108 µF)

4. CONCLUSION:

In this work here, a simple and unified mathematical model for six-phase self-excited induction generator (SEIG) has been developed for power quality. The paper presents the simulated results for six-phase SEIG under different loading conditions. With inclusion of series capacitors, the voltage regulation profile of SEIG improves because series capacitors provide the additional VAR requirement with increase of load current. . It is found that some of the major drawbacks such as voltage collapse and situations that results total demagnetization regarding the operation of a three-phase SEIG are improved in this case. The results of experimental investigations conducted on three phase SEIG are not included in this paper, a comparative study conducted on a three-phase and six-phase SEIG reveals that at reasonable amount of load that Variation in 6-phase SEIG terminal voltage and current is less; Variation in load voltage in case of 6-phase SEIG is less; Sensitivity of 6-phase SEIG with respect to speed during self-excitation is less.

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