IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 13, Issue 1 Ver. IV (Jan. – Feb. 2018), PP 61-66
www.iosrjournals.org

Six Phase Induction Motor Modelling For Submarine Application

Akpama, E. J.
Department of Elect/Elect Engineering, Cross River University of Tech., Calabar/Nigeria
Corresponding Author: Akpama, E. J.

Abstract: *Research in electrical machine design is tilting towards multiphase systems, due its numerous advantages. As the quest for energy efficient systems increases, research in this regard also increases. Mostly in the area of energy conversion systems, notably, the induction machines with the attended high energy demand. An energy efficient motor will definitely reduce cost of industrial processes and save energy. Research reveals that multiphase motors are more economical, efficient and reliable than the traditional three phase motors. In locomotion and ship propulsion systems, multiphase machines are highly recommended because of their improved reliability and efficiency. Depending on the complexity of design, submarines sometimes may need more than one propulsion motor for different operations within the submarine power system network. Some of these submarines are used as warships; as such the designer's interest is to reduce noise. In order to reduce machine noise, multiphase is proposed in this paper among other advantages comparing with three phase. This paper models a sixphase induction motor using state space method to develop models for simulation. Simulation in MATLAB environment carried transient stability studies. The single sixphase is cost effective, reliable and more efficient compared to the three phase machine.*

Key words*: six-phase motor, Submarines, MATLAB Simulation, Reliability, machine noise.*

Date of Submission: 15-02-2018 Date of acceptance: 01-03-2018

I. Introduction

The submarine industry is witnessing a burst in its daily operation with the presence of multiphase motors. Normally, every submarine is driven by two or more propulsion motors and the motors have their different control panels. The dc motor was the only choice in ship propulsion due to the ease of speed control, until the advent of AC drives. The induction motor is gradually replacing the dc motor industrially. It is possible now to control and regulate the speed of an induction motor and other ac motors using ac motor drives. Among the groups of multiphase motors, the six-phase has received more attention due its simplicity in converting a conventional three phase machine to six-phase [1]. This is achieved by splitting the phase belt of three phase machine, that is, two sets of three phase in the stator winding of the original three phase, with set I spanning 30^0 electrical from set II having a common magnetic structure[2-3]. Multiphase induction machine finds its applicability in the area of high degree reliability demand as in more electric aircrafts, electric ship propulsion, electric vehicles, (EH) and hybrid electric vehicles (HEV).

II. Evolution of Electric Propulsion

The advances in power electronics and machine drives technology have currently revolutionized the marine engineering industry. Specifically, new innovations in machines' design have brought increased reliability and cost reduction in propulsion system. New generation of electric propulsion and Integrated Electric System (IES) are establishing new configurations which are strong contenders for future surface combatants, [4-8]. At first, it was the traditional ship propulsion (TSP) shown in figure 1. This is a mechanical gear system which is characterized with high maintenance cost due to the gear transmission system. The introduction of integrating electric power generation and distribution system, figure 2, into ship system modified the marine industry, [9-11]. This gave rise to the development of the Integrated Electric Ships (IES) shown in figure 3.

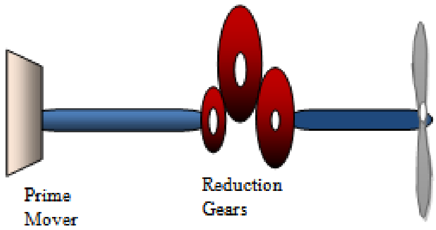

Figure 1: Traditional Ship Propulsion (TS)

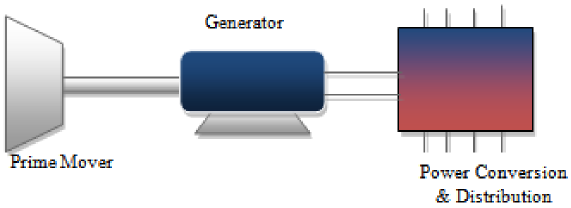

Figure 2: Ship Power Generation

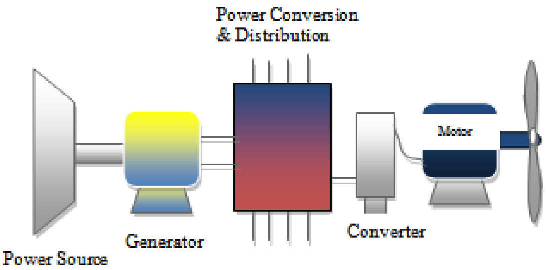

Figure 3: IES Ship Propulsion.

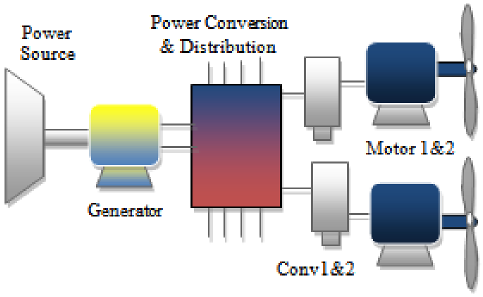

Figure 4: IES Ship Propulsion with Two

According to [8,9], IES is more advantageous than the Traditional ship, the advantages includes; superior survivability, a longer range, higher resolution sensing, a more effective self-defense, an improved speed and endurance, improved fight through capability, reduced signatures and vulnerability, superior affordability, use of datable platforms, reduced workload, superior mission performance, higher rates of fire, deeper magazines, increased weapons range, improved support for forces ashore etc. Propulsion in ships and submarines with electric motors is not new. It evolved in the 19^{th} century when a small battery-powered, electric-propelled passenger launch was built and operated in Russia [10]. Between the end of the 19^{th} and the early 20^{th} century research interest has grown in electric propulsion. In 1908, a turbine –driven generator and two propulsion motors were installed on a German vessel and a similar system was installed on a fireboat in the United States [11].The installation of a 5500 Hp wound Rotor Induction motor in the Collier Jupiter was carried out between the year, 1911 to 1913 by the U.S Navy and became Navy's first aircraft carrier Langley. The vessel operated for 31 years and was lost in combat action in 1943 due to reliability problems, [12]. Submarines were not left out in the use of electric propulsion. The past century has witnessed the presence of numerous individual ships with electric motors in the propulsion system. These include; the aircraft carrier Langley and Saratoga and the battle ships New Mexico, California, Maryland and West Virginia [13-14]. During World War II, electric propulsion was extensively used due to lack of gear cutting capacity in the U.S. A lot of escort ships were built that used electric propulsion during World War II. Due to the advances in power electronics, manufacturing techniques and materials for electromagnetic machines were developed. This resulted into different designs of electric drives system over the years depending on their applications. In the submarine power system, the propulsion system is one of the major units and the induction motor is the major unit in the propulsion system. This is depicted in figure 4, using only two motor drive systems for example. It is observed that the system in figure 4, is more advantageous having two separate motors. More advantages is recorded the two motors are replaced with a single six-phase motor

III. Modelling of Six Phase Induction Machine

In order to model the six phase induction machine, the Park's transformation is applied, and the rotor reference frame is adopted [18-19].

The voltage equation of a split phase induction machine is written as, where $\alpha=30^0$ elect

$V_{as}=V\cos\omega_e t$ (1)

$V_{bs}=V\cos(\omega_e t-2\pi/3)$ (2)

$V_{cs}=V\cos(\omega_e t+2\pi/3)$ (3)

$V_{xs}=V\cos(\omega_e t-\alpha)$ (4)

$V_{ys}=V\cos(\omega_e t-2\pi/3-\alpha)$ (5)

$V_{zs}=V\cos(\omega_e t+2\pi/3-\alpha)$ (6)

Using the appropriate transformation, the phase voltage of set I, ABC, is transformed to its equivalent d-q axis as below;

$V_{qs}=2/3(V_{as}-V_{bs}/2-V_{cs}/2)$ (7)

$V_{ds}=2/3(\sqrt{3}/2[-V_{bs}-V_{cs}])$ (8)

For a balance system, since

$V_{as}=-V_{bs}-V_{cs}$ (9)

Then equation (7) becomes

$V_{qs}=V_{as}=V\cos\omega_e t$ (10)

Simplifying equation (8)

$V_{ds}=1/\sqrt{3}(V_{cs}-V_{bs})$ (11)

$V_{ds}=1/\sqrt{3}(V\cos(\omega_e t+2\pi/3)-V\cos(\omega_e t-2\pi/3)$ (12)

Applying Euler's identity to equation (9), the result becomes

$V_{ds}=-V\sin\omega_e t$ (13)

Due to symmetry, the same analysis is carried out in the second set of winding set XYZ.
The dq voltage equations of a six-phase induction machine are readily written as in [19]:

$V_{q1}=r_1 i_{q1}+\omega_k\lambda_{d1}+p\lambda_{q1}$ (14)

$V_{d1}=r_1 i_{d1}-\omega_k\lambda_{q1}+p\lambda_{d1}$ (15)

$V_{q2}=r_2 i_{q2}+\omega_k\lambda_{d2}+p\lambda_{q2}$ (16)

$V_{d2}=r_2 i_{d2}-\omega_k\lambda_{q2}+p\lambda_{d2}$ (17)

$V_{qr}=0=r_r i_{qr}+(\omega_k-\omega_r)\lambda_{dr}+p\lambda_{qr}$ (18)

$V_{dr}=0=r_r i_{dr}-(\omega_k-\omega_r)\lambda_{qr}+p\lambda_{dr}$ (19)

The flux linkage equations are given below;

Let $I_{q1}=i_{q1}+i_{q2}$

$I_{d1}=i_{d1}+i_{d2}$

$I_{1q}=i_{q1}+i_{q2}+i_{qr}$

$I_{1d}=i_{d1}+i_{d2}+i_{dr}$

$\lambda_{q1}=L_{l1}i_{q1}+L_{lm}I_{q1}+L_{dq}i_{d2}+L_{mq}I_{1q}$ (20)

$\lambda_{d1}=L_{l1}i_{d1}+L_{lm}I_{d1}+L_{dq}i_{q2}+L_{md}I_{1d}$ (21)

$\lambda_{q2}=L_{l2}i_{q2}+L_{lm}I_{d1}+L_{dq}i_{d1}+L_{mq}I_{1q}$ (22)

$\lambda_{d2}=L_{l2}i_{d2}+L_{lm}I_{d1}+L_{dq}i_{q1}+L_{md}I_{1d}$ (23)

$\lambda_{qr}=L_{lr}i_{qr}+L_{mq}I_{1q}$ (24)

$\lambda_{dr}=L_{lr}i_{dr}+L_{md}I_{1d}$ (25)

Let

$Ldq=0$, $L_m=L_{mq}=L_{md}$, $L_1=L_{l1}+L_{lm}+L_m$,

$L_2=L_{l2}+L_{lm}+L_m$,

$L_3=L_{lm}+L_m$, $L_r=L_{lr}+L_m$ (26)

Where $\alpha=\omega_r-\omega_k$ (27)

Using state variable method, equation (31) is put in state variable form as in [20,21];

$$\text{idot}=[L][V]-[L]^{-1}[G][1] \quad (28)$$

where,

$$[V]=[V_{q1}\ V_{d1}\ V_{q2}\ V_{d2}\ V_{qr}\ V_{dr}] \quad (29)$$

$$[I]=[i_{q1}\ i_{d1}\ i_{q2}\ i_{d2}\ i_{qr}\ i_{dr}] \quad (30)$$

$$[L]=\begin{bmatrix} L_1 & 0 & L_2 & 0 & L_m & 0 \\ 0 & L_1 & 0 & L_2 & 0 & L_m \\ L_3 & 0 & L_2 & 0 & L_m & 0 \\ 0 & L_3 & 0 & L_2 & 0 & L_m \\ L_m & 0 & L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_m & 0 & L_r \end{bmatrix} \quad (32)$$

$J_m p(\omega_m)=(T_e-T_L)$ (33)

$$[G] = \begin{bmatrix} r_1 & w_k L_1 & 0 & w_k L_2 & 0 & w_k L_m \\ -w_k L_1 & r_1 & -w_k L_2 & 0 & -w_k L_m & 0 \\ 0 & w_k L_3 & r_2 & w_k L_2 & 0 & w_k L_m \\ -w_k L_3 & 0 & -w_k L_2 & r_2 & -w_k L_m & 0 \\ 0 & \alpha L_m & 0 & \alpha L_m & r_r & \alpha L_m \\ \alpha L_m & 0 & -\alpha L_m & 0 & -\alpha L_m & r_r \end{bmatrix} \quad (31)$$

Matlab m-files are developed based on equation (28) to simulate the transient performance of a six-phase, 4 pole, 50Hz, 24 slot squirrel cage six phase induction machine. The MATLAB program uses Ode 45, based on an explicit Runge-Kuta (4,5) which is a one-step ordinary differential equation solver to compute and predict the transient performance of the machine.

Fig. 5: A graph of abc phase currents of SET I

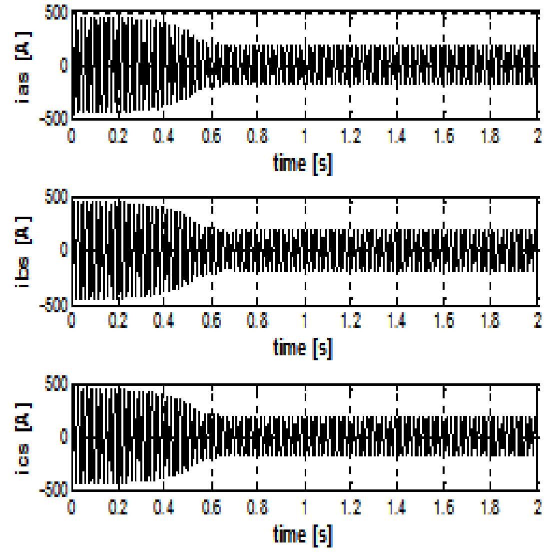

Fig. 5: A graph of abc phase currents of SET I

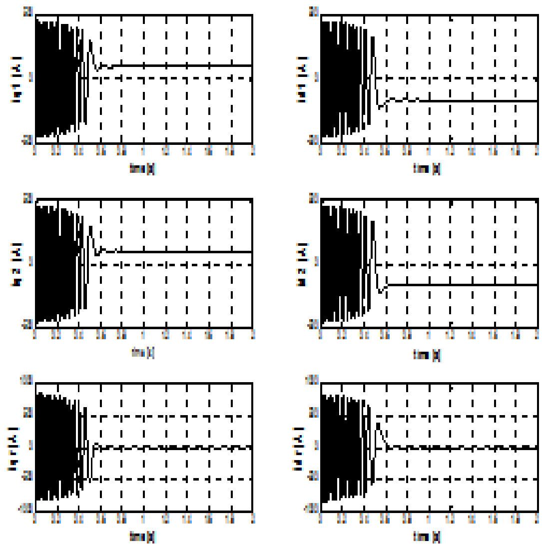

Fig 7: A graph of dq currents

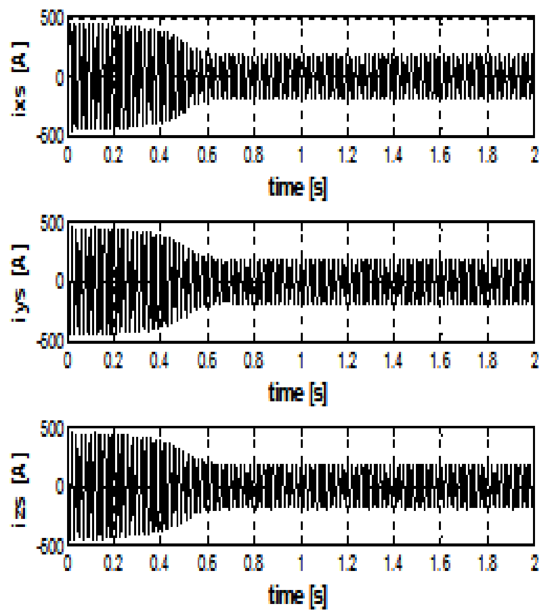

Fig. 6: A graph of xyz phase currents of SET II

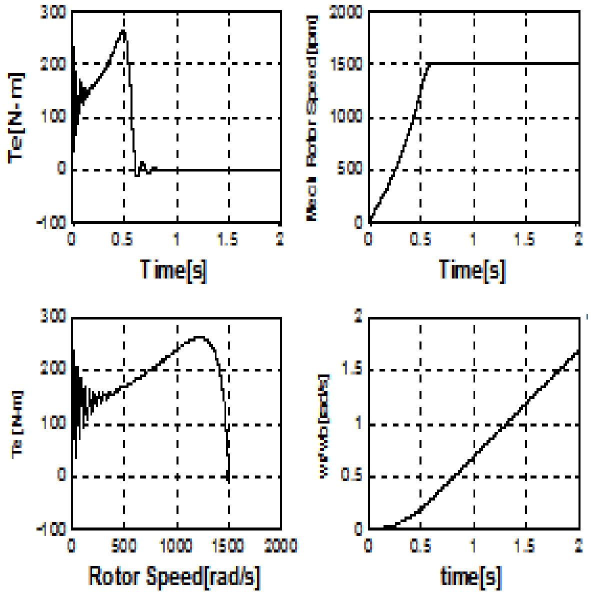

Fig. 8: Torque and Speed

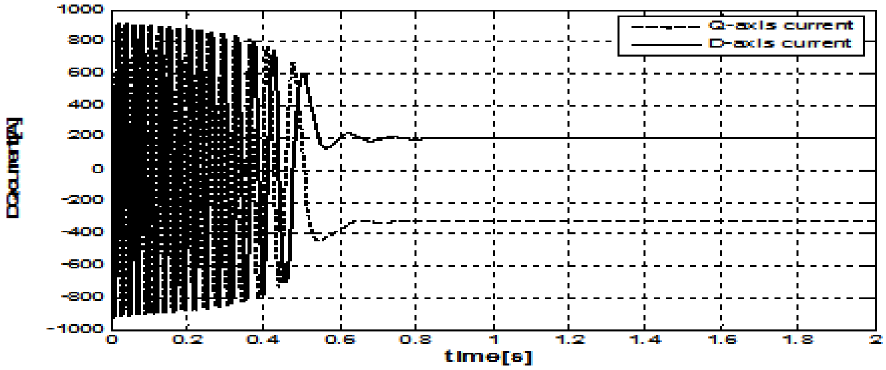

Fig. 9: A graph of Q- and D-axis currents against

The simulation results are as computer traces is presented in figures 5-9 above. The results are quite instructive, showing that the sixphase induction machine is a two-three phase machine in one. Figure 5 and 6, shows the six stator currents (Ias, Ibs, Ics and Ixs, Iys, Izs). Also in figure 7, the dq currents are presented and the speed and torque response in figures 8 and 9 respectively. The ABC and XYZ currents transient rises and stabilizes at 0.6 s, while the electromagnetic Torque is stable at 0.7s. The mechanical rotor speed reaches synchronous speed at 0.6s, the vector sum of the q-axis and d-axis is also presented for investigation purposes, this agrees favourably with the theoretical concept.

IV. Discussion of Results

The simulation results are as computer traces is presented in figures 5-9 above. The results are quite instructive, showing that the sixphase induction machine is a two-three phase machine in one. Figure 5 and 6, shows the six stator currents (Ias, Ibs, Ics and Ixs, Iys, Izs). Also in figure 7, the dq currents are presented and the speed and torque response in figures 8 and 9 respectively. The ABC and XYZ currents transient rises and stabilizes at 0.6 s, while the electromagnetic Torque is stable at 0.7s. The mechanical rotor speed reaches synchronous speed at 0.6s, the vector sum of the q-axis and d-axis is also presented for investigation purposes, this agrees favourably with the theoretical concept.

V. Conclusion

The simulation result shows that, the six phase machine is a dual stator induction machine (DSIM) with two sets of three phase currents; Iabc and Ixyz. This is expected because DSIM is like paralleling two three phase induction motors. So, instead of using two three phase induction motor for propulsion (submarines), a single DSIM can replace the two and the cost is reduced and reliability increased which in fact is the actual aim of this paper. There is a possibility of controlling Iabc and Ixyz independently for different functions, mostly when driven by variable frequency drives. Mostly importantly, the reliability, efficiency and torque are enhanced.

References

[1] G. K., Singh, “Multi-phase induction machine drive research-a survey”, Electr. Power Syst. Res., Vol. 61, 2002, pp. 139-147.
[2] J. Apsley, S. Williamson, “Analysis of multi-phase induction machines with winding fault”, IEEE Trans. on Ind. Applications, Vol. 42,issue 2, 2006, pp. 465-472.
[3] A.N. Golubev, S.V Ignatenko, “Influence of number of stator-winding phases on the noise characteristics of an asynchronous motor”, Russian Elect Eng’ring, Vol. 71, No. 6, 2000, pp. 41–46.
[4] L. Petersen, “Next Generation Integrated Power System: The Backbone of the Electric Warship (Hybrid Electric Drive: A Near Term Opportunity), keynote presentation given at IEEE International Electric Machines and Drives Conference, May 6, 2009.
[5] T. Eccles, Luncheon presentation given at ASNE Advanced Naval Propulsion Symposium, December 2008.
[6] C. G. Hodge, D. J. Mattick, “The Electric Warship I”, Transactions of International Marine Engineering, Vol. 108, Part 2, pp.102-114, 1996.
[7] C. G. Hodge, D. J. Mattick, “The Electric Warship II’’, Transactions of International Marine Engineering, Vol. 109, Part 2, pp. 127-144, 1997.
[8] C. G. Hodge, D. J. Mattick, “The Electric Warship III’’, Transactions of International Marine Engineering, Vol. 110, Part 2, pp.119-134, 1998.
[9] D. Parker, M. Bolton, ”The Electric Warship”, Proceedings of International Conference on the Naval Technology for the 21st Century, Hellenic Naval Academy, pp. 43-48, Piraeus (Greece), 29-30 June 1998.
[10] R. Ramshaw, R. G. V. Heeswijk, “Energy Conversion Electric Motors and Generators”, Saunders College Publishing, Orlando, FL, 1990.
[11] A. J. Mitcham, J. J. A. Cullen, “Motors and Drives for Surface ship propulsion: Comparrson of Technologies,” The Institute of Marine Engineers: Electric Propulsion, The Effective solution?, paper 4, 1995.

[12] T. B. Dade, R. A. Gellatly, "Permanent Magnet Propulsion Motor Technology and ship Design," AES97- First International Symposium and Exhibition on Civil or Military All Electric Ship, session A1 – Electric Propulsion Motors paper A.1.1, pp. 1-9, 1997.
[13] T. J. Doyle, H. O. Stevens, H. Robey, "An Historical overview of Navy Electric Drives," Procs: Naval Symposium on Electric Machines, pp. 137-147, 1997.
[14] U.S. Navy Bureau of Ships, 'Turbine Electric drives Basic Principles,' pp. 79-83, 1945.
[15] R. W. G. Bucknall, M. A. Waythe, "Full Electrical Propulsion for a future Warship," The Institute of Marine Engineers First Int. Naval Engineering Conference: Solutions to the Challenge of a New defence Environment, pp. 215-224, 1992.
[16] B. D. Thomas, 'Advance Electric Propulsion, Power Generation, and Power Distribution'. Naval Engineers Journal, March 1994. pp. 83-92,
[17] J. G. Ciezki, R. W. Ashton, "A survey of AC Drive Propulsion Options." Proceedings; Third Naval Symposium on Electric Machines, Dec, 2000. pp 4-7,
[18] A. R. Munoz, T. A. Lipo, " Dual stator winding induction machine drive," IEEE Transactions on Industry Applications, vol. 36, Sept 2000. pp. 1369 – 1379,
[19] J. C.Salmon and B. W. Williams, "A split-wound induction motor design to improve the reliability of PWM inverter drives," IEEE Trans. Ind. Applicat., vol. IA-26, Jan./Feb. 1990. pp. 143–150,
[20] K. Gopakumar, T. Ranganathan, S. R. Bhat, "Split-phase induction motor operation from pwm voltage source inverter," IEEE Transactions on Industry Applications, vol. 29, Sept 1993. pp. 927– 932,
[21] A. R. Bakhshai, G. Joos, H. Jin, "Space vector PWM control of a split-phase induction machine using the vector classification technique," Proceedings of Applied Power Electronics Conference and Exposition, 1998, vol. 2, pp 802 – 808,

Akpama, E. J. "Six Phase Induction Motor Modelling For Submarine Application"IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) 13.1 (2018): 61-66.