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A Comparative Study Between PI and ANFIS Controlled 6 Switch Inverter Fed Permanent Magnet Synchronous Motor Drive For Marine Applications

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ABSTRACT

The present scenario of excessive emission of greenhouse gases and the resulting pollution, the significance of measures for reducing this emission is immense. The fact that around 15% of the global emission of Nitrogen Oxide is caused due to marine system along with efficiency requirements and many more reasons paved way for the concept of All Electric Ship (AES). Permanent Magnet Synchronous Motor (PMSM) is supposed to be the best choice for marine vessel application because of the smooth torque, reduced losses, vibrations and noises. Also PMSM has a high performance in both higher and lower operation speeds. In order to increase the ease of implementing and executing the motor drive system, the control strategy for the system is designed using Adaptive Neuro-Fuzzy Inference system (ANFIS). In this paper, a comparative study is done between a PI and ANFIS controlled 6 switch inverter fed PMSM for marine vessel application with a wind power source. Both the control strategies along with the entire marine system were simulated in MATLAB Simulink and the outputs were analyzed.

Keywords: AES, PMSM, ANFIS, Wind power system

1. INTRODUCTION

Due to the steadily demanding environmental needs and the increasing power requisites new technologies are emerging the maritime industry [1]-[2]. Strict regulations were imposed on ship emission by the International Maritime Organization (IMO) in the regimentation of International Convention for the Prevention of Pollution from Ships (MARPOL) [3]. In order to meet the minimum efficiency needs, the IMO has proposed energy efficiency indicators. The power electronic converters (PECs) became popular in the marine industry in the 1980s by facilitating the electrification of the propulsion systems with the introduction of the 3VF (variable-voltage variable-frequency) drive technology [4]. The initial advancement took place in the late 1980s with the adapting of electrical propulsion on-board in Queen Elizabeth II which resulted in a fuel saving of up to 35% [5]. Improved maneuverability & compactness were the assets of employing PECs that resulted in the present scenario of fostering the concepts of more-electric ship (MES) or AES [6]. The ship power system has been continuously improving from a conventional Mechanical-Drive System to an Integrated Power System (IPS) with all the generators integrated to a single power grid that is used for power distribution to the entire marine vessel which is illustrated in figure 1. With the application of IPS, equal amount of power as the conventional electric power system can be generated at very low to medium speed ranges by using lesser number of prime movers. This is advantageous in both environmental and economic aspects in order to improve the fuel efficiency and also to reduce the emission of greenhouse gases. The fact about Ship Power System (SPS) is that it is an isolated system with the loads placed in close approximation with the power generation units termed as the Ship-board Microgrids (SMGs). In marine systems, a huge amount of power is supplied locally to the loads of a smaller area which has multiple challenges such as safety, power quality, reliability and accuracy.

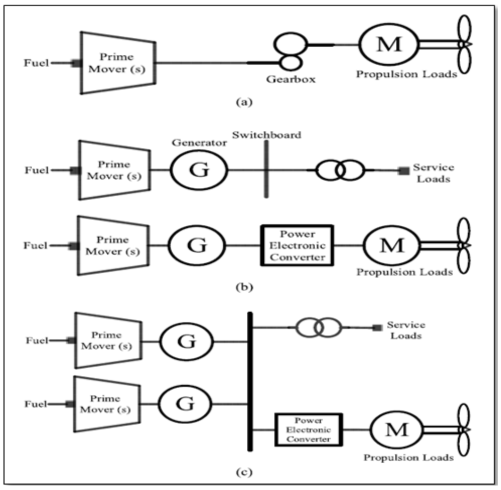

Figure 25: (a) Mechanical propulsion power system. (b) Conventional electric-drive system. (c) Integrated Power System (IPS).

The major stages of a marine electric power system are power generation, power distribution that consists of switchboards & transformers and the loads that consists of propulsive & service loads [7]. Figure 2 shows the general line diagram of a marine electric power system. Synchronous generators driven by prime movers fuelled by heavy oil or

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diesel constitute the power generation unit of a maritime network. Gas engines are also used in case of low cost energy source requirement for high speed vessel. Multiple power sources are used in a marine vessel in order to improve the efficiency, reliability & operating mode. For efficient, reliable & safe distribution of power to various parts of the ship switchboards and transformers are used. The various types of switchboards used are Main Switchboard, Distribution board & Emergency switchboard. Protection, monitoring & measuring devices and main bus bars constitute the main switchboard. An emergency generator is connected to the emergency switchboard along with the essential loads. Another important part of a distribution system is the power transformer which serves the purpose of isolating the various parts of the electric power system & provide voltage as per the load requirements. In certain marine vessels, the transformers behave as phase shift transformers in order to cancel the current harmonics from frequency converters. Reduced voltage distortion for the loads at PCC & generators is obtained as a result of reduced current harmonics. The high frequency noise is also damped by the transformers. The loads are mainly of two categories viz., Propulsion or Thruster loads and Service loads [8].

The research case for this paper is a real hybrid ferry. Hybrid refers to the DC/AC distribution structure and the

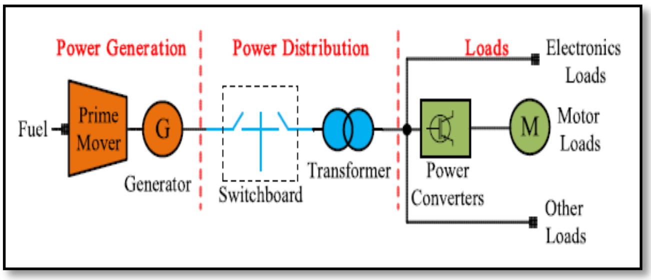

Figure 2: Line diagram of marine power system.

hybrid power sources. The proposed system is flexible for three operation modes of SMGs which are, the purely electrified mode of operation, the extended range mode of operation and the charging mode of operation [9].

In the first mode of operation, the SMG behaves as a purely electrified machine with a DC distribution system in order to control the DAB converter [10] for stabilizing the voltage at the DC bus and also for limiting the discharging current of the battery unit. The SMG behaves as a DC/AC hybrid system in the extended range mode of operation, in which case the major task is to control & coordinate the PMSG sets and DC/AC converter. And in the last mode of operation, the service loads are supplied & the battery units are charged.

2. PROPOSED HYBRID ELECTRIC FERRY SYSTEM

Figure 3 shows the modified design of the complete system of the hybrid electric ferry incorporating the propulsion motors are supplied by a battery units through a bidirectional DC/DC Dual Active Bridge (DAB) converter, two permanent magnet synchronous generators (PMSG) are connected to the AC bus in order to supply the service loads and a bidirectional DC/AC converter with an L filter constitutes the path for the power flow between the AC & DC bus.

The proposed system consist of a wind power system as a hybrid energy source. This system consists of a wind turbine, a Maximum Power Point Tracking (MPPT) system and a PMSG. The Simulink model of the Wind Power System is shown in figure 4. The system is designed in such a way that if the wind speed becomes equal to or less than a specific value then the battery unit will discharge and above the same the wind energy conversion system will behave as the power source. The proposed system consist of a wind power system as a hybrid energy source. This system consists of a wind turbine, a Maximum Power Point Tracking (MPPT) system and a PMSG. The Simulink model of the Wind Power System is shown in figure 4. The system is designed in such a way that if the wind speed becomes equal to or less than a specific value then the battery unit will discharge and above the same the wind energy conversion system will behave as the power source.

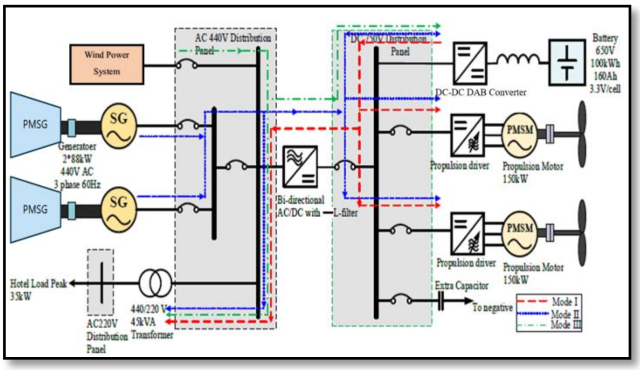

Figure 3: Design of Hybrid Electric Ferry

A DAB is a bidirectional DC/DC converter with two indistinguishable primary & secondary side full-bridges, an energy transfer inductance that refers to the transformer leakage inductance, DC link capacitors and a high frequency transformer.

The interleaved 3 phase DC/DC converter proposed in [9] is replaced by a bidirectional DC/DC DAB converter because of the easy implementation of ZVS and high power density. The DAB converter provides for the charging and discharging of the battery units based on the wind speed.

The control for the system is implemented using ANFIS. ANFIS is an artificial neural network based on Sugeno fuzzy inference system. The hardware implementation of an ANFIS based control circuitry is easier compared to any other control strategy. The feedback network for this system is designed by choosing the DC link voltage as the reference parameter.

With the output of the wind energy conversion system being a varying parameter, on using PI controller for the given system the control strategy is not adaptable and on simulating the system power factor is affected. The reason being that the PI controller is being designed for fixed

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parameters and any change in the parameters will cause instability. On the other hand ANFIS being an adaptive neural network, the system is adjusted in such a way as to maintain the system stability even with the change in parameters. In this methodology the system was initially modelled in MATLAB using PI controller and the corresponding input and output values were fed as the sample data for the ANFIS in order to train the adaptive fuzzy network.

The PI controller was designed by choosing the values of k_p and k_i using trial and error method with reference to the DC link voltage. The DC link voltage for the system is 1200V. For any value of DC link voltage that is varying, the value of k_p is adjusted accordingly by keeping k_i constant. The desirable value of k_p would be greater than 1. On obtaining a steady state error the value of k_p is kept constant and the value of k_i is varied. The value of k_i is chosen in such a way that $0 < k_i < 1$.

Later the system was modelled using ANFIS as the control strategy and the output waveforms were compared with the output waveforms for PI controlled system. FFT Analysis was done for both the cases and the Total Harmonic Distortion (THD) was also found to be slightly better while using ANFIS compared to the THD while using PI control which is an added advantage.

3. SIMULATION AND RESULTS

Initially the system was modelled using a PI control for the PMSM and later the same system was implemented using ANFIS. The Simulink models and the resultant waveforms are given below. The FFT window for either cases are also given below which shows that the TFD is improved on executing the control strategy using the ANFIS. The waveforms for torque and speed for both the cases are compared below.

The proposed system consists of the wind energy conversion system, battery units, motor and its control, non-linear load and the generator set. In order to prove that the control circuitry operates with high efficiency a delay of 0.2 sec is provided before the control circuit could start functioning.

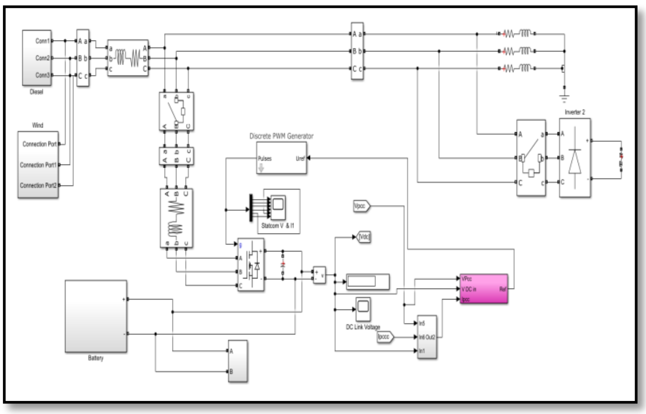

Figure 4: Simulink model for the proposed system

The non-linear load is modelled in MATLAB using a diode rectifier and an RL load which is made to operate during the time interval from 0.2s to 0.25s.

The wind energy conversion system is implemented using the MATLAB block for wind turbine which has three inputs. The three inputs for this block are pitch angle, wind speed and the generator speed. Based on the wind speed obtained the mode of operation changes. The battery charges and discharges depending on this parameter.

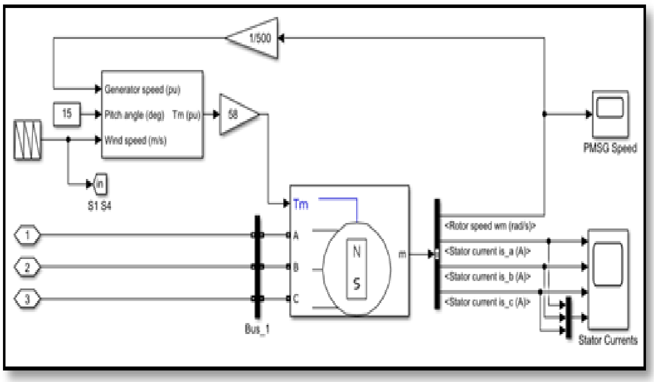

Figure 5: Simulink model for the wind power system

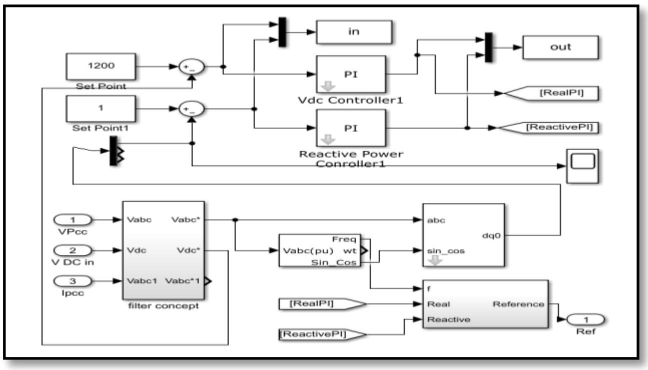

Figure 6: Simulink model for PI control

The MATLAB Simulink model for PI and ANFIS control is shown in figures 6 and 7 respectively. The input and output parameters for the PI controlled system was used as sample data for training the ANFIS network.

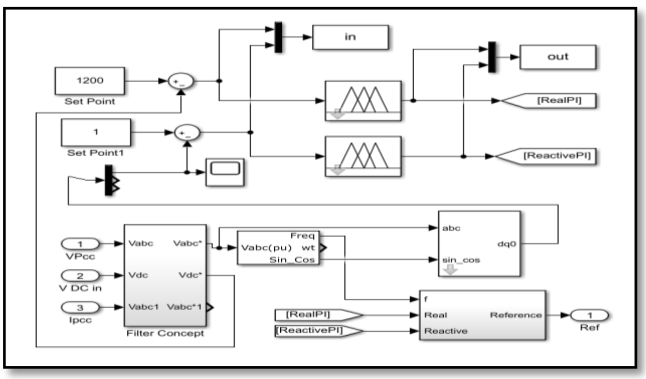

Figure 7: Simulink model for ANFIS control

In this case, the required rpm for the motor is set as 1000

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rpm. Initially, the motor runs at the rated speed of 1200rpm and at 0.2 seconds, the rpm is reduced to 1000rpm as per the requirement. The set point or the required speed can be changed manually in case of emergencies in order to control the speed of the ferry as per environmental conditions and the system will adapt to the change with no much delay.

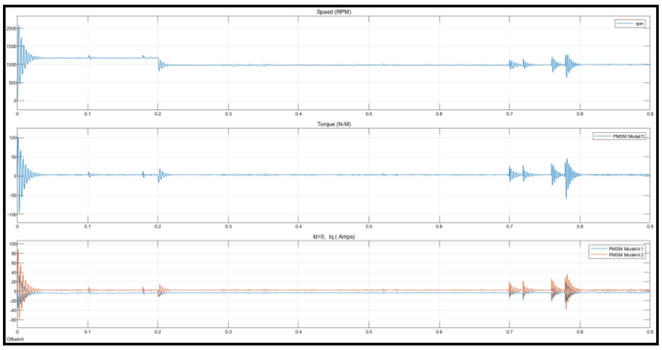

Figure 8: Output Waveforms for Speed, Torque and Id & Iq for ANFIS controlled system.

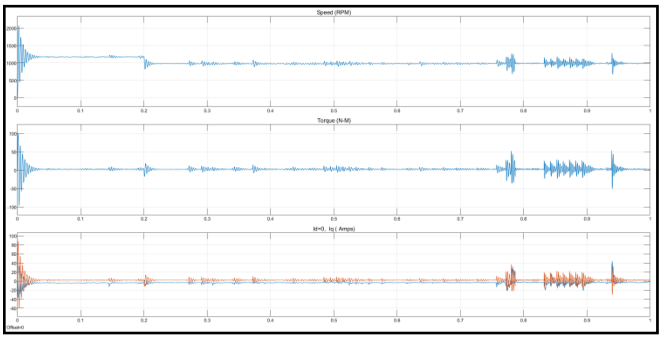

Figure 9: Output Waveforms for Speed, Torque and Id & Iq for PI controlled system.

The system is losing its stability beyond 0.7 seconds for the PI controlled system. The output waveforms for torque and speed shows that the characteristics are improved and that the efficiency is increased on using ANFIS control than while using PI control. The simulation is being performed for a duration of 0.9seconds.

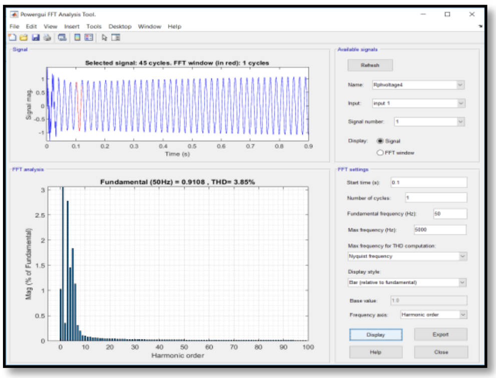

Figure 10: FFT Analysis for PI controlled system ANFIS controlled system.

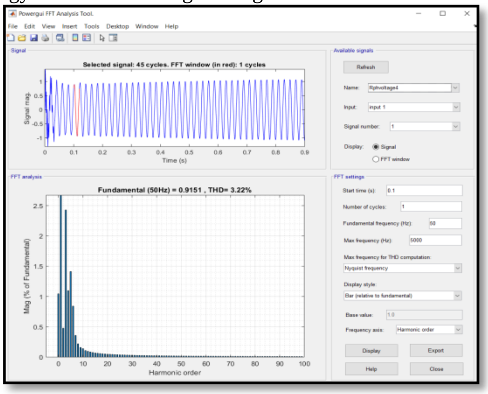

Figure 11: FFT Analysis for PI controlled system ANFIS controlled system.

The result of the FFT analysis shows that the THD for the PI controlled system is 3.85% whereas the THD for the ANFIS controlled system is 3.22%. Hence the THD has slightly improved for the system incorporating ANFIS control.

4. CONCLUSION

The system was proposed using a PMSM for propulsion employing PI and ANFIS control whose characteristics were studied in either cases and it was found that the system had better characteristics while employing ANFIS control. This control strategy was proposed due to its easiness in realizing the control algorithm. Absence of mathematical implementation makes the proposed system more accurate. The need of real time sample data is still a small concern which has to be met. The results from the FFT analysis shows the added advantage of improved THD. The proposed system also involves a wind energy conversion system which utilizes wind energy for propulsion and also for charging the battery. The application of bidirectional DC/DC DAB converter is also advantageous as the LCL filter of the actual system was replaced by an L filter in the proposed system. Thus it can be seen that the system was made more efficient, compact and accurate by incorporating the above changes.

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