DETAILED MODELLING OF PERMANENT MAGNET SYNCHRONOUS MOTOR (PMSM) FOR ELECTRICAL FORKLIFTS PART-I

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Abstract
The research work deals with Detailed modelling of permanent magnet synchronous motor for electrical drives. Permanent magnets to replace the electromagnetic pole with windings requiring a less electric energy supply source resulted in compact dc machines. Likewise in synchronous machines, the conventional electromagnetic field poles in the rotor are replaced by the PM poles and by doing so the slip rings and brush assembly are dispensed. With the advent power semiconductor devices the replacement of the mechanical commutator with an electronic commutator in the form of an inverter was achieved. These two developments contributed to the development of PMSMs and Brushless dc machines. Due to many applications of PMSM like sensor less speed control servo motor.
Key-Words:- *Permanent Magnet Synchronous Motor, Electrical driven Forklifts, Modelling of Permanent Magnet Synchronous Motor, Distributed Magneto motive force.*

1. Introduction
Permanent Magnets to replace the electromagnetic poles with windings requiring a less electric energy supply source resulted in compact dc machines. Likewise in synchronous machines, the conventional electromagnetic field poles in the rotor are replaced by the permanent magnet poles ad by doing so the slip rings and brush assembly are dispensed. With the advent power semiconductor devices the replacement of mechanical commutator with an electronic commutator in the form of an inverter was achieved. These two developments contributed to the development of PMSM and Brushless dc machines. due to many applications of PMSM like sensor less speed control, appropriate position control, servomotor and many others. In this paper we have discussed Mathematical modelling of permanent magnet synchronous motor is carried out and simulated using MATLAB. The most important features of PMSM is its high efficiency given with the ratio of input power after deduction of loss to the input power. There is no field current or rotor current in the permanent magnet synchronous motor.

2. Dynamic Modelling of PMSM
The dynamic model of the permanent magnet synchronous machine (PMSM) is derived using a two-phase motor in direct and quadrature axes. This approach is done because of the conceptual simplicity obtained with only one set of two windings on the stator. The rotor has no windings, only magnets. The magnets are modelled as a current source or a flux linkage source, concentrating all its flux linkages along only one axis. The flux linkages of the stator q and d windings are derived from first principles. The physical modelling of the machine is developed from which the circuit model is derived. Constant inductance for windings is obtained by a transformation to the rotor by replacing the stator windings with a fictitious set of d-q windings rotating at the electrical speed of the rotor. The equivalence between the three-phase machine and its model using a set of two-phase windings is derived and this approach is suitable for extending it to model an n phase machine where n is greater than 2, with a two-phase machine. The transformation from the two –phase to the three-phase variables of voltages, currents, or flux linkages is derived in a generalized way.
The following assumptions are made to derive the dynamic model: 1. The stator windings are balanced with sinusoidally distributed magneto motive force (mmf).

2. The inductance versus rotor position is sinusoidal.
3. The saturation and parameter changes are neglected

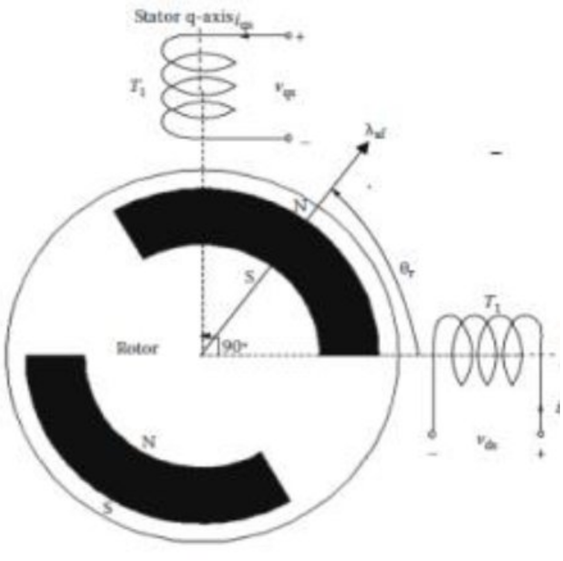

Fig1. A two-phase PMSM

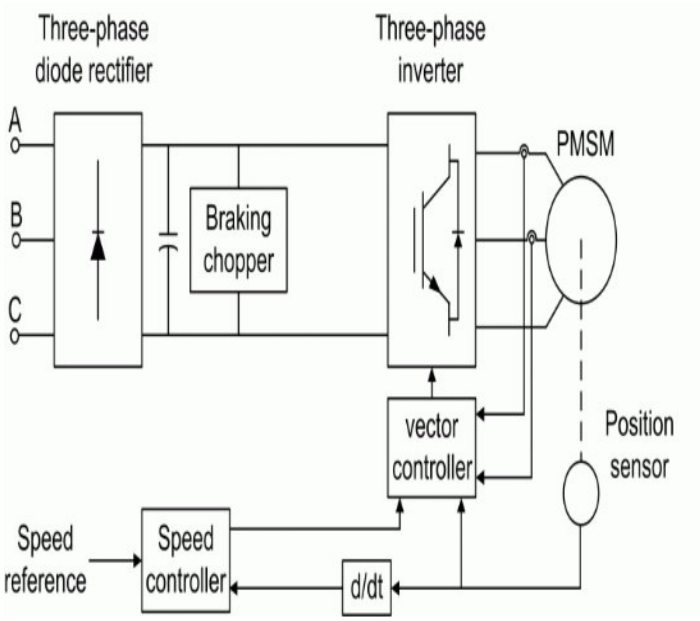

Fig 2. Actual diagram of a PMSM with speed controller

3. Modelling of Three-Phase Induction Motor

Electric motor drives are used in a very wide power range, from a few watts to many thousand kilowatts, in applications ranging from very precise high performance position controlled drives in robotics to variable speed drives for adjusting flow rates in pumps.

In All drives where the speed and position are controlled, a power electronic converter is needed as an interface between the input power and the motor. Above a few hundred watts power level, there are basically three types of motor drives: DC Motor drives, Induction Motor drives and Synchronous motor drives. AC Motor drives have replaced DC drives in most of the applications as they have more advantages to offer. The application or process determines the requirements of the motor drive For example, a servo-quality drive is needed in robotics, machine tools, paper mill or steel mill drives whereas only an adjustable speed drive is needed in air conditioning system.

In servo applications of motor drives, the response time and response time and the accuracy with which the motor follows the speed and position commands are extremely important. These servo system, using one of these motor drives, requires speed and position feedback for precise control. In addition if any AC Motor drive is used, the controller must incorporate sophistication, such as field oriented control, to make the AC motor meet the servo drive requirements. However in a large number of applications –e.g. process control, the accuracy and the response time of the motor to follow the speed command is not critical since the processes have large time constants. However, even where speed response is not critical, energy efficiency- both copper and total power demand for a given output power is always a very important consideration.

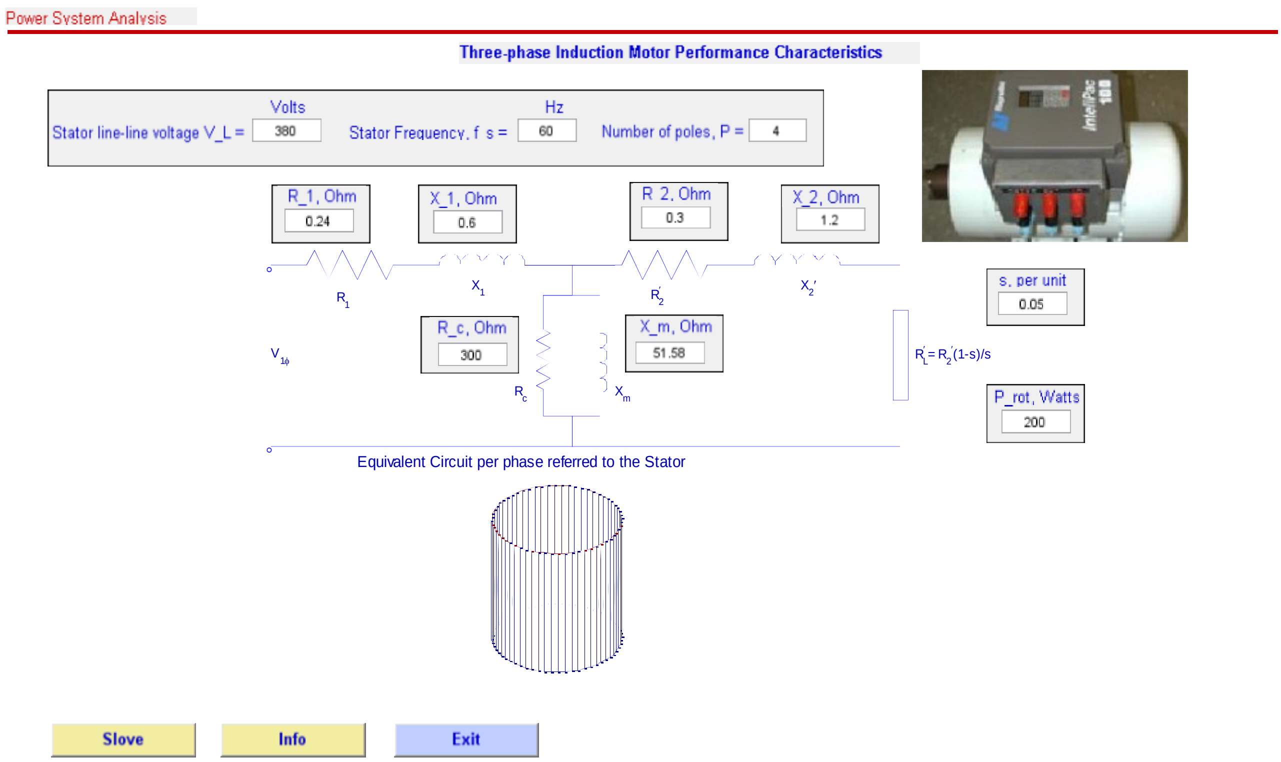

Fig 3 Designing and equivalent circuit of three phase Induction Motor

The analysis of the equivalent circuits at a given slip is shown here along with the characteristics of the motor.

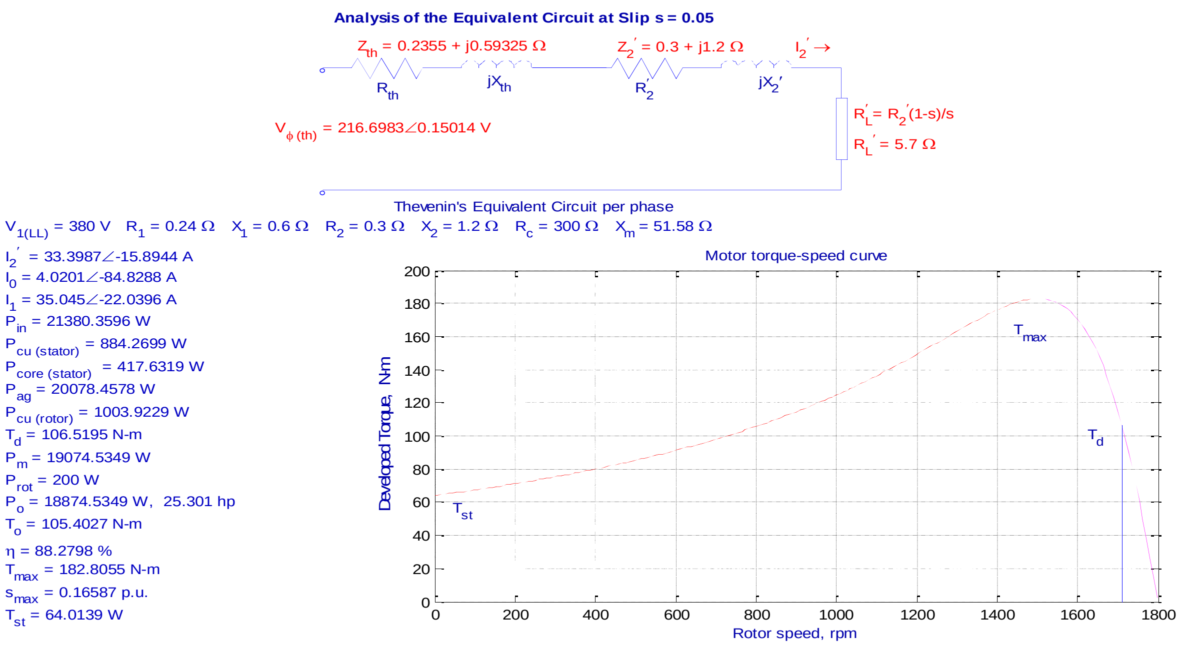

Fig 4: Performance Characteristics of Three phase Induction Motor

4. The Modelling of the Permanent Magnet Synchronous Motor (PMSM) Phase-I

The goal of the project is to investigate and develop permanent magnet synchronous motors (PMSM) for traction applications such as electric driven forklifts. An existing induction (asynchronous) traction motor that can be found in electric forklifts is used as benchmark for the study. The aim of the design is to have a high efficient permanent magnet motor drive that could be a feasible alternative to the induction motor drive in a longer perspective, despite a higher initial cost due to the expensive rare-earth permanent magnet (PM) materials that are preferably used in these types of motors.

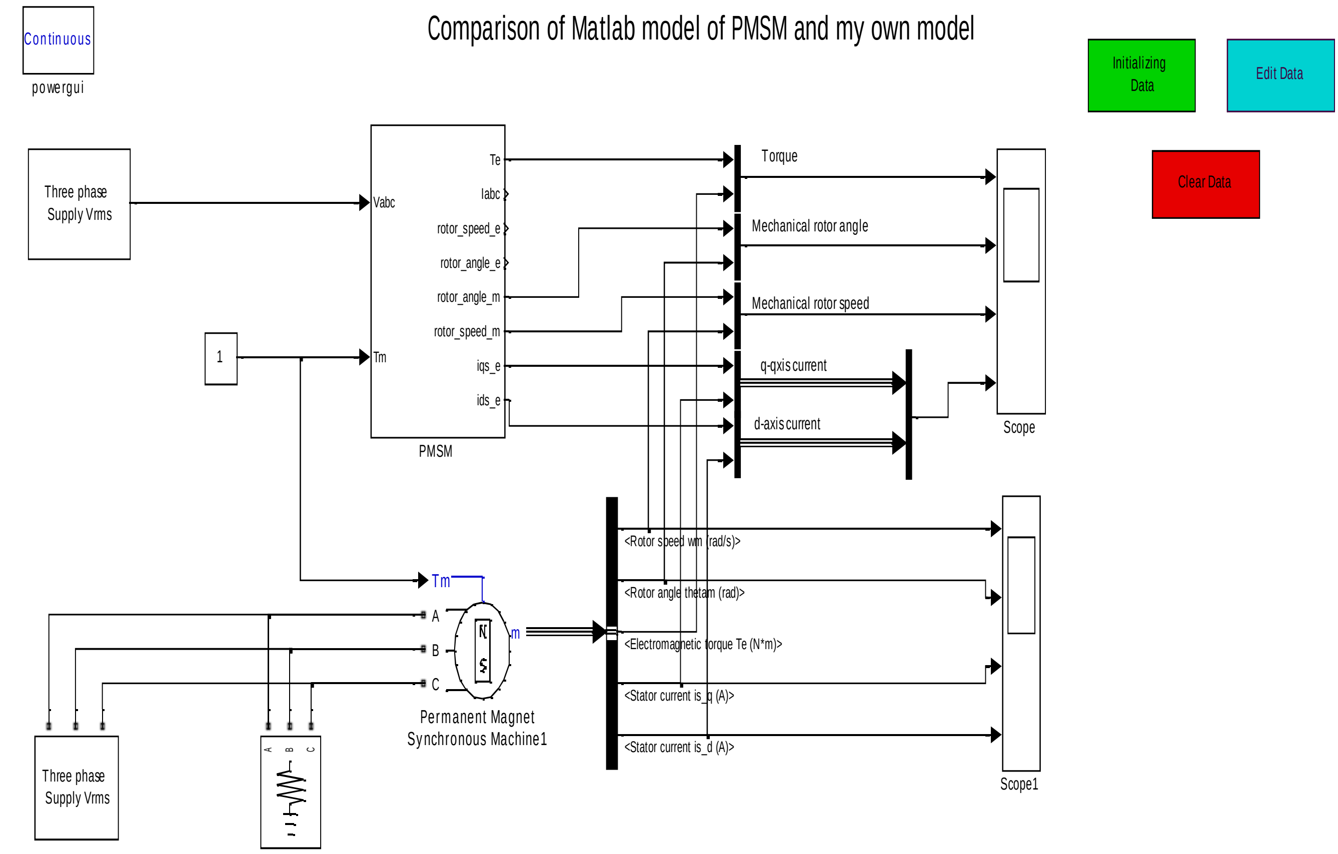

Fig. 5 Comparison of MATLAB model of PMSM and my own model

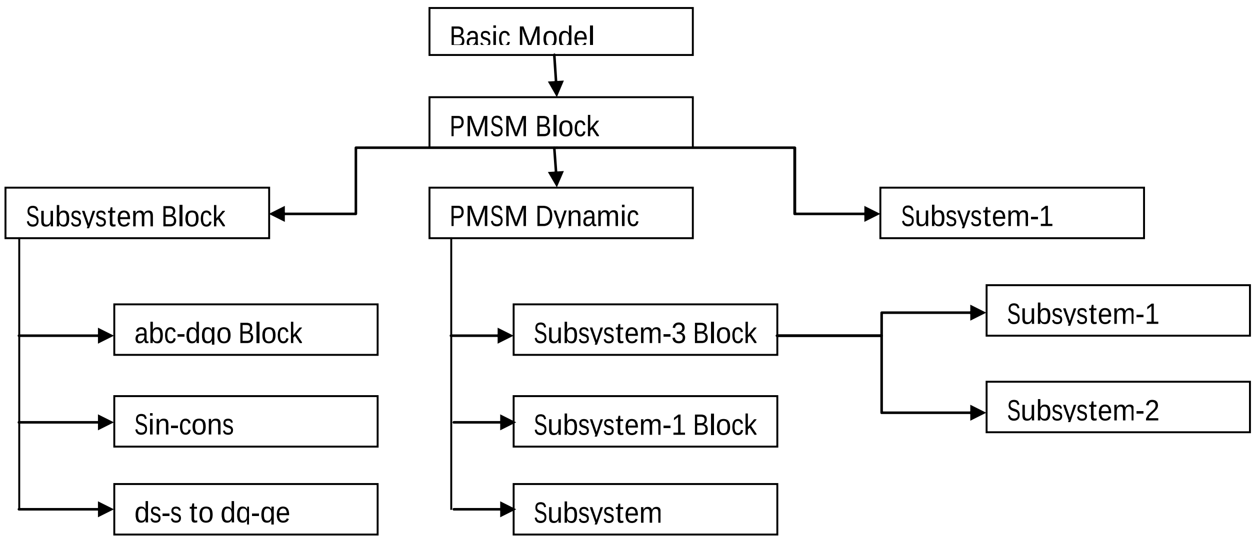

Fig. 6 Different Models in Comparison of MATLAB model of PMSM

There are multiple model inside the each block and subsequent programming has been done in order to find out or to calculate the desired parameters and characteristics. The details of various model inside the PMSM block are as shown in fig. 6.

Modelling of a permanent magnet synchronous motor is introduced in this section using the machine equations; with some assumptions like: saturation is neglected; the induced EMF is sinusoidal; Eddy currents and hysteresis losses are negligible; there are no field current dynamics; all motor parameters are assumed constant; Leakage inductances are zero. Detailed modelling of PM motor drive system is required for proper simulation of the system. The model has been developed on rotor reference frame. This dynamic simulation of PMSM is done with the aid of SIMULINK in MATLAB package. The voltage and load torque are considered as inputs, with speed and current as outputs.

5. Results:

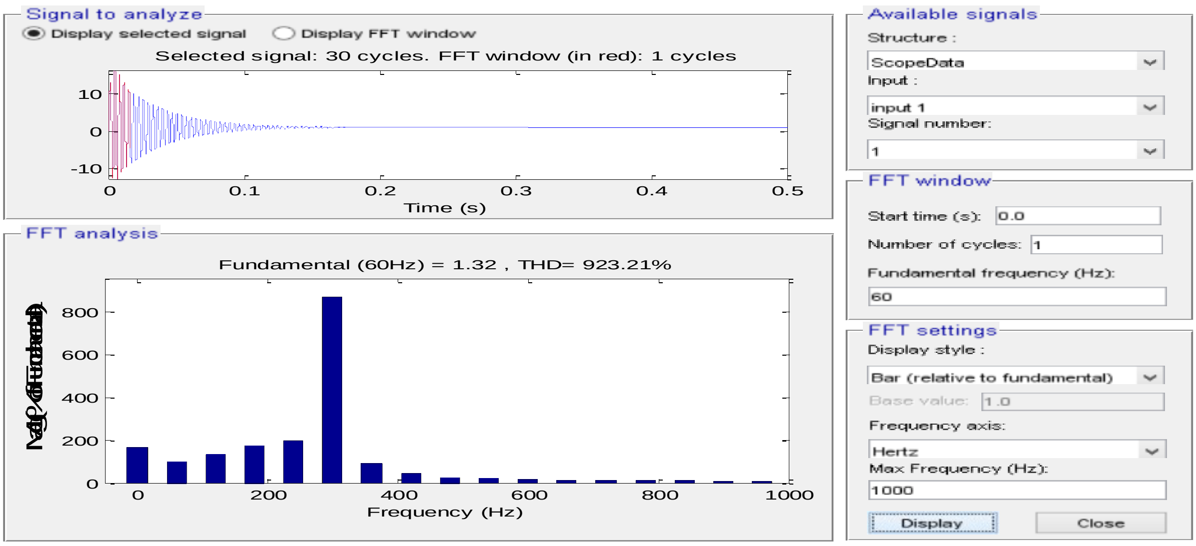

Fig. 7 Total Harmonic Distortion and Fast Fourier Transform (FFT) analysis for input 1 signal no. 1 for one cycle & 60 Hz fundamental frequency considered max. Freq. 1000Hz.

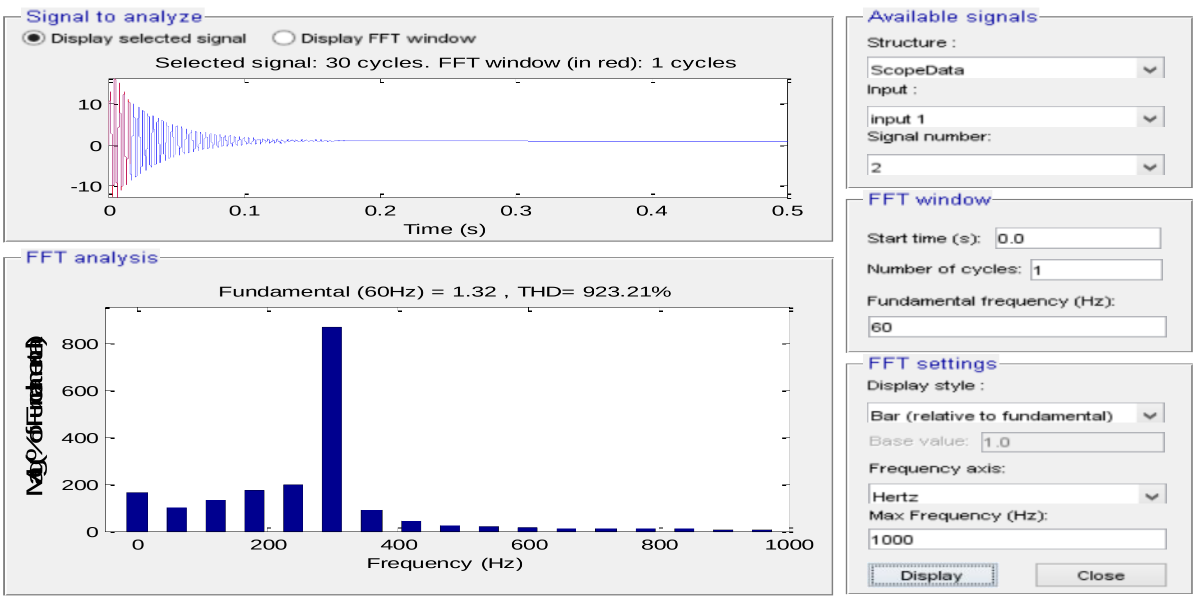

Fig. 8 Total Harmonic Distortion and Fast Fourier Transform (FFT) analysis for input 1 signal no. 2 for one cycle & 60 Hz fundamental frequency considered Max. Freq. 1000Hz.

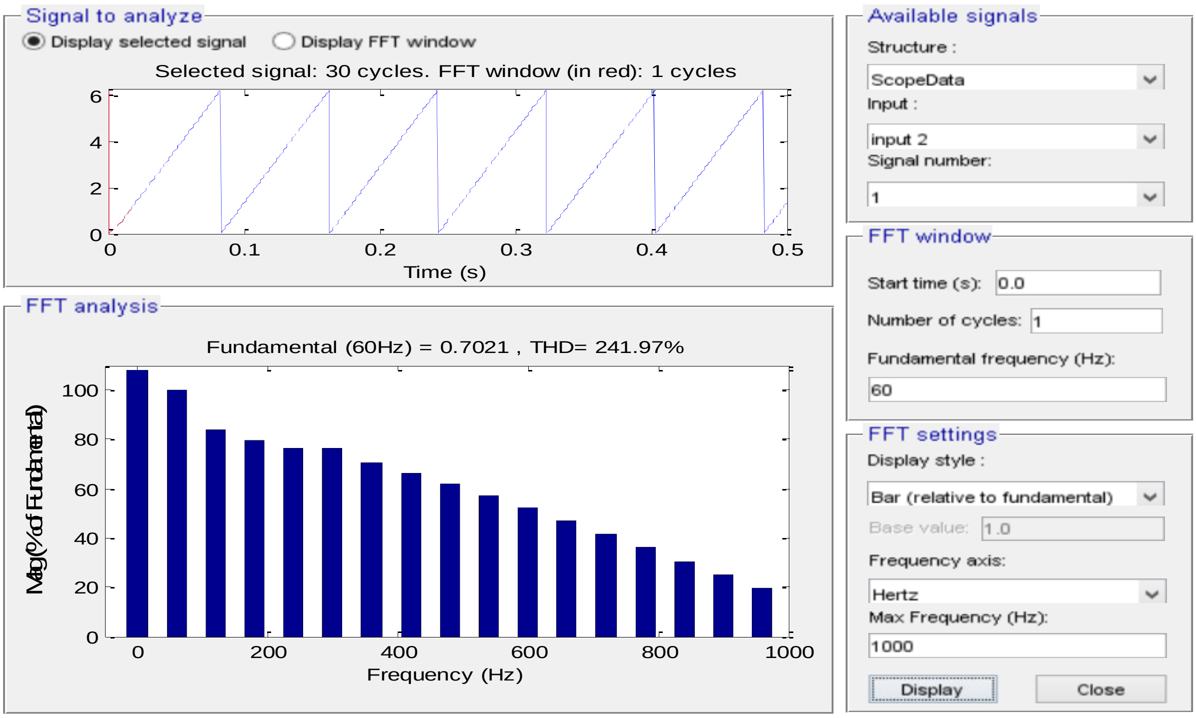

Fig. 9 Total Harmonic Distortion and Fast Fourier Transform (FFT) analysis for input 2 signal no. 1 for one cycle & 60 Hz fundamental frequency considered Max. Freq. 1000Hz.

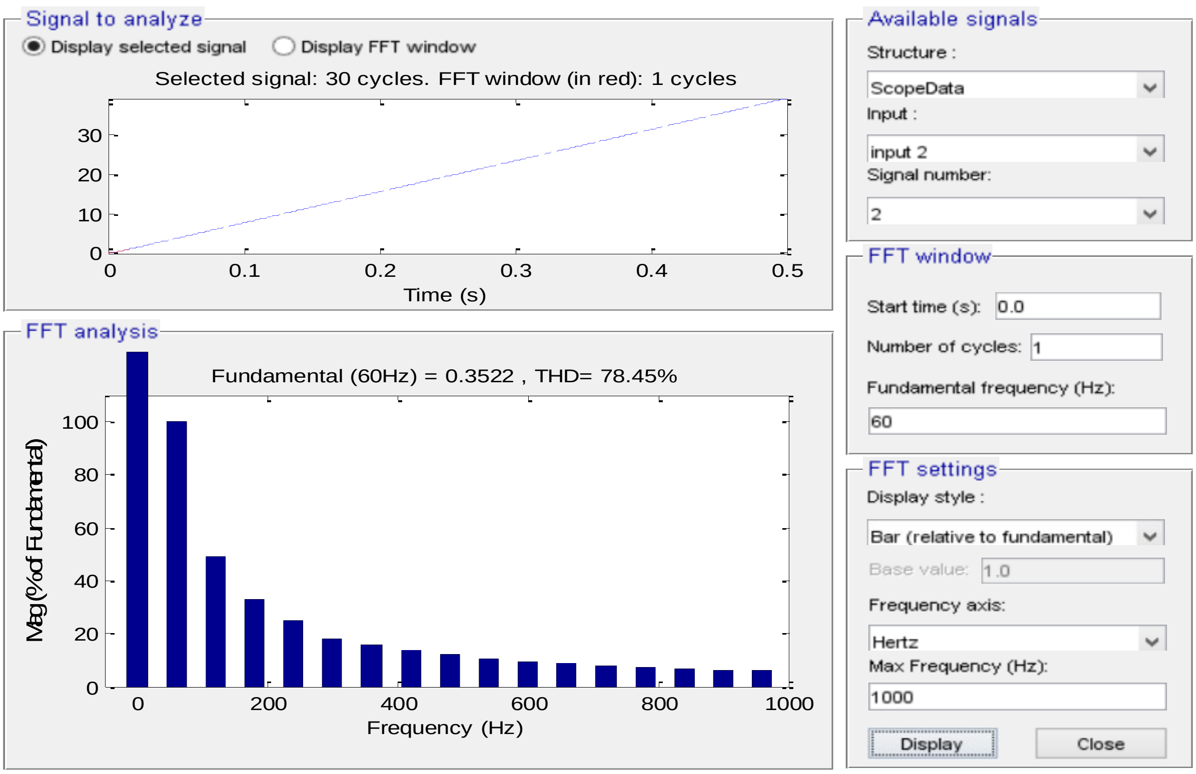

Fig. 10 Total Harmonic Distortion and Fast Fourier Transform (FFT) analysis for input 2 signal no. 2 for one cycle & 60 Hz fundamental frequency considered Max. Freq. 1000Hz.

6. Conclusion: For the first phase of the project, we have designed and made a prototype based on the same stator geometry of the induction machine that is running presently in electric forklifts. The objective of this project is to present and summarize the work that has been accomplished thus far and to lay the foundation for further research in the continuation of the project.

A detailed Simulink model for a PMSM drive system for forklifts with field oriented control has being developed and operation below and above rated speed has been studied using Simulink as it is flexible to work with analog and digital devices. Also mathematical models can be easily incorporated in the simulation and the presence of numerous tool box and support guides simplifies the simulation of large system compared to others.

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