DUAL SPEED CONTROL OF UNDERWATER AUXILIARY PROPULSION USING BLDC MOTOR

G. Narresh[1], Dr. N Prema Kumar[2]

[1]PG Student, Dept of Electrical Engineering, Andhra University College of Engineering(A), Visakhapatnam Andhra Pradesh, India
[2]Professer, Department of Electrical Engineering, Andhra University College of Engineering(A), Visakhapatnam Andhra Pradesh, India

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Abstract - *The auxiliary propulsion system in underwater vehicles is used during special and emergency regimes of operation. This system is also used during entering and leaving harbour. The Auxiliary propulsion system of an existing underwater vehicle consists of two propellers. Each auxiliary propeller and its shaft are directly coupled on to the respective DC motors. DC motors have been widely used in submarines propulsion systems due to their high power density, simple control strategies and the availability of DC sources in such applications. The main limitations of existing system are required to be overcome for efficient and optimal functioning of the Auxiliary propulsion system. The alternatives for the Brushed DC motor are mainly the AC induction motors and the Brushless DC motor (BLDC). BLDC motors have a higher efficiency, an improved power density and also a lower efficiency reduction in low load operations The Brushless DC motors also offer high torque, greater efficiency and control. Due to the numerous advantages that a BLDC motor has over a Brushed DC motor and the AC Induction motor, the proposed system brought in this thesis is a BLDC motor based Auxiliary propulsion system. This project investigates and highlights the use of two speed, bi-directional Control of brushless DC motor using PID controller for reserve propulsion system of underwater platforms along with Simulation and experimental results.*

Key Words: **BLDC, brushless, bi-directional, auxiliary, propulsion, underwater, motor, controller**

1.INTRODUCTION

DC motors have been widely used in underwater propulsion systems due to their high power density, simple control strategies and the availability of DC sources in such applications. Nowadays, with the advent of high energy permanent magnets, the brushless DC permanent (BLDC) motor and the permanent magnet synchronous (PMS) motor become as appropriate alternatives to the DC motor in such applications. BLDC motors have a higher efficiency, an improved power density and also a lower efficiency reduction in low load operations, with respect to DC motors. The Brushless DC motors are extensively used due to their high torque, greater efficiency and control. All the heat dissipating circuits are on the stator, cooling is much better than in a conventional motor, so higher specific outputs can be achieved. BLDC motors offer better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation and higher speed ranges. Due to their favorable electrical and mechanical properties, BLDC motors are widely used in servo applications such as automotive, medical, instrumentation, robotics.

BLDC motors are inherently electronically controlled for speed control of BLDC motor. A proper control scheme is devised for the operation of BLDC motor. Finally, the performance of proposed system is evaluated and compared. Simulation results confirm the effectiveness of proposed method in the improving the overall system efficiency.

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2. AUXILIARY PROPULSION SYSTEM

The underwater propulsion basically consists of the main propeller and its shaft directly coupled on to the main motor. This main propeller is used for all normal regimes of operation of the underwater vehicle.

The general propulsion system schematic of the underwater vehicle is depicted in Fig 1. Apart from the main propeller the underwater vehicle also consists of the reserve propulsion system. The auxiliary propulsion system consists of two propellers one on the starboard side (right hand side) and one to the port side (left hand side) of the underwater vehicle. Each auxiliary propellers and its shafts directly coupled on to the respective DC motors. The auxiliary propulsion system is used during underwater vehicles special and emergency regimes of operation. This system is also used during entering and leaving harbour of underwater vehicle.

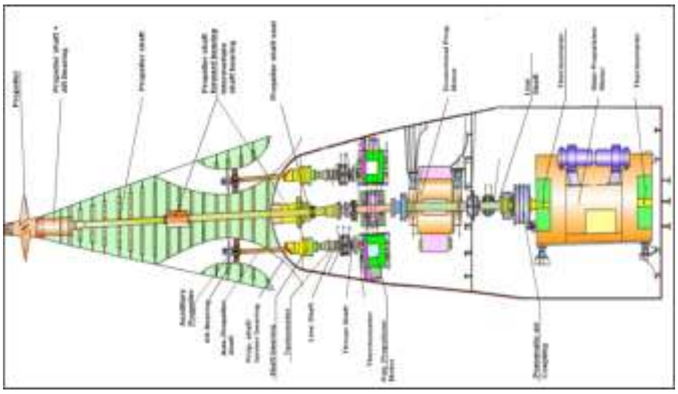

Fig -1 Propulsion system schematic of the underwater vehicle

3. DC MOTOR BASED AUXILIARY PROPULSION SYSTEM

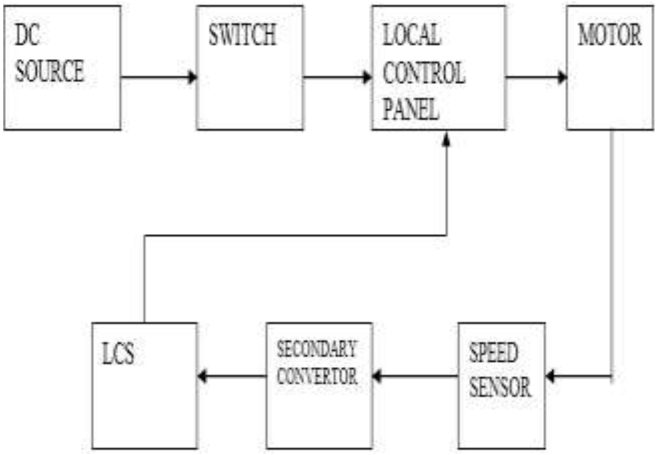

Fig -2 Components of the existing Propeller Chain

3. 1 DC SOURCE

Generally, in an underwater platform the DC power supply is fed from a common DC switchboard. There can be two switchboards for providing Main and Alternate power supplies to the consumers for redundancy/ uninterrupted supply. The source of DC supply to the switchboards can be from MMGs or through the Batteries of the underwater platform.

3.2 HAND CHANGE OVER SWITCH(HCOS)

As mentioned earlier, for uninterrupted supply/redundancy the main and alternate supplies are fed through the HCOS to the motor. Upon disruption or failure of one of the supply the same can be changed over to the available supply by the hand change over switch.

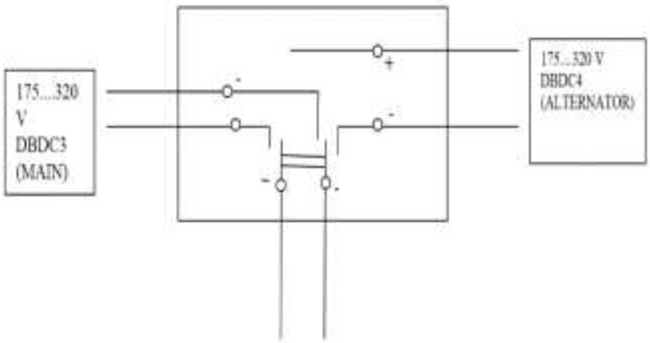

Fig -3 HCOS

3.3 CONTROLLER

The control of the motor in the present scenario can be either Local control through Local control panel (LCS) of the propulsion motor or Remote control through the Electrical Control System (LCS).

The Basic components of the control system are Local Control Panel consisting of Relays, Switches, Motor for Speed control, Potentiometers, Resistors, Diodes, etc. and Remote control system consisting of Electrical Control System (LCS), Relay, Energizing supply for coils of Relay contacts

3.4 SPEED SENSOR

The speed is measured through a speed sensor located below the shaft. The output is fed through a secondary convertor to be displayed either in the local post or at the remote control post.

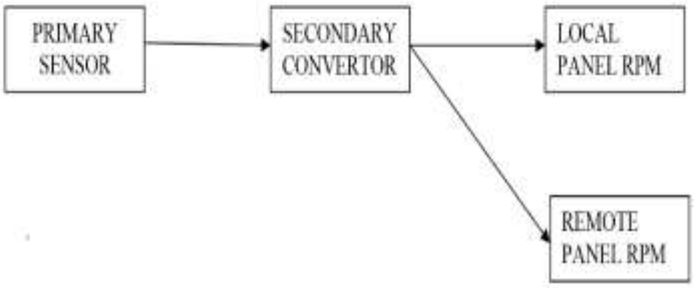

Fig -4 Sensor Chain

The speed of the motor in-turn propeller speed can be controlled locally by turning the handle of the switch to the right for higher speed and to the left for lower speed. In the remote control operation, the same can be controlled through the mimic display page of the electrical control system the up arrow indicated for higher speed and the lower direction arrow for lower speed.

3.5 FEEDBACK

The configuration discussed is of open loop feedback mechanism where in the speed is required to be monitored and adjusted to requisite speed manually. There is referencing of speed in this configuration so that it can be compared and adjusted to requisite speed automatically.

3.6 PARAMETERS MONITORED

Apart from basic parameters being monitored such as the voltage, frequency and power. The vital parameters of the reserve propulsion motors such as the Speed, Armature current, Excitation current and temperature is continuously monitored.

4 PROPOSED BLDC MOTOR BASED AUXILIARY PROPULSION SYSTEM

The main objective of the proposed system is to overcome the limitations brought out in existing system. The same is proposed to be achieved as follows: -

(a) Conversion of DC motor drive to a brushless DC motor

(b) DC drive for two speed and bidirectional control

(c) Maintaining smooth running of the machine for very essential consumers of marine platform.

(d) Selection of controller, feedback arrangement for achieving dual speed and smooth running of BLDC motor.

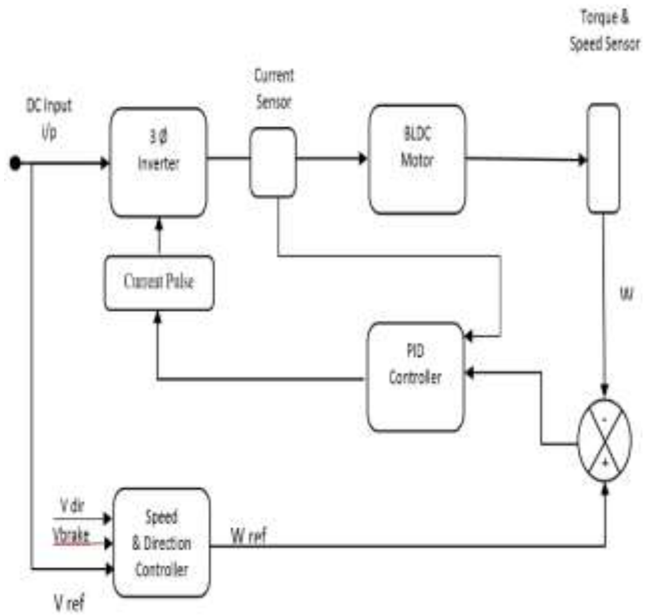

Fig -5 Proposed BLDC system

4.1 BASIC COMPONENTS

The Basic components of the proposed system are: -

(a) DC Input Supply

(b) Three Phase Inverter

(c) Current Sensor

(d) BLDC Motor

(e) Torque and Speed Sensor

(f) PID controller

(g) Speed and Direction Sensor

4.2 PRINCIPLE OF OPERATION

The DC input supply source is fed to the three phase converter which in-turn is fed to the BLDC motor. The PID controller is used as the controller to control the current pulses being fed to the three phase inverter. A current sensor placed in-between the BLDC motor and the 3phase inverter to sense the current flow which is given as an input to the PID controller. Speed and torque of the BLDC motor is sensed through a torque and speed sensor. The required speed and direction of the motor is controlled through a Speed and Direction controller. Vdir, Vbrake and Vref are fed as the inputs to the controller which in-turn feeds the Wref to the comparator where the W and Wref are compared and accordingly fed to the PID controller. The closed loop operation of the system through the PID controller the current pulses are accordingly fed to the three phase inverter. The speed of Motor, direction and braking is hence controlled through this circuit to deliver the required output of the platform.

4.3 SIMULATIONS AND RESULTS

The Basic simulation block diagram for the proposed system using BLDC motor drives are modeled and simulated in MATLAB version of 19A. In order to carry out the simulations the basic BLDC drive circuit for speed control is modeled as shown in Fig 6 and the results were presented in fig 7 to fig.10.

The simulation diagram consists of the following components: -

(a) Permanent Magnet Brushless DC Motor Block

(b) PWM inverter

(c) DC source

(d) Speed Regulator

(e) Hall Sensor

(f) PW gate module

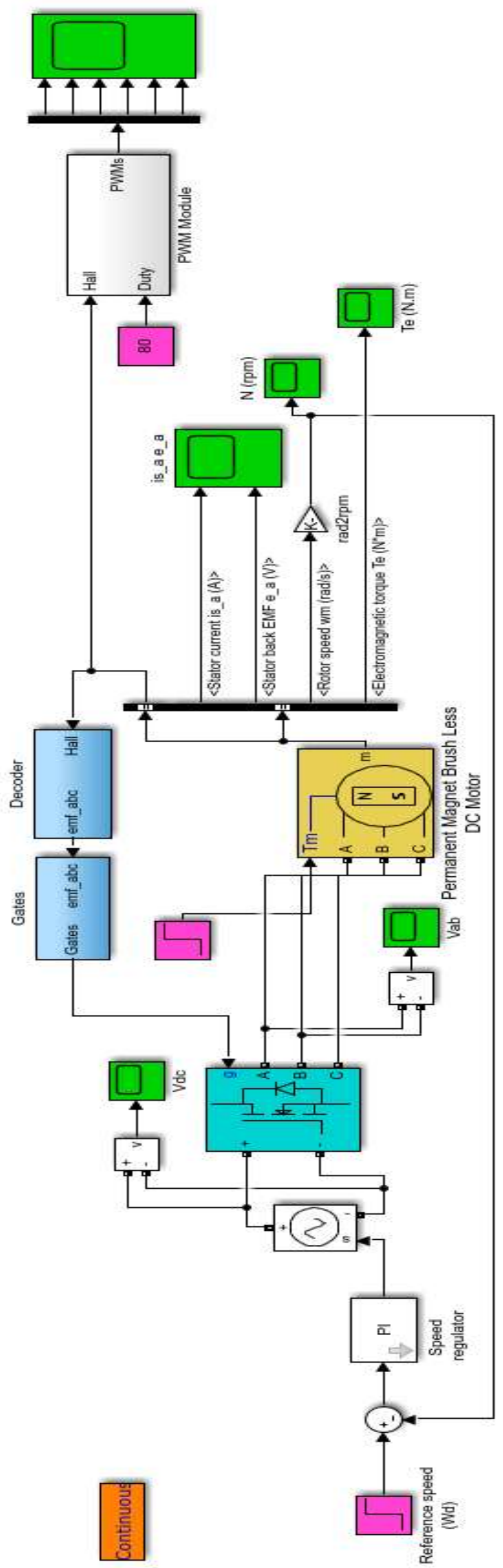

Fig -6 Simulation Block Diagram

Permanent Magnet Brushless DC Motor Block and is fed by 3 phase PWM controlled voltage sourced inverter. The Firing pulses are fed to the inverter by a means of a gate circuit that is used to produce firing signals from the decoder signals are received from hall sensor feedback system. The simulations are modeled to measure the stator currents, stator back emf, speed and electromagnetic torque produced in the motor along with the gate firing sequence.

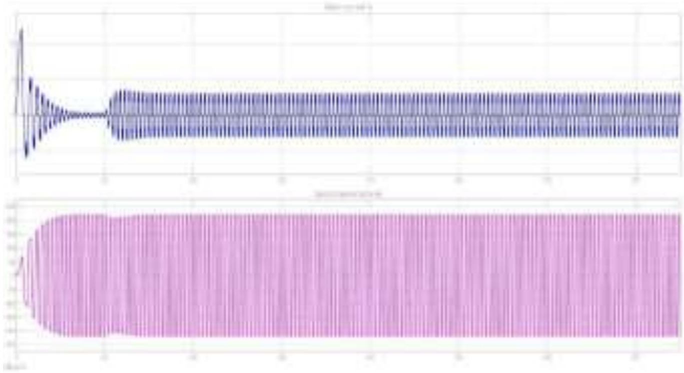

Fig -7 Stator Current and Electromotive force

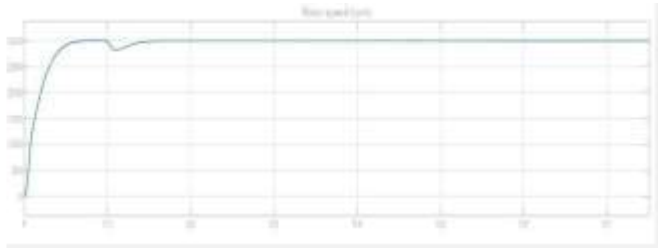

Fig -8 Rotor Speed

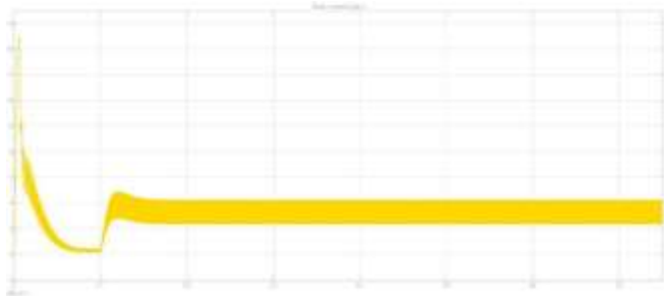

Fig -9 Torque

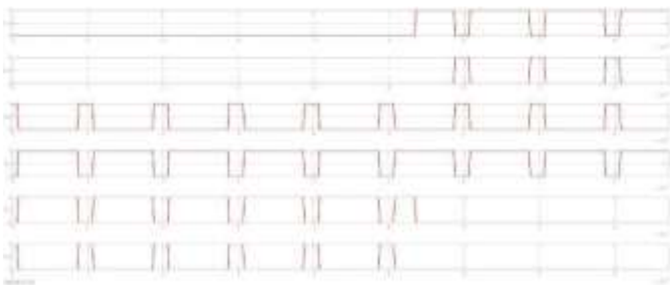

Fig -10 Pulse

5.6 Simulation Diagram for Direction Control and Results

The simulation modeled in fig. 6 was modified to have a direction and braking controls by inclusion of motor and driver circuit module. Direction control is required for the underwater platform propeller to rotate in clockwise or anticlockwise direction depending upon the operational requirement and braking is required whenever there exists a situation to completely stop/reverse the direction of propeller. The proposed simulation model consists of following components: -

(a) Speed controller which consists of forward and reverse Direction control and braking control

(b) Closed loop controller

The circuit diagram is shown in fig. 11. The components of motor and drive control (i.e) speed demand and its controller are shown in fig. 12. The control logic for change of direction of the propeller in forward and reverse direction is shown in block diagram. The logic for motor braking control is also present in the fig. 13. The corresponding efficiency of the motor during forward running, speed reversal, braking operations and output waveforms for rotor speed, electrical and mechanical power outputs are shown in fig14 and fig. 15 respectively.

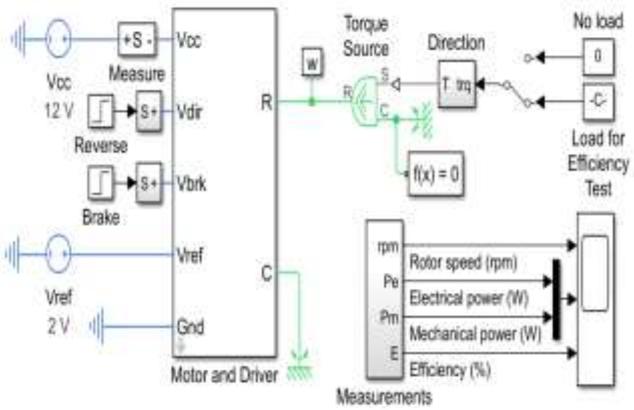

Fig -11 Speed Controller Block Diagram

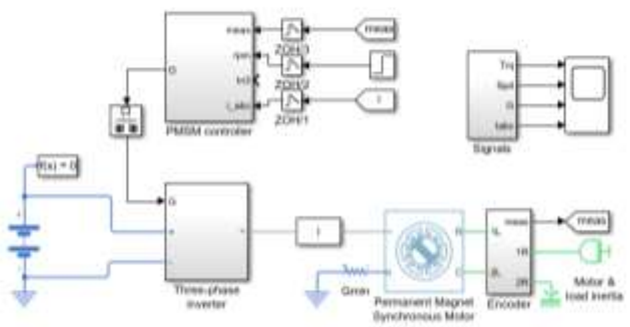

Fig -12 Block Diagram of Speed Demand Controller

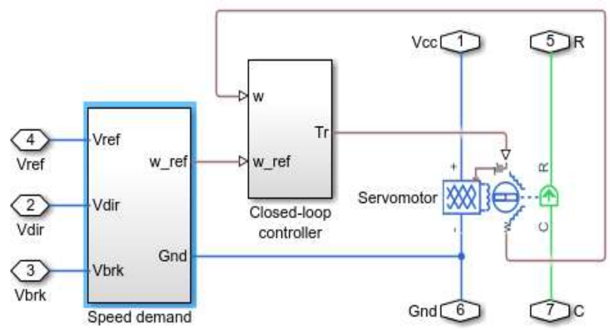

Fig -13 Control Logic for Forward and Reverse Direction

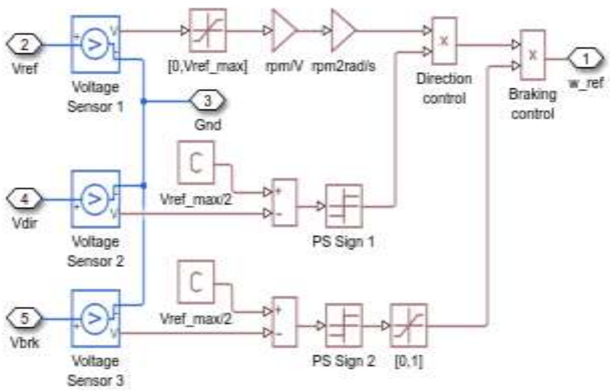

Fig -14 Control Logic for Braking

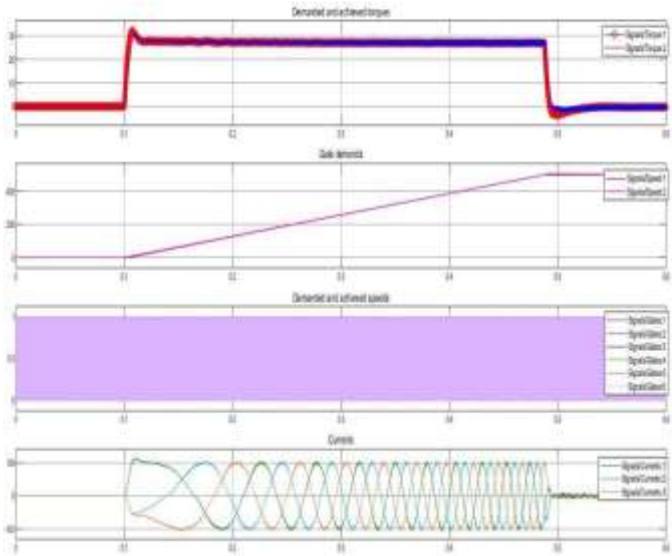

Fig -15 Efficiency of the motor during forward running, speed reversal, braking operations

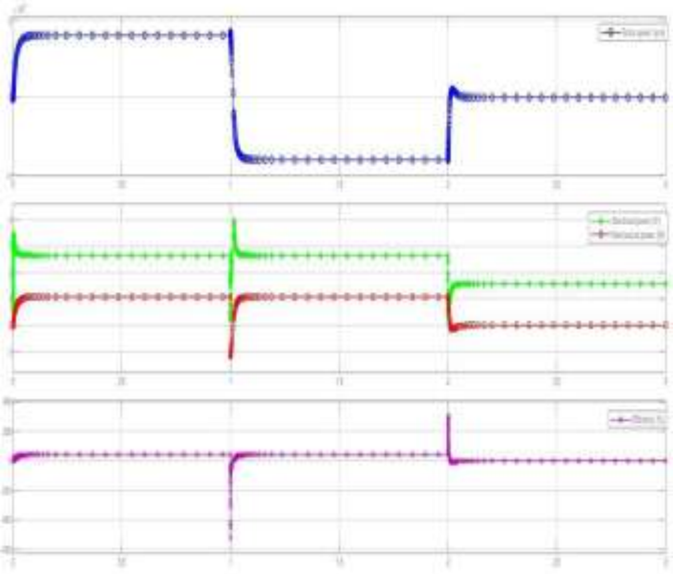

Fig -16 Rotor Speed, electrical and mechanical power outputs

The simulations were carried out to study the speed control operation of a proposed auxiliary propulsion system using BLDC motor drive. The simulations were modelled and executed in MATLAB 19A with intel core i5 4GB RAM system. The simulation results present satisfactory results for the performance of the propulsion system with the proposed BLDC motor model.

6 CONCLUSIONS

The main limitations of the existing system of the underwater platform are the Brush sparking, large size of motor, carbon deposits, large controller size due to numerous relays and switches, sparking of relays and switches, increased cable requirements and frequent maintenance requirement of both brushed DC motor and the control arrangement.

The aforesaid limitations are mitigated and overcome system by the replacing the existing system with the proposed system for efficient and optimal functioning of the Auxiliary Propulsion System.

It is pertinent to mention that where space considered as a premium in such underwater platform one of the main advantage of the proposed system being the significantly less space requirements of the system in comparison with the existing system by the use of BLDC motor and controller. Also, the precise/efficient operation which the proposed system delivers when required as compared to the existing system which uses numerous cables, relays and switches.

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