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Development of BLDC Motor Based Elevator System Suitable for DC Microgrid

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Abstract— This Paper presents a power factor corrected (PFC) bridgeless (BL) buck–boost converter-fed brushless direct current (BLDC) motor drive for Elevator Systems suitable for operating with DC Micro-Grid. An approach of speed control of the BLDC motor by controlling the dc link voltage of the voltage source inverter (VSI) is used with a single voltage sensor. This facilitates the operation of VSI at fundamental frequency switching by using the electronic commutation of the BLDC motor which offers reduced switching losses. A BL configuration of the buck–boost converter is proposed which offers the elimination of the diode bridge rectifier, thus reducing the conduction losses associated with it. BL buck-boost converter is designed to operate in discontinuous inductor current mode (DICM) to provide an inherent PFC at ac mains. It is known that the Brushless Direct Current (BLDC) motors have smooth speed control, high power density and fewer complexities in power converter and controller when operated with dc supply as compared to other electrical motors. For analyzing the proposed BLDC motor-based Elevator System, a MATLAB/Simulink model has been developed by inserting various electrical and mechanical components.

Keywords— Brushless Direct Current (BLDC) motors, voltage source inverter (VSI), power factor corrected (PFC) bridgeless (BL) buck–boost converter

I. INTRODUCTION

An Elevator is a vertical transportation vehicle used mainly for the transit of people and goods in high-raised buildings. Easy and efficient transportation within a building is of utmost importance, since the present day cities are considered to grow vertically. Generally an elevator uses a three phase induction motor to carry out the hoisting operation. However, considerable research has been carried out to replace the conventional motor to attain improved efficiency, reliability and speed[7]. Jung et al. have developed a nine phase permanent magnet motor drive system for an ultra-high speed elevator system and the feasibility of the drive system was tested in the world's tallest elevator test tower[1]. Such a design is very useful to meet the need for high speed elevator operation which cannot be suitably satisfied by conventional three phase electric drive systems. Other drives like linear switched reluctance motors have also been studied for the purpose of implementation in elevator systems [3].

A linear motor design capable of generating a magnetic field decoupled from the thrust generating magnetic field of the linear motor is presented system [6]. Mutoh et al. have presented a controller suitable for elevators which increases the efficiency and performance of an elevator system. Osama et al. have implemented and analyzed the performance of an elevator with three-phase induction motor drive and made a comparison with the traditional dual stator winding line-supplied elevator motor.

Brushless Direct Current (BLDC) motors have secured a very significant space in the modern drives industry primarily due to the added benefits of a dc input system along with a brushless drive. Various advantages such as, high torque/current ratio, high power density and higher efficiency make these motors very suitable for replacing conventional motors in many systems. Many studies have also been carried out to obtain higher efficiency and better control for BLDC motors[8]. Further, owing to the ease of control and scope for regenerative braking, considerable amount of research has been carried out to incorporate BLDC motors in Electric Vehicles (EVs). Hence, to have such improved performance, the application of BLDC motor has been studied in this work for elevator system in vertical transportation[9].

As a last paragraph of the introduction should provide organization of the paper as follows, Section I contains the introduction of BLDC motor , Section II contain the related work of system description, Section III contain the methodology and modelling of BLDC motor drive, Section IV describes results and discussion of BLDC motor based elevator system, Section V concludes research work..

II. SYSTEM DISCRIPTION

Figure.1 shows the block diagram of the proposed system. The inverter which sources the BLDC motor is supplied from a dc micro grid. Solar PV panels are integrated to the dc grid through power converter. The BLDC motor is coupled to the elevator system through a worm gear and is responsible for the motion of the EC. The EC and CWs are connected via suspension cables[8].

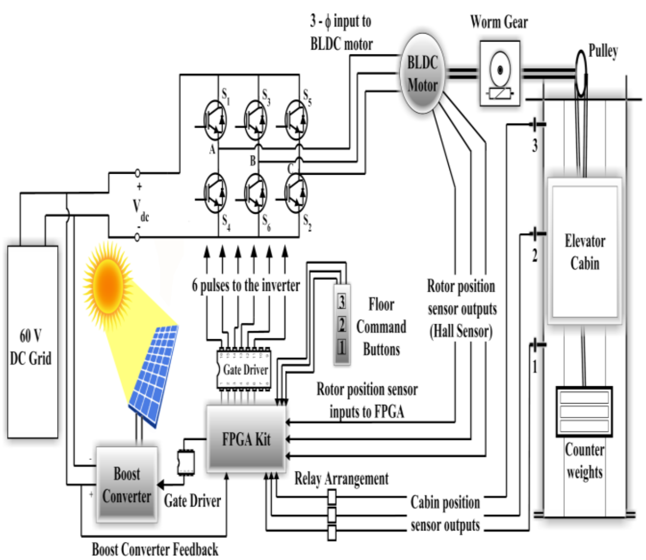

Figure 1. Overall setup of the proposed proto type elevator system

To have the proper movement of the elevator system, suspension cables are guided through a mechanical pulley. This pulley is coupled with a BLDC motor-worm gear system. Hall sensors have been used for identifying the rotor position of the BLDC motor. Similarly, magnetic position sensors have been employed for sensing the elevator position, i.e., floor level[5].

A**)** *FOUR QUADRANT OPERATION OF AN ELEVATOR*

The elevator system proposed in this paper operates in four quadrants depending upon the (i) relative weight of the EC and CW and (ii) direction of movement of EC. The four quadrant operation of the elevator system is shown in Fig 2. It is to be noticed that in quadrants I and IV, the EC is with passenger while in quadrants II and III it is empty. Upward motion of the EC corresponds to the forward rotation of the BLDC machine and reverse rotation is for downward motion of EC. In the first quadrant, the net EC weight is assumed to be more as compared to the CW and EC needs to move upward. Hence, the BLDC machine operates as a motor (forward motoring) with torque and rotational speed in the same direction as indicated in Fig 2. Similarly, the BLDC machine operates as a motor (reverse motoring) in the third quadrant as the net EC weight is less as compared to the CW and EC moves downward. In the second quadrant, the net EC weight is assumed to be lighter than the CW and EC needs to move upward. So, the BLDC machine acts as a brake (forward braking) with torque and rotational speed in the opposite direction along with the worm gear. The primary objective of worm gear in elevator system is to work as a natural brake such that the EC does not move due to the difference in net EC weight and CW with gravity. Thus, the presence of worm gear forbids any reverse mechanical power flow. If suitable gear arrangement is employed in place of worm gear then the BLDC machine can act as a generator (i.e., regenerative braking) in II quadrant. Similarly the BLDC machine acts as a generator or brake (reverse braking) in the IV quadrant. Identifying the appropriate vendors for supplying these components and assembling together has been a difficult task. Further, replacing the worm gear with other appropriate gear mechanism to achieve regenerative braking is a complex process and will be considered as future scope for this work[2].

Three magnetic position sensors have been placed, one at the top, one in the middle and one at the bottom of the elevator structure for detecting the position of the EC. The three signals from the Hall sensors and three signals from the cabin position sensors are fed to the FPGA board after appropriate signal conditioning[4]. Three floor buttons provide the commands to the controller for the EC to move to any floor as per the user requirement. LED driver circuit has been used to glow the LEDs for indicating the floor to which the EC is moving.

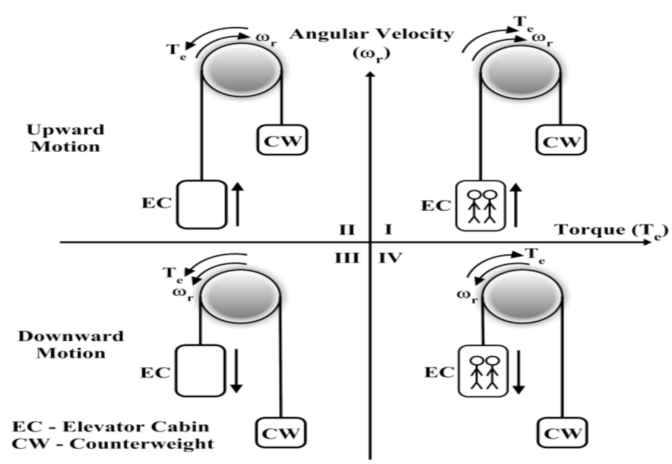

Figure 2. Four quadrant operation of an elevator system

III. ANALYSIS OF THE PROPOSED SYSTEM

The BLDC machine dynamic model assumes that the winding distribution and flux established by the permanent magnets produce three trapezoidal back EMF waveforms. Dynamic modeling of BLDC machine is implemented with the following set of equations

$$\frac{di_a}{dt} = \frac{1}{3L_s}\left[2v_{ab} + v_{bc} - 3R_s i_a + \lambda p \omega_r \left(-2\phi'_a + \phi'_b + \phi'_c\right)\right] \quad (1)$$

$$\frac{di_b}{dt} = \frac{1}{3L_s}\left[-v_{ab} + v_{bc} - 3R_s i_b + p \omega_r \left(\phi'_a - 2\phi'_b + \phi'_c\right)\right] \quad (2)$$

$$\frac{di_c}{dt} = -\left(\frac{di_a}{dt} + \frac{di_b}{dt}\right) \quad (3)$$

$$T_e = p\lambda\left(\phi'_a i_a + 2\phi'_b i_b + \phi'_c i_c\right) \quad (4)$$

The dynamic equations given in (2)-(4) are expressed in abc reference frame. Further, the stator resistance, Rs and inductance, Ls of the stator winding of BLDC are assumed to be constant. The mechanical model of a BLDC machine for motoring operation is given by

$$d\omega_r/dt = (1/J)(T_e - F\omega_r - T_m) \quad (5)$$

$$d\theta/dt = \omega_r \quad (6)$$

IV. MATLAB & SIMULINK

MATLAB is used in wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology. Add-on toolboxes (collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas.

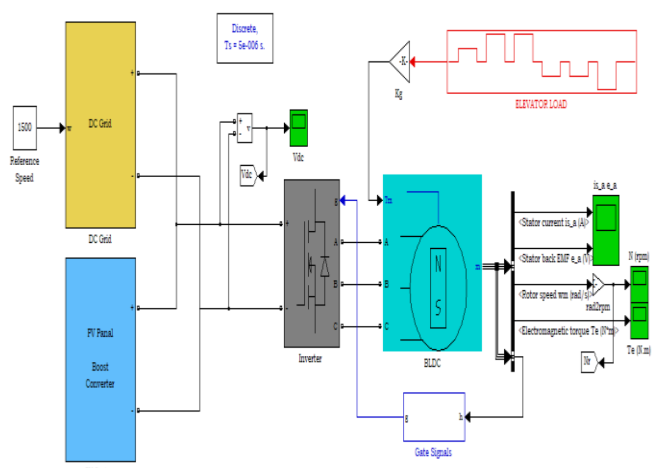

Figure 3. Simulation Overall setup of the proposed BLDC elevator system

The parameters of the BL buck–boost converter are designed such that it operates in discontinuous inductor current mode (DICM) to achieve an inherent power factor correction at ac mains. The speed control of BLDC motor is achieved by the dc link voltage control of VSI using a BL buck–boost converter. This reduces the switching losses in VSI due to the low frequency operation of VSI for the electronic commutation of the BLDC motor. The performance of the proposed drive is evaluated for a wide range of speed control with improved power quality at ac mains.

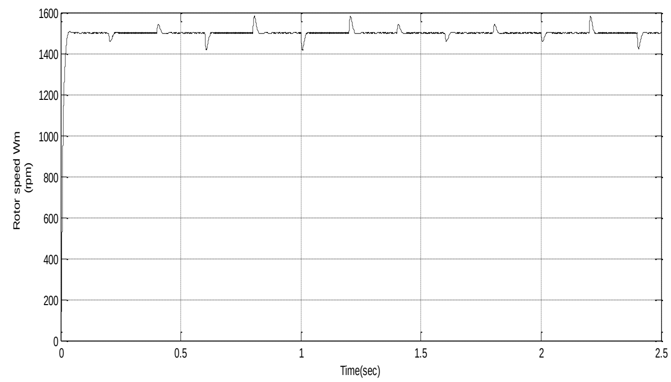

Figure 4 .Waveform of Rotor Speed

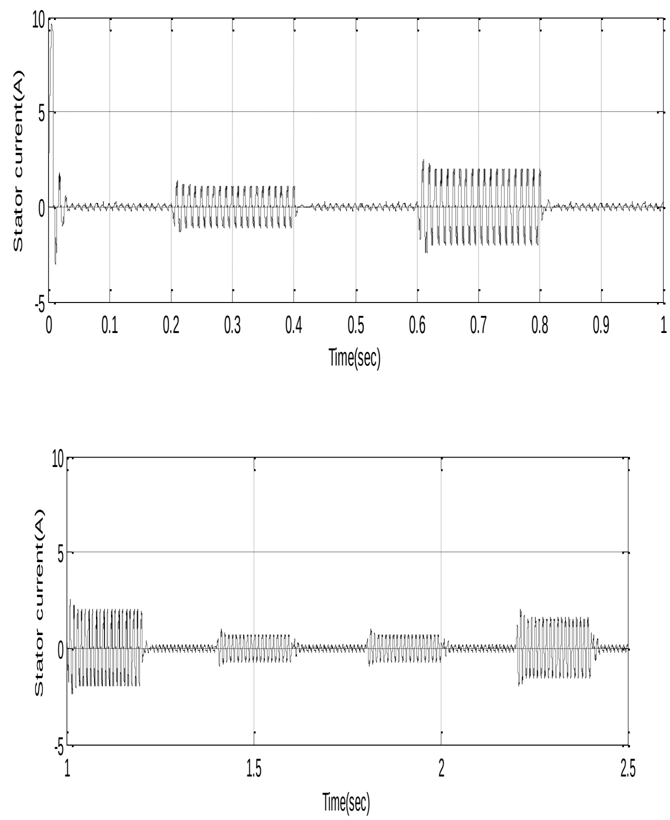

Figure 5. Waveform of stator current and time of BLDC motor, time limit from 0 to1, time limit from 1 to 2.5

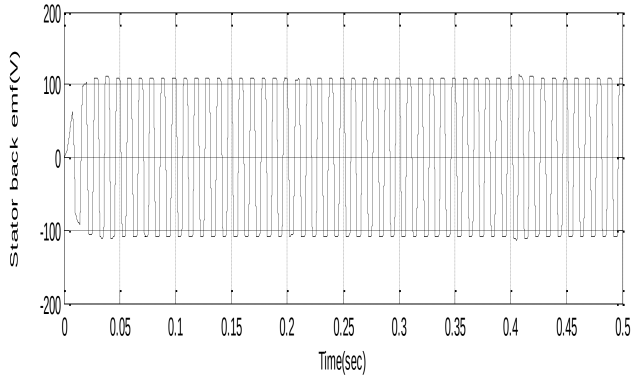

Figure 6.waveform of stator back EMF and time of BLDC motor

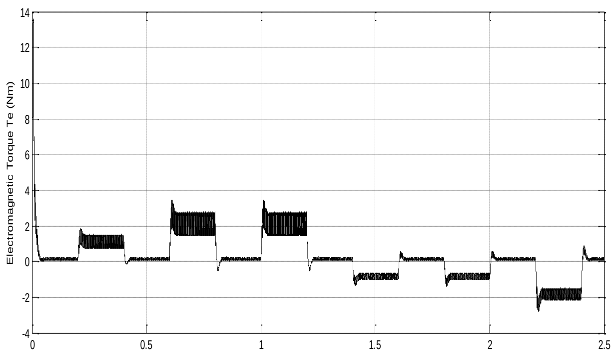

Figure 7. Waveform of Electromagnetic torque

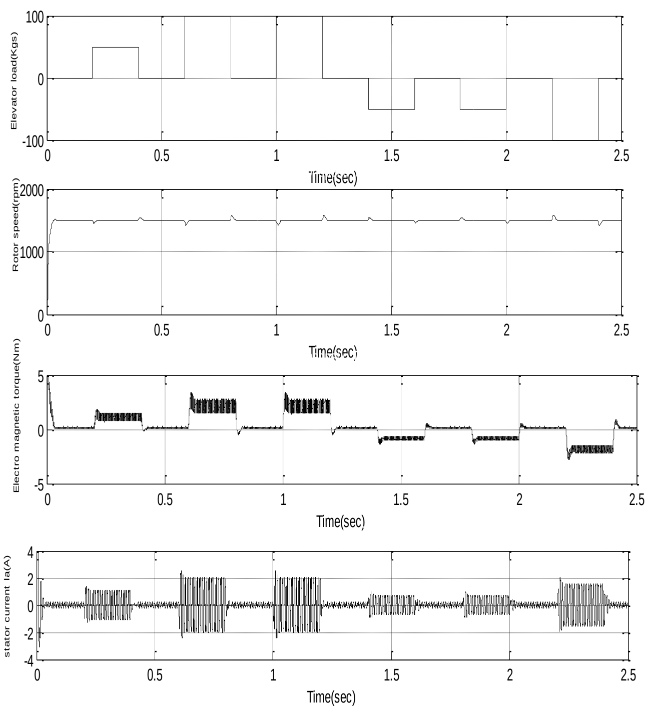

Figure 8.Simulation waveform of proposed BLDC elevator system - Elevator Load, Rotor Speed, Electric Torque and Stator Current-A

Simulated results of inverter output voltage and currents have been observed for these operating conditions. Phase shift has been noticed with upward and downward motions of EC for the inverter output current (i.e., input current to the BLDC motor), as the firing sequence of the devices is different for the forward and reverse direction of rotation of the BLDC motor.

V. CONCLUSION

A PFC BL buck–boost converter-based VSI-fed BLDC motor drive has been proposed for an Elevator System employing BLDC motor. The front-end BL buck–boost converter has been operated in DICM for achieving an inherent power factor correction at AC mains. A MATLAB/Simulink model has been developed utilizing the various electrical and mechanical components available in Simulink library for the proposed Elevator System. The performance of the system has been analyzed with the help of this model and results are furnished. Moreover, voltage and current stresses on the PFC switch have been evaluated for determining the practical application of the proposed scheme. It has been observed that the dc input current to the inverter supplying BLDC motor decreases as the load on the cabin weight increases for downward motion and vice-versa for upward motion. This validates the analysis of the system through MATLAB simulation and its successful working. The logic for operating the Elevator System as per the user commands in closed-loop has also been developed and tested. The proposed Elevator System can be easily implemented with the dc micro-grid.

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Mr. Subbi Naidu Bora pursed B.Tech degree in Electrical &Electronics, from SISTAM COLLEGE of Engineering, Srikakulam in 2008. His M.Tech from University College of Engineering JNTUK Kakinada on Advanced Power Systems in 2013. He is currently working as Assistant Professor in Department of Electrical Engineering from BVCITS, Amalapuram since 2014. He has published more than 9 research papers in reputed international journals and it's also available online. His main research work focuses on Renewable energy systems, Multi-level converter. He has 8 years of teaching experience.

