Efficiency and Loss Analysis of Proposed BLDC Motor Drive and Existing Universal Motor Drive Used in a Mixer Grinder

Deekshitha S. Nayak and R. Shivarudraswamy
Manipal Institute of Technology, Manipal, India
Email: deekshitha.nayak06@gmail.com, shivarudraswamy.r@manipal.edu

***Abstract*—In the commercially available mixer grinders, for controlling the speed of the universal motor, triac is used. The triac-based universal motor has lesser efficiency, so the voltage source inverter (VSI)-based brushless DC (BLDC) motor can be used in the application of mixer grinders. In the proposed VSI-based BLDC motor, the current and voltage sensors were eliminated. By adjusting the DC bus voltage of the VSI, the speed of the BLDC motor is controlled. The Triac-based 230V universal motor and the proposed VSI-based 48V BLDC motor was simulated by the Matlab/Simulink. The efficiency and loss of the Triac-based universal motor and the proposed VSI-based BLDC motor for mixer grinder is compared in this paper.**

***Index Terms*—universal motor, BLDC motor, Triac, VSI speed, efficiency, loss**

I. INTRODUCTION

The universal motor is generally used as the drive motor in most mixer grinders [1]. When the motor is switched on and the grinding/mixing of the ingredients continues, the requirement of the torque reduces and the speed increases. For maintaining the quality of the grinding/mixing, the speed is controlled to a set value, which in turn does not affect the quality output of the mixer grinder and also consumes less power [3]. In the commercially available mixer grinders, the triac-based universal motor is used for controlling its speed. In the triac- based universal motor, the motor can be controlled by changing the settings of the potentiometer [4]. The settings of the potentiometer determine the phase of the trigger pulse that fires the triac. The Diac has negative resistance characteristics, which permit to switch ON quickly once a certain applied voltage level is reached. The circuit includes the self-stabilizing method that maintains the speed of the motor even when it is loaded [9]. Fig. 1 shows the Triac- based universal motor.

The brush and commutator arrangements in the universal motor can cause sparking and the electromagnetic interference can lead to lower efficiency [4]. So, the VSI-based BLDC motor can be used in the mixer grinder because of its easy speed torque control and compact size. In rural India, the availability of power is low and the load connected is around 300W. So the proposed BLDC motor power output was fixed at 200W and the power input was limited to 250W. This paper contributes the efficiency and loss analysis of the existing triac-based universal motor and the proposed VSI-based 48V BLDC motor in the application of a mixer grinder.

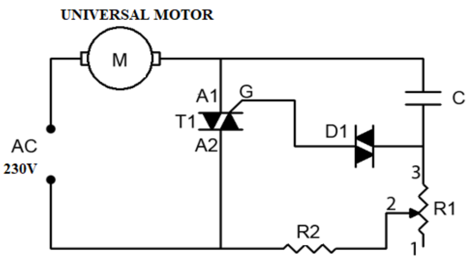

Figure 1. Triac-based universal motor [4]

II. WORKING PRINCIPLE OF PROPOSED SYSTEM

A detailed illustration of the proposed system is described in Fig. 2. The three hall sensors are used to produce gate signals to the VSI by electronic commutation. Electronic commutation refers to a commutation of a currents flowing through the windings of the BLDC motor in predefined sequences by the decoder such that direct current symmetrically is drawn from the DC bus of the VSI for 120 °and placed in phase with the back emf [10]. The DC bus voltage and phase currents sensors have been eliminated in the proposed system. The VSI is operated through the fundamental frequency switching pulses for reducing switching losses [11]. The actual speed of the mixer grinder and reference speed were fed to the speed regulator, i.e., the PI and DC bus voltage of VSI was varied and the speed of the motor was controlled.

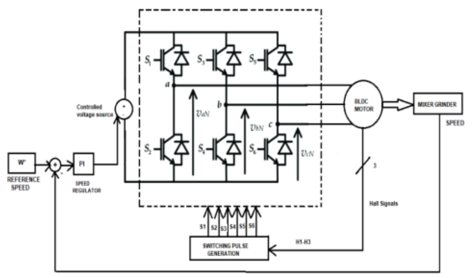

Figure 2. Proposed VSI-based 48V BLDC motor mixer grinder

Manuscript received March 30, 2019; revised March 14, 2020.

doi: 10.18178/ijmerr.9.6.808-812

III. System Design

A. Triac-Based Universal Motor

In the mathematical modelling of the 230V universal motor, the voltage equations are made with assumptions [4]: a) Magnetic fields show harmonic layout in the air gap; b) The effect of commutation is neglected; and c) Perfect commutating armature.

$$I_f = I_a \tag{1}$$

$$V_f = r_f I_a + L_{ff}\left(\frac{dI_a}{dt}\right) \tag{2}$$

$$E = L_{af}\,\omega I_a \tag{3}$$

$$V_a = r_a I_a + L_{aa}\left(\frac{dI_a}{dt}\right) + E \tag{4}$$

$$V_t = I_a(r_f + r_a + L_{af}\omega) + \left(\frac{dI_a}{dt}\right)(L_{ff} + L_{aa}) \tag{5}$$

Where, V_t is the supply voltage (volts), E is the back emf (volts), r_a (ohms) is the resistance of the stator, I_a (A) is the current in the armature, r_f (ohms) is the resistance of the rotor, I_f (A) is the excitation current, V_f (volts) is the excitation voltage, L_{ff} (H) is the self-inductance of the rotor, and L_{aa} (H) is the self-inductance of the stator.
Mechanical equations of the motor:

$$T_e = L_{af} I_a I_f \tag{6}$$

$$\omega = \int\left(\left(\frac{-B}{J}\right)\omega + \frac{(T_e - T_L)}{J}\right)dt \tag{7}$$

Where, B is the friction coefficient, T_e (Nm) is the electromagnetic torque, J (kgm^2) is the inertia coefficient, T_L(Nm) is the load torque, ω (rpm) is the mechanical speed of the rotor, and Ω (rps) is the angular velocity [5].
The losses equations of the universal motor were as follows:

Copper loss per slot:

$$J = \frac{IN}{A} \tag{8}$$

$$P_{Cu..slot} = I^2 R = J^2 A \rho l_{turn} \tag{9}$$

$$P_{Field..cu} = I_{se}{}^2 R_{se} \tag{10}$$

Where, J (Amp per square meter) is the current density, A is the slot, N is the number of turns, I (A) is a current, L_{turn} is the winding turn length, and ρ (Ω m) is the specific resistance of copper, R_{se} (Ω) is the resistance of series field winding, and I_{se} (A) is the current of a series field winding [4].
Iron loss:

The core of the armature is iron and it rotates in the magnetic field, so small amount of current gets induced. Because of this current, in the core of the armature hysteresis and eddy current loss occurs. The eddy current loss is influenced by the square of frequency, and the hysteresis loss rises linearly with the frequency.
Hysteresis loss and Eddy current loss:

$$P_h = k_h B^n fm \tag{11}$$

$$P_e = k_e B^2 f^2 m \tag{12}$$

Where, k_h is the constant of hysteresis and k_e is the Eddy current constant respectively. B (Tesla) is the maximum flux density, f (Hz) is the frequency, m is the mass, and n is the material dependent exponents (1.5 to 2.5).

TABLE I. Parameters Of The Ac Simulink Model Of Universal Motor [4]

Rated Power	500W
Input Voltage	230V AC
Current	4.17A
Speed	18000 rpm
Stator Resistance	2.04 ohm
Rotor Resistance	1.6 ohm
Rotor Self-inductance	87mH
Stator Self-inductance	73mH
Mutual Inductance	2.86mH
Friction Coefficient (B)	1.686e-5 Nms
Inertial Coefficient (J)	3.2e-4 kg.m2

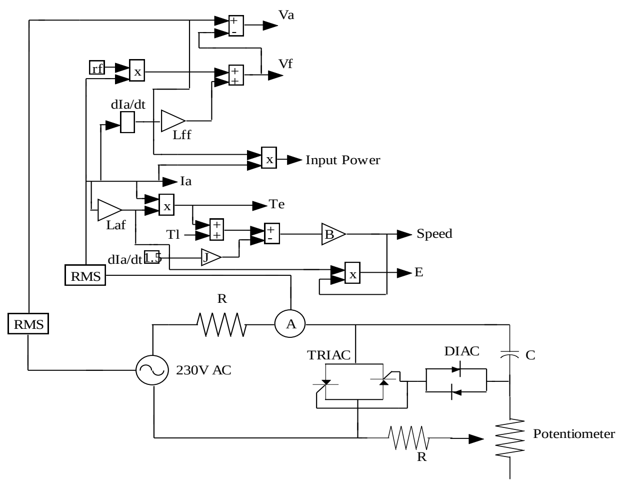

Figure 3. Simulink model of Triac based AC universal motor circuit

Table I shows the Simulink model parameters of the universal motor in the AC operating condition. An existing mixer grinder of 500W rated power with speed of 18000 rpm and voltage of 230V AC was considered. The operating torque depends on the materials used and the size of the jar (0.4 Litre,1.2 Litre, and 1.7 Litre). The required torque would be in the order of 0.2~0.4 Nm as per commercial available mixer grinders. Fig. 3 represents the Simulink model of the Triac-based AC universal motor circuit.

In the Triac-based AC circuit, the speed of the universal motor is controlled by a potentiometer. The values of the potentiometer are set as R_1=200 Ω, R_2=1k Ω, and R_3=500k Ω and the speed of the universal motor is controlled. Fig. 4, Fig. 5, and Fig. 6 shows speed vs. time characteristics for R_1=200 Ω, R_2=1K Ω, and R_3=500k Ω.

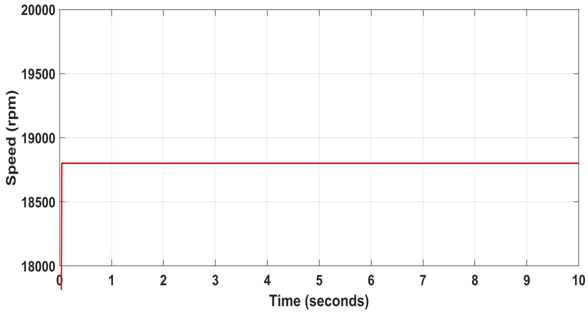

Figure 4. Speed vs. time characteristics for R_1=200 Ω

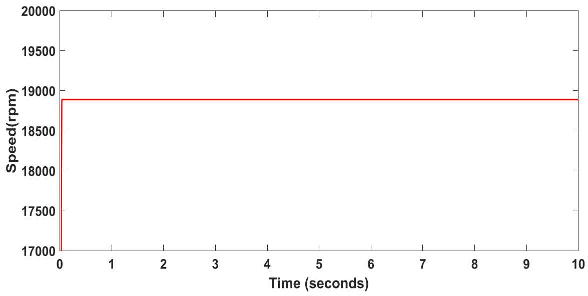

Figure 5. Speed vs. time characteristics for R_2=1kΩ

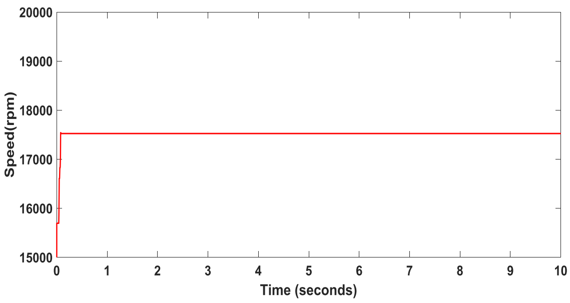

Figure 6. Speed vs. time characteristics for R_3=500k Ω

Efficiency is defined as the ratio between the output power and the input power. The output power is 500W for the mixer grinder. Table II represents the efficiency of the Triac-based AC driver circuit with 230V AC universal motor for different values of speed. The efficiency of the Triac-based AC driver circuit with the universal motor is 48.22% and the efficiency of the Triac-based AC driver circuit is 43.94%, while that of the 230V universal motor model is 52.16%.

TABLE II. EFFICIENCY OF THE TRIAC-BASED AC UNIVERSAL MOTOR CIRCUIT

Potentiometer values	Speed (rpm)	Input Power (watts)	Efficiency (%)
R_1=200Ω	19000	1030.5	48.52
R_2=1k Ω	18890	1039.72	48.10
R_3=500k Ω	17500	1040.3	48.05

Table II shows the efficiency of the Triac-based AC universal motor for different values of the of the potentiometer. For lower resistance value, the efficiency of the Triac-based universal motor was higher.

TABLE III. LOSSES OF 230V AC UNIVERSAL MOTOR

Percentage of losses in 230V AC universal motor	Wattage of losses in 230V AC universal motor
Efficiency =52.16%	Rated power =500W
Armature copper loss= 14.4%	Armature copper loss = 72W
Field winding loss = 8.4%	Field winding loss = 42W
Mechanical loss = 3.62 %	Mechanical loss = 18.1W
Stray load loss=2.14%	Stray load loss =10.7 W
Hysteresis loss=9.3%	Hysteresis loss = 46.5W
Eddy current loss= 8.07%	Eddy current loss = 40.35 W
Friction +Brush+ Ventilation loss=1.91%	Friction +Brush+ Ventilation loss = 9.55W

Table III shows the losses of the 230V universal motor. It consists of copper loss, mechanical loss, stray loss, hysteresis loss, winding loss, friction loss, eddy current loss, brush loss, and ventilation loss.

TABLE IV. LOSSES OF TRIAC-BASED DRIVER CIRCUIT

Rated power=500W; Efficiency of 230V universal motor=52.16%	
Efficiency of Triac-based driver circuit=43.94%	
Percentage of losses in Triac-based driver circuit	Wattage of losses in Triac-based driver circuit
Resistive loss=30.11%	Resistive loss=150.55W
Switching loss=15.48%	Switching loss=77.4W
Conduction loss=10.47%	Conduction loss=52.35W

Table IV shows the losses of the Triac-based driver circuit. It consists of resistive loss, switching loss, and conduction loss.

B. *Proposed VSI Based 48V BLDC Motor*

In the mathematical modelling of the BLDC motor, consider the cylindrical rotor and stator as having three phase windings a, b,and c. The rotor is made up of permanent magnets with uniform air gap, while the stator has three phases which are star connected [7]. The dynamic equations of phase a, phase b, and phase c are:

$$V_{an} = R_S i_a + L\frac{di_a}{dt} + M\frac{di_b}{dt} + M\frac{di_c}{dt} + e_a \tag{13}$$

$$V_{bn} = R_S i_b + L\frac{di_b}{dt} + M\frac{di_c}{dt} + M\frac{di_a}{dt} + e_b \tag{14}$$

$$V_{cn} = R_S i_c + L\frac{di_c}{dt} + M\frac{di_a}{dt} + M\frac{di_b}{dt} + e_c \tag{15}$$

Where, R_s (Ω) is the armature resistance, M (henry) is the mutual inductance of the armature, L is the self-inductance of the armature (henry), $V_{an,}$ $V_{bn,}$ and V_{cn} are the terminal voltages (volts), and $i_{a,}$ $i_{b,}$ and i_c are the input currents of the motor (A).

In the BLDC motor, the function of the position of the rotor relates to the back emf. Each phase of the back emf has 120^0 phase angle differences.

Therefore, the equations of each phase are as follows:

$$e_a = K_a f_a(\theta)\omega_r \tag{16}$$

$$e_b = K_b f_b(\theta + \frac{2\pi}{3})\omega_r \quad (17)$$

$$e_c = K_c f_c(\theta - \frac{2\pi}{3})\omega_r \quad (18)$$

The total torque was as follows:

$$T_e = \frac{P_m}{\omega_{rm}} = \frac{(e_a i_a + e_b i_b + e_c i_c)}{\omega_r} \frac{P}{2} \quad (19)$$

Mechanical part:

$$T_e - T_L = J\frac{d\omega_{rm}}{dt} + B\omega_{rm} \quad (20)$$

Where, T_L (Nm) is the load torque, T_e (Nm) is the electromagnetic torque, B (Tesla) is the flux density, and J (Amp per square meter) is the current density [7].

The losses equations of the BLDC motor were as follows:

Copper loss:

$$W_{cu} = I_{rms}^2 R_a \quad (21)$$

Where, I_{rms} (A) is RMS value of the current and R_a (ohm) is the armature resistance.

Hysteresis loss:

$$W_h = k_h B_{max}^{\alpha} f \quad (22)$$

Where, f (Hz) is the fundamental frequency supply, K_h is the hysteresis constant, and B_{max} (Tesla) is the maximum flux density of the stator core.

Eddy current loss:

$$W_e = k_e B_{max}^2 f^2 \quad (23)$$

Where, K_e is the eddy current constant, f (Hz) is the fundamental frequency supply, and B_{max} (Tesla) is maximum flux density of the stator core.

Switching and conduction loss:

$$W_{switch} = \frac{V_{min} I_{max}}{6}(T_{on} + T_{off}) f_{switching} \text{ watts} \quad (24)$$

$$W_{cond} = 2V_{min} I_{max} \text{ watts} \quad (25)$$

Where, V_{min} is the min voltage (volts), I_{max} is the maximum current (A) , T_{on} is the on-time period (sec), and T_{off} is the off time period (sec).

TABLE V. MOTOR PARAMETERS OF THE BLDC MOTOR [7]

Rated Power	200W
Input Voltage	48V
Speed	10000RPM
Stator Resistance(Rs)	0.06ohms
Stator Inductance (Ls)	0.006mH
Number of Poles (P)	4
Friction Coefficient (B)	0.0682e-3
Inertial Coefficient (J)	21.5e-3 J/kgm2

Table V shows the parameters of a 48V BLDC motor with rated power of 200W, input voltage of 48V, and speed of 10000 rpm. Fig. 7 shows the Simulink model of a 48V BLDC motor. It comprises of the current generator, emf generator, and speed generator.

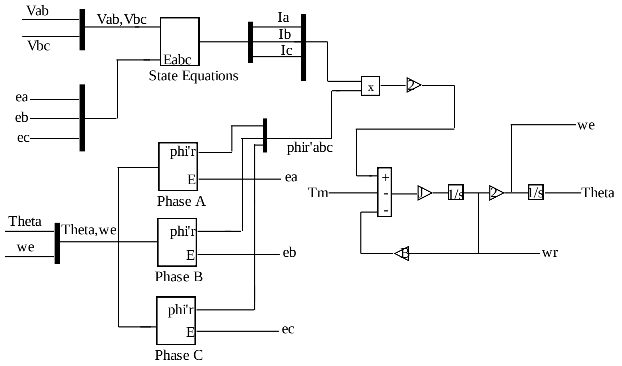

Figure 7. Simulink model of a 48V BLDC motor

The Simulink model of the VSI-based BLDC circuit for 48V is presented in Fig. 8.

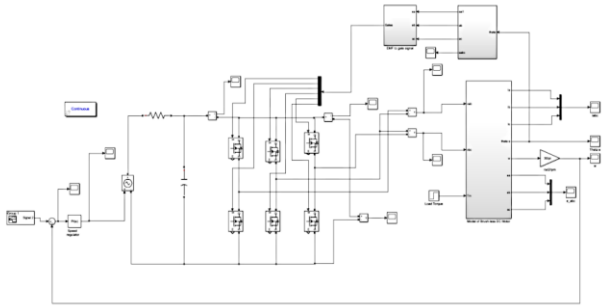

Figure 8. Simulink model of a VSI based BLDC circuit for 48V

In the VSI- based BLDC driver circuit for 48V, the speed of the BLDC motor is controlled by the PI controller. The value of the proportional (K_P) was 1.5 and the integral (K_I) was 0.9. The value of the DC link capacitor was 400μF.

TABLE VI. LOSS ANALYSIS OF 48V BLDC MOTOR

Percentage of losses in 48V BLDC motor	Wattage of losses in 48V BLDC motor
Efficiency=81.15%	Rated power=200W
Friction loss=0.5%	Friction loss=1W
Resistive loss=0.5%	Resistive loss=1W
Hysteresis loss=6.15%	Hysteresis loss=12.3W
Eddy current loss=4.35%	Eddy current loss=8.7W
Winding loss=3.76%	Winding loss=7.52W
Stray load loss=1.57%	Stray load loss=3.14W
Mechanical loss=2.02%	Mechanical loss=4.04W

Table VI shows the losses of the 48V BLDC motor. It consists of mechanical loss, stray loss, hysteresis loss, winding loss, friction loss, eddy current loss, and brush loss.

TABLE VII. LOSSES OF VSI-BASED DRIVER CIRCUIT FOR 48V BLDC MOTOR

Rated power=200W; Efficiency of 48V BLDC motor=81.15%	
Efficiency of VSI based driver circuit=81.04%	
Percentage of losses in VSI-based driver circuit	Wattage of losses in VSI-based driver circuit
IR loss=9.27%	IR loss=18.54W
Switching loss=6.24%	Switching loss=12.48W
Conduction loss=3.45%	Conduction loss=6.9W

Table VII shows the losses of the VSI-based driver circuit. It consists of IR loss, switching loss, and conduction loss. It can be observed that in the proposed-VSI based BLDC motor, the efficiency is 81.09 % and that of the VSI-based driver circuit is 81.04%.

IV. CONCLUSION

In the application of a mixer grinder, the existing Triac-based 230V universal motor and the VSI-based 48V BLDC motor, as per the specification data, was simulated by the Matlab/ Simulink. The comparative analysis of the Triac-based universal motor and the VSI-based BLDC motor was determined. The elimination of the phase current and the voltage sensor reduced the complexity and improved the efficiency of the mixer grinder. The efficiency of the proposed VSI-based BLDC motor was higher, i.e., 81.15% compared with the existing Triac- based universal motor, i.e.,48.15% due to the absence of the brushes in the BLDC motor. The losses in the proposed system were less compared with the existing mixer grinder.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The idea for this work is by Dr R Shivarudraswamy. Deekshitha S Nayak conducted the research, analyzed the data. Both the authors had approved the final version.

ACKNOWLEGMENT

I would like to thank my guide (Dr. R Shivarudra Swamy) for the guidance of this research paper. I would thank my HOD for his support and my college (Manipal Institute of Technology, Manipal) which provided expertise that greatly assisted the research.

REFERENCES

[1] D. Kamalakannan, M. Karthi, V. Narayanan, N. J. Singh, and N. S. Ramanathan, "Design and development of DC powered BLDC motor for Mixer-Grinder application," In *Sustainable Green Building and Community (SGBC), International Conference on*, IEEE,2016, pp. 1-6.

[2] Bhagat, D. Chinmay, B. G. Fernandes, and S. P. Nikam, "Design and development of sensorless controller for DC-operated mixer-grinder," *International Conference on Sustainable Green Building and Community*, IEEE, 2016, pp. 1-6.

[3] Gholase, B. G. Fernandes and Vaibhav, "Design of efficient BLDC motor for DC operated mixer-grinder," *2015 IEEE International Conference on Industrial Technology (ICIT)*, IEEE, 2015, pp. 695-701.

[4] Nayak, S. Deekshitha, and R. S. Swamy, "Loss and efficiency analysis of universal motor used in mixer grinder by mathematical modelling," in *Proc. 2018 IEEE International Conference on Automatic Control and Intelligent System (I2CACIS)*, IEEE, 2018, pp. 105-110.

[5] Ridwan, Mohamad, and M. N. Yuniarto, "Electrical equivalent circuit based modeling and analysis of brushless direct current (BLDC) motor," In *Intelligent Technology and Its Application (ISITIA), 2016 International Seminar on*, IEEE, 2016, pp. 471-478.

[6] Yildiz, A. Bekir, "Electrical equivalent circuit based modeling and analysis of direct current motors," *International Journal of Electric Power & Energy System*, vol. 43, no. 1, pp. 1043-1047, 2012.

[7] Laxminarayana and Tarakalyani, "Modeling and simulation of bldc motor for aiding and opposing loads," *IOSR J. Electr. Electron. Engg* , vol. 7, no. 4, pp. 9-67,2013.

[8] C. Mohankrishna, S. R. Gupta, A. Ramesh, and N. R. Kumar Gowd, "Modelling and simulation of BLDC motor using state space approach," *International Journal of Innovative Research in Electronics, Electrical, Instrumentation and Control Engg*, vol 4, no. 5, pp. 534-538, 2016.

[9] Electronics.Stackexchange [Online]. Available: https://electronics.stackexchange.com/questions/299961/problems-driving-auniversal-motor-with-triac

[10] K. Rajan and B. Singh, "BLDC motor-driven solar PV array-fed water pumping system employing zeta converter," *IEEE Trans. on Industry Application* , vol. 52, no. 3, pp. 2316-2322, 2016.

[11] K. Rajan and B. Singh, "Single stage solar PV fed brushless DC motor driven water pump," *IEEE Journal of Emerging and Selected Topic in Power Electronic*, vol. 5, no. 3, pp. 1377-1385,2017.

Deekshitha S Nayak is Research Scholar in the Department of Electrical and Electronics Engineering in Manipal Institute of Technology, Manipal. Completed B.E (Electrical and Electronics) degree at YIT Moodbidri in the year 2014 and M. Tech (Electronics) degree at Canara Engineering College in the year 2016.The area of interest are Renewable Energy, Power Electronics, Motor and Drives.

Dr. R. Shivarudraswamy is Working at Manipal Institute of Technology, Manipal, in the Department of Electrical & Electronics as an Associate Professor from last 15 Years, before worked in the Industry as an Electrical Maintenance Engineer about 3 and half years. Completed B.E (Electrical) degree at SIT Tumkur in year 1994 & M.Tech degree at Malnad College of Engineering in the year 2002 & completed Ph.D degree at NITK Surathkal ,Karnataka in the year 2013, The area of research Interest are Distributed Generators and Energy conservation and Management..