"UTILIZING MODIFIED DIRECT CONTROL AND ADAPTIVE CONTROL THEORY FOR REGENERATIVE BRAKING IN ELECTRIC VEHICLES"

D. Shivaji , Associate Professor EEE, Tkr College of Engineering and Technology(Autonomous), India
K. Narender, UG student, EEE, Tkr College of Engineering and Technology (Autonomous), India
Jorigala Sriwin, UG student, EEE, Tkr College of Engineering and Technology(Autonomous), India
Kommu Arjun Kumar, UG student, EEE, Tkr College of Engineering and Technology(Autonomous), India
Janampeta Saikiran, UG student, EEE, Tkr College of Engineering and Technology(Autonomous), India

***Abstract*— This paper represents a novel regenerative braking approach for electric vehicles. The proposed method solves the short-range problem which is related to the battery discharge. The direct torque control switching algorithm is modified to recover electrical energy from an electric vehicle, driven by brushless direct-current motor, without using the additional power converter or the other electrical energy storage devices. During regenerative braking process, a switching pattern is applied to the inverter which is different from the normal operation due to the special arrangement of voltage vectors. The new switching pattern is considered to convert mechanical energy into electrical energy. State of charge of the battery is used as a performance indicator of the proposed method. Simultaneously, a model reference adaptive system is designed to tune the system's parameters. Several simulations are conducted to validate the performance and effectiveness of the proposed methods. The results show the high capability of designed methods.**

1.INTRODUCTION:

Present global scenario the Electric Vehicles (EVs) draws every one's attention to substitute conventional fossil fuel viz. petrol, diesel and natural gas operated vehicles. The ecological and financial instability is major problem of fossil fuel. The higher diminishing of crude oil source at one hand and exponential rate of demand on the other hand create high inflation, pollution and global warming issues for every government and every common man. The prevailing situation forces us to go for green fuel, abundant sources at cheaper prices to stabilize the economy and environmental protection at the global level.

The results of recent research on electric vehicles. The greatest alternative to replacing current fossil fuel-powered cars is to use batteries, motors, and related controllers. Performance and mileage are comparable to those of traditional car engines. The dedicated charging stations make it simple to move from fossil to green fuel for electric vehicles by providing fast charging.

1.1. Current Scenario

The global level of environmental pollution is rising because of the release of greenhouse gases. Additionally, the price of fuel is rising. Electric vehicles must take the place of vehicles powered by fossil fuels to address these issues. Electric vehicle motor and battery usage is a significant component that needs effective and appropriate control strategies. In many ways, BLDC motor performance characteristics are better. Overall performance indicates that lithium-ion batteries are more economical for electric vehicles. The longevity and capacity of the batteries are another challenge with electric vehicles. Regenerative braking is one remedy to the mentioned problems. With the use of simulation findings, this project compares the performance characteristics of various controllers that are best suited for driving and regeneration modes. Using MATLAB SIMULINK, the suggested controllers and driving systems are simulated.

1.2. Purpose of the Project

The use of non-renewable energy sources, which will exhaust in a few decades, is being replaced with renewable energy sources, which can last indefinitely. Similar efforts are being made to develop EVs by engineers, designers, and scientists in the automotive industry. The achievement of specific objectives will bring magnificent benefits in automobile manufacturing and revolutions in general transportation.

The automotive sector consistently doing researches for alternative fuel technology to global economy moves to sustainable energy in response to climate change. The only solution to this global crisis in future is only the electric vehicles. But major issue is how to extend the range of electric vehicles.

2. CURRENT SOURCE INVERTER

A dc power flow, these static power converters generate ac output current waveforms. For sinusoidal ac outputs, its magnitude, frequency, and phase should be controllable. Due to the fact that the ac line currents ioa, iob, and ioc feature high di=dt, a capacitive filter should be connected at the ac terminals in inductive load applications (such as ASDs).

Should be closed at any time; however it cannot be opened because the dc bus is of the current-source type hence there must be one top switch and another bottom switch. Although both constraints can be expressed concisely as ‘at each instant only one top switch and one bottom switch shall close. Three-phase CSIs have nine admissible states which yield zero ac line currents. In this case either through S1-S4 or S3 –S6 or through S5-S2, freewheels dc link current.

2 Relevant Research Papers:

The order of papers discussed below is are same as the list of references.

PAPER [1]: The different types of regenerative braking methods for electric vehicles are discussed in this paper. A suitable suggestion given to resolve the short-range issues due to battery drain. In order to recover electrical energy from electric vehicles by brushless direct-current motors without the use of an additional power converter, the direct torque control switching algorithm evolved to convert mechanical energy into electrical energy. The battery's state of charge is used as a performance indicator. A model reference adaptive system is simultaneously created to adjust the system's parameters. A number of simulations are run to verify the efficiency and performance of the suggested methods.

PAPER [2]: This research paper explained regenerative braking method using a battery, converters, brushless direct current motor and energy storage devices. In order to control and regulate power, four quadrant operations with no power loss with three-phase BLDC motor uses fuzzy PID logic control employed. The analysis carried out to power flow during acceleration and braking mode. The power is transferred from the battery to the motor during acceleration and normal operation, while during braking or regenerative mode, the motor's kinetic energy is converted to electrical energy and returned back to the battery. The simulation carried out using MATLAB/Simulink for BLDC with fuzzy-PID controller

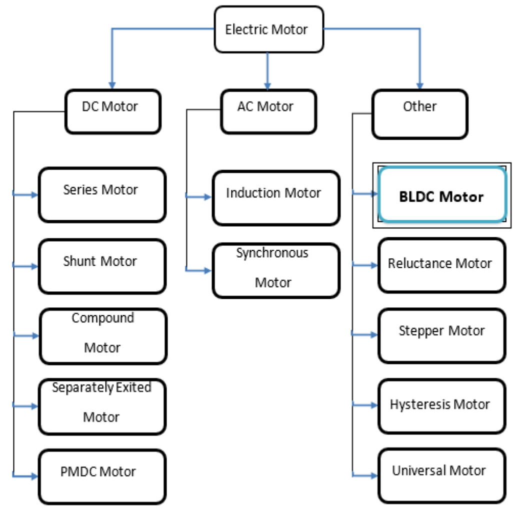
3 ELECTRIC VEHICLE SUBSYSTEMS

This chapter discusses the history and electric motors, the brushless DC motor's benefits over other electric motors, how it is used, how current is controlled, and other BLDC motor-related applications.

3.1. Electric Vehicle and Electric Motors

Although they are not particularly new to this planet, electric vehicles now have the reputation of being the form of transportation of the future thanks to technological advancement and growing concern over pollution. Electricity serves as the primary source of propulsion for EVs. The electrical energy is getting converted into mechanical energy using BLDC motor with regenerative braking system and stored in electric vehicle battery.

Through the use of the proper transmission system, the wheels of the



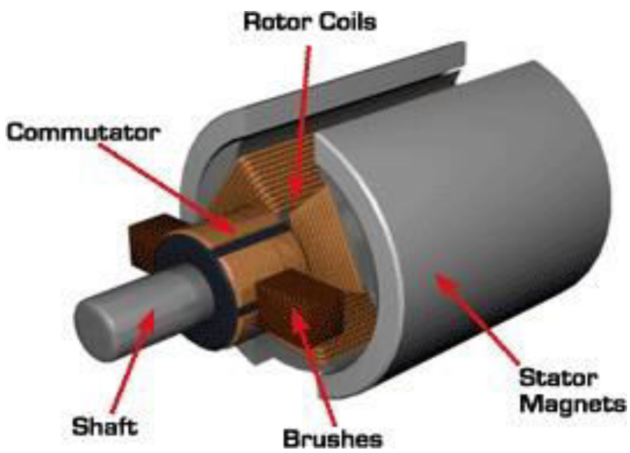
vehicle are connected to this rotational energy. In hybrid electric vehicles, batteries work in tandem with gasoline engines to power the engine. Electric vehicles can also run entirely on electricity. The three main parts of any electric vehicle are the battery, motor drive system, and controller.

Electric motors are used to convert electrical energy into mechanical energy. The magnetic field of the motor is coupled with electric current in a wire winding in the electric motor to produce mechanical force in the form of torque, supplied to the motor shaft. Electric motors can be powered either by direct current sources like batteries, motors, or rectifiers and powered by alternating current sources like power grids, inverters or generators.

The fundamental force for a vehicle's propulsion is provided by the motor, which makes it an important part of electric vehicles. While technically equivalent to an electric motor, an electric generator uses a reversed control flow to convert mechanical energy into electrical energy.

3.1.1 DC motor with brushes:

In a dc brushed motor armature of motor and the external supply circuit are connected by brushes and commutators. The brush used in motor is generally rectangular in shape made up of carbon, copper, graphite or metal graphite. The main problems with dc brushed motors is wear and tear of commutators by continuous use of the brushes. The mechanical friction between brushes and commutators reduces the motor output. However, DC brushed motor is used in traction systems



since it provides better torque at low speeds.

3.3.1 Types of Electric Battery & Comparison

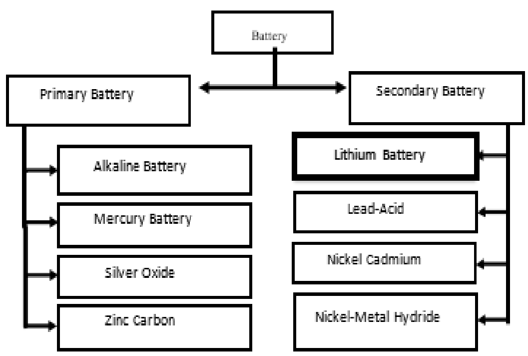


Figure 3.7 Types of electric battery

4.CONVERTERS:

Basically, An AC-DC bidirectional converter is a power electronic device capable of converting electrical power bidirectionally between alternating current (AC) and direct current (DC) forms. It allows energy to flow in both directions, enabling power transfer from AC to DC and vice versa. These converters are commonly used in applications such as renewable energy systems, energy storage systems, electric vehicle charging, and grid-tied systems where energy needs to be efficiently managed and transferred between AC and DC sources. These are the forms of signals needed for variable frequency drives (VFDs), uninterruptible power supplies (UPSs), static var compensators (SVCs), active filters, FACTS, and voltage regulators. For a sine wave ac output; we need to be able to control amplitude, frequency as well as phase. Based on the type of ac output waveform, these topologies can be classified as voltage source inverters (VSIs), where the independent controlled ac output is a voltage waveform.

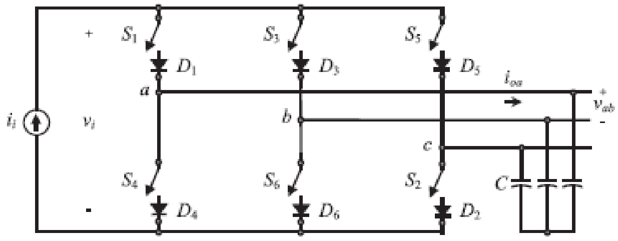
4.1 TYPES OF INVERTERS:

Here Generally inverters are of Two Types:

1. VOLTAGE SOURCE INVERTER
2. CURRENT SOURCE INVERTER

1. VOLTAGE SOURCE INVERTER

A Voltage Source Inverter (VSI) is a power electronic device used to convert DC power to AC power. It's a crucial component in various applications including renewable energy systems, motor drives, and uninterruptible power supplies.



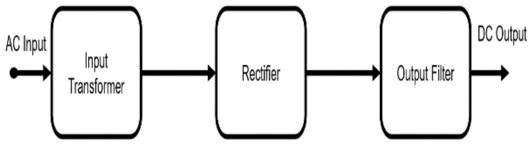


Fig Single-phase half-bridge VSI.

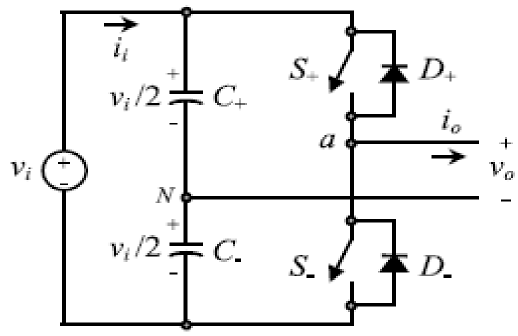
4.2 Design methodology of BLDC motor drive system

Figure 4.2 shows the block diagram for operating a BLDC motor using a voltage source inverter. The two operating modes for an inverter are motoring mode and regenerating mode. The inverter gives power to the motor while in motoring mode, functioning as a rectifier. The inverter feeds the battery during the regenerating mode using motor. A voltage source inverter serves to charge and discharge the battery. In need for the battery to power the BLDC motor drive. All four quadrants can be handled by the brushless motor. The mechanical energy created during braking condition is converted into electrical and stored in the battery.

Control

Choosing a control scheme, running simulations, tweaking parameters, and other sophisticated processes are all part of the actual design of the BLDCM drive. For the servo system's controller parameters to be tuned for optimum performance, system expertise is the Power and Force of Electric Vehicles

The force that propels the electric vehicle must overcome the forces of rolling resistance **(F_{rr})**, hill climbing force **(F_{hc})**, aerodynamic drag force **(F_{ad})**,



and acceleration force **(F_{la})**. In this dissertation, the required motor power rating and other electric motor specifications are chosen while taking into account an automobile with a gross weight of 1500 kg (m). To determine the overall force required to move a vehicle, use the equation below.

In order to move the vehicle, the motor must overcome the total force **(F_{tot})**, so the motor of choice must produce a force greater than total force in order to prevent wheel sliding. Changes in the inclination angle of the road surface can cause havoc with the system, as shown in Figure 4.4. The controller must has the ability to eliminate disturbances.

Mathematical Design Equations related to Project:

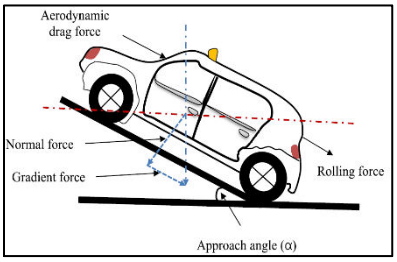
$$F_{tot} = F_{rr} + F_{hc} + |F_{ad} + F_{la} \quad \textbf{(4.6)}$$

$F_{hc} = M.g.\sin\varphi$ **is the hill climbing force (4.7)**

$F_{ad} = \frac{1}{2}\rho.C_d.A.V^2$ **is the aerodynamic drag (4.8)**

$F_{la} = M\frac{dv}{dt}$ is the acceleration force (4.9)

The total torque load can be calculated as:



$T_L\ F_{tot} * R_w$ where R_w

$P = P_{max}$ X 0.15 + 0.85 X P

(@Zero grad & constant speed)

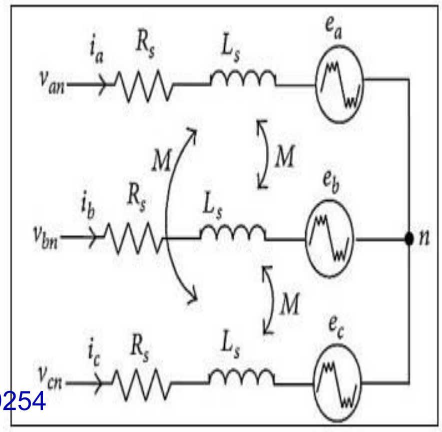
$$P_m = \frac{P}{\eta_m}$$

$$W_{road} = P_m\, t = \frac{P_m\, S}{V} \quad (4.13)$$

$$\text{SOC}\ \% = \frac{(W_{rated} - W_{road})}{W_{rated}}\ X\ 100\ \%$$

4. Mathematical Modeling of BLDC Motor for Electric Vehicle:

When modeling the BLDC motor, only Phase A is taken into account for simplicity's sake. Figure 4.8 provides the equivalent current of the BLDC motor's phase A winding. V, the terminal voltage, is assumed to be V.



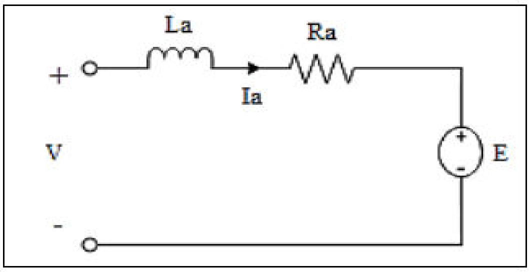
Current of the Phase-A

The literature contains the current formulae for the three windings' phase variables. The following is the model of the armature winding for the BLDC motor:

$$V_{as} = R_s I_a + L_a\frac{di_a}{dt} + L_{ab}\frac{di_b}{dt} + L_{ac}\frac{di_c}{dt} + e_a \quad (4.15)$$

$$V_{bs} = R_s I_b + L_b\frac{di_b}{dt} + L_{ba}\frac{di_b}{dt} + L_{bc}\frac{di_c}{dt} + e_b \quad (4.16)$$

$$V_{cs} = R_s I_c + L_c\frac{di_c}{dt} + L_{ca}\frac{di_b}{dt} + L_{cb}\frac{di_c}{dt} + e_c \quad (4.17)$$



frequently utilized in electric vehicles (EVs) to improve performance. Fig. 3 depicts the BLDC drive system's general switching circuit. The BLDC comparable dynamic model is represented as

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

$$L = L_s - L_m$$

Where,

V_{an}, V_{bn}, V_{cn} - phase voltages, i_a, i_b, i_c **-** phase currents, **R** - phase resistance, **L** - equivalent inductance in each stator windings, **Ls** - inductance of each phase, **Lm** - mutual inductance between phases, **e_a, e_b, e_c** back emf of each phase

The literature contains the current formulae for the three windings' phase variables. The following formulas are the model of armature winding for BLDC motor:

$$V_{as} = R_s i_a + \frac{di_a}{dt}(L - M) + e_a$$

$$V_{bs} = R_s i_b + \frac{di_b}{dt}(L - M) + e_b$$

$$V_{cs} = R_s i_c + \frac{di_c}{dt}(L - M) + e_c$$

Rearranging Equations (4.20), (4.21), and (4.22) given the two phases of current difference equations as follows:

$$\frac{di_a}{dt} = \frac{V_m}{(L-M)} - \frac{R_s i_a}{(L-M)} - \frac{e_a}{(L-M)}$$

$$\frac{di_b}{dt} = \frac{V_m}{(L-M)} - \frac{R_s i_b}{(L-M)} - \frac{e_b}{(L-M)} \quad \textbf{(4.18)}$$

$$\frac{di_c}{dt} = \frac{V_m}{(L-M)} - \frac{R_s i_c}{(L-M)} - \frac{e_c}{(L-M)}$$

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} -\frac{R_m}{(L-M)} & 0 & 0 \\ 0 & -\frac{R_m}{(L-M)} & 0 \\ 0 & 0 & -\frac{R_m}{(L-M)} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L-M}\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} - \frac{1}{L-M}\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad \textbf{(4.26)}$$

State space form is given by:

$$\frac{dx}{dt} = Ax - b(V - e)$$

$$= \begin{bmatrix} -\frac{R_m}{(L-M)} & 0 & 0 \\ 0 & -\frac{R_m}{(L-M)} & 0 \\ 0 & 0 & -\frac{R_m}{(L-M)} \end{bmatrix},$$

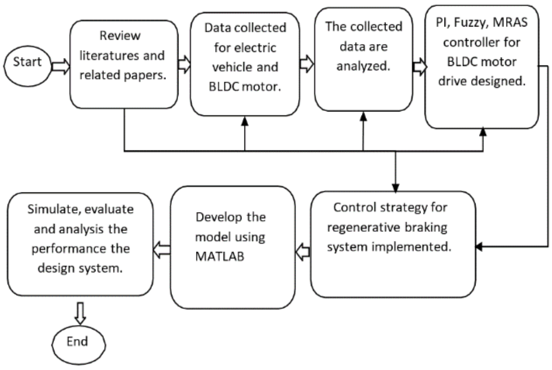
$$b = \frac{1}{(L-M)},$$

$$V = \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}, \quad e = \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

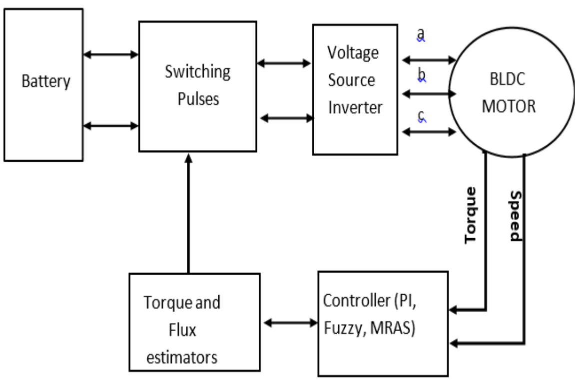
5.0

necessary. For the speed control design of BLDC motors, numerous order to help ensure solutions have recently been put forth. However, the standard PI controller algorithm is simple, trustworthy, and easy to alter. It also uses a normal speed control scheme.

The technique, data analysis, controller design, and mathematical modeling of the BLDC motor drive are all covered in this chapter. Analyses of the vehicle



dynamics and the identified motor specification are performed. The system is finally modeled using the MATLAB/Simulink program.



5.MODELING OF EVS CONROLLERS WITH RBS

Introduction:

This chapter presents various controllers, BLDC motor drive system data analysis, controller design, and mathematical modelling. Analysis of the controllers' specification that were obtained was performed. The system is then simulated using the MATLAB / Simulink software.

P-I controller disadvantages: high starting overshoot, sensitivity to controller gains and sluggish response to sudden disturbances. The non-interactive PI-controller is the optimum PI controller because it is not suitable for direct field contact. If the derivative function is enabled, it is very responsive to electrical noise on the process variable input.

5.1 Conventional DTC Controller:

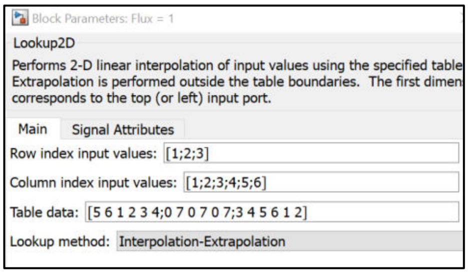
Conventional direct torque controller is one of the method used in variable frequency drives to control the torque and thus finally the speed of three-phase AC electric motors. This involves calculating an estimate of the motor magnetic flux and torque based on the measured voltage and current of the motor. Conventional Direct Torque Control is an optimized AC drives control principle where inverter switching directly controls the motor variables: flux and torque. The measured input values to the DTC control are motor current and voltage. The voltage is defined from the DC bus voltage and inverter switch positionS

Switching Logic

The suitable voltage vector is selected based on change in torque, change in flux and sector. In the above block diagram, there are to input stages, one for selecting flux table based on the obtained sector and Torque values. The second stage, from the

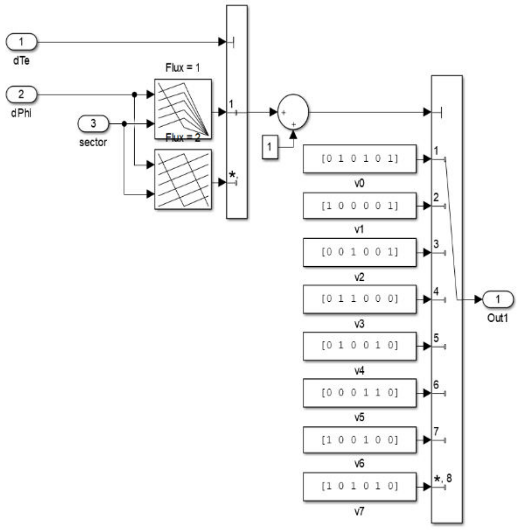
selected flux table correct voltage are selected and sent to voltage source inverter switches.

The first stage, inputs are change in toque (dte), change in flux (dfe) and sector. Change in torque is either 1 or 2 and sectors are 1, 2, 3, 4, 5, and 6. Both change in torque and sectors are used to



select correct flux table. To implement the table logic we use a control block that compares the values of reference torque and estimated torque and generate output. Change in torque value is determined by the difference between reference torque and estimated torque. Change in torque is 1, if the reference torque is less than estimated torque, this means the estimated torque value should decrease to meet reference torque value change in torque is 2, if the reference torque is less than estimated torque, estimated torque value should decrease to meet reference torque value.

To implement the logic 2 multi switch port is used, one is used for selecting flux table from change in torque and sector values. Multi-port switch consists of two types of inputs, one for magnitude the other data. The magnitude port decides which data input is to be passed to output of multi -port switch. In this case, change in torque value is used for input of magnitude port and sector value is given to flux tables. Flux 1 table is for values of change in torque: -1, change in flux: 1, 0 and for



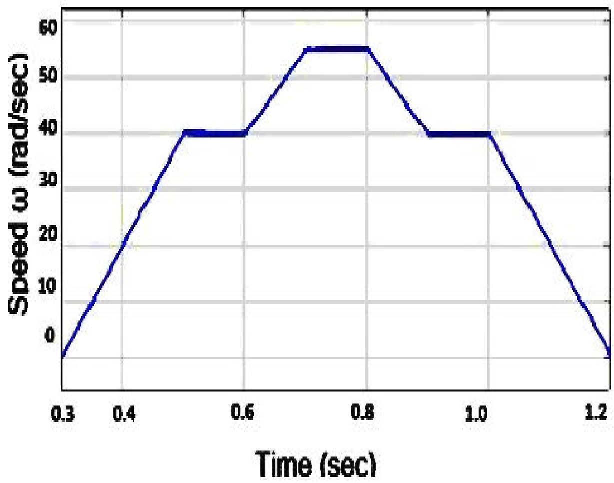
sector: 1, 2,3,4,5 and 6. (From table).

Flux 2 table is for values of change in torque: 1, change in flux: -1, 0 and for sector: 1, 2,3,4,5 and 6 (From table). The change in torque values 1 and -1 are converted to 1 and 2 by control bloc which follows same switching logic. The change in torque (dte) values decides which flux able to be selected. If the change in torque (dte) value is 1, then flux – 2 table passes through the switch output port. If the change in torque (dte) value is 2, then flux –1 table passes through the switch output port.

The second stage, from the selected flux table, suitable voltage vector is selected. There are 8

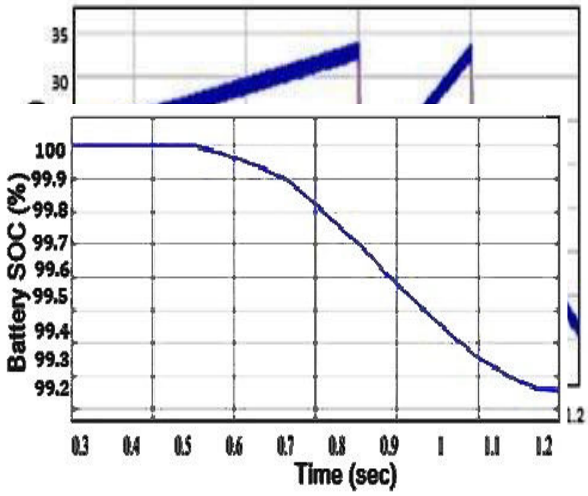
voltage vectors: v0, v1, v2, v3, v4, v5, v6 and v7. Two are zero vectors: v0 and v7 remaining six are non-zero vector: v v1 v2 v3 v4 v5 v6.From the values of change in torque, change in flux and sector suitable flux table is selected and sent to input of second multi – port switch. The output from first multi-port switch can be any of these values: 0,1 2,3,4,5,6,7 as representation of 8 voltage vectors. Second multi-port switch consists of one magnitude port and 8 data ports. The 8 data ports are for 8 voltage vectors: V0, V1, V2, V3, V4, V5, V6 and V7. The output from multi-port switch 1 is input to magnitude port of multi-port switch 2, the maximum output from multi-port switch 1 can be 7 whereas multi -port switch has 8 data ports from the output of multi-port switch 1 only up to data port 7 that is v6 can be selected, to compensate this we use constant value 1 to addition block alonG
with multi-port switch 1 output.

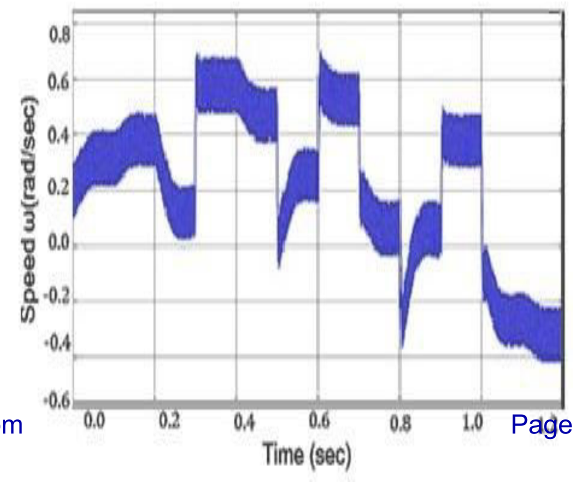
By this addition constant value 1, the switching logic is same. The output of multi-port switch 1 is 0 that means v0 is to be selected similarly for all other values: 1 for V1, 2 for V2, 3 for V3, 4 for V4, 5 for V5, 6 for V6 and 7 for V7 .For all output of multi-port switch 1 addition constant value 1 is added. The magnitude port can now select all 8 data ports that is till V7 .The selected voltage vector is then sent as output from multi-port switch 2 to VSI switches: s1, s2, s3, s4, s5 and s6. If voltage vector v0 is selected, [0 1 0 1 0 1] is sent voltage source inverter switches: s1 - 0, s2 - 0, s3 - 0, s4 - 1, s5 - 0, s6 – 1.

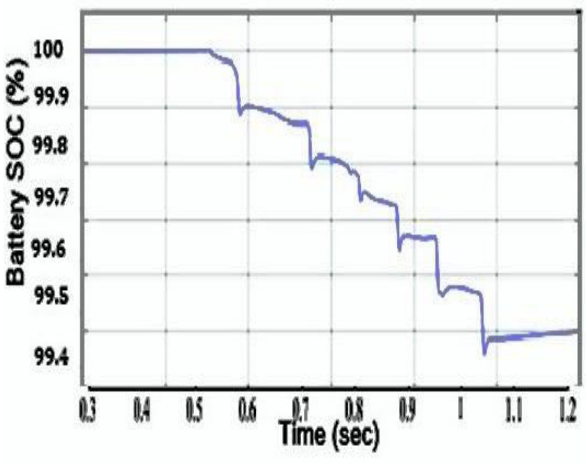


6.SIMULATION RESULTS AND DISCUSSION

. Speed Tracking for Conventional DTC (PI):







Types of Controller	Positive Torque (Nm)				Negative Torque (Nm)				Battery Discharge (%)
	Time (Sec)		SoC (%)		Time (Sec)		SoC (%)		
	I	F	I	F	I	F	I	F	
Conventional DTC (PI)	0.3	1.00	100	99.45	1.00	1.2	99.45	99.27	0.73
Modified DTC(PI)	0.3	1.05	100	99.48	1.05	1.2	99.48	99.50	0.50

7.CONCLUSION AND FURTHER SCOPE OF WORK

7.0 Conclusion:

The performance characteristics like Battery SoC, Torque Error and Speed Error are analyzed for different control techniques. In case of Battery SoC, the Modified DTC with MRAS controller performs better, compare to other controllers. Hence it improves energy regeneration. In case of Torque Error, Modified DTC strategy is perform better than Conventional DTC strategy. Hence it is good at tracking reference torque and reducing ripples. In case of Speed Error, Modified DTC with PI controller performs better compared to other controllers. Hence it is good at tracking reference speed and reducing errors. The controllers can be selected, based on specific applications.

The MRAS controller handles better at unexpected disturbances in system dynamics. Variation of system parameters and to maintain system stability. The Regenerative Braking System increases driving range and improves energy efficiency. Modified DTC converts mechanical braking energy into electrical energy and used to charge the battery. Driving cycle consists increasing, constant and decreasing of speed and torque respectively.

The simulation results are plotted for speed and torque tracking along with their errors and battery SoC From battery SoC plot, MRAS controller with modified DTC shows improved energy generation compared to other controllers. The torque ripples and tracking errors are reduced using modified DTC strategy. The results show that torque ripples are reduced by designed strategy with different controllers compared to conventional strategy

The simulations results shows that model reference adaptive controller with modified DTC improves battery energy efficiency. The battery's state of charge with modified direct torque control compare to conventional direct torque control for 1.2sec simulation. Subsequently, a portion of energy needed to drive an electric vehicle is compensated by the energy generated using regenerative breaking

The advantages of the model reference adaptive controller include stability control, increasing energy efficiency with good speed and torque tracking characteristics. When compared to other controllers, PI controller with modified DTC provide faster response, low speed error and less energy generation. The modified DTC with Fuzzy-logic controller moderately perform in battery SoC, torque tracking and speed tracking. This controller is best suited for medium range applications.

7.1. Further Scope of Works:

For further scope of the research works, it is proposed to use the hardware components to design exactly match with the simulated result output or latest components to design more efficient controllers. The control methods can also be used for hysteresis current controller to overcome present limitations of MRAS controller. There are superior methods are available to control current of BLDC motor.

In the advanced technology development in the area of sensors, controllers, batteries, motors and other associated control circuitries will open many opportunities for remarkable achievements in future applications in transportation and relevant fields of research.

References

[1] Da Xie, Haoxiang Chu, Chenghong Gu, Furong Li, Zhang Yu. A novel dispatching control strategy for EVs intelligent integrated stations. IEEE Trans Smart Grid 2015;8(2):1–10. [2] Mohan V, Singh JG, Ongsakul W. Sortino ratio based portfolio optimization considering EVs and renewable energy in microgrid power market. IEEE Trans Sustainable Energy 2017;8(1):219–29. [3] Chi-lan C, Xiao-gang W, Yue-wei B, Yan-chun X, Kai L. Motor drive system design for electric vehicle. IEEE international electric information and control engineering conf. 2011. p. 15–7. [4] Long B, Lim ST, Ryu JH, Chong KT. Energy-regenerative braking control of electric vehicles using three-phase brushless direct-current motors. Energies 2014;7:99–114. [5] Tashakor N, Farjah E, Ghanbari T. A bi-directional battery

charger with modular integrated charge equalization circuit. IEEE Trans Power Electronics 2017;32(3):2133–45. [6] Mohammad A, ZiaurRahmanKhan MD. BLDC motor controller for regenerative braking. International conference on electrical engineering and information & communication technology (ICEEICT). 2015. p. 1–6. [7] Niapour SKM, Garjan GS, Shafiei M, Feyzi MR, Danyali S, &Kouhshahi MB. Review of Permanent-magnet brushless DC motor basic drives based on analysis and simulation study. Int Rev Electr Eng (IREE) 2014;9(5):930–57. [8] Jafarishiadeh SM, Amini M. Design and comparison of axial-flux pm bldc motors for direct drive electric vehicles: conventional or similar slot and pole combination. Int J Eng Innovations Res 2017;6(1). [9] Shirvani Boroujeni M, et al. Torque ripple reduction of brushless DC motor based on adaptive input-output feedback linearization. ISA Trans 2017. http://dx.doi. org/10.1016/j.isatra.2017.05.006i. [10] Nian X, Peng F, Zhang H. Regenerative braking system of electric vehicle driven by brushless DC motor. IEEE Trans Ind Electron 2014;61(10):5798–808. [11] Sajitha P, Jashper A. Direct torque control of a BLDC motor based on computing technique. IOSR J Electr Electron Eng 2013;6(6):01–8. [12] Karthikeyan J, Sekaran RD. Current control of brushless DC motor based on a common DC signal for space operated vehicles. Electr Power Energy Syst 2011;33:1721–7. [13] Sadat AR, Pashaei A, Tohidi S, Sharifian MBB. A novel SVM-DTC method of in- wheel switched reluctance motor considering regenerative braking capability in electric vehicle. Int J Tech Phys Prob Eng (IJTPE) 2016;8(4):19–25. [14] Qiu CN, Wanga G. New evaluation methodology of regenerative braking contribution to energy efficiency improvement of electric vehicles. Energy Convers Manage 2016;119:389–98. [15] Khashayar Asadi, Hariharan Ramshankar, Harish Pullagurla, Aishwarya Bhandare, Suraj Shanbhag, Pooja Mehta, Spondon Kundu, Kevin Han, Edgar Lobaton, Tianfu Wu Buiding an integrated mobile robotic system for real-time applications in construction, arXiv:1803.01745, 2018. [16] Zaky MS, Metwaly MK. A performance investigation of a four-switch three-phase inverter-fed IM drives at low speeds using .