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Robust Power Flow Control of PV and Battery Powered Electric Vehicle with Single Stage Interaction Converter

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Abstract

Electric vehicles (EV's) are becoming an interesting topic for research and development, which give a reasonable solution for decreasing the greenhouse gas emissions. Brushless DC (BLDC) motors are one among the guaranteed motors for EV applications. Regenerative braking (RGB) enhances energy usage effectiveness as well as extends Electric vehicles the driving distance. In this research, mono foot lever, and reformative as well as mechanical braking coordination is attained, and braking force spread takes on fuzzy logic controller (FLC).With the intention of prolonging EV's travelling distance, photovoltaic (PV) panel's usage over EV decrease reliance on vehicle batteries. The proposed system, Single Stage Interaction Converter (SSIC) is presented to coordinate progression of vitality in the midst of the PV board, battery and BLDC motor. The performance assessment is done in the environment of MATLAB Simulink, in which the speed, stator current and voltage, and state of battery are evaluated. When compared to other approaches, the novel proposed approach provides improved performance in terms of robustness, realization, and efficiency.

Keywords: PV fed EV's, BLDC machine, Regenerative braking (RGB) method, single stage interaction converter (SSIC), physically challenged person

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1 Introduction

The major beneficiary features of EV's include greater efficiency, less emission, quiet operation, and so on. [1], [2]., the EV's turn out to be the most hopeful alternate to the traditional fuel vehicles by means of the growth of battery and motor technology [3].The Energy Storage System (ESS) is mainly used in chemical battery applications. In electric bike/car industry, they are presently the leading technology. On the other hand, because of the inadequate battery capacities, EV's still experience the foremost issue of shorter driving range when matched up with the fuel vehicles [4].With the intention of prolonging EV's distance travelled, PV panels usage on vehicle reduces dependence on vehicle batteries. At present, since the PV performance is increasing and the silicon PV cells price is dropping (see Figure 1), reassuring the extensive application of PV fed EVs [5], [6].With the aim of acquiring the greater efficiency as well as improved control for BLDC motors, numerous researches were performed[7] – [9]. Additionally, because of the simplicity of control and scope for RGB, to integrate BLDC motors in EV's, numerous research have been performed [10] – [12]. Main driving source of applications of EV uses BLDC motor. In deceleration process, electrical energy is obtained by converting kinetic energy and BLDC is enforced to work as an alternator for recovering it. Energy storage devices like super capacitors or batteries can be recharged using this process. Back electromotive force (BEMF) is used in a technique known as regenerative charging (RC) for generating opposite torque to brake. Performance of braking can be enhanced by RC method, as proven by various researchers in recent days and without any additional investment, driving range can be extended.

One among the most researched RGB techniques the super capacitor/battery topology [13] where in the set of batteries is directly involved to dc-link. A DC/DC converter operable in either direction is used to regulate flow of power amid battery and super capacitor. They are not cost-efficient as two individual ESS's and an extra power converter are needed for this technique, [14].

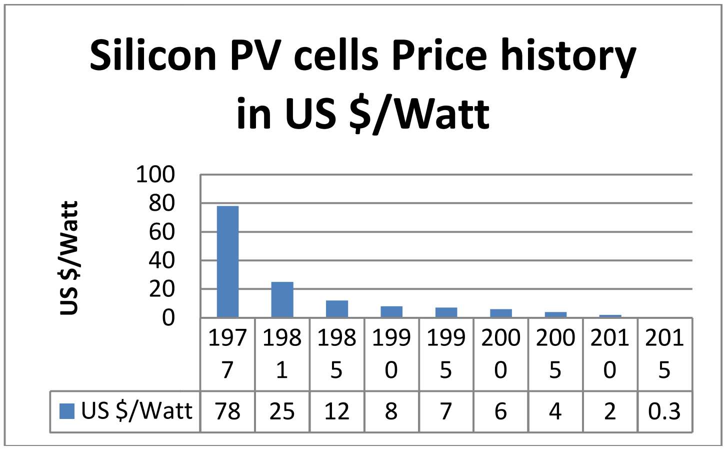


Figure 1 Silicon PV cells Price history in US$ per watt

2 Block diagram of the proposed system

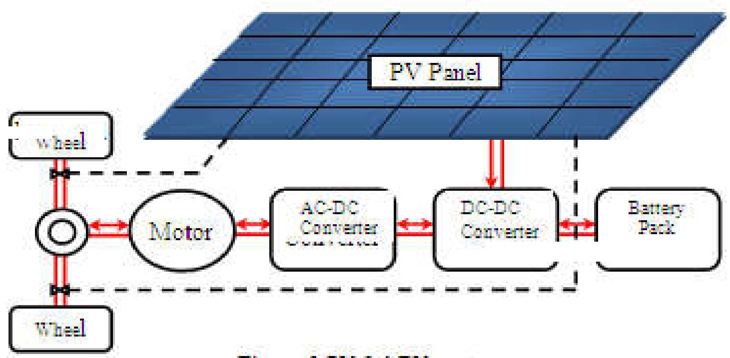


Figure 2 PV fed EV system

The PV-fed EV's contains an identical grid to Series Hybrid Electrical Vehicle (SHEV). The Internal Combustion Engine (ICE) of SHEV is substituted using PV panel. In Figure 2, PV-fed EV system is exemplified. The grid comprises of PV, ESS and power converters [15].According to the power electronics stand point, there are two fundamental topologies for these power converters: The conventional PWM inverter is powered by battery and DC/DC converter. On the other hand, to PV-fed EV's, an efficient topology with RGB technique is not yet implemented. It is mostly in light of the fact that, PV contains different highlights to ICEs, sun oriented vitality utilization is particular angles and Maximum Power Point Tracking (MPPT) and PV-nourished EV's. With the aim of attaining less expense and changeable (adaptable) energy flow modes, a SSIC is introduced in this research to direct the PV panel, BLDC motor and battery. In proposed EV system, a novel RGB technique is implemented to enhance braking performance.

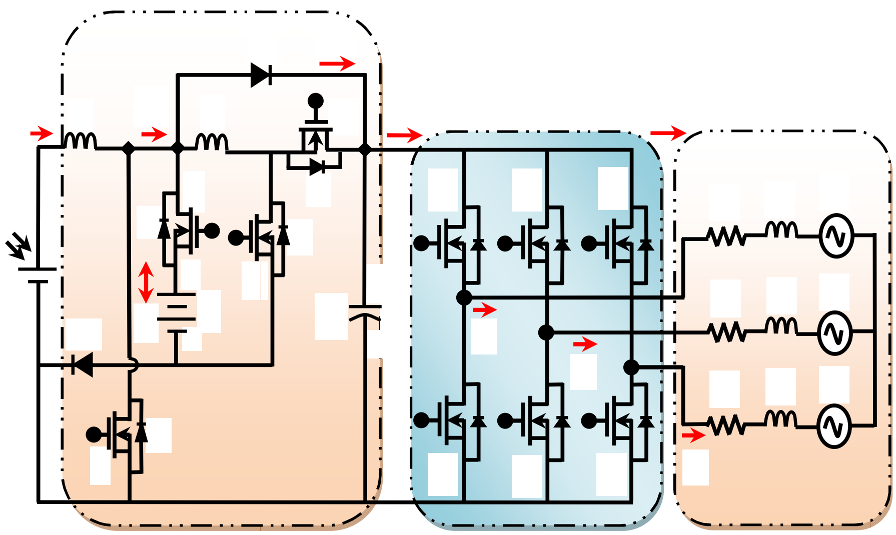


Figure 3 Equivalent circuit of the proposed PV fed EV system

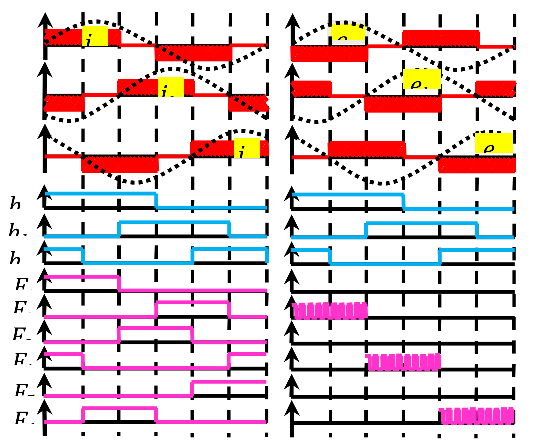
3 Proposed EV System and Supported Operating Modes

Figure 3 shows proposed PV fed EV's structure and a BLDC motor, voltage source converter (VSC), SSIC, battery and PV are included in it. Power flow between EV motor, PV and battery are managed by proposing SSIC in this work. It can also be stated as, through SSIC, dc-link is connected to battery and PV and which makes a constant dc-link voltage relatively. Via VSC, BLDC is supplied using SSIC. For driving BLDC in motor mode, VSC will act like an inverter. It is termed as six-step commutation. In VSC, on MOSFET's, conduction order is controlled for achieving this six-step commutation.

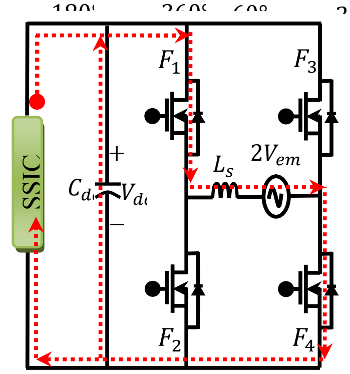
Rotor position should be known for controlling BLDC motor. Commutation is determined by this rotor position. To predict the position of rotor, most commonly used sensor type is hall-effect sensors. BLDC machine is acting as a generator in vehicle braking process. A boost chopper can be formulated by using a perfect switching pattern and in motor inductance and VSC; MOSFETs are used for the same. In dc-link, stored a regenerative energy in braking process. In can also be stated as, in SSIC, MOSFET's duty cycle variation is used for adjusting dc-link voltage. So, with proposed SSIC, battery packs effectively harvest dc-link energy.

Figure 4 (a) shows, relevant switching patterns, Hall-effect signals (h_a, h_b and h_c), three-phase stator currents (i_a, i_b and i_c) and three-phase BEMF's (e_a, e_b and e_c). There exist a six commutation in motor mode and during every interval, two VSC switches is turned between "OFF" and "ON". Figure 4 (b) shows, one commutation state's equivalent state ($240° - 300°$) in motor mode including battery. There are six commutation intervals in RC mode and during every interval; one VSC switch is turned between "OFF" and "ON".

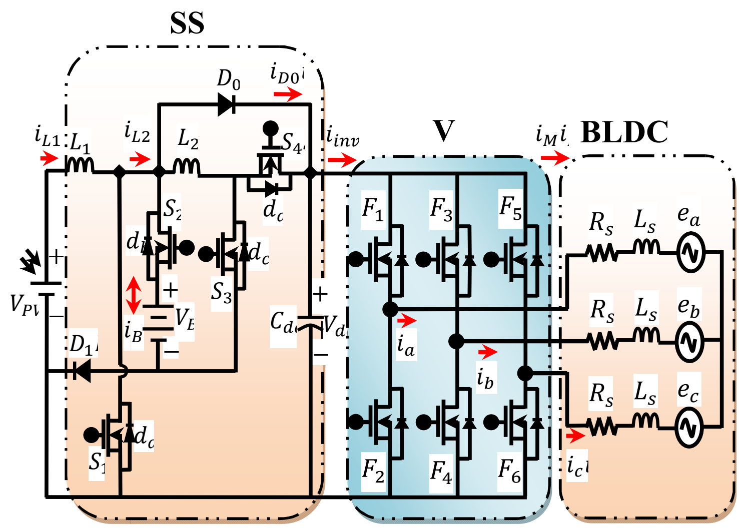
Figure 4 (c) shows, one commutation state's equivalent state ($0° - 60°$) in RC mode including battery. In Figure 4 (b) and (c), armature's inductance is represented as L_s and armature's induced voltage is represented asV_{emf}. Within 120 electrical degrees, every switch is modulated for RC process's entire electrical cycle. So, electrical energy is produced by converting braking energy of vehicle. Energy waste is avoided by this and batteries lifetime is lengthened with driving range improvement.



(a)



(b)



(c)

Figure 4 waveforms of the BEMF's, stator currents, Hall-sensors output and switching pulse (a) Motor and RC mode, operational behavior of the VSC under (b) motor mode at (240° − 300°) (c) RC mode at (0° − 60°)

Figure 5 shows six operating modes of EV, which can be supported by controlling SSIC. In mode 1, BLDC motor is supplied by battery, if electricity is not generated by PV due to low solar irradiation. In mode 2, BLDC motor is supplied by battery and PV, if operation of BLDC motor is in heavy load condition like acceleration or uphill driving. In mode 3, under the sun, EV is parked and charging of battery is done by PV. EV is driven by a only energy source called PV, if battery is in idle condition. This is mode 4 operation of a system. In mode 5 operation, battery is charged by RC method during braking process. Battery is charged by RC method and PV in mode 6 operation.

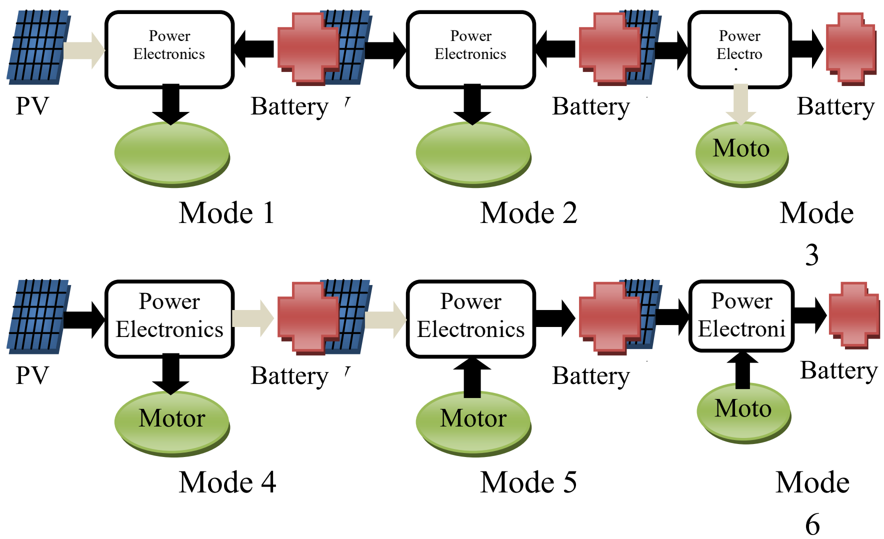


Figure 5 Supported operating modes in proposed EV system

3.1 SSIC Current Flow Analysis

The EV system comprises of the PV, battery, BLDC motor and the SSIC. The SSIC is intended to work in the motor mode or in the RGB mode in keeping with the driver's command. The control of this converter based upon the energy management technique amid the PV, battery and the demanded or provided energy by the electrical machine.i_{L1} and i_{L2}, denotes the current of the inductor L_1 and L_2 correspondingly, $S_1 - S_4$ are the gate pulses of SSIC MOSFET's, $i_{S1} - i_{S4}$ are the switch current of MOSFET's $S_1 - S_4$, i_B represents battery current, i_{D0} denotes output diode current, i_{inv} is the VSC current, i_M is the BLDC machine current and the V_{C0} is the output voltage.

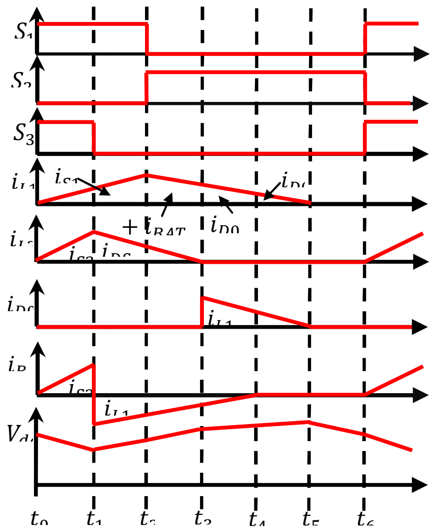
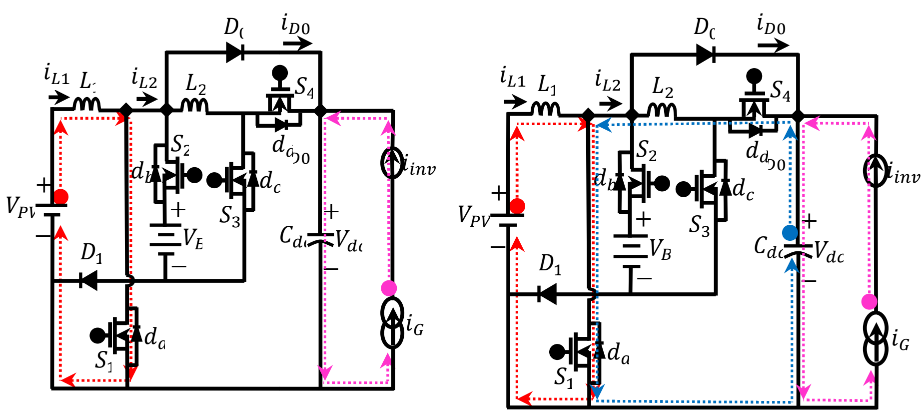


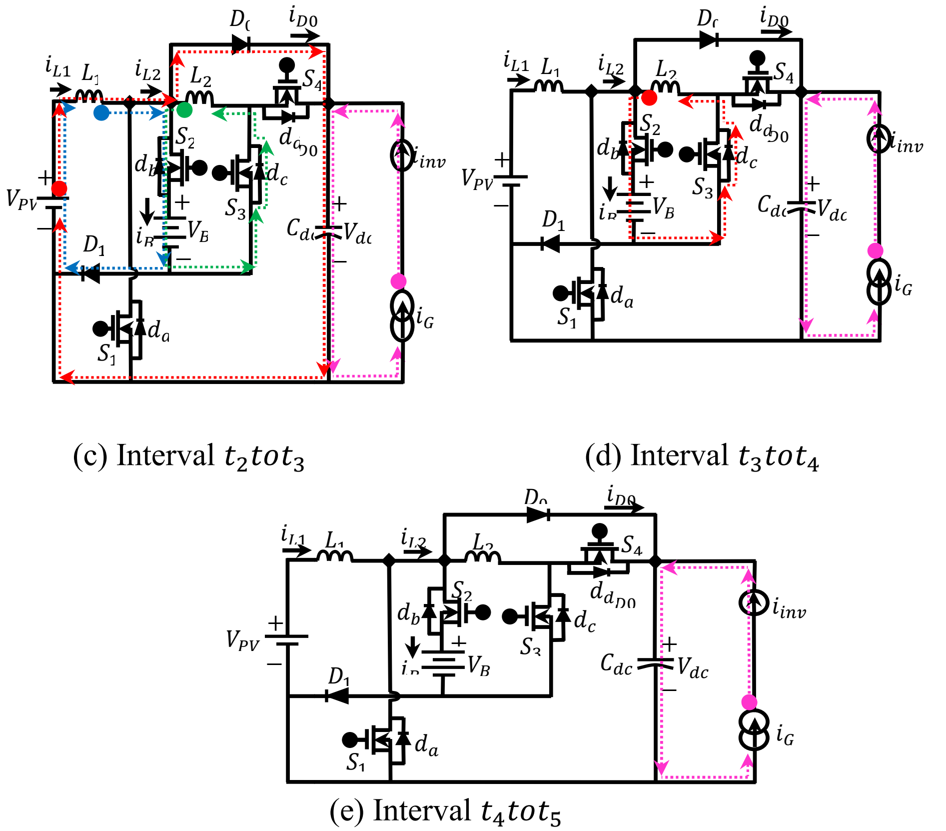
Figure 6 Associated key waveforms of SSIC at motor mode

4 Working principle of SSIC under motor mode

Through accelerator activation, drive signal is given to control system. So, in motor mode, operation of BLDC machine can be done. In VSC, MOSFET's conduction sequence is controlled for initiating rotation of BLDC machine. This is done according to instantaneous rotor position from battery and PV, current or voltage to motor is regulated in this method by dominating SSIC. In SSIC, switch S_4 will be off condition entirely in motor mode and in switching period, associated waveforms are illustrated in fig.6



(a) Interval $t_0 to t_1$ (b) Interval $t_1 to t_2$



(c) Interval $t_2 to t_3$ (d) Interval $t_3 to t_4$

(e) Interval $t_4 to t_5$

Figure 7 Current flow analysis of the SSIC during different intervals at RC mode

In off state, switchS_2 is maintained and in on state switches S_1 *and* S_3 are maintained in intervalt_0 *to* t_1 as shown in figure 7(a). Now, using PV voltage, linear charging of input inductor L_1 happens and using battery, linear charging of input inductor L_2 happens through diode d_b. Figure 6 shows, linear current increase of inductors L_1 *and* L_2. In off state, switches S_1 *and* S_3 are maintained and in on state, switchS_2 is maintained in intervalt_1 *to* $t_2$as shown in figure 7(b). Now, using PV voltage, linear charging of input inductor L_1 happens and inductor L_2, dc-link capacitor is charged and it happens through diode d_d *and* d_a.

In on state, switchS_2 is maintained and in off state switches S_1 and S_3 are maintained in intervalt_2 to t_3 as shown in figure 7(c). Through antiparallel diode d_d, discharging of inductors L_1 and L_2 and PV current happens for transferring its energy to dc-link capacitor C_{dc}. There will be linear decrease in inductors L_1 and L_2 current as illustrated in figure 6, in this mode. In on state, switch S_2 and diode D_0 is maintained in this mode. So, there will be transfer of energy to battery and C_{dc} from stored energy of inductor L_1.

The output diode D_0 is forward biased in interval t_4 to t_5 as shown in figure 7(e) and complete discharging of inductor L_1 happens and its current i_{L1} reduces to zero as illustrated in figure 6. Conduction of diode D_0 is stopped in interval t_5 to t_6 as shown in figure 7(f). So, via VSC, energy is supplied to BLDC motor form dc-link capacitor. Analysis of EV in maintaining continuous supply and regulation of battery and PV ports through SSIC is shown in figure 7(a)-(f).

5 Working principle of SSIC under RGB mode

Operation of BLDC machine is changed to RC mode from motor mode, after receiving brake signal by control system. First, turn off all the switches of VSC and make a BLDC machine as a generator. From motor to battery, regulation of current and voltage by dominating SSIC is a major component of this technique. In off mode, switch S_3 is maintained in RC mode and in a switching period, figure 8 shows its associated waveforms.

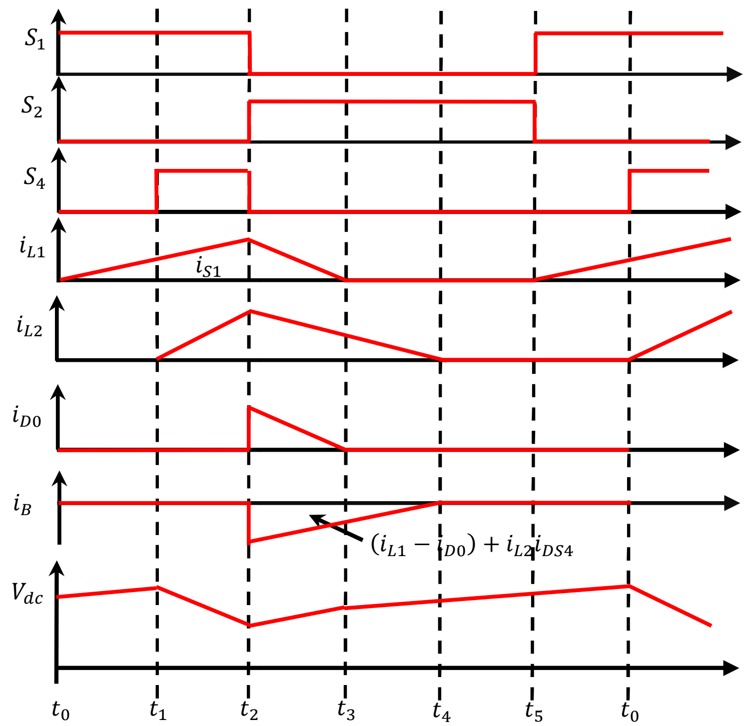
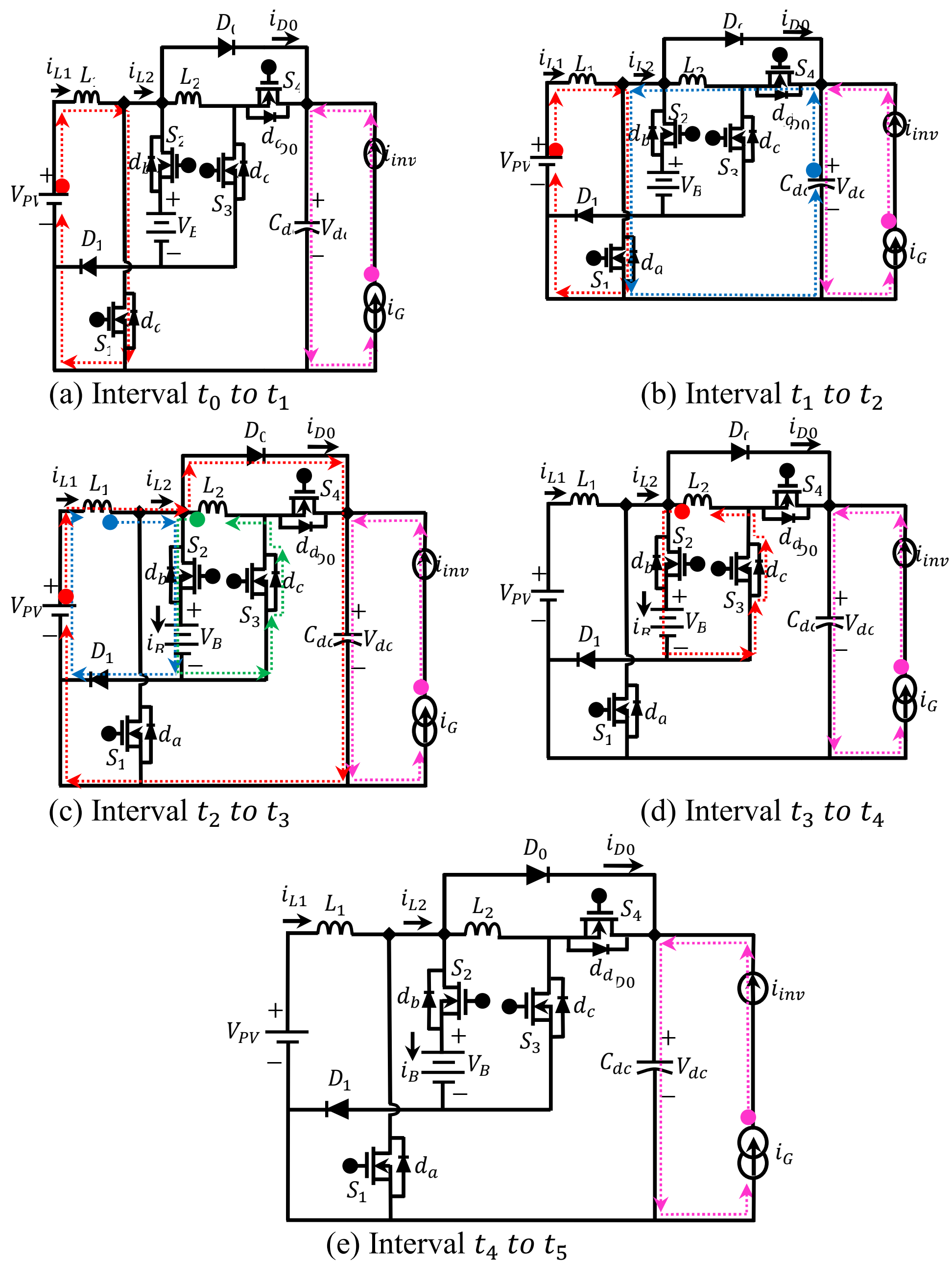


Figure 8 SSIC associated key waveforms in RGB mode



(a) Interval t_0 to t_1 (b) Interval t_1 to t_2

(c) Interval t_2 to t_3 (d) Interval t_3 to t_4

(e) Interval t_4 to t_5

Figure 9 Current flow analysis of the SSIC during different intervals at RC mode

In on state switch S_1 is maintained in interval t_0 to t_1 as shown in figure 9(a).Now, PV voltage is used for linearly charging input inductor L_1. As shown in figure 8, there will be a linear increase in inductorL_1 current. In on state, switchesS_1 and S_4 are maintained in interval t_1 to t_2 as shown in figure 9(b)], Now, PV voltage is used for linearly charging input inductor L_1 and viaS_1 and S_4, dc-link capacitor C_{dc} is used for charging inductor L_2. As shown in figure 8, there will be a linear increase in inductorL_2 current. In off state, switches $S_1 and\ S_4$ are maintained and in on state, switch S_2 is maintained in interval t_2 to t_3 as shown in figure 9(c)]. So, antiparallel diode d_c and diode D_1, battery is charged by inductors L_1 and L_2 current. So, there will be a linear increase in battery current and decrease in inductors L_1 and L_2 current in this mode, as shown in figure 8. The antiparallel diode d_c is forward biased in interval t_3 to $t_4$as shown in figure 9(d). So, there will be a complete discharging of inductor L_2 and its current i_{L2} becomes zero as illustrated in figure 8. The dc-link capacitor C_{dc} is energized by BLDC machine's regenerative current in interval t_4 to $t_5$as shown in figure 9(e). Analysis of EV in maintaining continuous supply and regulation of battery and PV ports through SSIC is shown in figure 9(a)-(f).

6 Proposed EV'S Control Strategy

Figure 10 demonstrates control chart as well as modulation strategy of proposed SSIC converter, where V_m is a MPPT algorithm yield (utilizing Perturb and Observe method [16]), V_{PV} and $i_{PV}$are potentional difference and flow of current of PV board, V_B and $i_B$are flux and current of battery, V_B^* and i_B^* are the battery's steady current and voltage control reference esteems, V_{dc} and $V_{dc}^*$are the genuine and reference dc link voltage of SSIC, at that point ω_r and $\omega_r^*$are the real and reference rotor speed of BLDC engine individually.

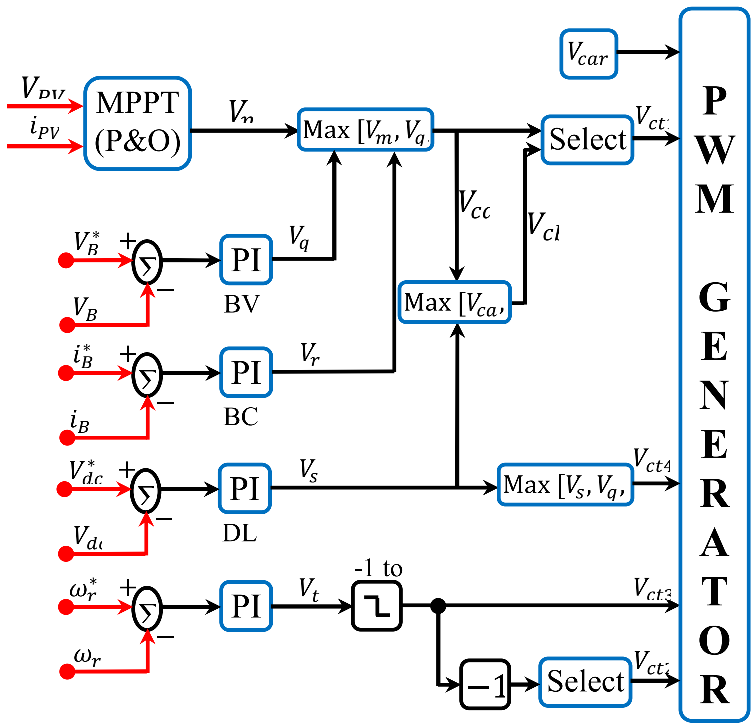


Figure 10 Control diagram and proposed SSIC's modulation method for RC and motor mode

For directing EV parameters like speed, current and voltage, actual esteem is ascertained and distinguished with a standard esteem; voltage distinction, or error of regulation, is amplified as per regulation controllers (RC)'s integral and proportional gain, which conveys a control voltage. Battery voltage controller (BVC) which maximizes charging control voltage, Four RC's, battery current controller (BCC) which maximizes control current charging, dc-link controller (DLC) to control SSIC output voltage and speed controller (SC) to control BLDC motor speed are utilized to actualize power administration of proposed EV framework. V_q, V_r, V_s *and* $V_t$are the yield of RC resembles BVC, BCC, DLC, and SC individually. Also, proposed PWM plan and its generation were explained in Figure 10, where $V_{car}$is carrier voltage's peak value, and $V_{ct1}, V_{ct2}, V_{ct3},$ *and* $V_{ct4}$are control voltages created by utilizing aoptimization technique. With the control chart appeared in Figure 10, the SSIC can work in the six diverse operation modes (see Figure 5), contingent upon the connection between the power, battery power and demand load power.

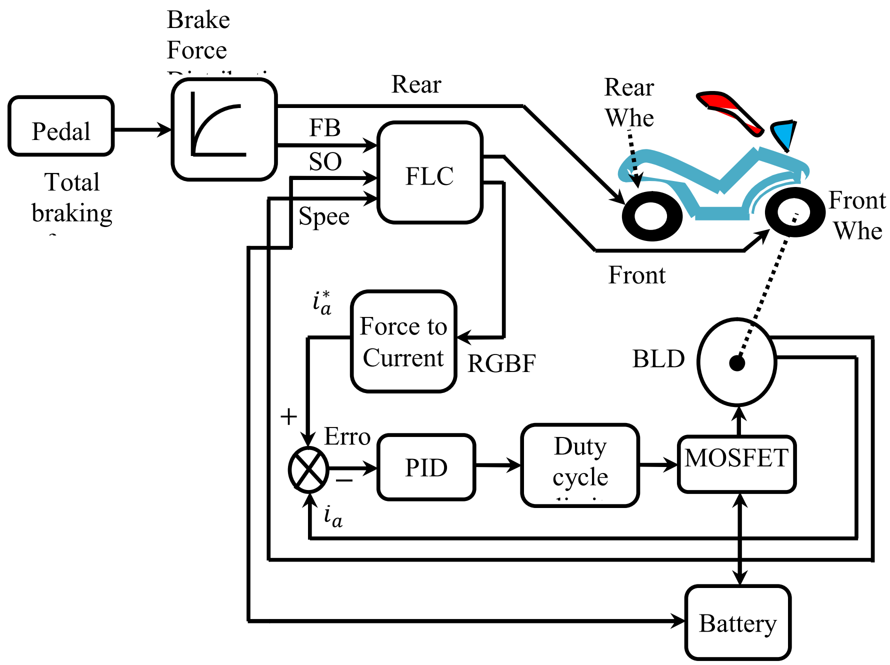


Figure 11 Braking control strategy structure using FLC

Figure 11 represents strategy used to control brake in FLC. Amid braking, EV's kinetic energy is exchanged to battery and in few braking events, battery will achieve its greatest limit, it can't acknowledge additionally charge from BLDC motor, which restrains reproducing capability. Hence, association of mechanical braking is basic to finish braking objective. Rquired braking power of driver is computed using foot

Level sensor. Subsequently, EV's total force (F_{EV}) is addition of front (F_{front}) and rear (F_{rear}) braking forces:

$$F_{EV} = F_{front} + F_{rear} \tag{1}$$

Front (F_front) and rear (F_rear) braking force is computed according to regulations for breaking force spread between rear and front wheels as.

$$F_{front} = \varphi \times \frac{L_V \times g(B_d + a \times h_{EV})}{l} \tag{2}$$

$$F_{rear} = \varphi \times \frac{L_V \times g(A_d - a \times h_{EV})}{l} \tag{3}$$

In (2) and (3), h_{EV}represents EV centroid's height, $A_d$represents vehicle centroid to front axis center line remove, $B_d$represented vehicle centroid to back hub distance, φ is adhesion coefficient, $L_V$is vehicle stack, g is the

Gravitational consistent, and l is a separation betweenEV's raise to front axle (l= A_d + B_d). In addition, a is characterized as $a = \frac{\alpha}{g}$in which, α is vehicle's speed up.

By summing equations (2) and (3) outputs, breaking force required at EV's front and back wheels can be computed.

$$F_{EV} = F_{front} + F_{rear} = \varphi \times L_V \times gF_{EV} \quad (4)$$

Front braking force (FBF) is made out of two sections for front-wheel driven EVs: mechanical braking force (MBF) and RGB force (RGBF). RGBF in EV is impacted by many components, and numerous parameters are continually changing, so reusing technique is hard to be communicated. In this manner, Fuzzy Logic Control (FLC) technique to force distribution of EV braking is effortlessly shown by various elements impact. In FLC, the three inputs are the FBF, RPM and stare of charge (SOC).

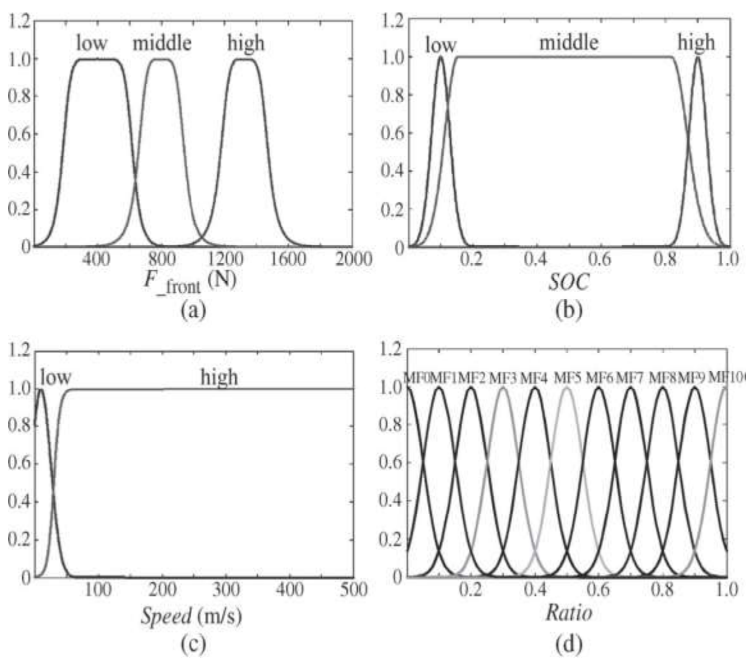


Figure 12 FLC Membership functions (a) FBF (b) SOC (c) Speed and (d) Ratio

Table 1 FLC rules

Speed	SOC	FBF	Mf	Speed	SOC	FBF	mf
L	L	L	2	H	L	L	5
L	L	M	1	H	M	M	5
L	L	H	0	H	H	H	4
L	M	L	4	H	L	L	10
L	M	M	2	H	M	M	9
L	M	H	3	H	H	H	8
L	H	L	3	H	L	L	5
L	H	M	1	H	H	M	3
L	H	H	2	H	M	H	1

The yield variable is the proportion which is relative to the RGBF taking in the FBF. The estimation of the FBF speaks to distance and time as required. It inclines towards concourse of speed to be low and high as like [0, 2000]. Figure 12 (a) represents membership functions. At the point, when state of charge is under 10%, membership function of battery is top, inadmissible energizing for this situation; RGBF ought to be a little extent. At the point, when the SOC is in the vicinity of 10% and 90%, t battery can accuse of an expansive current; the proportion of the RGBF ought to be correspondingly expanded. At the point SOC is more prominent than 90%, charging current ought to be lessened for keeping inordinate charging of battery; estimation of RGBF ought to be low. The SOC arrangement to be high, middle low and discourse universe is [0, 1]. Figure 12 (b) represents membership functions. Likewise, vehicle speed assumes an imperative part in guaranteeing brake security. To consent to significant legislation, RGBF is low extent when speed is low. RGBF is expanded to a fitting level when speed is middle of road. At the point when speed is high, we can expand proportion of RGBF to greatest esteem. We favor speed arrangement to be low and high, and discourse universe is [0, 50]. Membership functions are found in Figure 12(c). The kind of FLC is Ratio = {mf0, mf1, mf2, mf3, mf4, mf5, mf6, mf7, mf8, mf9, mf10} = (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0). Yield membership functions are found in Figure 12(d). We incline toward fuzzy rules appeared in Table 1. In Figure 11, PID control is utilized to guarantee a consistent brake torque; diverse braking power esteems will give distinctive PWMs. It is assumed that PID control is rapidly altering coveted PWM to keep up braking torque always.

7 Simulation Results

In MATLAB environment, modeled the battery fed EV including BLDC machine and PV for demonstrating proposed system's working as well as effectiveness. To feed control voltage to BLDC machine employed a SSIC along with VSC using MOSFET's. Table 2 summarizes the proposed EV structure's input and output specifications.

Table 2 Input and output specifications of proposed EV

Objects	Specifications
PV Panel specifications at standard test conditions (STC)	
PV voltage V_{PV} @ STC	12 V
PV current i_{PV} @ STC	12.5 A
PV power P_{PV} @ STC	150 W
Battery specifications	
Battery voltage V_B	24 V
Battery current i_B	14 A/h
Battery power P_B	336 W
BLDC machine specifications	
Voltage	48 V
Power	250 W
Speed	227 rpm (45 km/h)
Maximum Torque	15 Nm

A 250 W three-phase BLDC machine is used for validating proposed EV. Input sources used are 24 V, 14 A/h battery and 150 W PV panel. Assume, maximum insolation of $1000\,\mathrm{W/m^2}$is received by PV in both braking and motor conditions. Bidirectional converters used as VSC and SSIC and for closed-loop control PI algorithm is utilized. From standstill, EV is accelerated to constant speed of 40 km/h using information about rotor position in Hall-effect signals at 0 to 1 sec. Between 1 s to 1.18 s, it is again decelerated to stationary condition using regenerative braking through battery. At 1.18 s, applied mechanical braking for increasing deceleration performance speed as shown in figure 13 (a). Figure 13 (b), shows, three-phase Hall-effect sensors status in braking and motoring conditions.

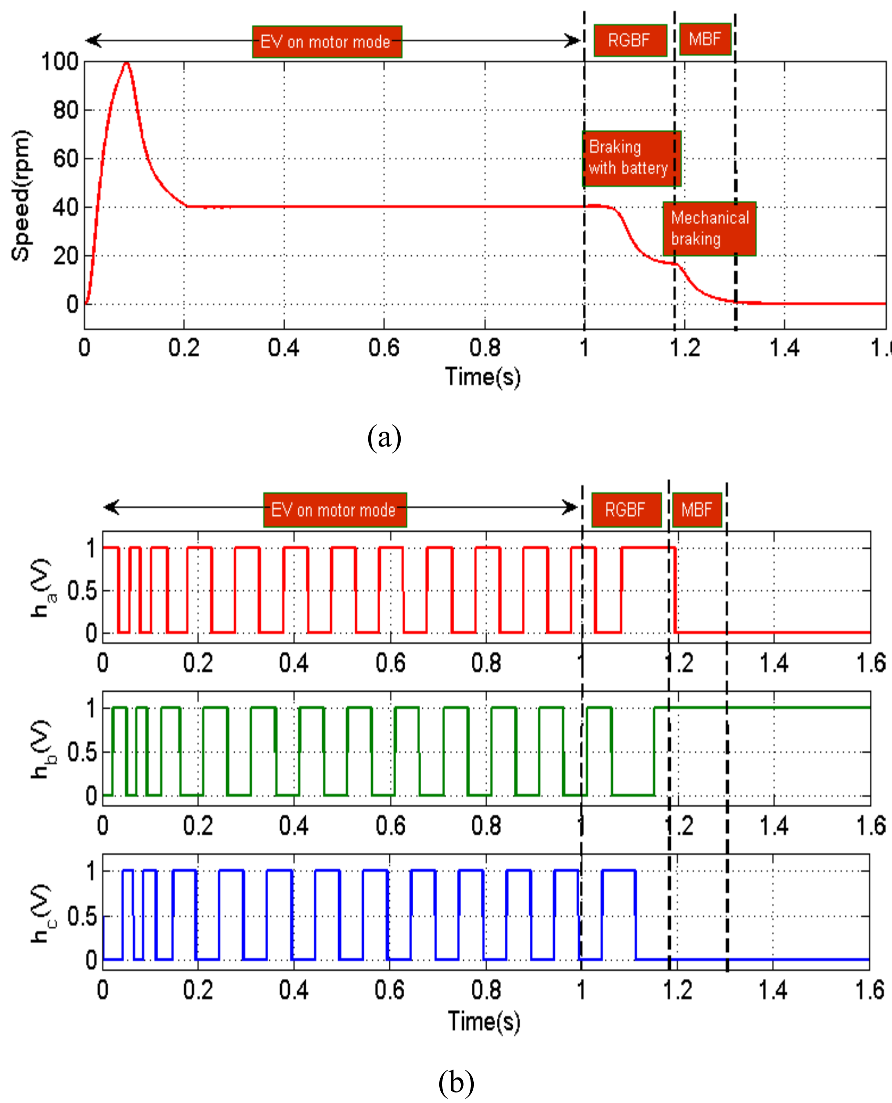
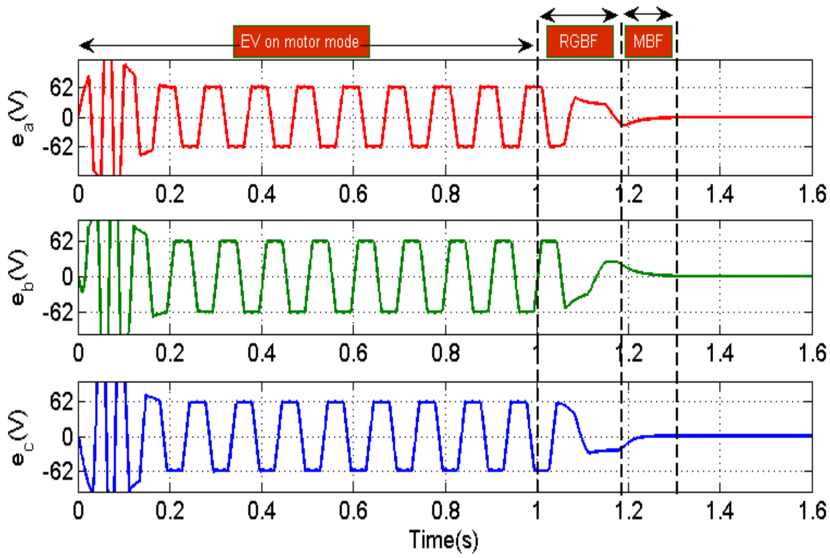
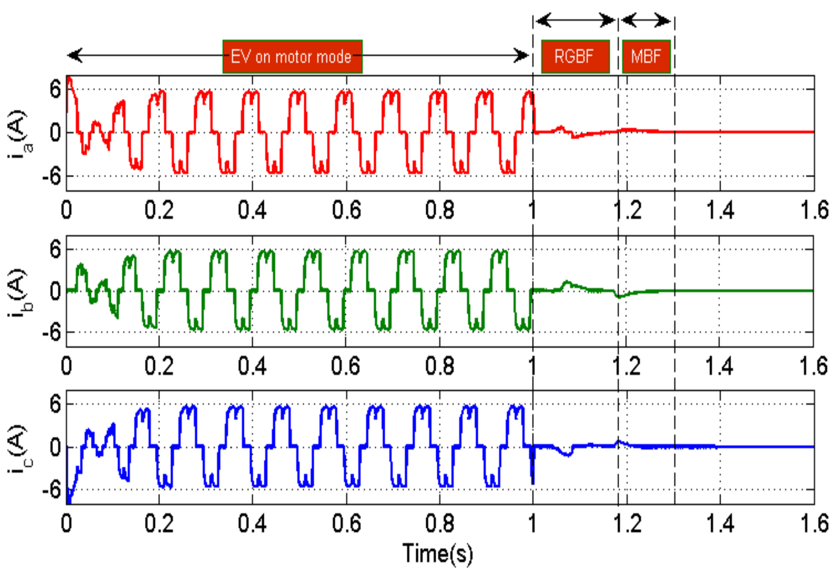


Figure 13 Simulation results of proposed EV in motor and braking modes (a) speed of EV in km/h (b) Hall-effect signals

Figure 14 (a) and (b) shows stator windings armature currents and BEMF's waveforms in braking and motoring state. There will be a decrease in generators stator and BEMF's current after the start of braking procedure. Armature currents are very less with these three-phase BEMF's. So, to mechanical braking, the controller switches and as shown in figure 14, it is zero relatively. In SSIC and VSC, battery sate and dc-link voltage can be controlled by adjusting PWM duty-cycle.



(a)



(b)

Figure 14 Waveforms of proposed EV during motor and braking conditions (a) BEMF's (e_a, e_b, e_c) (b) stator current (i_a, i_b, i_c)

Be that as it may, regenerative braking is not working well in all circumstances, e.g., when induced BEMF's is very small or when battery charged completely, braking should be affected by disseminating vitality in a resistive load. Consequently, mechanical brake in EV is as yet utilized. In this work , regenerative and mechanical braking is accomplished usingsingle foot pedal: Foot pedal’s initial segment manages regenerative braking, and mechanical brake is managed by next part. At the point when brake command is connected, controller alters dc-link voltage to steady torque braking including battery. In this mode, load corresponds to battery, subsequently giving a braking power to EV. Amid this time interval from 1 to 1.18 s, the vast majority of dc-link current is reaped by battery) as appeared in Figure 15.

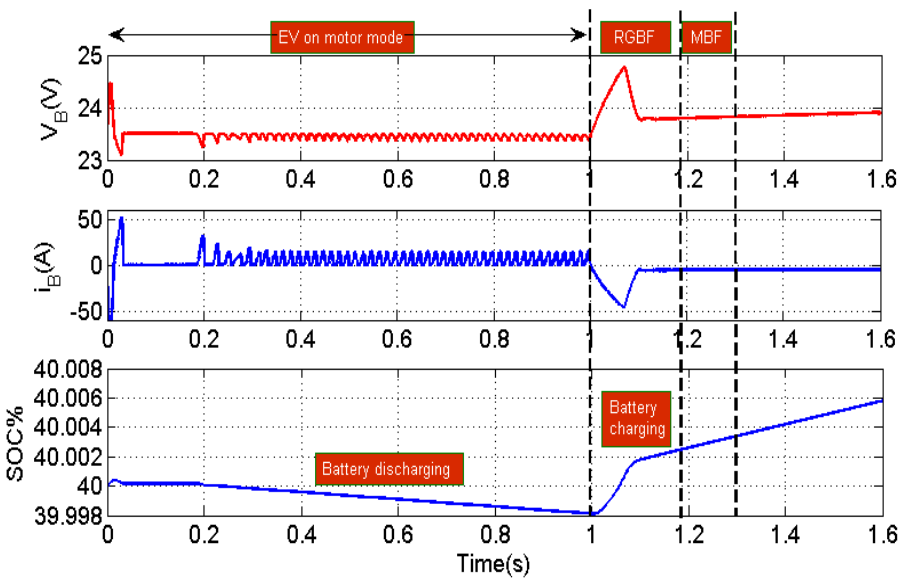


Figure 15 Performance of battery in SSIC during motor and braking conditions

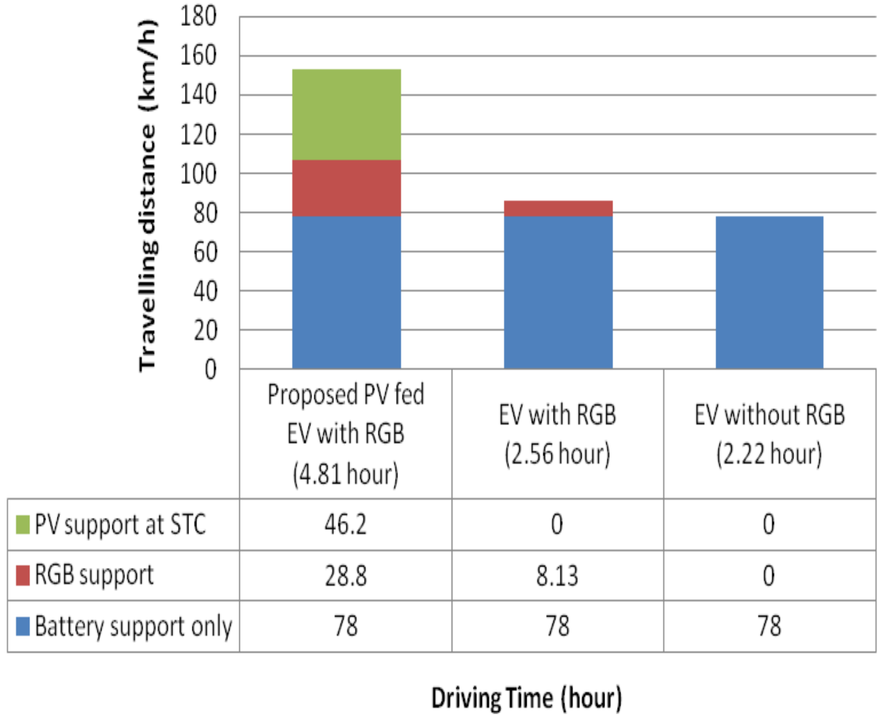


Figure 16 Simulated EV with battery, RGB, and PV's driving range analysis

Fundamentally an extensive part, vehicle's kinetic energy is squandered by front and back mechanical braking. Consequently, vehicle's drive scope is registered to assess execution of RGB framework all the more instinctively. It is expected that the battery is completely charged. Henceforth, the underlying SOC of the battery is picked 98% and the outcome is appeared in Figure 16. The best possible use of RGB energy of proposed EV can expand the driving reach up to 36.92% and 23.99% as for EV without and with the RGB framework, individually.

8 Conclusions

Here, another RGB technique in view of usage of battery is proposed to EVs which are driven by BLDC machine. Amid increasing speed as well as deceleration, EV's kinetic energy is gathered by battery utilizing proper switching format of VSC and SSIC. In the interval, the FLC is used for controlling braking force distribution amongst EV's back and front wheels. Also, PI controller is utilized for controllingPWM duty-cyclein VSC to acknowledge steady torque braking. In correlation with other comparable

Sorts of RGB plans, proposed technique has superiorities of being basic and being high-productive (i.e. long driving extent 153 km/h).

References

[1] M. Ortuzar, J. Moreno, and J. Dixon, “Ultra capacitor-based auxiliary energy system for an electric vehicle: Implementation and evaluation,” IEEE Transactions on Industrial Electronics, Vol. 54, no.4, pp. 2147–2156, 2007.

[2] P. J. Grbovic, P. Delarue, P. Le Moigne, and P. Bartholomeus, “A bidirectional three-level dc-dc converter for the ultra-capacitor applications,” IEEE Trans. Ind. Electron., Vol. 57, no.10, pp. 3415–3430, 2010.

[3] J S. M. Lukic, J. Cao, R. C. Bansal, F. Rodriguez, and A. Emadi, “Energy storage systems for automotive applications,” IEEE Trans. Ind. Electron., vol. 55, no. 6, pp. 2258–2267, 2008.

[4] A. Rowe, G. Sen Gupta and S. Demidenko, "Instrumentation and control of a high power BLDC motor for small vehicle applications," IEEE International Instrumentation and Measurement Technology Conference Proceedings, Graz, pp. 559-564, 2012.

[5] A.Tashakori and M. Ektesabi, “Fault Diagnosis of In-wheel BLDC Motor Drive for Electric Vehicle Application,” in Proc. IEEE Intell. Veh. Symp. pp, 925 – 930, 2013.

[6] M. Yilmaz and P. T. Krein, "Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles," IEEE Transactions on Power Electronics, vol. 28, no. 5, pp. 2151-2169, 2013

[7] A. Emadi, Handbook of Automative power electronics and motor drives, CRC press, Oct. 2005.

[8] J.H. Choi, J.S.Park, J.-H.Kim and I.-S. Jung, “Control Scheme for Efficiency Improvement of slim type BLDC Motor,” in Proc. Int. Power Electron., Elect. Drives, Autom. Motion, pp. 820 – 824, 2014.

[9] F. Yang, C. Jiang, A. Taylor, H. Bai, A. Kotrba, A. Yetkin and A. Gundogan, “Design of a High-Efficiency Minimum-Torque-Ripple 12-V/1-kW Three-Phase BLDC Motor Drive System for Diesel Engine Emission Reductions,” IEEE Trans. Veh. Technol., Vol. 63, no.7, pp. 3107 – 3115, 2014.

[10] Y. Kim and N. Chang, “Design and Management of Energy-Efficient Hybrid Electric Energy Storage Systems”,Hoboken,Springer, pp. 19–25, 2014.
[11] R.Shanmugasundram, K. M. Zakariah and N. Yadaiah, “ Implementation and Performance Analysis of Digital Controllers for Brushless DC Motor Drives,” IEEE/ASME Trans. Mechatron., vol. 19, no. 1, pp. 213 – 224, 2014.
[12] X. Nian, F. Peng and H. Zhang, "Regenerative Braking System of Electric Vehicle Driven by Brushless DC Motor," IEEE Transactions on Industrial Electronics, vol. 61, no. 10, pp. 5798-5808, 2014.
[13] A. G. Sarigiannidis, S. A. Stathis and A. G. Kladas, "Performance evaluation of MPPT techniques for PV array incorporated into Electric Vehicle roof," International Conference on Renewable Energy Research and Applications (ICRERA), Palermo, pp. 1069-1073, 2015.
[14] S. Lee, J.-E. Kim, and H. Cha, “Design and implementation of photovoltaic power conditioning system using a current-based maximum power point tracking,” Journal of Electrical Engineering & Technology, vol. 5, no. 4, pp. 606–613, 2010.
[15] Y. Hu, C. Gan, W. Cao and Y. Fang, "Tri-port converter for flexible energy control of PV-fed electric vehicles," IEEE International Electric Machines & Drives Conference (IEMDC), pp. 1063-1070, 2015.
[16] P. Madhuri, T. Ranga, M. Sekhar “Solar PV-Powered SRM Drive by Using Tri-Port Converter for Electric Vehicles” International Journal of Research, Vol.04, no.14, 2017.

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