Implementation of DSM-PI Controller in SEPIC-ZETA Integrated converter for Plug-in Electric Vehicle

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Abstract: *In this paper, an integrated converter is used for plug in electric vehicles. This converter operates in all three modes i.e. charging, regenerative braking and propulsion modes. Compared to existing converters which have buck/boost operation in each mode this converter has fewer components which makes it feasible, easy to implement and control in PEVs. The DSM-PI controller is implemented and compared with PI controller which shows improved characteristics of battery pack. The simulation results are validated and verified through MATLAB/Simulink environment.*

***Keywords*: SEPIC-ZETA Integrated Converter, proportional integral (PI), Dual sliding mode proportional integral (DSM-PI) Controller, Permanent magnet synchronous motor (PMSM), Plug in electric vehicles (PEVs)**

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I. INTRODUCTION

The use of IC engine vehicles that potentially cause high pollutant levels in the air is one of the leading causes for global warming and respiratory diseases in humans and that's why such engines are needed to replace with zero or low emission vehicles. In order to do this, electric vehicles that operate on rechargeable batteries, electronic power converters and electric motors are used. Buck and boost converters are used in all PEVs for charging and discharging batteries. The Buck circuits are implemented to charge the battery and the Boost circuits are implemented to drive the engines [1]. Multiple ways to charge the battery pack including solar panel electricity, high rating DC charging station, AC main supply. Three modes of the integrated SEPIC-ZETA converter are charging mode, propulsion mode and regenerative charging mode.

This converter is essentially consist of fewer components, thereby reducing the power losses and switching losses of passive and active devices. The gains in classic PI controller are set at one specific value but in case of DSM-PI controller the gain values are continuously updated as error produced [10, 11]. In this paper, the controller is implemented to extract the current signal from the error signal. It tracks and achieves PI gains and thus minimizes the response time. The primary benefit of such control method is that the settling time is reduced with less disturbances and oscillations.

II. SYSTEM DEVELOPMENT

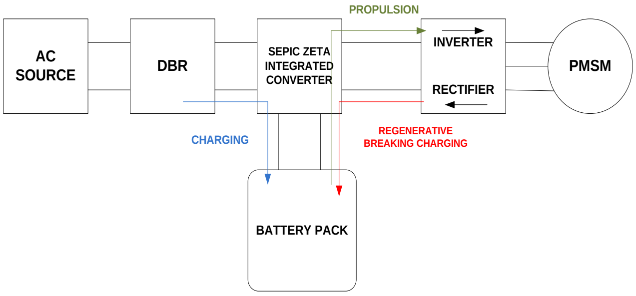

Fig. 1. Block diagram of Plug-in EV.

The above System consists of AC source, diode bridge rectifier (DBR), SEPIC-ZETA integrated converter, rechargeable battery pack, inverter and PMSM is as shown in Fig. 1.

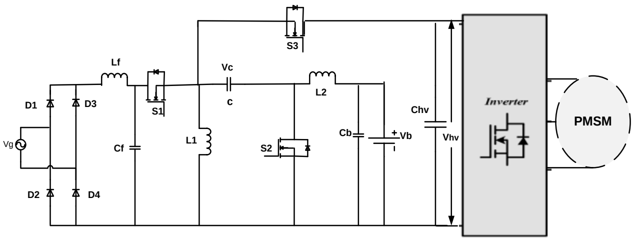

Fig. 2. Proposed SEPIC-ZETA converter.

In this system, the AC supply is provided to the diode bridge rectifier to convert a fixed AC to variable DC. Depending on the switching state, the integrated circuit operates in buck as well as boost mode. A three-phase inverter running a PMSM is connected to the integrated converter as shown in Fig. 2. Motor speed is controlled by an inverter using the SPWM technique.

Where

Lf ,Cf =Input filters

L1, L2=Charge storing elements

C=Resonance capacitor

S1, S3=Buck switches

S2=Boost switch

III. CIRCUIT OPERATING MODES

The proposed converter works in following modes

A. *Charging Mode*

To charge the battery pack, the plug is connected to the socket. In this mode, circuit operates in buck mode. Only switch S1 operates in this mode, while other two switches are OFF, i.e. When S1 is ON as shown in Fig. 3. Inductor L1 and L2 stores energy and when the S1 is OFF state as shown in Fig. 4. L1 transfer energy to C while L2 supplies energy to battery and capacitor Cb. To avoid circulating current diode of S2 acts as freewheeling diode [2-6].

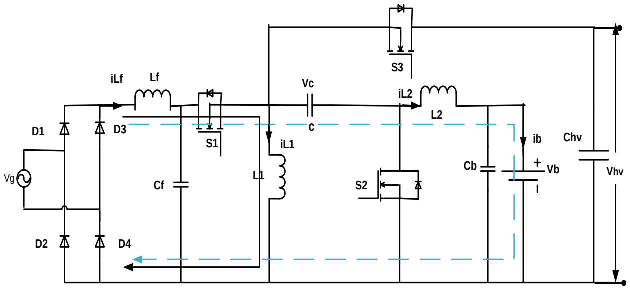

Fig. 3. Battery charging when S1 is ON.

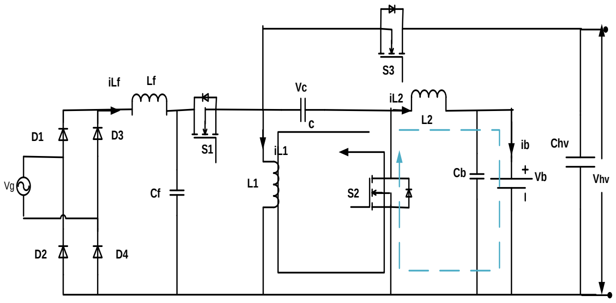

Fig. 4. Battery charging when S1 is OFF.

B. *Propultion Mode*

Only switch S2 operates in this mode, while other two switches are OFF. When S2 is ON as shown in Fig. 5. Battery charges the L2.while L1 and C charged with small amount of current. When S2 is OFF as shown in Fig. 6. The battery is in series with charged L2 which increases voltage at S3 node. This discharged into inverter through diode of S3 and operates the motor [2-6].

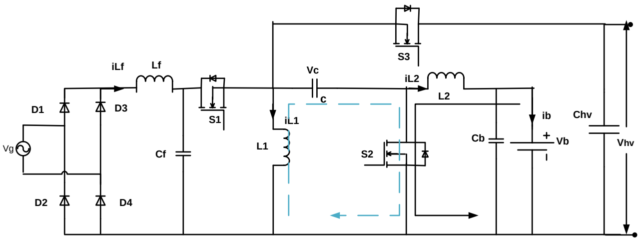

Fig. 5. when S2 is ON.

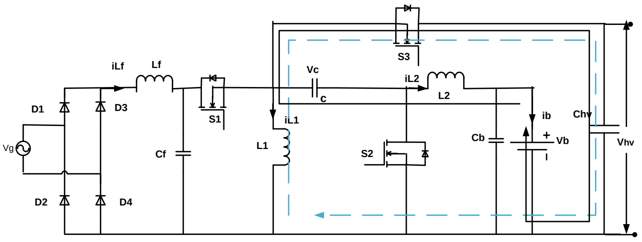

Fig. 6. when S2 is OFF.

C. *Regenerative Charging Mode*

In this mode only switch S3 works, while other two switches, i.e. S2 and S1 are in OFF state. The machine operates as generator. This mode is similar to charging mode. When S1 is ON as shown in Fig. 7. Inductor L1 and L2 stores energy and when the S1 is OFF as shown in Fig. 8. L1 transfer energy to C while L2 supplies energy to battery and capacitor Cb [2- 6].

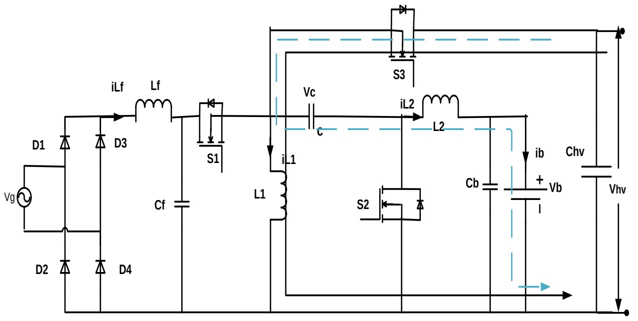

Fig. 7. when S3 is ON.

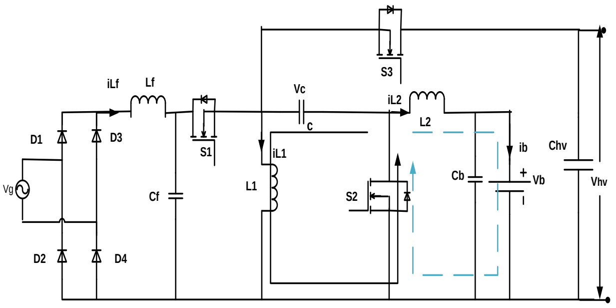

Fig. 8. when S3 is OFF.

The simulation parameters of circuit are shown in TABLE I.

TABLE I. SIMULATION PARAMETERS

PARAMETER	VALUE
Grid voltage (Vg)	220 V
L_f	1.5 mH
C_f	1 µF
Nominal battery voltage(V_b)	300 V
Nominal charging power(P_b)	15 kW
Capacity	50 Ah
Switching Frequency (f_s)	20 KHz
L1/L2	2 mH
C_{hv}/C/C_b	5500/10/2200 µF
Line frequency(f_L)	50 Hz

IV. CONTROL SCHEME

The control scheme is as shown below. PI controllers are used as current controller in control scheme. For improved performance it is replaced with DSM-PI controller. The entire control scheme consists of four parts.

A. *Control Scheme During Charging Mode*

During charging mode, this controller controls the S1. The Control scheme is shown in Fig.9. In which, the measured and reference values are compared and fed to PI controllers that are used as current controller providing reference signal. The values generated from PI controllers are duty ratio which compared to sawtooth wave of high frequency i.e. 20KHz and generated pulse is used to operate switches. The battery voltage (Vb) is taken in this scheme as feedback from which ib* is calculated which then compares with ib and the error given to PI controller. Which then generates the maximum current value (Im) that then multiplies with |Sinωt| gives inductor current i_{Lf}^*.This value is compared with measured i_{Lf} and given to PI controller which provides necessary duty ratio for S1.Pb* is reference battery power.

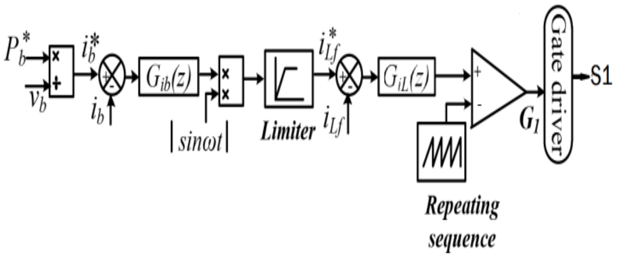

Fig. 9. Control scheme for charging mode

B. *Control Scheme During Propolsion and Regenerative Braking Mode*

The Control scheme is shown in Fig.10 Where feedback is taken from electromagnetic torque and DC link voltage. The error between reference and measured values gives reference value of current i_b^*. The error between Currents $i_b$and i_b^* are given to Pi controller which gives duty ratio of S2 and S3.

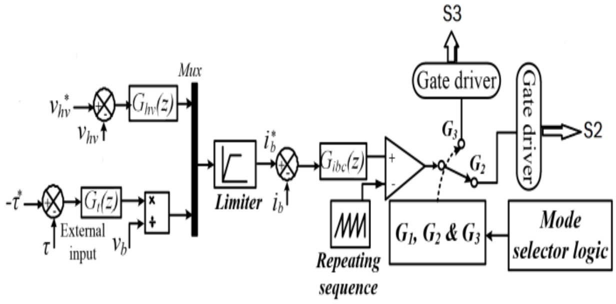

Fig. 10. Control scheme for discharging and regenerative braking charging mode

C. *PI Controller*

The most popular and useful control system algorithm is proportional integral controller. It controls the feedback loop. Feedback is crucial to attaining the set point regardless of disturbances or any form of characteristic variation. This controller is designed for error correction between set point value and measured value. Kp and Ki are gain parameters. Fig.11 Shows block diagram of current control scheme. From sensing the actual current value from output it is sent to the P and I terms having gain value Kp and Ki respectively.sum block summons the output value and sent towards the saturation block which then gives the output which is error between actual and reference value [7].

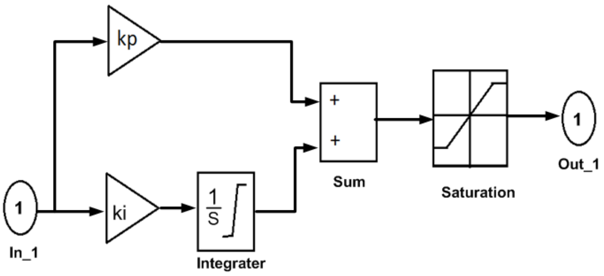

Fig. 11. Current control scheme by PI controller

D. DSM-PI Controller

This is a non linear control possessing properties like accuracy, robustness, simple implementation and easy tuning. The two key advantages of this controller are i.e. by selecting a proper sliding function dynamic behavior can be customized. And the close loop response turns insensitive [8].

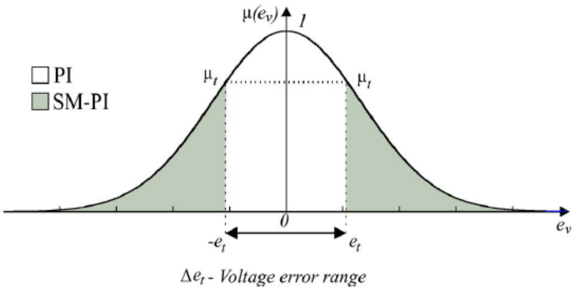

Fig. 12. Transition criteria graph

Fig. 12. represents transition criteria graph for various conditions.

Sliding surface is represented by

$$\sigma = ce_v + e_v^* \qquad (1)$$

Where, $e_v = v_c^* + v_c$

e_v^* is derivative and C is constant.

Gains are summed as follow

$$\widetilde{kp} = \left[\left(1 + sgn(\sigma)\right)kp^{+} - \left(1 - sgn(\sigma)\right)kp^{-}\right] + k_p^{av} \qquad (2)$$

$$\widetilde{ki} = \left[\left(1 + sgn(\sigma)\right)ki^{+} - \left(1 - sgn(\sigma)\right)ki^{-}\right] + k_p^{av} \qquad (3)$$

Where,

$$sgn(\sigma) = \begin{cases} 1\ for\ \sigma > 0 \\ -1\ for\ \sigma < 0 \end{cases}$$

And others are constant.

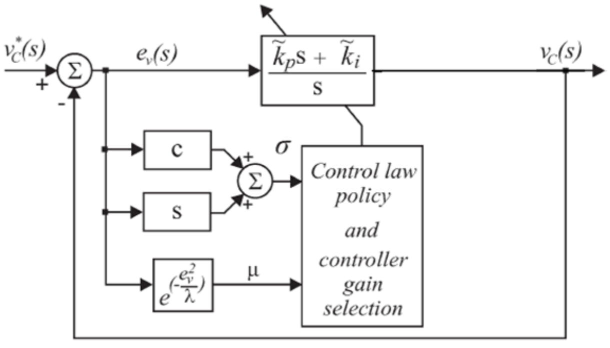

Fig. 13. Tra Control scheme block diagram of DSM-PI

Consider a Gaussian function

$$\mu(e_v) = e^{-\frac{e_v^2}{\lambda}} \qquad (4)$$

μ is decision variable, e_v is DC link voltage error and λ is Gaussian parameter. The value of $\mu(e_v)$ is calculated constantly for e_v. If $\mu(e_v) < \mu_t$ then DSM-PI is chosen and when $\mu(e_v) > \mu_t$ then fixed gain controller is selected. The control scheme block diagram is shown in Fig. 13. If λ is high then $\mu(e_v)$ and e_v is less sensitive and when λ is lower then $\mu(e_v)$ and e_v is highly sensitive [8-11].

V. RESULTS AND DISCUSSION

The simulation model is validated for 1 second. The parameters of PMSM are shown in TABLE II.

TABLE II. PARAMETERS OF PMSM

PARAMETER	**VALUE**
Torque	24 N-m
Voltage	300 V
Speed	230 RPM
stator phase resistance	0.0918 ohms
inductance of Armature	0.975 mH
Inertia	0.003945 kg.m^2
Flux linkage	0.1688
pole pairs	4

The simulation model for integrated converter is presented in Fig. 14.

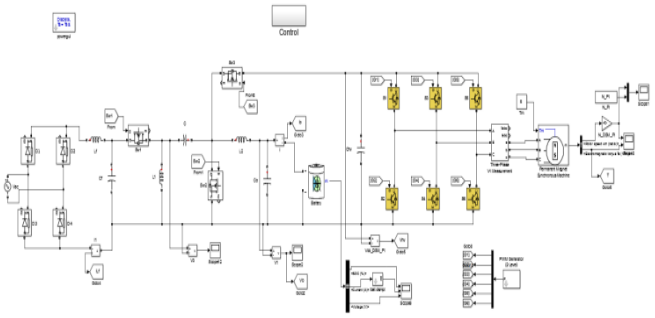

Fig. 14. Simulation Model

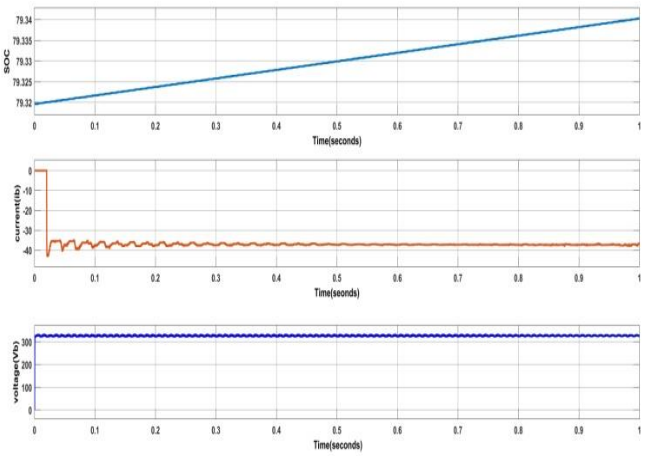

Fig. 15. Battery characteristics under charging mode

AC supply charges the battery, state of charge (SOC) is raising and the current in negative direction as shown in Fig. 15.

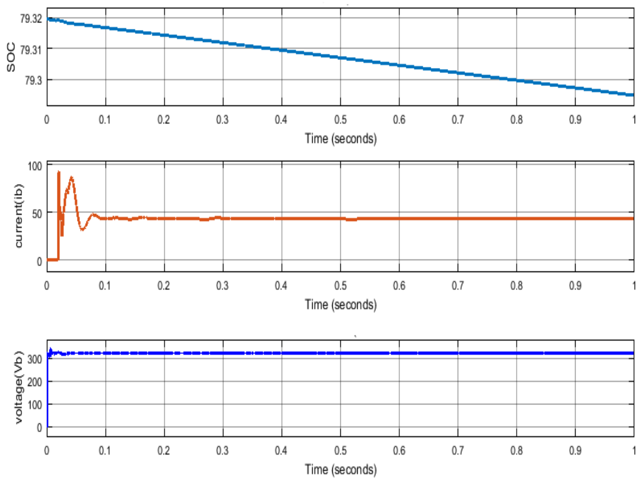

Fig. 16. Battery characteristics under discharging mode

The Fig. 16. Shows the discharging of battery as the SOC is dropping and the current is in positive direction.

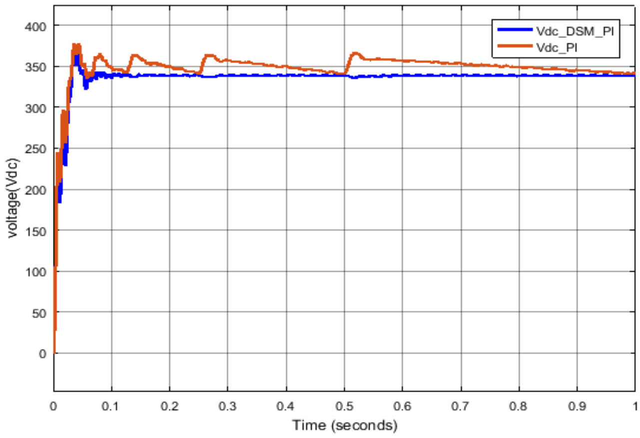

Fig. 17. DC link voltage Comparison

From Fig. 17. It is validated that DC link voltage settles faster & with less disturbances in DSM-PI controller as compared to classic PI controller.

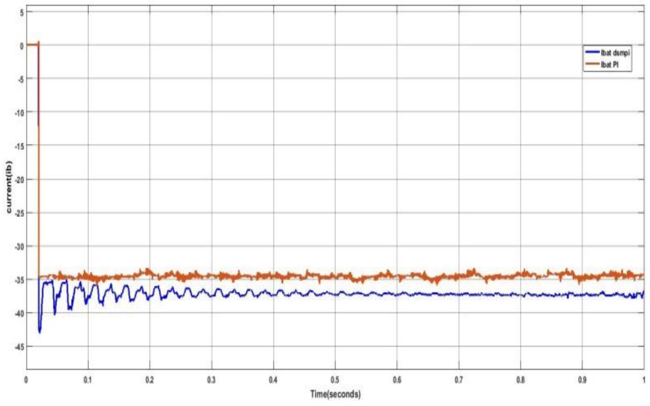

Fig. 18. Comparison of battery current under charging mode

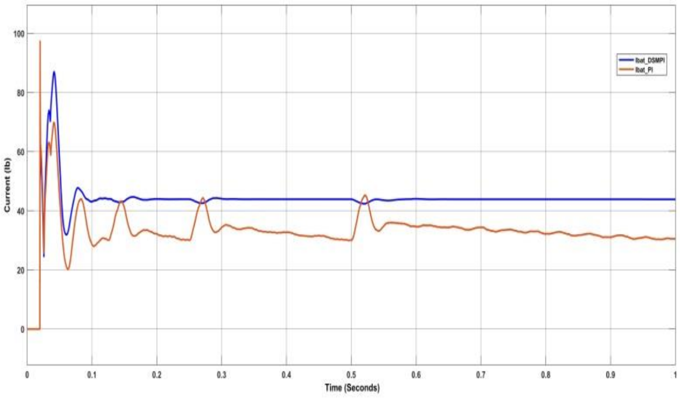

Fig. 19. Comparison of battery current under discharging mode

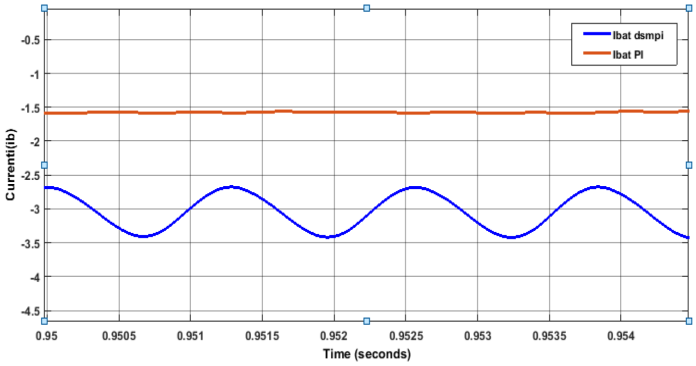

Fig. 20. Comparison of battery current under regenerative charging mode

The above mentioned Fig. 18, Fig. 19. & Fig. 20. represents the comparisons of battery currents under charging, discharging and regenerative charging modes with PI and DSM-PI controller. As the charging current of battery increases the charging time of battery reduces. The proposed DSM-PI controller has shown better results compared to classic controller.

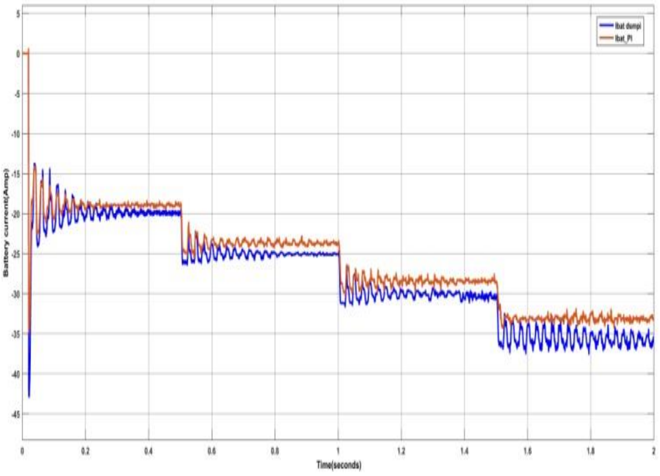

Fig. 21. Comparison of battery current under charging mode using different conditions

TABLE III. COMPARISON OF BATTERY CURRENT DURING CHARGING MODE USING DIFFERENT CONDITIONS

SR. NO	Input Battery Power (kWh)	Battery Charging Current using PI controller (A)	Battery Charging Current using DSM-PI controller (A)
1	8	19	20
2	10	23.5	25
3	12	28.5	30
4	14	33	35

The proposed model is validated for 2 seconds to show different battery power conditions in above Fig. 21. and TABLE III.

VI. CONCLUSION

The classic integrated sepic-zeta with PI controller is works in charging, regenerative braking and propulsion modes. It operates as zeta converter during charging and regenerative charging modes and operates as sepic converter during propulsion mode. The problem associated with classic converter has shown enormous effects in DC link voltage stability and the performance of battery pack in PEVs. Due to fluctuations at DC link Voltage, the system stability deteriorates. To avoid the above mentioned drawbacks, a new DSM-PI controller is proposed. In this paper, an integrated SEPIC-ZETA converter with DSM-PI controller is validated and verified with MATLAB/Simulink Software package. The simulation results have shown better performance compared to the classic converter.

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