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Design and Implementation of SEPIC Converter using PI controller for PQ Improvement

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ABSTRACT: Abstract— In this paper integrated converter is proposed for plug in electric vehicles which operates in all three modes i.e. charging, regenerative breaking and propulsion mode. The DSM-PI controller is implemented and compared with PI controller which shows improved characteristics of battery pack. The results and simulations are presented using MATLAB/SIMULINK.

KEYWORDS: SEPIC-ZETA Integrated Converter, Dual sliding mode proportional integral (DSM-PI) Controller, Permanent magnet synchronous motor (PMSM)

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 it 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 plug-in electric vehicles for charging and discharging the batteries. The Buck circuits are used to charge the battery and the boost circuits are used to drive the engines of the vehicle. 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 essentially consists of fewer components, thereby reducing the power losses and switching losses of passive and active devices, respectively.

The gains in normal PI controller are set at one specific value but in case of dual sliding mode-PI controller the gain values are continuously updated as error generated.

The DSM-PI controller is used in this paper to extract the current signal from the error signal. It tracks and achieves proportional and integral gains and thus minimizes the response time. The primary benefit of this method is the settling time is reduced with less disturbances and oscillations.

II. SYSTEM DEVELOPMENT

The block diagram of the entire system is as shown in Fig. 1

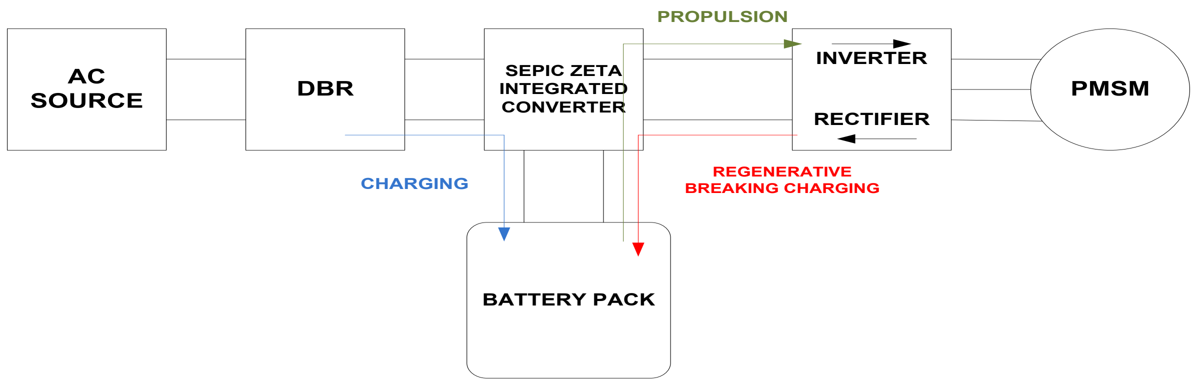

Fig (1) block diagram of Plug-in EV

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The proposed 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)

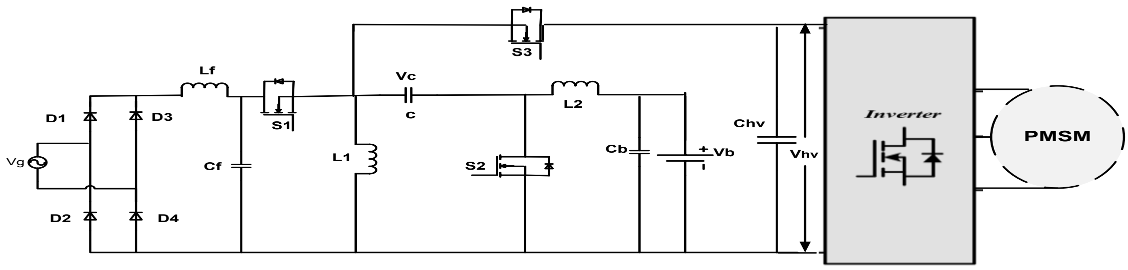

Fig (2) proposed SEPIC-ZETA converter

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). The SPWM technique is used to control the speed of motor through the inverter.

In above circuit L_f and C_f are input filters and inductors L1and L2 are charge storing elements. To reduce ripples across battery voltage V_b Capacitor C_b is implemented and for resonance capacitor C is used. Switches S1 and S3 are buck switches while S2 is boost switch.

III. WORKING OF CIRCUIT

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, i.e. S2 and S3 are in OFF state. When S1 is ON inductor L1 and L2 stores energy and when the S1 is OFF state L1 transfer energy to C while L2 supplies energy to battery and capacitor C_b. To avoid circulating current diode of S2 acts as freewheeling diode.

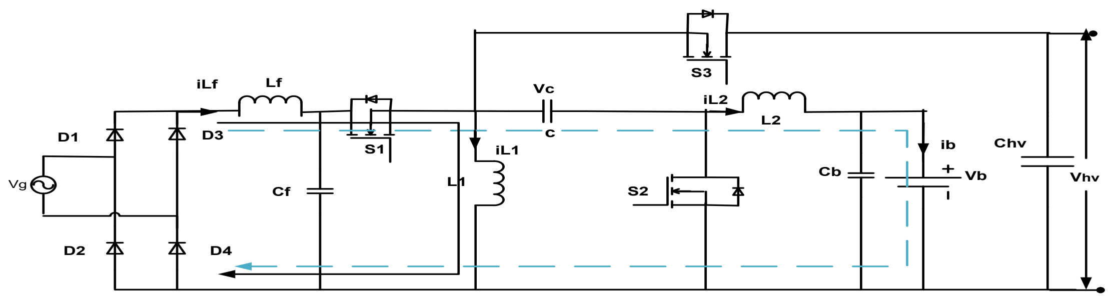

Fig (3) battery charging when S1 is ON

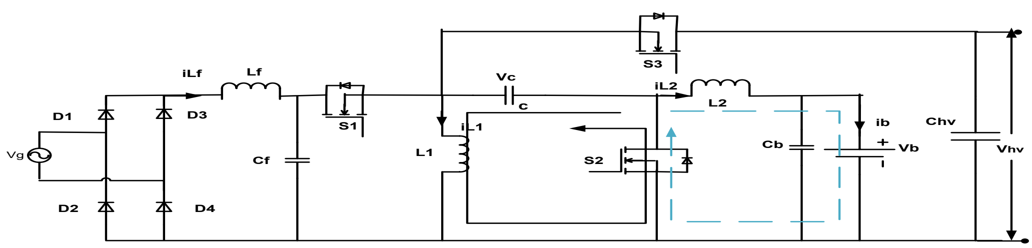

Fig (4) battery charging when S1 is OFF

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B. Propulsion Mode

Only switch S2 operates in this mode, while other two switches, i.e. S1 and S3 are in OFF state. When S2 is ON battery charges the L2.while L1 and C charged with small amount of current. When S2 is OFF 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.

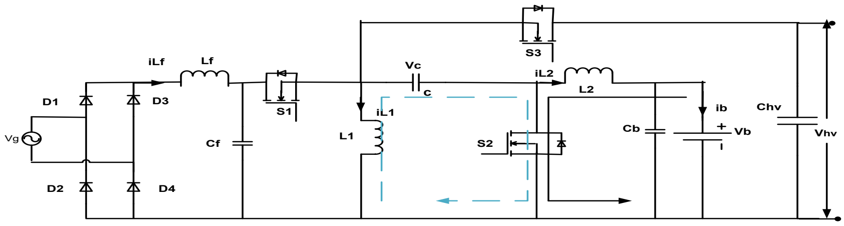

Fig (5) when S2 is ON

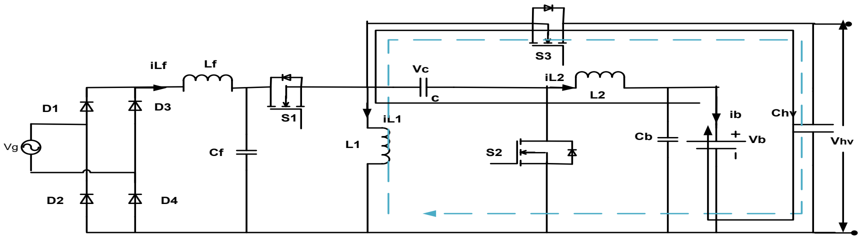

Fig (6) when S2 is OFF

C. Regenerative Breaking 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 inductor L1 and L2 stores energy and when the S1 is OFF state L1 transfer energy to C while L2 supplies energy to battery and capacitor C_b.

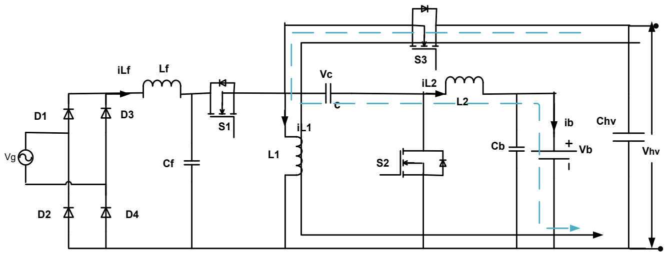

Fig (7) when S3 is ON

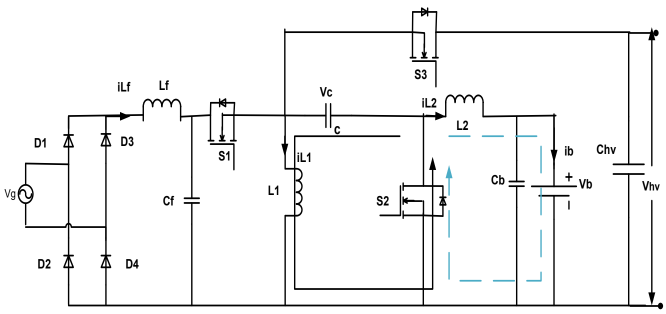

Fig (8) when S3 is OFF

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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 chargimg mode

During charging mode, this controller controls the S1. In this, 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 fed to the pi controller. Which then generates the maximum current value (Im) that then multiplies with |Sin wt| gives inductor current iLf*. This value is compared with measured inductor current iLf and fed to Pi controller which provides necessary duty ratio for S1.Pb* is reference battery power

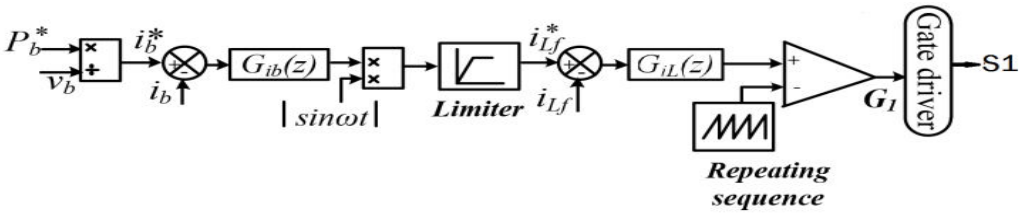

Fig (9) Control scheme for charging mode

B. Control scheme during propulsion and regenerative breaking mode

The Control scheme is shown in Fig (10) where feedback is taken from electromagnetic torque and DC link voltage (Vhv).The comparison of reference and measured values gives reference value of current ib*. Currents ib and ib* are compared and fed to Pi controller which gives duty ratio of S2 and S3.

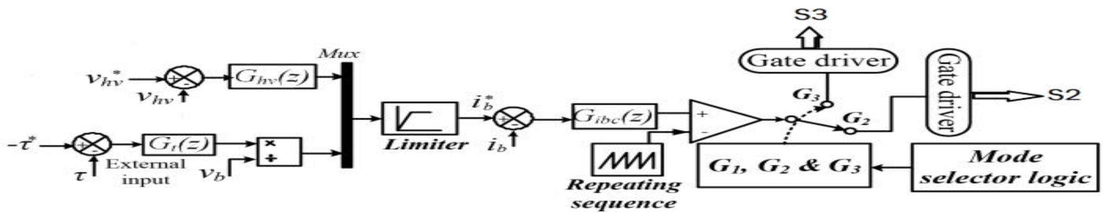

Fig (10) Control scheme for discharging and regenerative breaking charging mode

C. PI Controller

The most popular and useful control system algorithm is proportional integral controller. it controls 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. K_p and K_i 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 K_p and K_i 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.

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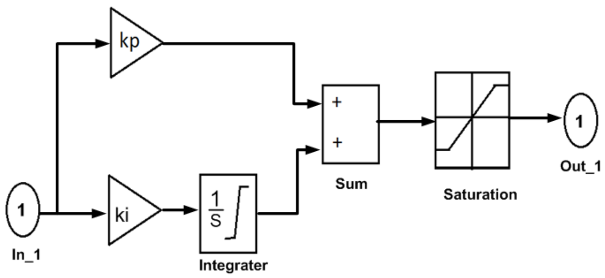

Fig (11) current control scheme by PI controller

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 is i. by selecting a proper sliding function dynamic behavior can be customized.

ii. the close loop response turns insensitive.

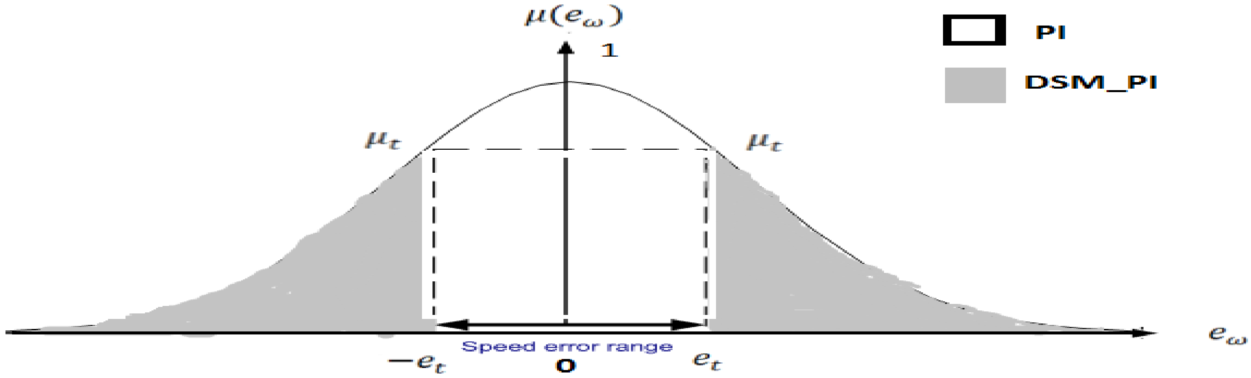

Fig (12) Transition criteria graph

Sliding surface is represented by

$$\sigma = ce_\omega + \dot{e_\omega}$$

Where, $e_\omega = \omega_c^* + \omega_c$,

e_ω^* is derivative and C is constant.

Gains are calculated as follow

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

Where,

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

And others are constant.

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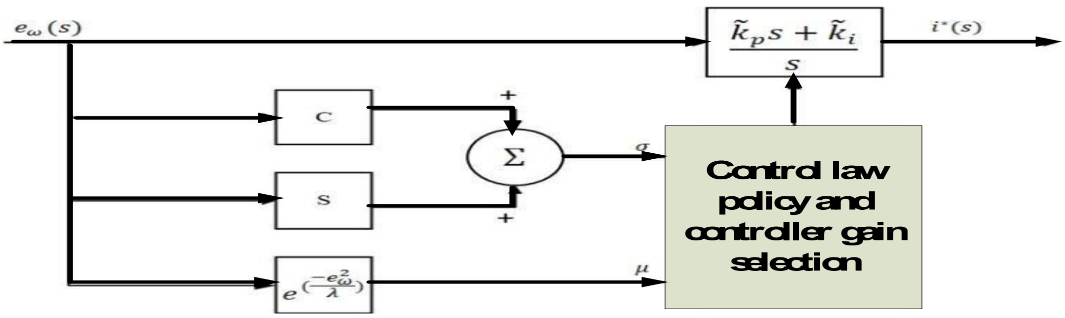

Fig (13) control scheme block diagram of DSM-PI

Consider a Gaussian function

$$\mu(e_\omega) = e^{\frac{-e^2\omega}{\lambda}}$$

μ is decision variable, e_ω is speed error and λ is Gaussian parameter. The value of μ is calculated constantly for e_ω. If $\mu < \mu_t$ then DSM-PI is chosen and when $\mu > \mu_t$ then fixed gain controller is selected. If λ is high then μ and e_ω is less sensitive and when λ is lower then μ and e_ω is highly sensitive [4].

V. EXPECTED RESULTS

The simulation of proposed model with PMSM is run for 1 second. The ratings of PMSM are 24 Nm, 300VDc 2300 RPM, resistance of stator phase Rs (ohm) =0.0918ohms, inductance of Armature (H) =0.975mH, Flux linkage=0.1688, J=0.003945 Kg.m^{2,} pole pairs=4, sampling time=1µsec.

The simulation model for integrated converter is presented in Fig (14)

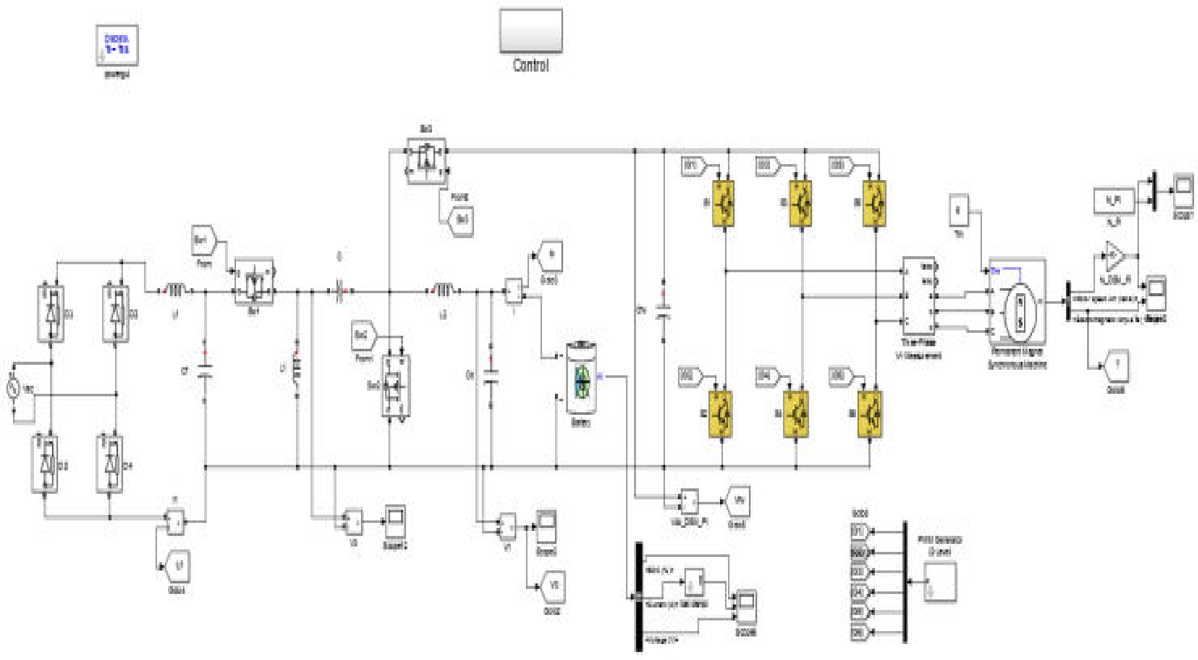

Fig (14) Simulation Model

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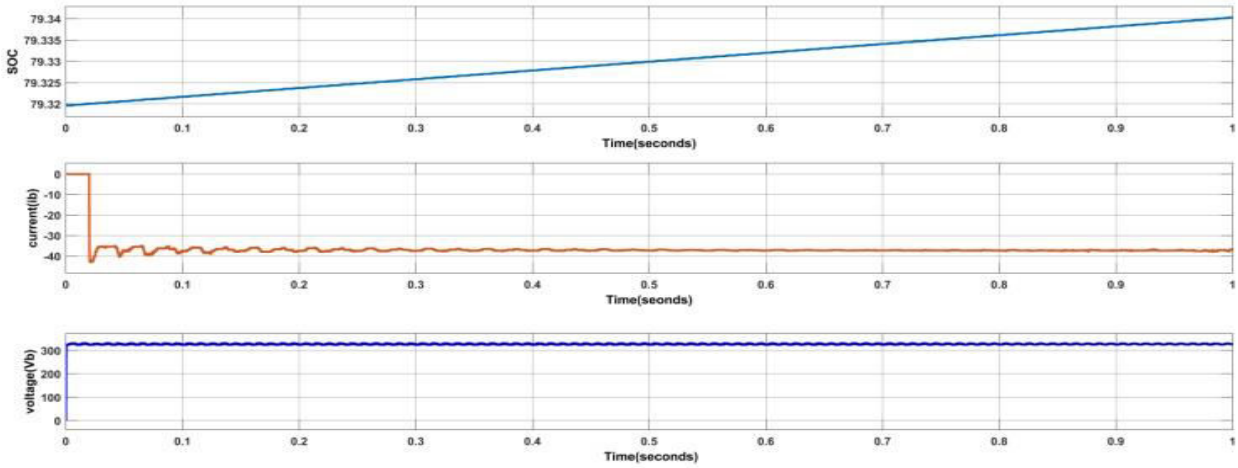

Fig (15) Battery characteristics during charging mode

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

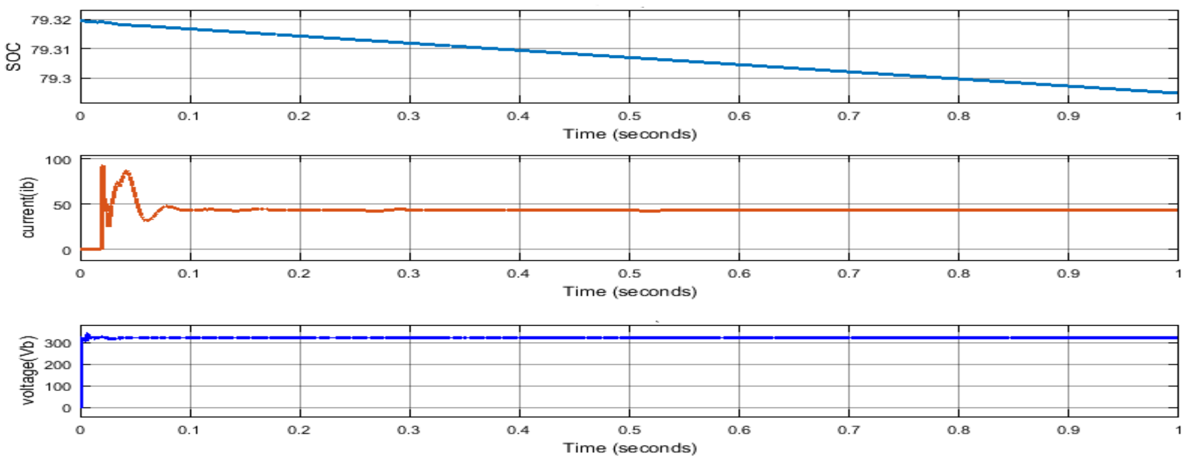

Fig (16) Battery characteristics during discharging mode

The Fig (16) shows the discharging of battery as the SOC is dropping and the current is in positive direction

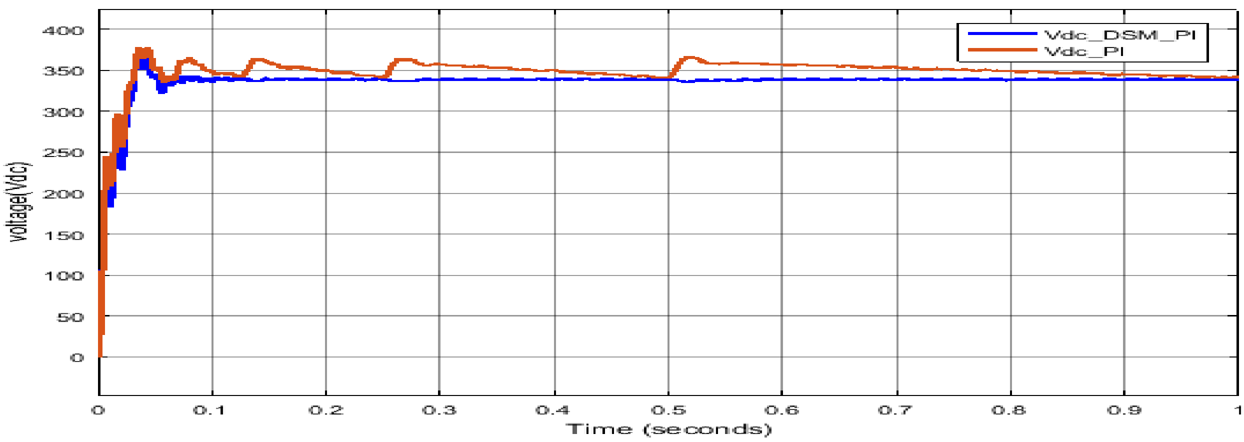

Fig (17) DC link voltage comparison

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From the above Fig (17) it is shown that dc link voltage settles faster in DSM-PI controller as compare to normal PI controller and also having fewer disturbances.

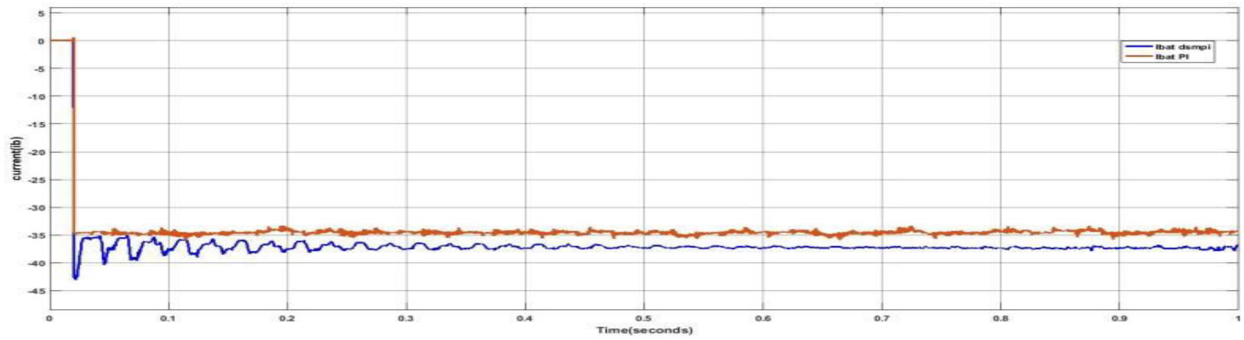

Fig (18) Comparison of battery current during charging mode

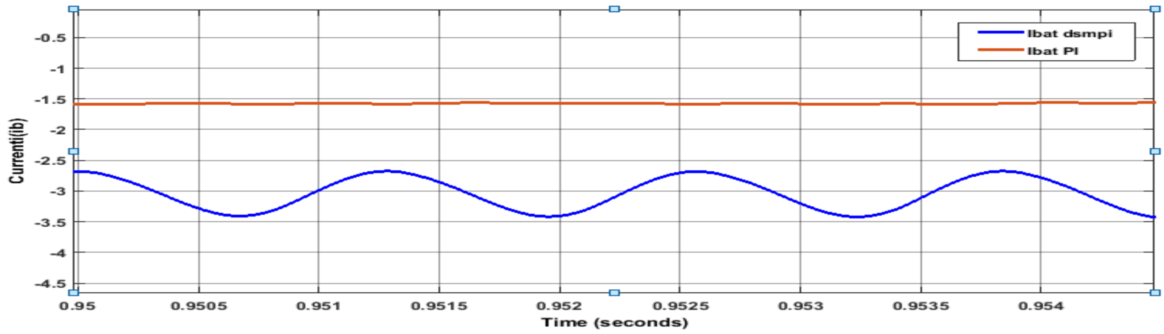

Fig (19) Comparison of battery current during regenerative charging mode

In above Fig (18) and Fig (19) comparisons of battery currents are shown during charging and regenerative charging mode using PI and DSM-PI controller.

VI. EXPECTED CONCLUSION

We can observe the charging, discharging mode and regenerative breaking mode parameters of the battery pack from the above simulation results of the proposed converter. By comparing PI and DSM-PI controller it can be observed that DC link voltage settles faster in case of DSM-PI Controller and charging current is also greater in case of DSM-PI controller.

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