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Grid tied EV Applications with Investigation of Controlled Bidirectional Converter and Design of Battery Management System

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Abstract: Electric vehicles (EVs) are very useful for reducing carbon emission and energy-efficient transportation. Minimization of emissions and green energy are always the demands which are regularly thriving researchers to analyze the electric transportations. Electric vehicles market is highly increasing day by day and its share will be growing even more higher in the upcoming future. AC-DC converters and DC-DC converters are needed to build up EV battery chargers and EV chargers can optimize some grid-tied operations such as vehicle-to-grid (V2G) and grid-to-vehicle (G2V) applications structured and collaboration with bidirectional AC-DC converters. The Split-Pi converter is a recently invented DC-DC converter that can be used in EV batteries and can support V2G and G2V operation for the profits on electric vehicle uses with its bidirectional functionalities. This paper presents a detailed analysis and control of Split-Pi converter for grid-tied V2G and G2V simulations altogether, and development of battery management operation with storage of charge across supercapacitor-batteries in EVs. The energy management combination of lithium-ion batteries and supercapacitors can minimize cost maximizing its range, efficiency and reliability. The EV charging system employing bidirectional converter presented for grid-tied applications has been performed in the MATLAB/Simulink software. Although many topologies and ideas were modified regarding those applications, there are still some processes to identify the new methodologies. There are so many battery problems such as battery aging, power losses, and slow charging problems. Bidirectional converter-based battery and battery management topology must be taken into consideration to prevent battery problems. Both battery lifetime and efficiency can be improved by implementing this process.

Index Terms: Split-Pi Bidirectional Converter, Battery Charger, Electric Vehicle, Vehicle to Grid (V2G), Grid to Vehicle (G2V), Energy Management.

I. INTRODUCTION

Electric vehicles are getting popularities day by day because of their advantages of zero carbon emissions, protection from pollution, and free of dependency from fossil fuels. Fossil fuels are greatly responsible for climate change and environmental damage. The battery needs constant and frequent charging all the times because battery continuously supplies the necessary power to run the motor drive in electric vehicles. The battery chargers need to be fast, efficient, smooth and reliable which is commonly made of simultaneous connection and operation of AC-DC and DC-DC converters [1]. EV batteries are getting charged from the AC power coming from the grid which is regulated into DC power smoothly through bidirectional DC-DC converters. This is known as grid to vehicle (G2V) operation. However, in modern power systems, EVs can also generate power to the grid as a contribution to the power grid resource whenever necessary and through vehicle to grid (V2G) process, EV batteries can supply power to the grid during peak load and local load conditions which is beneficial for powering the grid. Bidirectional DC-DC converters play a very important role for V2G applications in EV managements [2][3]. Among many kinds of bidirectional DC-DC converters, Split-Pi converter has been chosen for EV charger and grid-tied applications here because of its advantages of low cost, less components, higher power ratings, and higher efficiency. For all of those advantages, the Split-Pi converter is the best solution used in power electronics now for electric transportation and battery fast charging applications as well. This converter is a combination of boost and buck converter with a capacitor used between them, and this can be highly useful in electric vehicles. The main advantage of Split-Pi converter is that it has two operational modes – buck and boost mode. MATLAB/Simulink software has been used to model and analyze the V2G and G2V performance of battery charger system highlighting of the Split-Pi bidirectional converter in this article. Vehicle to grid concept can be allowed while charging at night and the load demand is low, and sending power back to the grid is required whenever demand is high.

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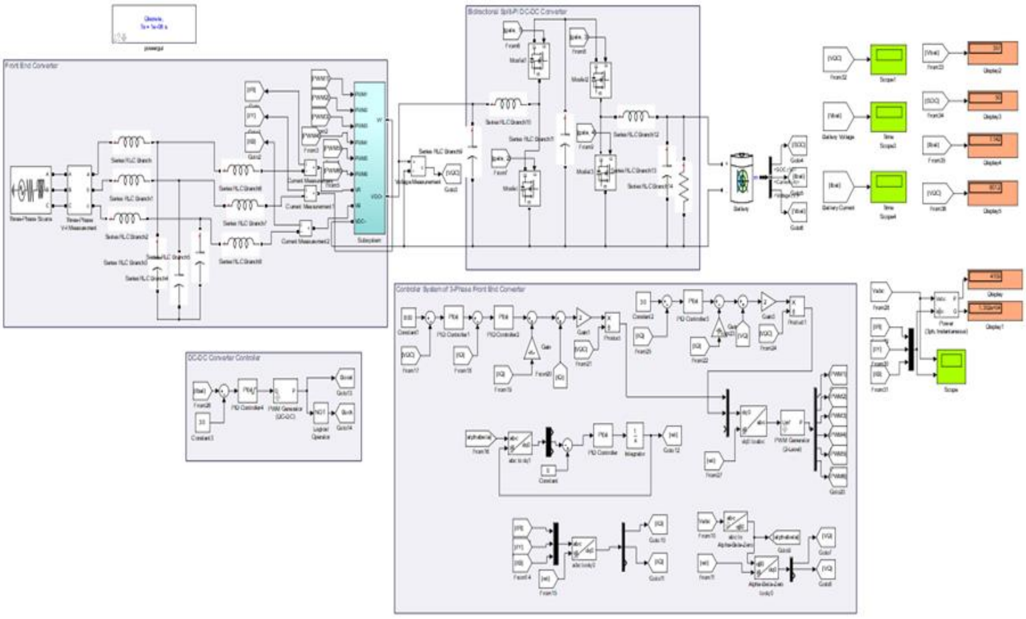

Fig. 1. MATLAB/SIMULINK model for energy transfer from vehicle to grid and grid to vehicle using Split-Pi

An electric vehicle pack has a large amount of energy stored in its battery and the energy from electric vehicle can be transferred to the grid where there is peak demand of loads or where electric vehicle is kept in parking to charge in the lean period of loads [4][5][6]. Besides, the battery management system of an electric vehicle is very important to maintain good battery life, safety, and reliability and battery management in EV demonstrates the feasibility of the energy operating system. The battery is an electrochemical device and it can fall down losing its stored capacity and so it needs replacement or further management [12][13]. In order to solve this, hybrid energy storage system combining of batteries and ultracapacitors has been studied in recent years. An efficient energy management system is needed to control the battery lifetime and performance for further battery transformations. Hence, a new improvement on battery management strategies has also been shown in this article.

II. MODELING ON MATLAB SIMULINK

A. Design of the System Parameters

The MATLAB/Simulink model of the proposed topology for vehicle to grid and grid to vehicle power transfer applications is shown in Fig.1. We have front end converter/AC to DC rectifier at the input which converts the AC grid voltage to DC and maintains the constant voltage across the DC bus. Bidirectional Split-Pi converter has been used to control the battery current during charging and discharging operation. IGBT is used in the inverter bridge in the simulation.

Grid voltage: 415V RMS at 50 Hz
Filter inductance: 5mH
Capacitance: 30 mF
Bus capacitance: 5600 mF
Battery nominal voltage: 360V (Lead acid battery)
Switching frequency of converters: 10 KHz
Total rated power: 2.55KW
DC reference voltage across the bus: 800V

Let us assume that the input source voltage V_s is given as,

$$V_s = V_{sm} \text{Sinwt} \qquad (1)$$

Here, Vsm is the maximum value of the source voltage. The value of Vsm is 586V, Grid voltage V_s = 415V RMS and $\omega = 2\pi f$.

The input current will be,

$$Is = \frac{V_s}{R_e} = Ism \text{ Sinwt} \qquad (2)$$

Here R_e is the emulated resistance and V_s is 415V RMS. The normalized input voltage Ms can be given as,

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$$Ms = \frac{V_{sm}}{V_{dc}} = Mg\ Sinwt \quad (3)$$

Here the value of V_{sm} is 586V and the value of V_{dc} is 800V. The calculated value of Ms from equation (3) is 0.7325. The value of emulated resistance R_e will be,

$$R_e = \frac{V_{sm}^2}{2Po} \quad (4)$$

Here, V_{sm} is 586V and Po = 2.55KW. Hence, the calculation of R_e is 67.33Ω.

$$\text{Power factor } \cos\theta = \cos\left[\tan^{-1}\left(\frac{X_L}{R_e}\right)\right] \quad (5)$$

The calculated value of the power factor from equation (5) is 1.

Split-Pi converter parameters: Inductors (L1, L2): 100mH, Capacitor (C1, C2): 100µF, Capacitor C: 500µF.

The design of the various components of proposed configuration for energy transfer from vehicle to grid and grid to vehicle consists of a three-phase front-end converter, Split-Pi bidirectional DC-DC converter, controllers, and a battery pack for EV system. The detailed design of the control scheme is given in the following section.

B. Converter fed Controllers

The controllers of the proposed system are described in this section. Controller plays an important role in grid-tied applications for both bidirectional converter and front-end converter, and controller diagrams are showed here.

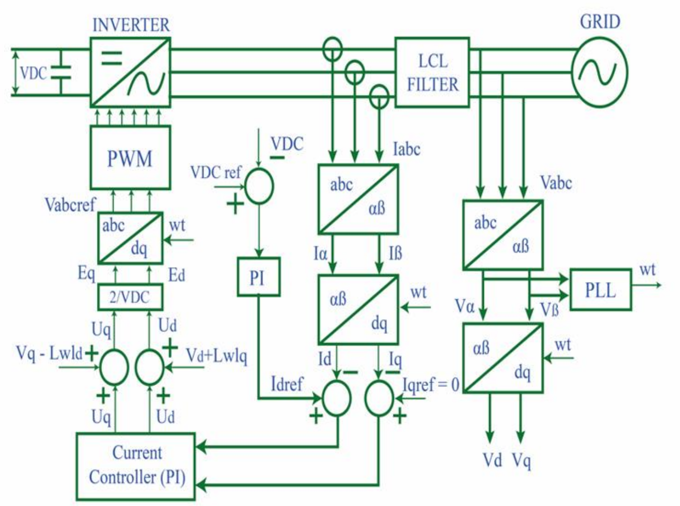

Fig. 2. Control Block Diagram of Three Phase Front-End Converter

Fig.2 shows the controller block diagram of three-phase front end converter. This controller is used to regulate 800VDC across the bus.

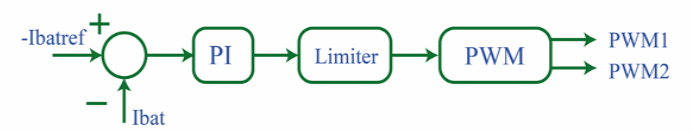

Fig. 3. Control Block Diagram of Bidirectional Split-Pi Converter

Fig.3 shows the controller block diagram of bidirectional Split-Pi converter. This controller is used to control the battery charging and discharging current.

III. RESULT AND DISCUSSION

Simulation is carried out in 7.8 toolbox of sim power system analyzing MATLAB Simulink through ode (23tb/stiff/TR-BDF-2) solver at 1e-6 step size in discrete mode.

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A. Simulation Output on Vehicle to Grid Power Transfer:

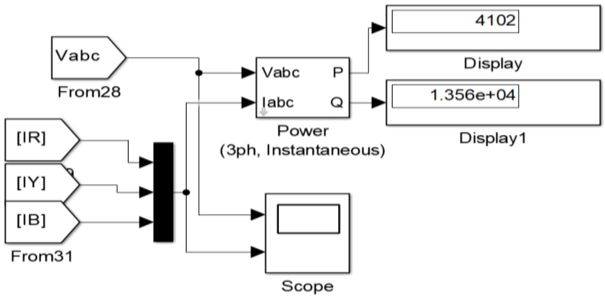

Fig.4. Simulation Output on Vehicle to Grid Mode (V2G)

From Fig. 4, the values of active power P and reactive power Q is positive. The result shows that power flow continues from battery to the grid and the system is operating on vehicle to grid mode.

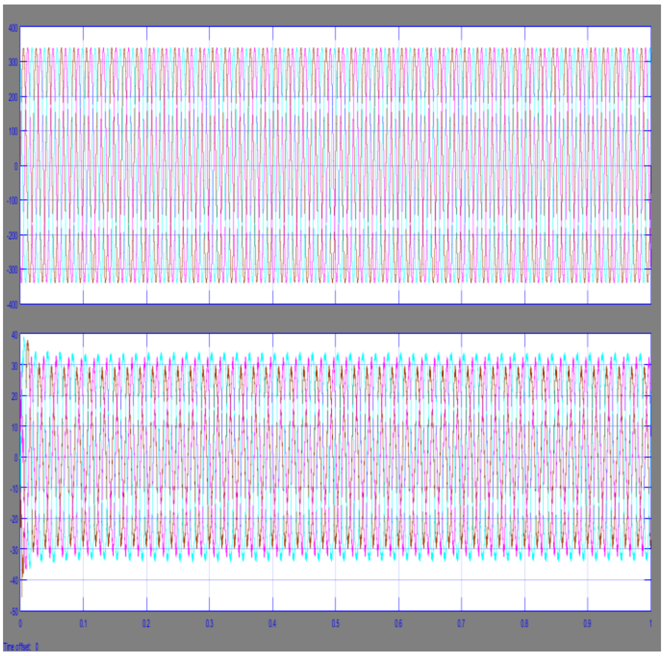

Fig. 5. Voltage and Current Waveform on Vehicle to Grid Operation

From Fig. 5, both voltage and current waveforms are on the same line and phase. This proves that power is transferred from vehicle to the grid.

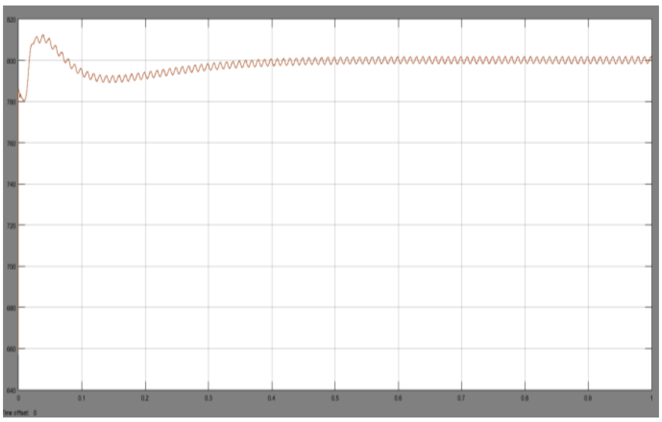

Fig. 6. DC Bus Voltage Output (800V Approx.) on V2G Mode

DC Bus voltage is 800V during vehicle to grid operation shown in Fig.6.

B. Simulation Output on Grid to Vehicle Power Transfer:

The grid to vehicle system will start its operation while assuming the current reference is negative (-30A in simulation) analyzing controller subsystem in case of front-end converter.

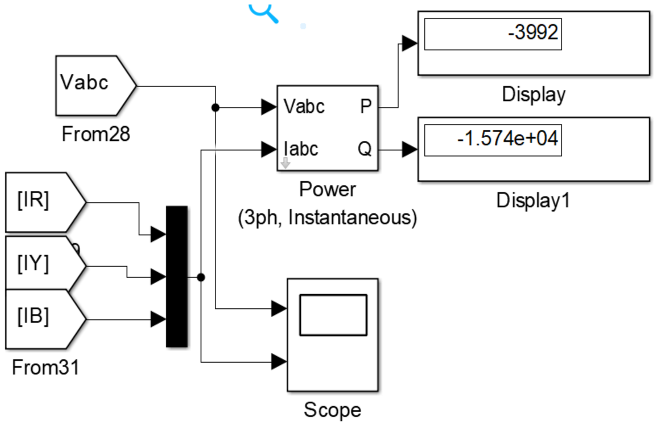

Fig. 7. Simulation Output on Grid to Vehicle Mode (G2V)

From Fig.7, we find the values of active power P and reactive power Q is negative. This proves that power flow is transferred from the grid to the battery. Power is taken from the grid to charge the battery and by this way, the system is working on the grid to vehicle mode.

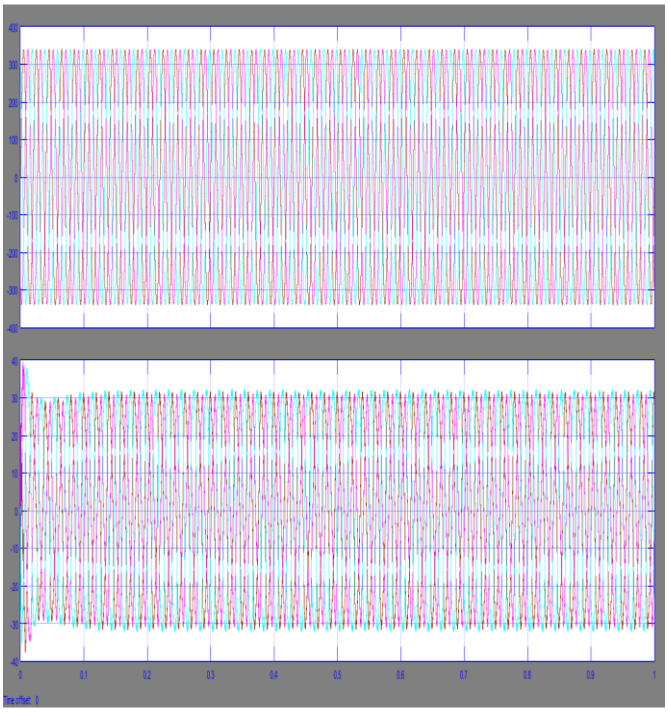

Fig. 8. VGRID and IGRID Output on G2V Operation

From Fig. 8, both the voltage and current waveform is on the same line and phase. Power is taken from the grid which is proved from the simulation result.

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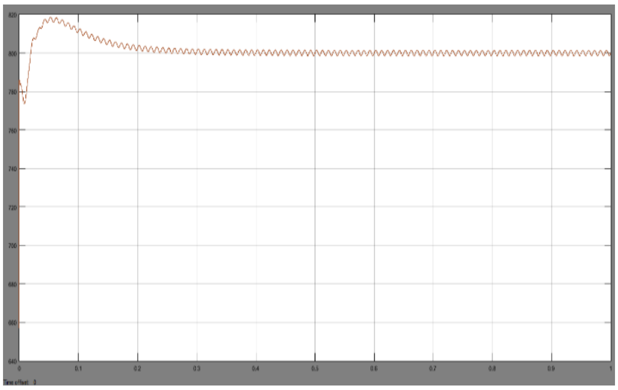

Fig. 9. Bus Voltage (800V Approx.) During Grid to Vehicle Operation

DC Bus voltage is same as 800V during grid to vehicle operation shown in Fig.9

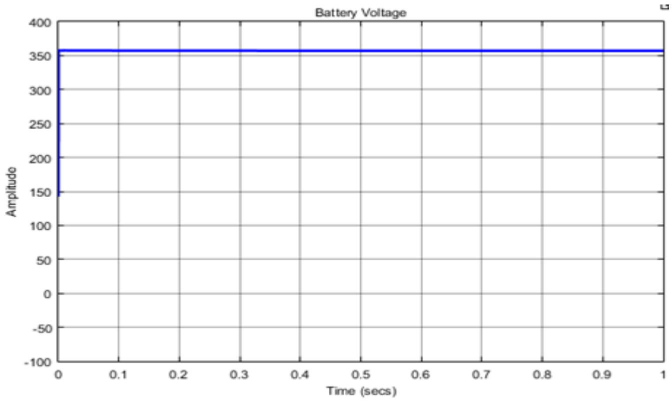

Fig. 10. Battery Charging Voltage (360V Approx.) during V2G and G2V Operation

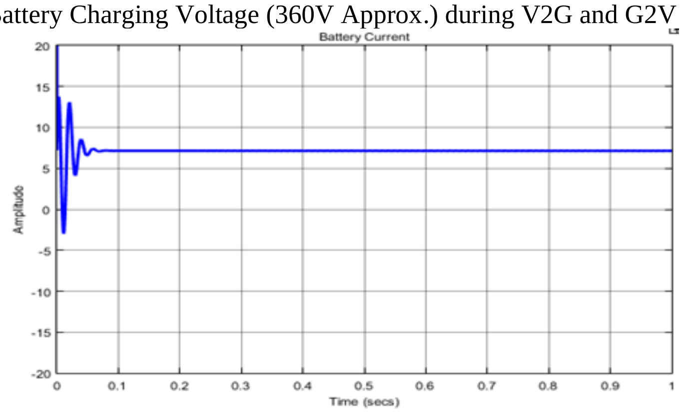

Fig. 11. Battery Charging Current during V2G and G2V Operation

Battery charging voltage is 357V and battery charging current is 7.142A found on the simulations shown in Fig.10 and Fig.11 developed and verified using MATLAB/Simulink. Lead acid battery has been chosen as the power source for the proposed system for smooth operation and high performance.

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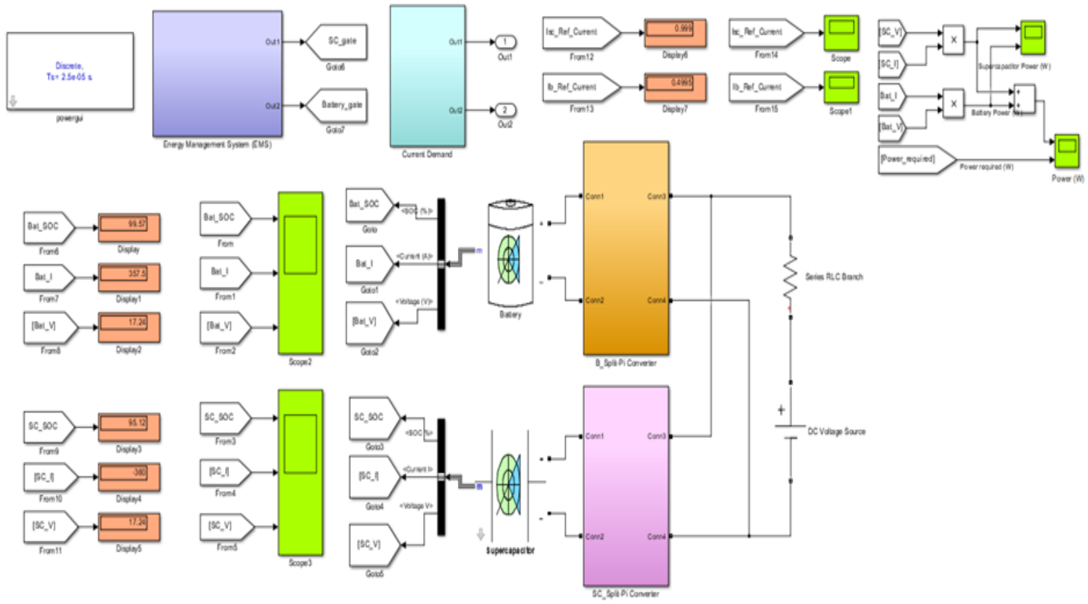


Fig. 12. MATLAB Model of Battery Management System with Combination of Split-Pi Converter fed Battery and Supercapacitor

IV. BATTERY MANAGEMENT SYSTEM

While the supercapacitors first inject energy to Li-ion battery and further on inverter through the converter, then the battery voltage starts decreasing. The battery output goes to the power inverter, and by this way the battery maintains its constant voltage at maximum times and helps the EV for better acceleration [7]. EV maintains better speed and range as the energy is recovered by the supercapacitors during regenerative braking and overvoltage is reduced at the battery terminals. The simulation model of battery management system including hybrid battery-supercapacitor used in EV for energy management between li-ion battery, supercapacitor, and the traction system is shown in Fig.12.

The energy management system is maintained at battery SOC adjusting the stored supercapacitor energy and with a small amount of energy stored in the supercapacitor, the battery maintains its full charge and works very well in most of the times [8][9]. The supercapacitor stores the energy recovered from regenerative braking and the battery also gets charged then. Additional power is also produced at the same time.

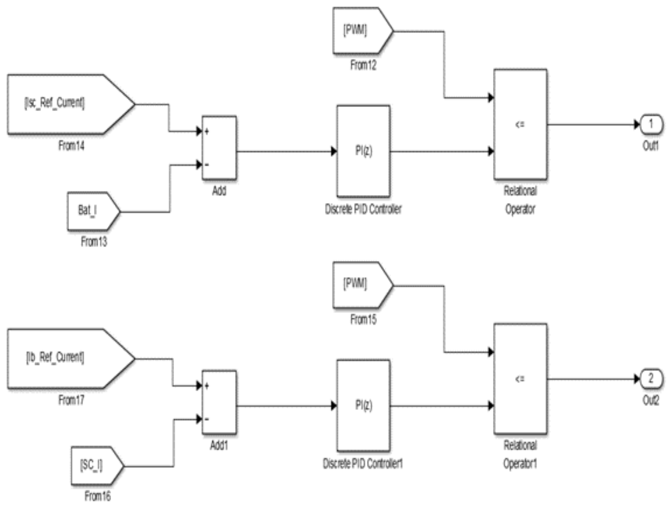
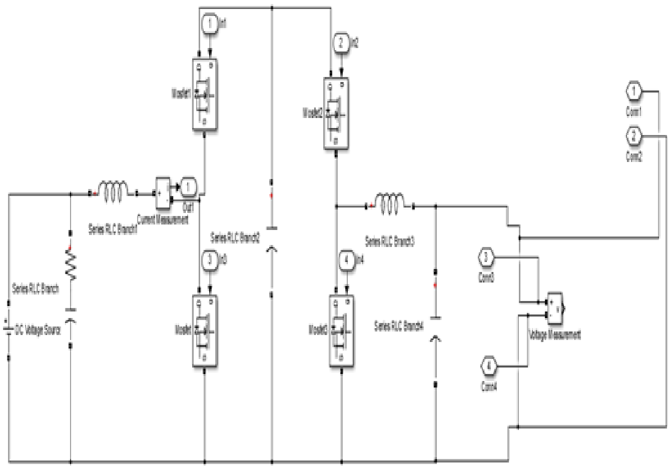


Fig. 13. Energy Management System Block with PWM and PI Control in MATLAB/Simulink

A typical energy management subsystem with conventional PI controller is proposed in Fig. 13. The pulse width modulation (PWM) signals control the four switches of the Split-Pi converter. The combination of li-ion battery across with supercapacitor helps an electric vehicle operate with higher range, good acceleration, and full regenerative braking capability. The supercapacitor should store a minimum level of energy higher than its normal conditions to quick charge the battery whenever required [10][11] and the battery SOC may not be enough in several cases.



ssFig. 14. Operational Split-Pi Converter Circuit for Battery and Supercapacitor

Selection of parameters in the simulation diagram are given as: Inductors (L1, L2): 1000mH, Capacitor (C1, C2): 200µF, Capacitor C: 500µF. The simulation diagram of bidirectional Split-Pi converter is stated in Fig.14 for battery management functionalities including combination of both the battery and supercapacitor.

V. SIMULATION RESULTS

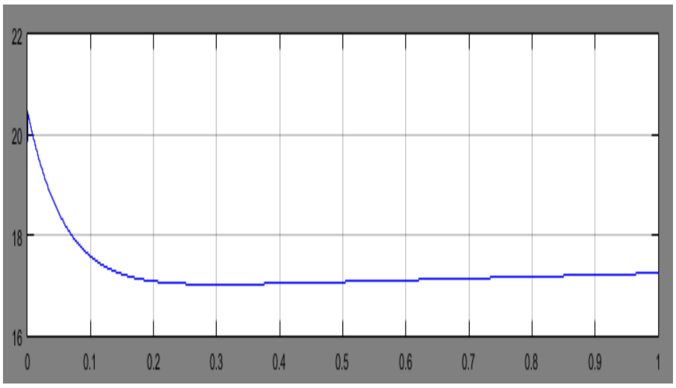


Fig. 15. Battery Charging Voltage (17.24V)

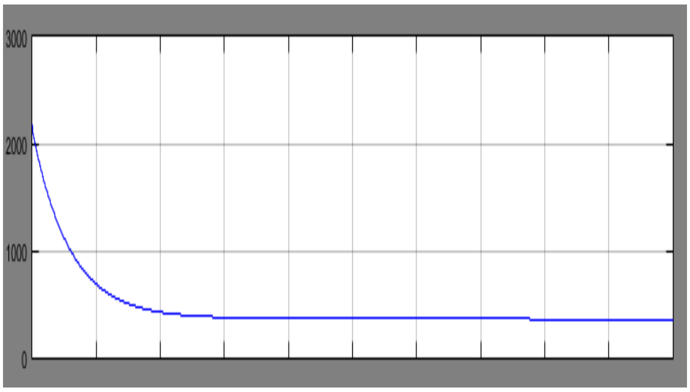


Fig. 16. Battery Charging Current (357.5A)

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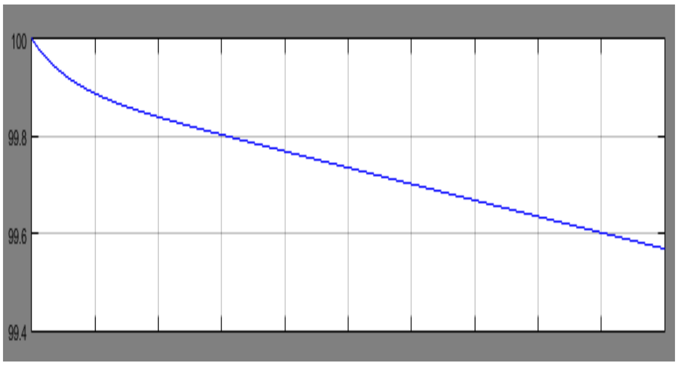

Fig. 17. Battery SOC (99.57%)

From the simulation results for li-ion battery (Fig.15, Fig.16, and Fig. 17), Split-Pi controlled battery maintains the regulation of charging voltage and charging current initiated up to state of charge running through equilibrium of energy management and battery parameters.

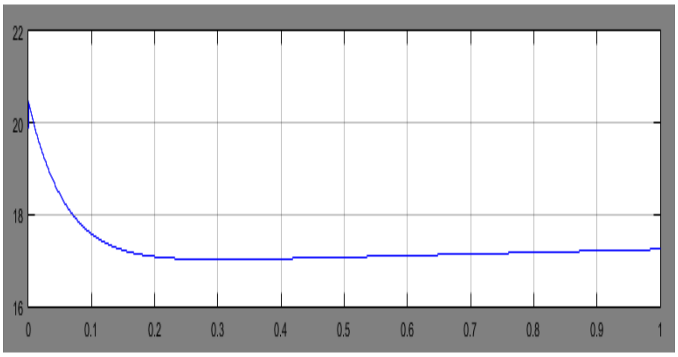

Fig. 18. Supercapacitor Voltage (17.24V)

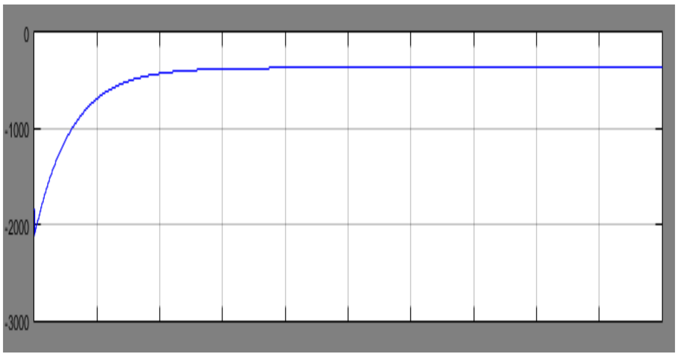

Fig. 19. Supercapacitor Current (-360A)

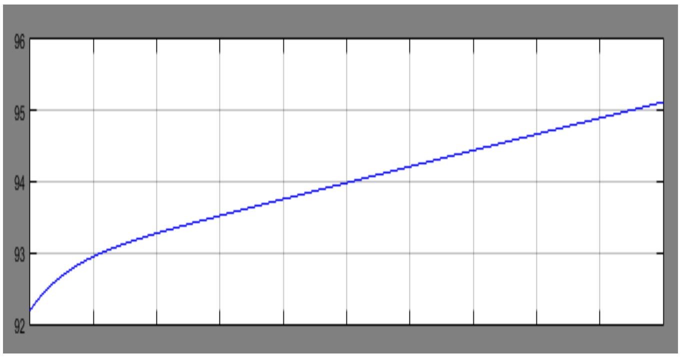

Fig. 20. Supercapacitor SOC (95.12%)

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From the simulation results with supercapacitor accordingly (Fig.18, Fig.19, and Fig. 20), formulation of bidirectional converter fed supercapacitor indicates a decent range of voltage and current with accomplishment of charge control on its state of charge.

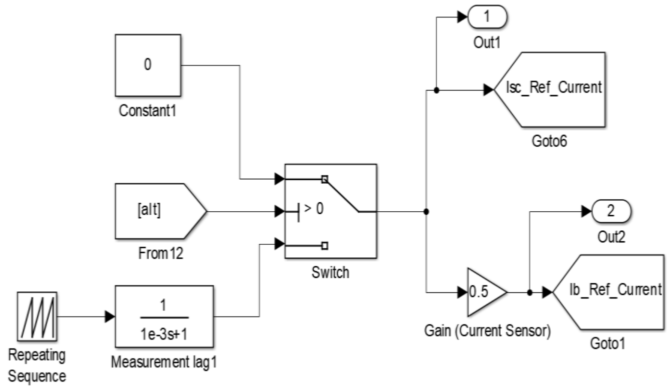

Fig. 21. Current Demand and Alternator

The alternator has been maintained as a sensor to divide the whole current (Gain 100%) and then the battery is supplying 50 percent (0.5) of the required current which means that the battery will supply to the load during zero to two seconds, and it will start charging as the alternator works as origin. The battery and supercapacitor current reference will be almost zero and the switch will be closed afterwards. The current demand and the hybrid current based on the reference current is applied by the current sensor to the bidirectional converter shown in Fig.12 and Fig.21 subsystem.

The current demand is therefore zero and the DC bus voltage starts charging of the battery using the bidirectional converter. Both the battery and supercapacitor are connected to the load and the battery is being charged by the load by ±360A current (Approx.). Fig.22 and Fig.23 indicates the battery reference current and supercapacitor reference current on development of energy management system. Battery reference current is 0.4995A consisting of supercapacitor reference current and increased battery power observed on alternator optimization, and configured with the simulation (Fig. 12).

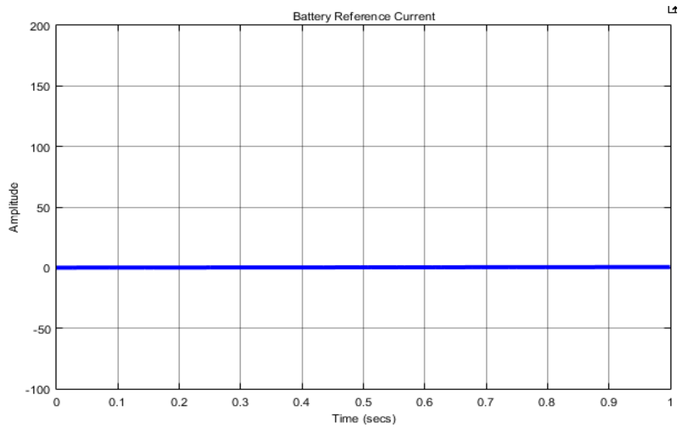

Fig. 22. Battery reference current

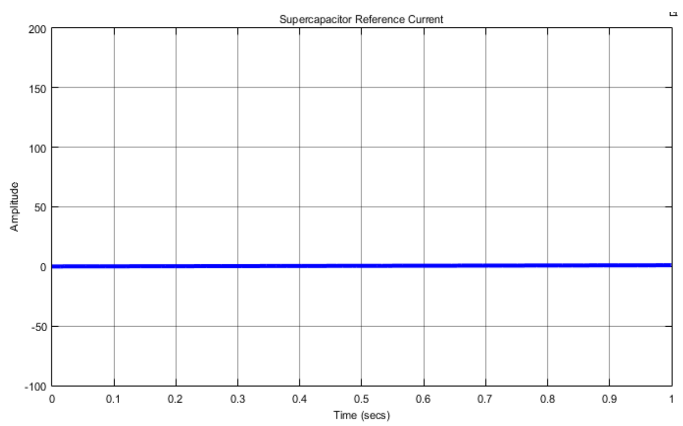

Fig. 23. Supercapacitor reference current

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The overall block diagram of the battery management system of hybrid battery-supercapacitor (Detailed improvement throughout EV battery and process of battery management powering on supercapacitor) are shown in Fig. 24.

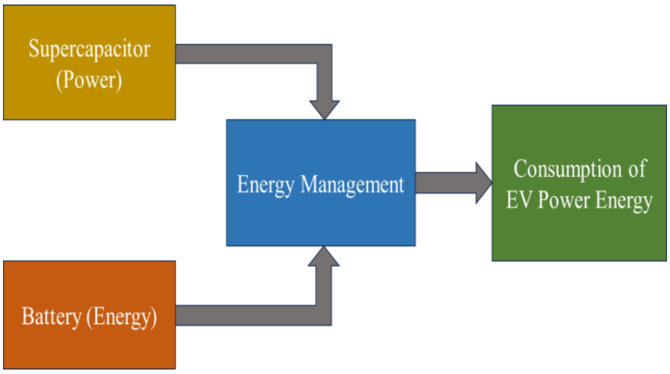

Fig. 24. Block Diagram of the Proposed Battery Management Scheme

VI. CONCLUSION

Split-Pi converter is a newly added and modified invention by which the topology is always essential for EV charging applications because of its bidirectional power flow, lower components, less switching losses and so on. In addition to these, this converter provides power quality control, scalability, advanced control options, and it has the stabilization power for smooth and reliable energy transfer between the electric vehicle and the power grid. The performance and benefits of the Split-Pi converter system have been investigated through simulation studies. Simulation results have been verified and necessity of storage battery management for vehicle to grid and grid to vehicle operations empowering through charging on a specific time is observed. The simulation results and discussion for a combination of a battery with supercapacitor in order to maintain a proper battery storage system is explained. While working on energy collaboration across supercapacitors/ultracapacitors, the electric vehicles behave very nicely and safely combining battery management module and to run the motor. Split-Pi converters structure, component selection, and control strategy has been presented in detail, providing an insight into the technical aspects of its operation. The converter's feasibility to facilitate grid powering electric vehicle applications properly has been discussed, and implying a useful battery management system possibility is improved.

VII. REFERENCES

[1] Yan Y, Bai H, Foote A, Wang W. Securing full-power-range zero-voltage switching in both steady-state and transient operations for a dual-active-bridge-based bidirectional electric vehicle charger. IEEE Trans Power Electron 2020; 35:7506–19.
[2] Adireddy R, Pratap KNGA, Himaja T, Murthy KVSR. Circuit analysis and modelling of dual active bridge bidirectional converter. Mater Today Proc 2021.
[3] Han Sekyung, Han and Soohee K.Sezaki., Development of an Optimal Vehicle-to-Grid Aggregator for Frequency Regulation IEEE Transactions on Smart Grid, vol.1, no.1, pp.65-72, 2010.
[4] Kempton. W. and Tomic J., June, 2005.Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. J. Power Sources, vol. 144, no. 1, pp. 280–294.
[5] Kisacikoglu M.C., Ozpineci B., and Tolbert L.M. Examination of a PHEV bidirectional charger system for V2G reactive power compensation. in Proc. of Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), 2010, pp.458-465.
[6] Medina J., Muller N. and Roytelman I. Demand Response and Distribution Grid Operations: Opportunities and Challenges. IEEE Transactions on Smart Grid, vol.1, no.2, pp.193-198, 2010.
[7] Massimo Ceraola, New Dynamic models of lead-acid batteries. IEEE Trans. on Power Systems, vol.15, no.4, pp. 1184-1190, Nov. 2000.
[8] A. F. Burke, "Batteries and ultracapacitors for electric, hybrid, and fuel cell vehicles," Proc. IEEE, vol. 95, no. 4, pp. 806–820, Apr. 2007.
[9] J. Dixon, M. Ortúzar, and J. Moreno, "Monitoring system for testing the performance of an electric vehicle using ultracapacitors," in Proc. EVS19, Busan, Korea, Oct. 2002, p. 137.
[10] M. Ortúzar, J. Moreno, and J. Dixon, "Ultracapacitor-based auxiliary energy system for electric vehicles: Implementation and evaluation," IEEE Trans. Ind. Electron., vol. 54, no. 4, pp. 2147–2156, Aug. 2007.
[11] J. Moreno, M. E. Ortúzar, and J. W. Dixon, "Energy-management system for a hybrid electric vehicle, using ultracapacitors and neural networks," IEEE Trans. Ind. Electron., vol. 53, no. 2, pp. 614–623, Apr. 2006.
[12] S.F. Tie, C.W. Tan. A review of power and energy management strategies in electric vehicles. 2012 4th International Conference on Intelligent and Advanced Systems (ICIAS2012). Kuala Lumpur, 2012, pp. 412-417. 2012.

[13] M.A. Hannan, M.S.H. Lipu, A. Hussain, A. Mohamed. A review of lithium-ion battery state of charge estimation and management system in electric vehicle applications: challenges and recommendations, Renew. Sustain. Energy Rev. 78 2017 834–854.

VIII. APPENDIX

I. The DC bus voltage can be further smoothed by increasing the proportional and integral gains on the controller system of the front-end converter. The DC output bus voltage is shown here with reduction of the overshoot in the voltage-to-grid system simulation.

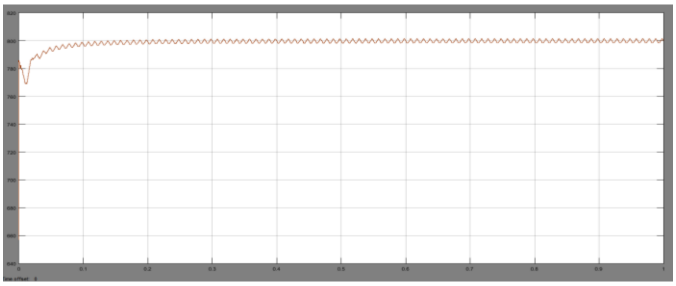

Fig. 25. DC Bus Voltage Output (800V Approx.) on Vehicle to Grid System with Zero Peak Overshoot

II.PI controller is trial-error tuned in controller systems to further reduce the overshoot completely, and make the DC output voltage constant as well as the voltage-to-grid system more reliable which is shown in Fig. 25.

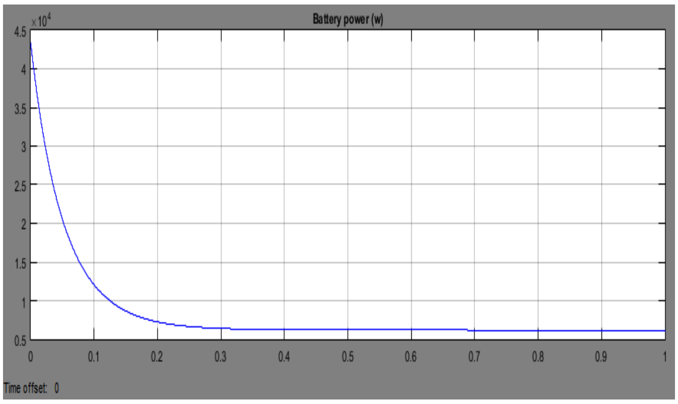

Fig. 26. Battery Power Measurement on Hybridization of Battery-Supercapacitor

The battery management process with the supercapacitor has increased the total battery power (6.5 KW approx.) almost three times compared to other conventional conditions. Fig. 26 shows the simulation of increased battery power with energy management combination of li-ion battery and supercapacitor.

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BIOGRAPHY

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