Design of DC/DC Converter for Charging Series Hybrid Electric Vehicle Traction Battery

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***Abstract*- This paper presents the design of DC to DC converter for charging the traction battery of series hybrid electric vehicle. To design a DC to DC converter for high power applications size, losses and cost of the components are very important. Considering these factors a simple interleaved buck converter with fuzzy logic controller is implemented to charge the battery. Because of its minimized inductor ripple current and extent step-down transformation ratio this converter is applicable for high power applications with high step down transformation ratio. The simulink model of the series hybrid electric vehicle traction battery of 48v is charged with the input voltage of 60v using the MATLAB/SIMULINK.**

***Keywords:* interleaved buck converter, fuzzy logic control, traction battery, series hybrid electrical vehicle.**

I. INTRODUCTION

With today's persistently high oil prices, people are spending more money on gasoline than ever. Due to reducing world oil and gas reservoirs as well as environmental considerations have make the automobile application to develop more energy saving and virtuous vehicles to diminish the fuel consumption and save the environment. The newly designed hybrid vehicle has the ability to solve both the obstacles of energy and environment. It helps to diminish global warming and to slash the fuel reliance. Our hybrid vehicle employs both an internal combustion engine (ICE) and a switched reluctance motor to give an optimum efficiency and reliability using the power from the energy storage system (ESS).The hybrid electric vehicle can be operated in four modes of operation.

1. Solar alone mode of operation.
2. Wind alone mode of operation.
3. combined solar and wind mode of operation.
4. Engine mode of operation.

These various modes of operation confirm that the battery is completely charged to enable the vehicle to operate primarily in electric mode thus reducing the pollution and the fuel consumption of the vehicle. In a plug-in hybrid electric vehicle (PHEV), the battery can be immediately charged when plugged into an electric power source, thus having the characteristics of both compound and electric vehicle (EV).Like the Electric vehicle, it has the advantage of using less electricity with the another advantage of having a power assistance, and the engine can be filled fastly to increase its range. A small ICE is sufficient for a compound operation in comparison with regular vehicles. This is an added advantage as a small engine system can upgrade notable fuel economy with extent mileage values in city driving. This is due to the fact that the operating points of small engines are in a more optimal region. With smaller engine the discharge rate is minimized.

Most of the research work have been taken so far is to design the battery charger for the hybrid electric vehicle which consists of AC-DC converter with PFC followed by an isolated DC/DC converter [1-2].These architecture requires soft switching technology to reduce the switching losses. So many charger configuration with soft switching technologies were introduced [3-6].This will increase the cost and losses of the system further for high power applications. And the entire semiconductor devices will suffer at high input voltage [5-7].Various charging techniques has been employed to charge the battery depends upon the battery type. Among these charging techniques constant voltage charging is simple and reliable. This paper describes the simple converter design used to charge the traction battery of the series hybrid electric vehicle during engine mode of operation. By using constant voltage charging technique the battery is charged through interleaved buck converter. The output of the converter is controlled through the fuzzy logic control which is very robust and easily upgraded. This designed interleaved buck converter has the benefit of fewer ripples with high step down conversion ratio in comparison with normally used interleaved buckconverter.

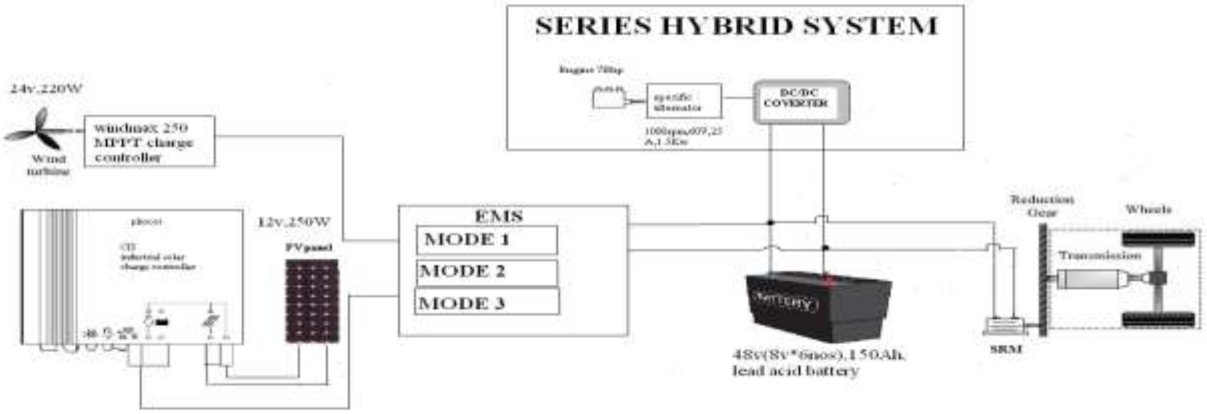

Fig.1.Schematic diagram of series hybrid electric vehicle.

II. CIRCUIT DESCRIPTION

An interleaved buck operation consists of number of mini-converter cells (or phases) which are placed in parallel. The power is distributed equally among the converter cells using active phase shifting and this method removes the current ripples at the output. The effective ripple frequency will be increased and reduces the requirement of output filter capacitor.

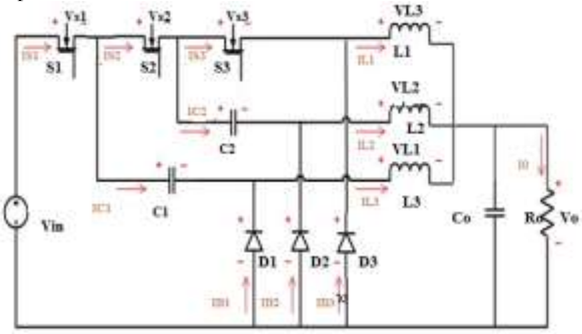

Fig.2. Circuit diagram of interleaved buck converter.

This interleaving approach can also significantly reduces the input inductor and capacitor requirements. In this configuration three agile switches are connected in sequence and two connecting capacitors are situated in the power path. The switches S_1, S_2 and S_3 are switched on with the 180 degree phase angle. Each switching period is divided into six modes. In order to demonstrate the working principle of the designed interleaved buck converter, some aspects are created as follows:

1.The three inductors L_1, L_2 and L_3 are identical.

2.All power semiconducting devices are ideal.

3.The connecting capacitors C_1 and C_2 are viewed as the voltage source.

Working principle when D ≤ 0.5

Mode 1 [t_0 –t_1]: At t= t_0 the switch S_1 is switched on to start the mode1 operation. Then, the inductor current $I_{L1}(t)$ flows through the switch S_1 , capacitor C_1 , and the inductor L_1 then the coupling capacitor V_{C1} is charged. The inductor current $I_{L2}(t)$ and $I_{L3}(t)$ freewheels via the diodes D_2 and D_3.In this operation the voltage over the inductor L_1 , is equal to distinction between the source voltage V_S and the voltage of the connecting capacitor V_{C1} , The output voltage V_O and its level is positive. Therefore the inductor current $I_{L1}(t)$ rises linearly from the beginning value. Then the inductor voltages $V_{L2}(t)$ and $V_{L3}(t)$ becomes negative. Therefore, $I_{L2}(t)$ and $I_{L3}(t)$ reduces linearly from the beginning value. The voltage $V_{S2}(t)$ becomes two third of the source voltage and the voltage $V_{S3}(t)$ is equal to one third of the source voltage. The voltage $V_{D1}(t)$ is equal to the distinction between V_S and V_{C1}.

Mode 2 [t1-t2]: At t=t_1 the switch $S_1$is switched off to initiate the mode two. Then, the three inductor currents I_{L1}, I_{L2}, I_{L3} are freewheels through the diodes D_1, D_2 and D_3 respectively. The voltages $V_{L1}(t)$, $V_{L2}(t)$, $V_{L3}(t)$ become the negative output voltage(-V_0). Therefore, the inductor current $I_{L1}(t)$, $I_{L2}(t)$ and $I_{L3}(t)$ reduces linearly. Throughout this mode, the voltage over every switch is $V_S/3$.

Mode 3 [t_2-t_3]: When the switch S_2 is switched ON at t_2 mode 3 starts. The energy stored in the coupling capacitor V_{C1} during mode 1conduction is now discharged and coupling capacitor V_{C2} is charged. The inductor current $I_{L2}(t)$ passes through S_2, C_2, L_2. The current $I_{L1}(t)$ freewheels through the diode D_1 and the current $I_{L3}(t)$ freewheels through the diode D_3. At this mode operation, the voltage $V_{L2}(t)$ is the difference between connecting capacitor voltages $V_{C1}(t)$, $V_{C2}(t)$ and the output voltage,V_0 and its level is positive. Therefore, $I_{L2}(t)$ rise linearly. The voltage $V_{L1}(t)$ and the voltage $V_{L3}(t)$ are the negative voltages. Therefore the inductor currents $I_{L1}(t)$ and $I_{L3}(t)$ reduces linearly from its starting values. The voltage $V_{S1}(t)$ becomes one third of source voltage V_S and the voltage $V_{S3}(t)$ becomes two third of source voltage V_S. The voltage over the diode D_2, $V_{D2}(t)$ is equal to the difference between connecting capacitor voltages $V_{C1}(t)$ and $V_{C2}(t)$.

Mode 4[t3-t4]: When the switch S_2 is switched OFF at t_3 mode 4 conducts and mode 4 operation is similar to mode 2.

Mode 5[t4-t5]: Mode 5 starts when S_3 is switched ON at t_4.The energy stored in the connecting capacitor V_{C2} is discharged. The current $I_{L3}(t)$ passes through the capacitor C_2, switch S_3 and the inductor L_3. The current $I_{L1}(t)$ freewheels through D_1 and the current $I_{L2}(t)$ freewheels through D_2. During this mode, the voltage $V_{L3}(t)$ is the difference between $V_{C2}(t)$ and V_0 and its level is positive. Therefore, $I_{L3}(t)$ rises linearly. The voltage $V_{L1}(t)$ and the voltage $V_{L2}(t)$ are the negative output voltages. And hence, $I_{L1}(t)$ and $I_{L3}(t)$ reduces linearly from its beginning values. The voltage $V_{S1}(t)$ and $V_{S2}(t)$ are one third of V_S the The voltage $V_{D3}(t)$ is equal to $V_{C2}(t)$.

Mode 6[t5-t6]: When S_3 is switched OFF at t_5, the mode 6 starts and its operation is similar to mode 2.

III. DESIGN DETAILS

A. Battery

The charging of a battery depends on two things charging time and battery discharge rate. A voltage source should be strong enough to move current through a battery. The battery can be charged faster by applying more current into the battery. Charging at too high rate however can overheat the battery.

Therefore the battery should be charged with minimum charging voltage and current.The formula to calculate the charging voltage for the battery is as follows.

$$\text{Peak hours required} \equiv \frac{\text{voltage}_{\text{batt(v)}} \times \text{capacity}_{\text{batt(Ah)}}}{\text{power(kw)}} \quad (1)$$

$$\text{Charging voltage} \equiv \text{charging V per cells} \times \text{No.of cells} \quad (2)$$

$$\equiv 2.30\text{V} \times 24$$

$$\text{Charging voltage} \equiv 55\text{V}$$

From the formula we calculated the maximum charging voltage for the battery is 48V-55V.The charging current will be $1/10^{th}$ of the battery capacity.Here the capacity of the lead acid battery is 150Ah.Therefore the maximum safe charging current will be 15A.There are various charging techniques are used to charge the battery.The most commonly used and reliable charging technique is constant voltage charging.In this method the charging voltage of the battery is maintained constant over the charging period and the charging current is reduced gradually.The charging characteristics of a constant voltage charging method is shown in fig.3.

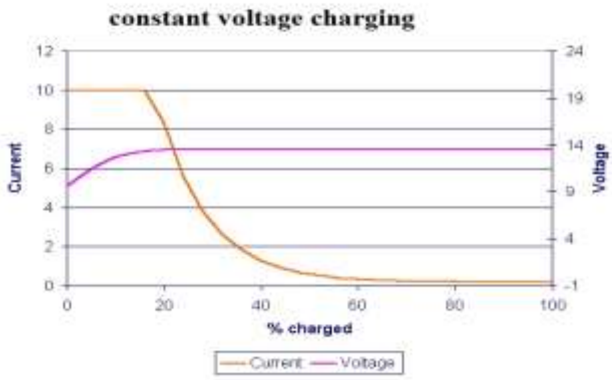

Fig .3. Characteristics of constant voltage charging.

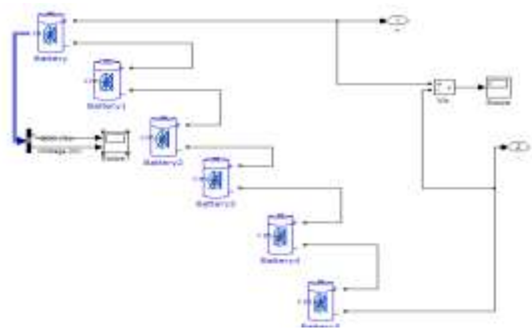

Fig.4. Simulink model of 48v battery.

B. Engine

A small internal combustion engine is used to rotate the DC alternator in this electric vehicle. When the vehicle is operated in engine mode of operation the traction battery is charged through the interleaved buck converter. Here the engine is designed to rotate the Dc alternator at a speed of 1000rpm.The output of the DC alternator is given as input to the interleaved buck converter. The propulsion of the vehicle is mainly depends on the battery. The simulink model of an engine is shown in fig 5.

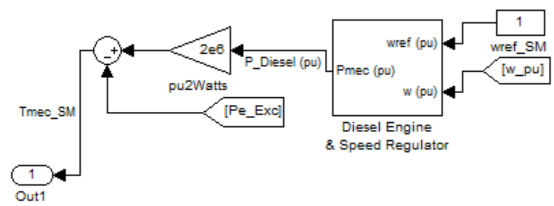

Fig.5.Simulink model of engine.

III. CONTROL TECHNIQUE

The Fuzzy control is a non-linear and adaptive control technique and it is most commonly preferred alternative for a various control applications. It will process the data through membership functions rather than crisp variables. There are four main elements in the fuzzy logic controller system named as Fuzzifier, Rule base, Inference engine and defuzzifier. Three main steps are followed in fuzzy logic.i.Fuzzification. ii. Inference. iii. Defuzzification.In fuzzy procedure, crisp set used as input data or non-fuzzy data, Table 1 shows the crisp set used in the simulation. With the help of linguistic variables and membership functions these are changed as fuzzy sets using fuzzifier. Membership functions vary such as Triangular, Gaussian, Trapezoidal, Generalized Bell and Sigmonoidal. Rule base is the foundation of it. The membership function of triangular is used to create the fuzzy rules in this paper .According to the requirement; nine fuzzy rules are updated to generate the triggering pulse for the converter based on the converter output. The input pulses to the converter are shown in fig.6.

Table 1.Fuzzy rules.

I/O	0.3	0.6	0.9
0.3	low	Low	medium
0.6	low	medium	High
0.9	medium	High	high

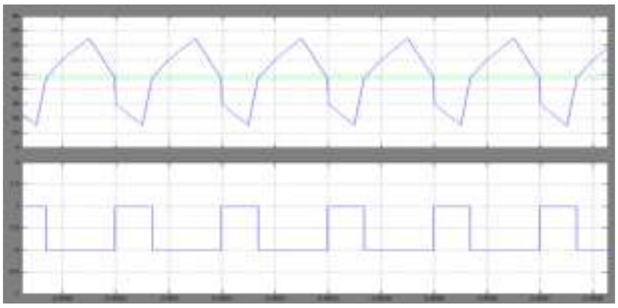

Fig.6.Input pulses to the converter.

IV. SIMULATION RESULTS

The complete model of a series hybrid electric vehicle is designed .The simulink model is simulated with following values.
Speed of the DC alternator=1000rpm.
Input current to the converter=25A.
Input voltage to the converter=60v.
Output voltage of the converter=48v.
Output current of the converter=15A.

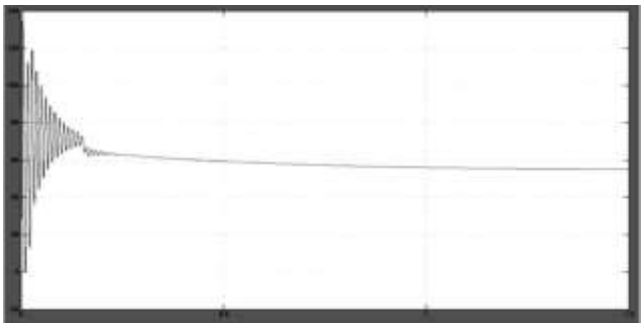

Fig.7.Input voltage to the converter from the DC generator.

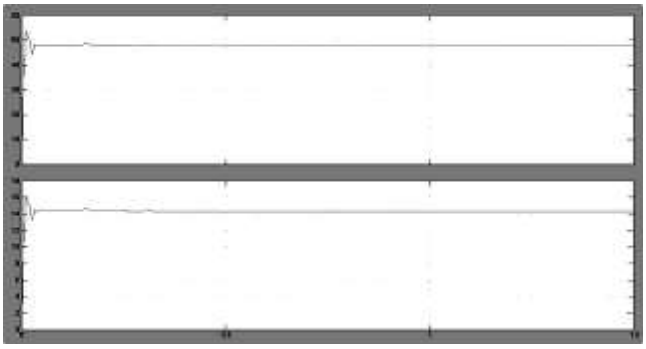

Fig.8.Output voltage from the converter.

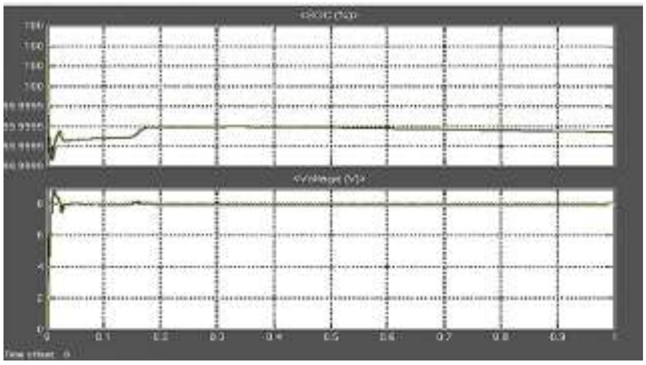

Fig.9.Output of the battery.

Fig .9 shows the state of charge of the battery. Each of the battery cells is charged with minimum cell voltage of 8V.Thus we obtained the constant 48v voltage through the converter for charging the battery.

V. CONCLUSION

Series hybrid electric vehicle traction battery is charged with safe charging current and charging voltage without any ripples through the designed DC/DC converter. The safe values of charging voltage and charging current are calculated using the formula according to the battery capacity. The proposed interleaved buck converter with fuzzy logic control produces the constant voltage output with less ripples and switching losses. Therefore the series hybrid electric vehicle traction battery can be charged safely with constant voltage charging method through the designed converter. The simulink model is analyzed and results were obtained.

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