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PHASE SHIFTED FULL BRIDGE CONVERTER FOR BATTERY SYSTEMS WITH PARTIAL POWER PROCESSING

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Abstract :Due to increased CO2 emissions from the transport section sector, day-by-day demand for Electric vehicles is increasing. The problem associated with EVs is the battery due to their weight and charging time. The prolonged charging time of batteries leads to driving anxiety. To reduce the charging time, there is a need to implement fast charging methods. In this work, a partial power processing system is implemented employing a PSFB converter for battery charging applications, in which a fraction (20-35%) of the power is supplied by the converter, and the remaining amount of power is supplied through a direct path which lossless. By developing a partial power processing system, the efficiency of the system will increase, and the size of the system will be reduced.The suggested system undergoes mathematical analysis, is put into practice, and is verified using the MATLAB Simulink environment.In summary, since the converter will only be processing a small quantity of electricity, there will be fewer losses and an overall boost in system efficiency.

Keywords: **Partial Power Processing Systems (PPPS), Phase-Shifted Full Bridge Converter(PSFBC), State of Charge(SOC), Constant Voltage(CV) and Constant Current(CC).**

I. Introduction

1.1. Need for EV

The transport sector accounts for about 20% of greenhouse gas emissions. India has 14 of the 20 most polluted cities in the world. Petrol and diesel vehicles do contribute very significantly to the poor-quality air and that's why the world is looking for alternatives which are Electrical vehicles (EVs). EV is four times as energy efficient as an ICE vehicle and has 50 times fewer moving parts[1].

Here are some of the primary reasons why EVs are becoming increasingly important:

1. Environmental Benefits
2. Reduction of Greenhouse Gases
3. Energy Independence
4. Lower Operating Costs
5. Innovation and Technological Advancement
6. Noise Reduction
7. Consumer Demand
8. Corporate Responsibility

1.2. Types of available DC charging stations

Table1 Types of available DC charging stations

Charge Method	DCVoltagerange(V)	MaximumCurrent(A)	Powerlevel(KW)
DClevel-1	20-450	≤ 80	≤ 36
DClevel-2	200-450	≤ 200	≤ 90
DClevel-3	200-600	≤ 400	≤ 240

The charging time of the DC fast charging system is still higher than the refilling time of the ICEvehicle.So,toreducedrivinganxietyweneedtogowithextremelyfastcharging methods [2].

1.3. Introduction to Batteries

Even though there are so many energy storage devices available such as batteries, fuel cells, andultra-capacitors,thebatteryisthemainenergystoragedeviceinEVsduetoitshighspecific energy [3].

Thetypes of batteries available are

1. Lead-acid
2. Nickel-Cadmium
3. Li-ion
4. Nickel-metal hydride

1.4. Problems associated with EV

ThemajorproblemsassociatedwithEVsarebatterycost,volume,andweight.Theweightof the battery is high compared to the petrol tank of ICE vehicle, also the refiling time of ICE vehicle is very less compared to the charging time of battery[4]. The prolonged charging time and lack of charging infrastructure for EV lead to driving anxiety[5].

1.5. Partial Power Processing Converter (PPPC)

The conventional DC-DC converters process the full amount of power taken from the source [6]. So, to process the full amount of power the convertershould be rated. In processing, the rated amountofpowerlosses willbehigh,and thesize oftheconverteris alsolarge. Asopposed to theconventionalsystempartialpowerprocessingsystems(PPPS)wereproposedtoreducethe losses of the converter and to improve the efficiency in different applications [7].

The proposed partial power processing system has numerous advantages compared to the conventional system.

1.6. Motivation and outline

Partial power processing is a solution to decrease the charging time, to improve the system efficiency[8].Theaimisheretoimplementapartialpowerprocessingsystemforbatterycharging applications.

II. INTRODUCTION TO THE PARTIAL POWER PROCESSING SYSTEM AND DEVELOPMENT OF A PARTIAL POWER PROCESSING SYSTEM EMPLOYING PHASE SHIFTED FULL BRIDGE CONVERTER

2.1. Introduction to PPPS

AsopposedtotheconventionalsystemthePPPSwillprocessafractionoftheratedpowerand the remaining amount of rated power will be processed through the direct path. The block diagram of PPPS is shown below[9].

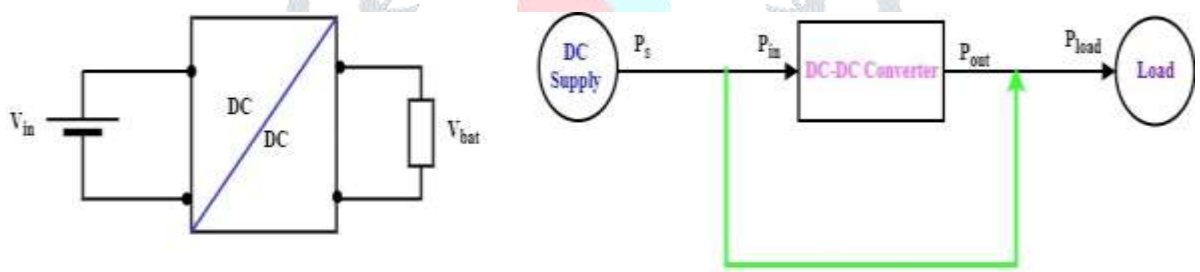

Fig.1 Block diagram of Fullpowerprocessing converterand PPPS

2.2. Types of partial power processing systems

Partial power processing converters are classified into two main configurations based on their connection to DC-DC converters in the system, they are

1. Input-parallel output-series (IPOS) configuration
2. Input-series output-parallel (ISOP) configuration

2.3. Implementation of a partial power processing system employing phase shift full bridge converter

The PSFB converter is a double-ended power converter that can be operated up to 5 KW and with SiC, GaN it can extend up to 15 KW[10].

The proposed partial power processing system consists of the following stages,

- Partial Path
- PSFB converter
- Direct path

This is the direct connection between the input DC voltage source and the battery, and this path will transfer the major amount of power with a very small number of losses due to which the efficiency of the system will increase.

The circuit diagram of the partial power processing system employing a PSFB converter is given in Figure 2

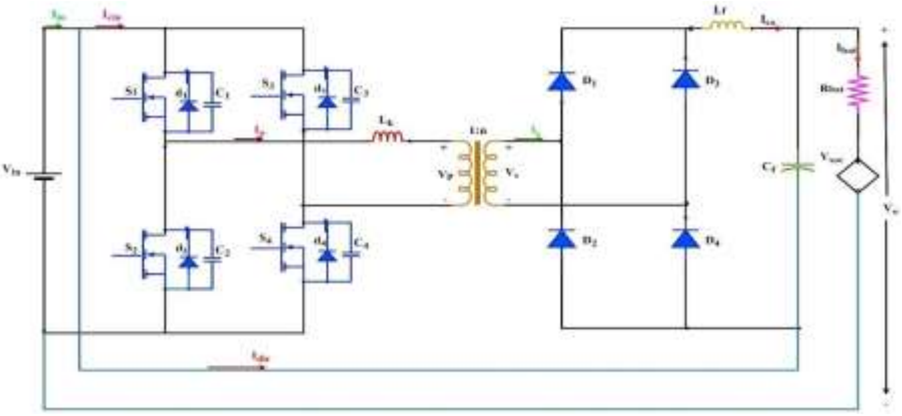

Fig.2Circuit diagramof PPPS

In the topology shown in the Fig,

Vin is the input voltage, S1, S2, S3, and S4 are the switches which are MOSFETs, D1, D2, D3, and D4 are diodes of the bridge rectifier, Lk is the leakage inductance of the transformer, d1, d2, d3, and d4 are body diodes of the MOSFETs S1, S2, S3, S4 respectively, C1, C2, C3, C4 are the capacitances of the switches S1, S2, S3, and S4 respectively, Lf and Cf are the output filter inductor, capacitor respectively, Vo is the battery voltage which is the output voltage of the system, Icin is the converter input current, Iin is the input current, Ico is the converter output current, Ibat is the battery current Idir is the direct path current, Rbat is the internal resistance of the battery, Vsoc is the open circuit voltage of the battery, n is turns ration of the transformer, and Vp,Vs are transformers primary and secondary voltages respectively.

2.4. Modes of operations PPPS system

The different modes of operation of the PPPS system with waveforms are given in the following.

In all the modes of operations, we will transfer some amount of power directly through the direct path. Direct path operation is similar in all the modes of operation [11].

Mode I (to-t1): Loss of Duty cycle
Mode II (t1-t2): Transfer of power
Mode III (t2-t3): ZVS of S3
Mode IV (t3-t4): Freewheeling period
Mode V (t4-t5): ZVS of S2
Mode VI (t5-t6): loss of Duty cycle
Mode VII (t6-t7): Transfer of power
Mode VIII (t7-t8): ZVS of S4
Mode IX (t8-t9): Freewheeling period
Mode X (t9-t10): ZVS of S1

2.5. Partial Power Processing Converter Design(PPPC)

From the circuit diagram of PPPS,
The reference values for proposed system:

Vin = 48 V
Vo = Vbat = 60 V (nominal)
Vomax = 68 V
Io = Ibat = 10 A
Transformer turns ratio n N2/N1= 48/40
Frequency = 50 KHz
D = duty ratio = 0.5

Filter Inductance:

$$L_f = \frac{(nV_{in} - V_o) * D_{eff}}{2 * \Delta I_o * f_o} \qquad (1)$$

$$L_f = 66.67\ \mu H \qquad (2)$$

Filter Capacitance

$$C_f > \frac{I_o * D_{eff}}{\Delta V_o * f_s} \qquad (3)$$

$$C_f \geq 7.2\ \mu F \qquad (4)$$

Leakage Inductance:

$$L_K = \frac{V_{in} * (1 - D_{eff})}{4 * n * \Delta I_o} \qquad (5)$$

L_k= 6.2 µH (6)

III. BATTERIES AND THEIR CHARGING TECHNOLOGIES

3.1. Introduction to Batteries

Thevarious types ofavailableenergy storagedevices are

1. Batteries
2. Fuel cells
3. Fly wheel
4. Ultra-capacitors

Types of batteries

The major rechargeable batteries available for EV applications are

1.Nickel-cadmium (NiCd)
2.Nickel-metal-hydride (NiMH)
3.Zinc-air (Zn-Air)
4.Lead-acid (Pb-acid)
5.Lithium-ion (Li-ion)
6.Sodium-sulfur (NaS)
7.Lithium-polymer (Li-poly)

3.2. Battery Modelling

For simplicity, a battery is modelled as an ideal voltage source (VSOC) in series with an internal resistance (Rbat). The values VSOC and Rbat are not constants but varies with SOC, age of the battery, and its maintenance. During charging and discharging, the voltage drop in internal resistance (Rbat) of the battery will be in opposite polarities due to different direction of the current which will causes different battery terminal voltages**.**

Battery Equations:

Theproposedequivalentmodel of the battery is given in Figure 3

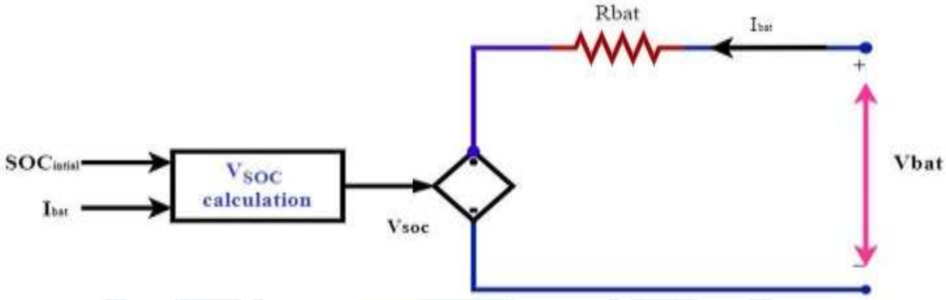

Fig.3 Equivalent model of battery

$$SOC = SOC_{initial} - \frac{1}{Ah}\int I_{bat}\,dt \quad (8$$

$$V_{SOC} = a * e^{-bSOC} + c * SOC^3 + d * SOC^2 + e * SOC + f \quad (9)$$

$$V_{bat} = V_{SOC} + I_{bat}R_{bat} \quad (10)$$

3.3. Li-ion Battery Specifications of the Proposed System

Thespecifications ofLi-ion battery forthe proposed system is

Table2 Specificationsof Li-ionbattery

S.No	Parameter	Rating
1	Nominalvoltage($V_{nominal}$)	60 V
2	Maximumvoltage (V_{omax})	68 V
3	Chargingcurrent (I_{bat})	10 A
4	Capacity	12.5 Ah
5	$SOC_{initial}$	10%

3.4. Batterycharging methods

The available charging techniques are

- Constant current (CC) charging
- Constant voltage (CV) charging
- Two-step (CC-CV) charging

IV. RESULTS AND DISCUSSION

The Figure 4 shows the circuit diagram of the proposed system. All the waveforms associated with system are discussed in the following sections.

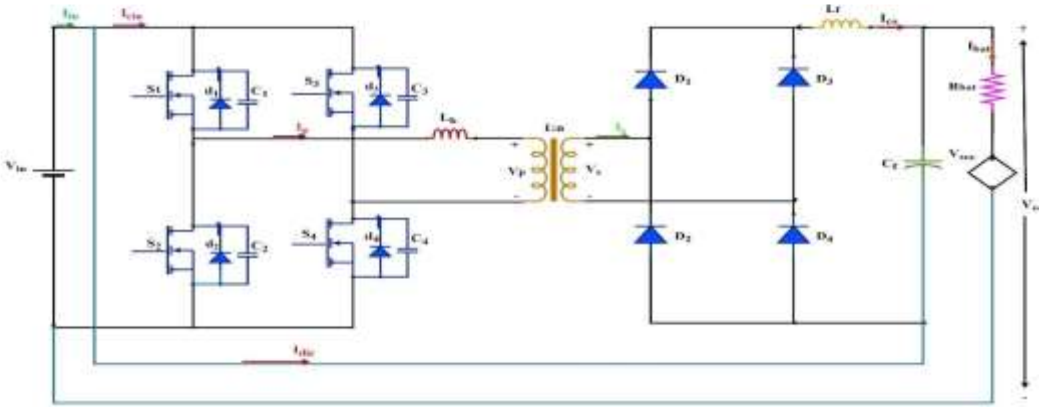

Fig.4 circuit diagram of proposed system

4.1. Gating signals for MOSFETS

In Figure 5, the gating signals of the switches generated by the function generator with phase shift are shown. From Figure 5, it is observed that PWM1, PWM4 are phase shifted and PWM2, PWM3 are also phase shifted with an angle instead of turning on simultaneously.

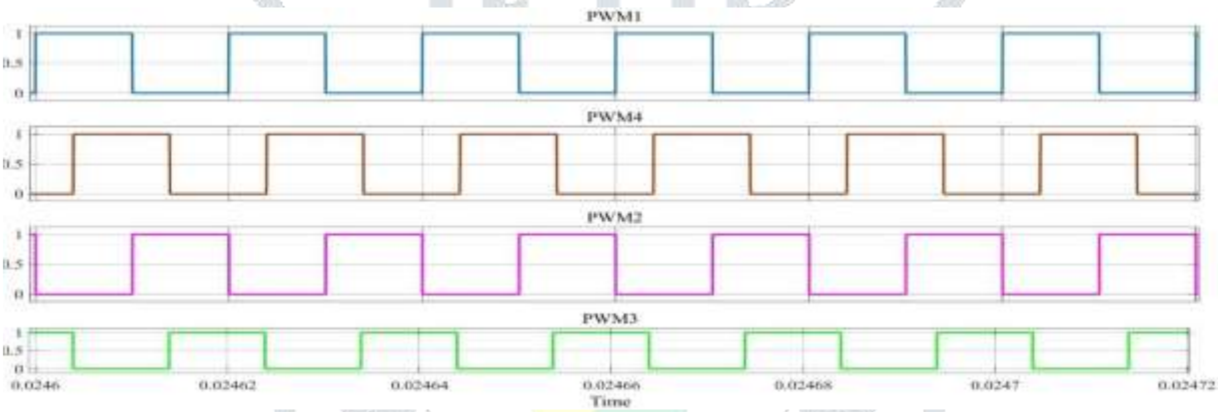

Fig.5gatingsignalsoftheswitches

4.2. Battery charging

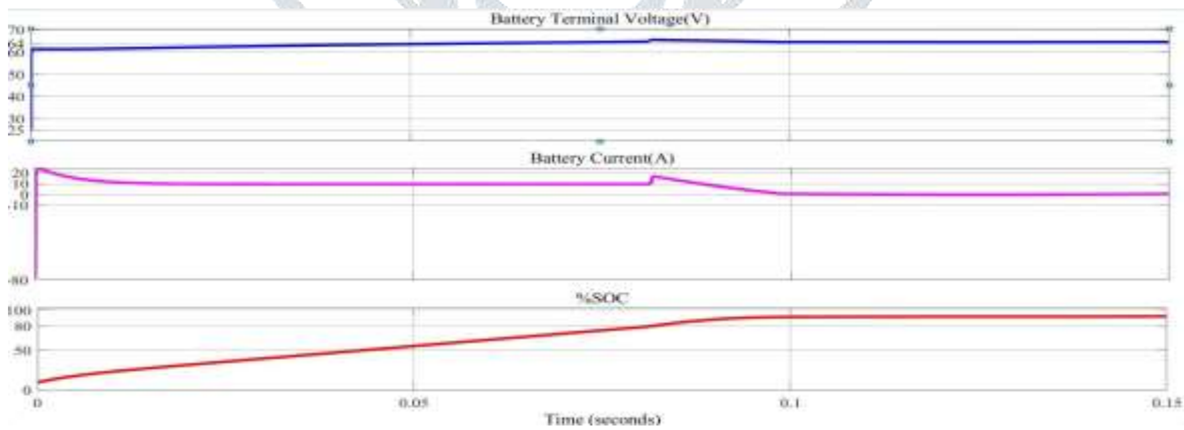

Fig.6Chargingcharacteristicsofthe battery

In the Figure 6 battery terminal voltage (V_{bat}) which is output voltage of the system, battery current (I_{bat}), and %SOC are shown. From Figure till 80% of SOC charging of the battery was done through CC mode where battery charging current is 10 A and after80% of SOC the chargingofbatterywasdonethroughCVmodewherebatteryvoltage64V.AfterSOCreached to 90% approximately the battery current is zero.

4.3. System power and efficiency

In the following Figure7, the system input power, output power, direct path power and system efficiency are shown. At 10 A of battery current, direct path power is 480 W, the system input power is the sum of converter input power and direct path power which is equals to 635.3 W and the system output power at this point is 622 W, which gives the efficiency of the system as 97.90%.

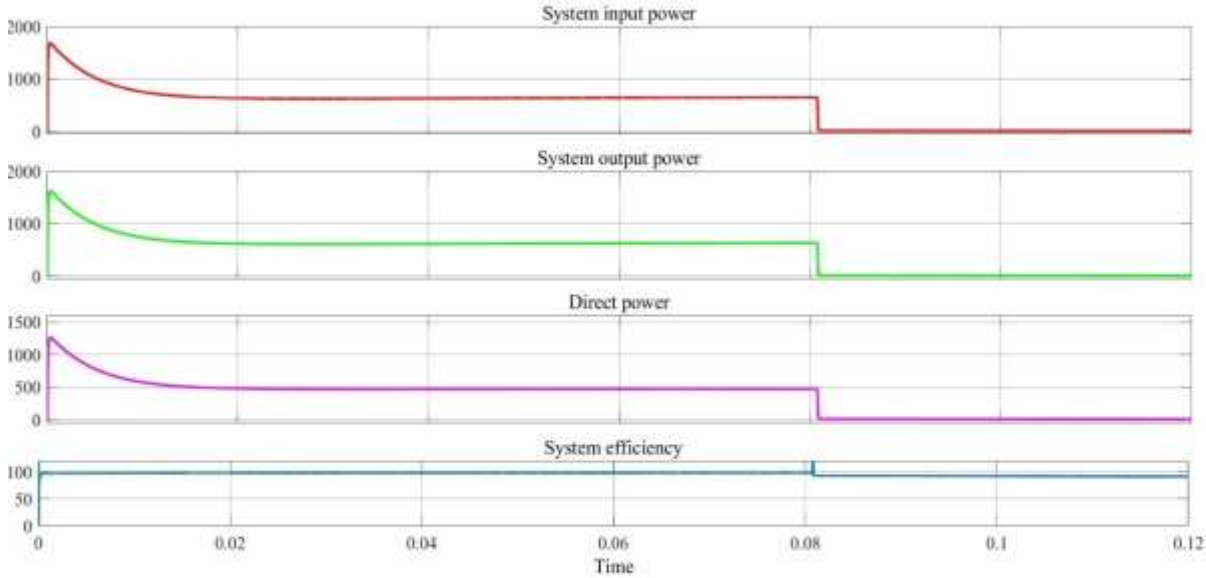

Fig.7 System powers, direct path power, and system efficiency

V. Conclusion and References

5.1. Conclusion

In this work, a PSFB-based partial power processing converter model and 60 V, 12.5 Ah battery model is developed for EV battery charging applications through MATLAB Simulink environment. This proposed system's converter is operated through single phase-shift scheme. The charging mode of the battery is controlled through CC until the SOC reaches to 80% and after 80% SOC it is controlled through CV mode. In this work, at different battery currents, voltages, and input voltages the converter efficiency, system efficiency, and fraction of power supplied by the converter are tabulated.

When battery current is 10 A, the output power of the converter ranges from 50 W to 280 W and output power of the system ranges from 480 W to 760 W.

By changing the battery current, output power range of the converter can be increased and battery charging time decreases.

The proposed system is analyzed mathematically and implemented and validated in MATLAB Simulink environment.

The conclusion is that as the converter is going to process a small amount of power the losses will be less and the overall system efficiency increases.

5.2. Future Scope

- Renewable energy sources can be use in the supply side.
- Instead of employing a PI controller with any advanced AI controllers, including fuzzy, ANN, hybrid, deep learning, and machine learning, in the suggested system cc/cv control technique, we employed a PI controller.

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