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Development and Performance Examination of Switch Mode Power Supply based Battery Charger for Electric Vehicle.

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Abstract

Objectives: The study's primary goal is to investigate a Switch Mode Power Supply (SMPS)-based battery charger for electric vehicles (EV) and compare the use of various charging techniques. **Methods:** This study provides ideas for the requirements of an SMPS-based battery charger; design and development of the charger; and operation of the charger with different charging techniques. Further, the development of the proposed charger, its testing and performance examination are carried out. This study also gives details about circuit components; circuit selection criteria of an SMPS-based battery charger; charging methods; and technical specifications of the charger. Verification and testing of the proposed charger is also done with the help of a 24 V battery. **Findings:** It is found that the proposed battery charger can be more advantageous than conventional battery chargers in a variety of ways, including improved efficiency (nearly 88%), light weight, better protection (reverse battery connection, short circuit, overload), and reliable operation (no need to monitor, automatic cut off, and so on). **Novelty:** Work was done for the development of an SMPS-based battery charger to eliminate existing issues as mentioned in the findings with traditional charger systems. The proposed charger helps to eliminate the sulfation effect on lead acid batteries to improve battery life (50–100 cycles). It helps to not only promote the ”Made in India” scheme but also mass adoption of electric vehicles.

Keywords: SMPS based charging system; microcontroller; IGBT; sulfation; lead acid battery

1 Introduction

Lately, there is a rapid increase in large scale adoption of electric vehicles due to adverse environmental hazards and health issues [1]. EV's possess various advantages like less pollution, eco-friendly, high efficiency, low maintenance etc. Also considering the exponential rise of oil prices across the globe, there is a need to find an alternative solution to the existing internal combustion engine transportation system[2]. Regional and international policies like National Action Plan on Climate Change (NAPCC), Paris Climate Accords etc. are further promoting the wide acceptance of EV's. Currently, the batteries used for EV's are Lithium-ion (Li-ion) battery, Lithium-Titanate Oxide (LTO), Lithium polymer batteries which exhibit high energy density with respect to its weight[3]. Further types of rechargeable batteries are Lead acid battery, Nickel-Metal Hydride batteries, Nickel cadmium, etc. Amongst these, the two popular types are Li-ion battery and lead acid battery as they are advantageous in many aspects like fast charge-discharge operation, constant power, low-cost, high-energy density, high life etc.[4]. Currently, chargers which are used for battery charging purpose are conventional charger which uses iron core-based transformer. SMPS based charging technique is an alternative, efficient and reliable solution for existing system (flaws in conventional chargers such as more losses result in low efficiency, higher weight, non-reliable, non-availability of monitoring system etc.). As it has major advantages such as high efficiency, low charging losses, less weight, ease in handling, portable, suitable for fast charging, better protection, and recognition system etc.[5].

But still SMPS based charging system has got disadvantage like complex electronics technology. Detailed investigation of SMPS based charging system and performance analysis is carried out and research gap is identified in this paper.

This paper is arranged in following way: Section 2 Methodology sub sequent discusses about design and development of proposed battery charger system, gives idea about charger operation and charging technique**,** Section 3 focuses on testing and performance analysis followed by Section 4 which includes conclusion and future scope.

- **Requirement of SMPS based charge r**

A. SMPS based chargers are highly efficient compared to conventional charger which uses iron core-based transformer technique[6]. Efficiency of proposed SMPS based charger shall be between 85-90 %.

B. Portability of charger – Battery charger should be a portable device as it provides easy operation for user. Weight of charger should be 4-5 kg. They have comparatively less weight compared to conventional chargers which are bulky in weight due to iron core-based transformer.

C. Monitor of charging is not needed for SMPS based battery charger. It follows pre-defined pattern for charging. Thus, it becomes easy for user to monitor the operation.

D. Suitability for charging of deep discharged battery – In deep discharged battery, sulphur gets collected on the plate. This sulphur can be removed from plate with the help of high frequency current pulses. This feature is absent in conventional charger due to unavailability of high frequency power[7].

E. Protection system for charger – Over current and short circuit are major cause for failure of charger. This problem can be avoided with micro-controller and protection circuitry. Also, reverse battery connection can be avoided.

F. Currently conventional charger is high in cost. Also, India is dependent on other countries for good charger thus implementation of proposed SMPS charger system will promote "MAKE IN INDIA" initiative.

2 2. Methodology

2.1. Design of Charger

Working of SMPS : SMPS operate using high frequency switches, these switches can be MOSFET/IGBT. Basic requirement of high frequency is to reduce the transformer core area and further to increase the overall efficiency[8]. Other advantages of use of SMPS are such as control over circuits result in fast control in charger and can avoid the failure of charger, by using of micro-controller, system become flexible for operation and no major changes to be done in circuity for modification. Design and development consist of selection of components, circuits as per requirement with development of PCB and assembly of charger. Block diagram of charger is given in Figure 1 Proposed battery charger specifications are given in Table 1 .

A. Input power
B. Filter – rectifier.
C. IGBT with gate driver.
D. Step down transformer.
E. Rectifier and filter with combination.
F. Micro-controller.
G. Feedback.
Detailed Sub section of charger is described as follows.

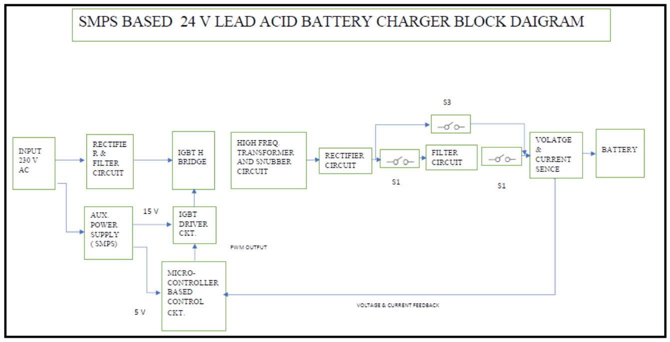

Fig 1. Battery charger block Diagram

Table 1. Specification of proposed battery charger

Parameter		**Range**
Output voltage	Voltage	18 – 28.8 volt
	Current	10 to 50 A
	Power	1440 Watt
	Ripple	< 2 %
	Load Regulation	< 2.5 %
	Voltage	230 V +- 10 %
Input Voltage AC	Frequency	50 Hz
	1Ph / 3 Ph	1 Phase
	Short circuit Protection	110 % of rated current
Protection	Overload Protection	105 % of selected range
	Reverse Battery Detection	Yes. with Micro-controller.
Efficiency	-	88 % app.
Deep Discharge charging	-	Yes, With high frequency pulse.
System switching frequency	-	20 kHz
Indication	-	LED Display

2.1.1 Power source

As battery charger is passive device, power source is required for operation of charger. Availability of power source should be high. Required power supply capacity calculation is given below. 1 phase AC supply is easily available and capable to deliver power up to 4 kW which is less than power charger requirement.

Total power requirement for charger (watts)

$= (Max.\ charging\ voltage * Max.\ current * Efficiency)$

$$= 28.8V * 50A * 0.90 \ = 1600\ watts$$

2.1.2 Line filtering and Rectification circuit

Line filtering**:** To avoid and protect charger system from grid noise, spikes, etc. line filtering is required[9]. Filtering circuit consists of spike arrestor MOV (Metal Oxide Varistor) and pie (π) filter (capacitor – inductor – capacitor) which is called low pass filter.

Rectification circuit: This circuit is needed to rectify the 1 phase AC power source to required DC source. It consists of 2 steps:

A. Rectification which converts pure sine wave into pulsating DC.

B. Further this rectified DC is filtered with help of filter capacitor.

*2.1.3. **Auxiliary Power Supply***

Auxiliary power supply is essential for working of charger system. System requires following ratings of supply:

1. 5 Volts DC for micro-controller and sensors (voltage and current sensor)
2. 15.5 Volts for IGBT gate drive.
3. 12 Volts for system protection devices.

2.1.4. ***High frequency switching circuit***

High frequency power is used to reduce transformer area, losses and weight of transformer[10]. To meet this requirement, rectified DC power is given to high frequency switching devices to generate the high frequency power at 20 KHz. Another major reason for selection of high frequency switching devices is that it is fast in operation and easy to control with gate drive[11]. Further, this control feature is used to control power of system (current and voltage).

Topology used for formation of IGBT is H bridge due to high efficiency.

System parameter used for selection of IGBT:

1. Operating frequency of system – 20 kHz
2. Rated voltage 600 V which is more than operating voltage (325 V DC peak)
3. Rated current 40 A which is more than operating current (6.5 A).
4. Less turn ON losses
5. Robust in operation.

Snubber circuits are used for protection of IGBT during switching operation.

Gate driver: Gate driver is also equally important for design of charger. Micro-controller cannot directly control IGBT due to its low voltage pulses and low sink current. To turn ON and OFF IGBT, 15-volt pulse is required, and isolation is also equally required between micro-controller and IGBT. These pulses are generated with two steps:

1. First step: Gate driver IC (coverts 5 volts wave form to 15 Volts).
2. Second step: Make gate pluses suitable for H-bridge.

In first step micro controller output is given to IC. This IC converts into 15-volt pulses. In second step these pulses are converted to four gate waves for H-bridge operation.

2.1.5 Ferrite core step down transformer

Transformer which is ferrite core type is used to step down the potential level from 230 to 30 Volts. IGBT generated power is in pulsating square form which is suitable for transformer operation. Selection criteria for ferrite core transformer is:

1. Magnetic permeability is higher in ferrite cores.
2. Degree of magnetization is very high
3. Eddy current losses are less.
4. Low switching losses.
5. Core area required is less.
6. Suitable for high frequency.

Transformer's primary winding is helical winding. Centre tap winding construction is used for secondary due to high current requirement[12].

2.1.6. ***High frequency (HF) Rectifier and Filter circuit.***

2.1.6.1. **Rectifier circuit** . Output voltage of transformer is fed to rectifier and filter circuit for rectification and filter purpose because battery requires DC power for charging. DC power should have low ripple in output. For rectifying operation, high frequency diodes are used. Diode requirements are given below:

1. It shall be suitable for high frequency
2. It shall have ultrafast recovery and low recovery losses.
3. Surge current capacity shall be high.
4. Leakage current shall be low.

To fulfil this requirement D92-D diodes are selected. It is suitable for 200 Volt DC, Current rating is 28 A of each diode (two such pairs are used). Along with that, to protect the system from reverse energy surge freewheeling diodes are used.

2.1.6.2 Filter Circuit. Further this rectified power is provided to filter circuit for filtering purpose. LC type filter is used for this operation which results in very low ripple in output voltage. Advantages of LC filter are such as:

1. Very low ripple factor.
2. Using inductor, direct loading on circuit component is less.
3. Very good for load regulation

2.1.7. ***Sensing circuit (Voltage and Current)***

Close looped system is appropriate solution for better operation. To meet this requirement, voltage and current sensors are used which helps for control of overall operation of charger and monitoring of charging parameters. Sensors give feedback to micro controller. Accuracy of sensor shall be high and this shall be isolated from main supply as micro-controller is sensitive for high voltage and noise.

These sensors are passive so auxiliary power is required for operation. Resistor divider with opto-coupler is used for voltage sensor. Hall effect sensor (WCS1500) is used for current sensor.

2.1.8 Relay control and Operation circuit

For control and operation purpose relays are used. Relays are controlled by micro-controller, but they cannot directly be controlled by micro-controller due to less sink capacity. For this, amplification of signal shall be used. In this system three relays are used, two for CC/CV and protection purpose and one for pulse charging purpose.

Relay details are given below:

Relay one: Operating voltage 12 V DC. Contact rating 60 A

Relay two: Operating voltage 12 V DC. Contact rating 15 A

2.1.9 Protection system

Protection system is very necessary for charger. Faults occur in system due to improper connection of battery, failure of cooling system, over loading of charger etc[13]. To avoid or reduce damages in charger step wise protections are provided

1. To avoid reverse battery connection: Reverse battery protection is provided.
2. To avoid the over loading / short circuit: short circuit protection is provided with micro-controller logic.
3. MCB is used to control the power and turn off system under faulty condition.

2.1.10. ***Micro-Controller.***

Overall control, operation, monitoring, protection, etc. of charger is carried out by micro-controller. ARM core (32 bits Cortex M451 family M453LE6AE is used for this system. This controller is selected due to[14]:

1. Speed of controller is high
2. Very low power consumption.
3. Availability of controller in the market.
4. Suitable for generating the dual PWM pulse which are required for IGBT.

2.2. Working of Battery Charger with Charging Technique .

In section 3.1 we seen all circuit selection of battery charger. Refer Figure 2 for charger power flow in charger. 3 technics are used for charger.

A. Pulse mode

B. Constant current mode

C. Constant voltage mode

Sequential operation of charging from input to output are described. Power Source for charger is 230 Volt 1 Phase AC power supply which is by an larger available. Input side MCB is used for system control and protection purpose against the internal fault and isolate faulty & health. Which result in avoid major failure in charger & easy to control. This power supply passing from filter circuit for removal of unwanted signal and spikes from power supply. semiconductors are sensitive for spike and abnormal signal. 230 Volts supply is rectified and filtered using filter and rectifier circuit which converts AC to DC supply by using of H bride rectifier diode & ripple in power supply reduce by filter circuit. Principally reduce core area of transformer operating frequency of system need to increase. To generate the DC square wave at high frequency (20KHz) H-bridge IGBT's are used. Relatively IGBT driver circuit is used to drive IGBT as gate driver controls the IGBT firring angle. For IGBT protection purpose, snubber circuit is adopted. Generated square wave needs to further step down to get desired low volt DC supply, for this purpose ferrite core transformer is used which converts 230 Volt to 30 Volt.

Output of transformer can not use for all mode of charger therefor 30 V square wave power needs to be rectified and filtered for battery charging purpose. For that rectifier and filter circuit is developed. Charger is also design for pulse charging. To achieve this mode bypass relay is used which can provide the DC pulses to battery for pulse charging without filtering of DC power. Another set of relays are used for protection against reverse battery and abnormal condition. For proper operation, voltage and current sensors are used which gives output voltage and current feedback to micro-controller. To set the voltage

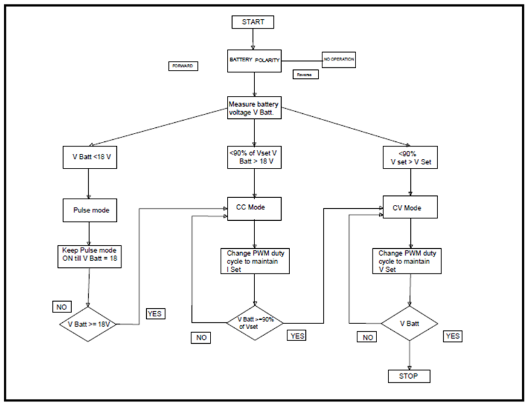

Fig 2. Flow diagram of charger

and current parameter according to battery sizes variable resistors are provided which scales from 26-30 Volts and 5 to 50 A. For mode selection of charger, protection system and output display are controlled by the micro-controller[15].

Safety function of charger are as below –

A. MCB are used for short circuit protection & easy operation.

B. Against the floating voltage & leakage current filter circuit are used.

C. Reverse battery connection – Inappropriate use of charger by operator many of cases. It seen that during connection of battery charger operate fuse for connection and it connect the wrong lead to battery terminal. Due to this diode used for rectifier start conducting at terminal get short by internal circuit. Result in failure of battery charger to avoid this conduction reverse battery protection adopted. Until charger does not sense healthy battery voltage it will not allow to start the charging operation.

D. Use LED for human interference – Indication is min. requirement of charger. Charger consist of indication are such as all mode indication, reverse battery connection. Short circuit indication. Etc.

Following method for charging used in charger.

A. Pulse mode

Major problem in lead acid battery is deep discharger due to sulfation on battery. After multiple times of battery use, sulphur gets accumulated on battery electrode (plate). This sulphur can be removed by applying high frequency current pulse on the battery. This method can remove placed sulphur from plate and improves chemical reaction in battery with enhance of battery life[16].

Pulse mode or deep-discharge mode is simple solution for reduce sulfation effect in battery. In this mode current pulses (unfiltered) are applied to battery with time slot. Magnitude of these pulses are settable as per requirement (battery capacity). PWM of gate wave form are constant for set period . In this mode, filter circuit at 30 Volt is bypassed with help of relay and rectified pulsating DC supply is provided to battery for charging. when battery is at deep discharged mode that time voltage of battery is below 18 volts so cut point for pulse mode set below 18 volts.

B. Constant current mode

For healthy battery Constant current charging preferred. In this mode constant flittered current (min ripple) is used for charging. Filtered DC power is supplied to battery till battery reaches to 90% of V set. In industry battery are available with various Ah range to full fill the requirement wide range of set point are given in charger. Current range for charging is settable from 5 to 50 A. as per battery capacity. In this mode main relay (S1) contacts are close and are providing continuous current to battery for charging.

C. Constant Voltage Mode

With constant current battery cannot charge charging rate need to reduce. Once battery reaches to 90% of V set then constant voltage mode take place, this is uninterrupted process of charging. Rate of charging is slow in this mode. In this mode, constant voltage is provided to battery for charging purpose. Once this battery voltage reaches to V set/ V max, system automatically reduces PWM and further stops charging operation. Battery has itself discharge capacity. Once it become below 95 % and of V set, again trickle charging takes place, and it maintains the battery charging. Battery sense voltage and charging mode given in Table 2.

Table 2. Battery voltage and mode of charging

Battery Voltage	Mode of Charging
Less than 18 V	Pulse method
18 V to 90 % of V set	CC
90% V set to V set	CV

2.3 Development of charger

Selection of charger component and circuit selection is seen in Section 2 along with part assembly of circuits, operation and charging method are discussed in Section 3. Assembled battery charger is shown in Figure 3 .

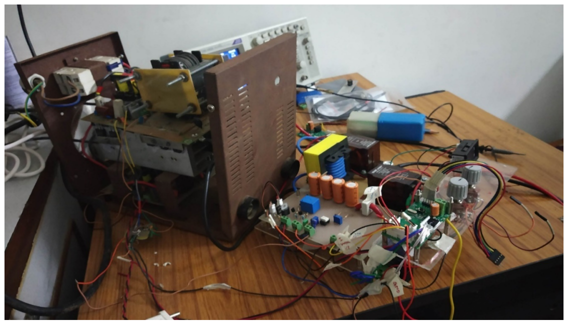

Fig 3. Assembled Battery Charger photograph.

3 Result of charger and Examination Check

To ensure the result of charger, testing on charger need to carry out, following tests are conducted on charger

3.1 Operation check/verification of charger mode

In this check, all three modes of charger will be verified as per charging method as specified in working.

1. Pulse mode: Pulse mode will be active once battery voltage senses below 18 V. seen that when battery voltage is below the 18-volt charger activates the pulse mode. Sample current waveform of charger is shown in Figure 4 . Charger will not give continuous current pulses. It will be sampling based with time delay.

2. Constant current – It observed that if battery voltage is above the 18-volt charger operate in constant current mode and this mode active till battery voltage reach to 90 % of V set/max.

3. Constant voltage mode: This mode has shall be active one's battery voltage above 90 of V set/max.it observe that CV mode activated once battery voltage senses above 90% of set voltage.

Trickle mode – Battery has self-discharger capability, when battery connected to charge & battery get full charge. When battery voltage sense voltage below 95 % of V max again battery charger start trickle mode.

All modes of charger are verified, and they all operate as per requirement. Pulse mode is commonly not available in all chargers as conventional charger does not have facility to generate the high frequency.

4. Verification of reverse battery connection – Ideally charger + & - terminal shall be connected to + & - battery. For verification purpose terminals swapped and seen that no operation by charger and LED indication glow.

5. Verification of short circuit protection - Output terminal of charger shorted to ensure the short circuit protection. It has seen that no operation by charger and short circuit LED indication glow.

3.2. Verification output of voltage and current test

In this test, voltage and current output of charger was measured during charging condition with respect to set voltage and current. Test results are mentioned in Table 3.

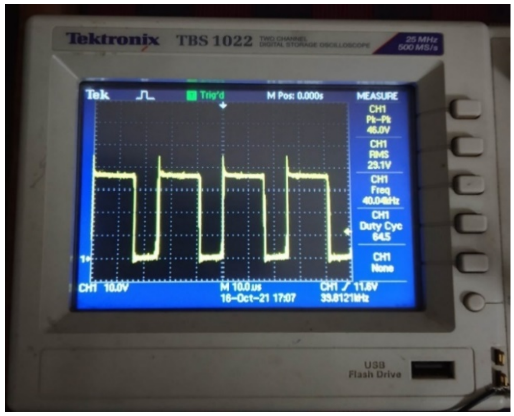

Fig 4. Current Wave Form

Table 3. Test result of output parameters.

Sl. no.	Voltage		Current	
	Set Voltage	Measure voltage	Set current	Measure current
1	24	23.8	5	5.1
2	24.5	24.3	10	10.1
3	25.5	25.5	15	15.1
4	26.	26.5	20	20.5

3.3. Ripple check of charger

Ripple test is conducted during battery charging condition. Peak to peak voltage measurement is carried out. Test results are shown in Figure 5.

Peak to Peak voltage during charging condition is 600 mV.

$\%\ Ripple = peak\ to\ peak\ voltage\ /\ Avg\ voltage * 100$

$$= 0.600/25.3 * 100 \; = \; 2.3\,\%$$

It is seen that % ripple is slightly higher than calculated ripple.

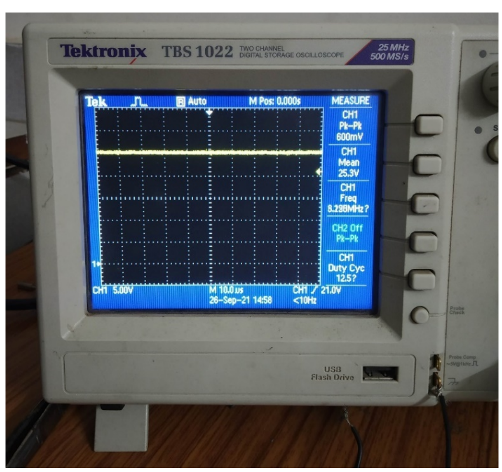

Fig 5. Charger Voltage Wave Form

3.4. Efficiency of charger

Efficiency of charger shall be higher. In this test, input power and output power are measured during different charging condition. Test result of efficiency is shown in Table 4 and some test results are given in Figure 6 [17].

$$\%\ Efficiency = OutputPower\ /\ Input\ Power * 100$$

Table 4. Test report of Efficiency

Sl. no.	Output Power (Voltage * current) in watts	Input Power (voltage *current * power factor) in watts	% Efficiency
1	119	134.8	88.27
2	245.43	279.8	87.74
3	385.05	431.4	89.25
4	539.72	607.8	88.79

It is seen that % efficiency of charges is as desired. Efficiency of conventional charger is around 70 % which is less then developed charger.

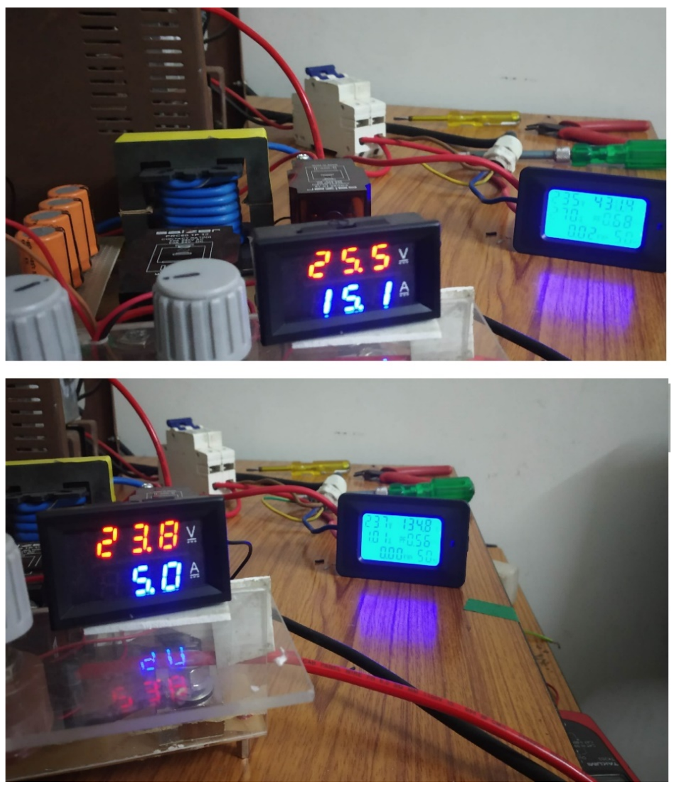

Fig 6. Test results.

3.5. Performance Examination

In performance check, battery charger is used for different battery rating (Ah) for charging purpose. Charger is tested with its max rating, no major temp. rise found in charger component (IGBT, Transformer, Diode, etc.). Through this heat run of charger is also carried out and battery successfully got charged. Input power and output power graphs for different rating are given in Figure 7 . For reliability check purpose charger is kept in operational condition.

Complex technology for SMSP battery charger developed. Preparation of printed circuit board, assembly of charger is also executed. Disadvantages of conventional charger like less efficiency, high in weight, required monitoring for charging, etc. are eliminated by making use of SMPS battery charger. sulfation is major problem of lead acid battery. This sulfation effect is reduced by SMPS charger system.

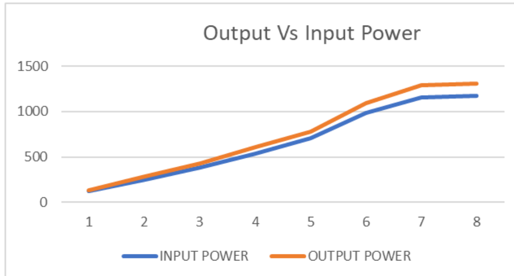

Fig 7. Output power and input power

4 Conclusions

Developmental process of charger is carried out. and performance examination of this proposed battery charger is also executed with help of 24 Volt lead acid battery. This proposed system has advantages over traditional charger like improvement in efficiency, better protection. light in weight, easy to operate etc. Major challenge for use of lead acid battery is sulfation which can be resolved using pulse charging method, thus life of battery can be improved. It is found that efficiency of charger is more than 89 % for different charging capacity, weight of charger is near to 4 kg thus charger is portable. Display & indicating LED help user to understand the mode of charger, system healthiness and charging current & voltage. Charger is tested for different abnormalities like reverse battery connection, output terminal dead short, charger different mode, etc. charger operates as per specified condition. Charger is capable for various rating of batteries. This proposed battery charger is system suitable for 24 Volts lead acid batteries. System is simpler by use of microcontroller new input can added and enhance the operation of charger. Now day vehicle batteries are available in 48 V. With minor charge in charger, charger will be suitable for charger the 48 Volt battery i.e., transformer ratio feedback circuit. By Changing philosophy charger can charge the li-ion battery as well. As controller have a capability to charge the program easily. Change in operating frequency to 40 kHz, which can result in improvement in sulfation effect & efficiency for charger. To enhance the charging of battery (reduce charging time) temperature-based control can be archive. Algorithm can develop in micro-controller. It helps to not only promote "MAKE IN INDIA" scheme but also mass adoption of electric vehicles.

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