

Optimum charging scheme of Electric Vehicle (EV) battery

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Abstract –Tubular plate lead acid deep cycle batteries are becoming more and more popular in Bangladesh to run electrical vehicles. A China made low cost charger is commonly used to charge these batteries which takes approximately 10 hours to full charge. In this paper, comparative results of charging EV tubular battery using conventional charger as well as Universal Battery Tester (UBT) have been reported. Total 8 different types of charging methods have been tested and different parameters like temperature rise, change of specific gravity of the electrolyte in the battery, variation of voltage and current, stored Ampere-Hour etc. have been observed. Thereby a comparatively quick charging method has been proposed which can ensure less temperature rise and therefore better efficiency and longer battery life.

Keywords – *Electrical Vehicle, Charging, Tubular Battery, Specific Gravity, Ampere-Hour, Tubular Plate.*

I. INTRODUCTION

Electrical vehicles are becoming more and more popular day by day and it is expected that a big percentage of the petroleum based cars will be replaced from the road by electrical vehicles by the year of 2030 [1]. Petroleum cars are responsible for carbon-di-oxide emission, temperature rise of the environment as well as sound pollution. Electrical vehicles are free from such objections. However, the major drawback of electrical vehicles is long recharging (refueling) time. While petroleum cars can be refueled within a few minutes, electrical vehicles require 8 to 10 hours for recharging [2]. This issue made electrical vehicles unfit and less popular for long distance travel.

Usually most electrical vehicles in Bangladesh use lead-acid deep cycle batteries of different capacity ratings from different manufacturers [3]. High temperature rise is observed when these batteries are forced charged to reduce the charging time. Temperature rise is harmful for batteries; it affects the ampere-hour capacity, responsible for low efficiency and ultimately reduces battery life [4, 5, 6].

Different attempts have been made to reduce the charging time of batteries which are being used to run electrical vehicles to

make them suitable for long distance travel [7].

New battery technologies have been proposed which can be charged within very short time (as low as 10 to 15 minutes) and can supply energy for longer period (several hours), thus are suitable for long distance travel [8]. However such battery technologies are comparatively costly (because of new technology and less commercial production) and need special charging stations as well [8, 9].

In Bangladesh mostly tubular plate Lead-acid batteries are used for EV operation. One such popular model is EV140AH [3,10]. The voltage ratings of these batteries are 12V. An inverter converts DC 48 - 60V energy (depending on EV size) into 220V AC. A motor is used to run most of the electrical vehicles using this AC energy [11]. Therefore total 4 - 5 numbers of such batteries are connected in series and charged by a 48 - 60V charger (Charging voltage should be a bit higher to allow current to flow while charging) [11]. In this research two different chargers, one is Chinese made 30A charger (called as ‘Local Charger’ afterwards in this paper) and another is a standard Universal Battery charger (called as ‘UBT’ afterwards in this paper) have been used to charge EV140AH batteries. Different charging methods have been tested on same samples of batteries. After each charge/test, the batteries were discharged through C20 rate [6] to make them ready for next charge/test.

II. SPECIFICATION OF BATTERY AND CHARGER

The specifications of the battery used for testing in this research are given in Table 1 below. It is a deep cycle low maintenance lead-acid battery designed to be regularly deeply discharged to utilize most of its capacity. Low maintenance batteries can be refilled with distilled water [12] only (water without any minerals) when acid level goes down below the level marked as “LOWER LEVEL” on the container.

TABLE 1. SPECIFICATIONS OF EV140AH BATTERY UNDER TEST

Parameter	Type	Remarks
Brand and country	S FORCE	Saif Powertec Battery Limited, Bangladesh.
Battery Type	Deep Cycle Battery	Low Maintenance lead-acid Battery
Positive Plate	Tubular Sulphated Plate	20 numbers of tube on each positive plate, 4 numbers of plate per cell
Negative Plate	Green pasted plate	Rectilinear Flat Grid plate, 5 numbers of plate per cell
Numbers of cell in one battery		6 cells
Grid Alloy	Lead	Mixed with 2.5% antimonial grid

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Separator Types [13]	PE Sleeve Type	60% porosity
Container [14]	EV	Weight is 1.645 kg
Specific gravity of acid	1.280 – 1.295 when fully charged	1.050 when fully discharged.
Volume of acid per cell	1290 ml	Sulfuric acid
Terminal Voltage	12V	
Ampere-Hour rating	140AH	
Weight	24.89 kg (Without acid)	37.28 kg (with acid)

A photograph of the Battery is given below in Fig. 1.



Fig. 1. Photograph of the Battery

The specification of the Local charger used for charging the battery is given in Table 2 below.

TABLE 2. SPECIFICATIONS OF 'LOCAL CHARGER'

Brand and country	Ningbo Dowedo International Co., Ltd., China
Input	220V, 50Hz, ac
Output Charging Voltage	60 Volts, DC
Charging mode	Constant voltage
Maximum Charging Current	30Amperes
Voltage rating of each battery	12 Volts
Number of batteries can be connected in series at a time	5 Nos.
Maximum Charging Current	30Amperes
Min Charging Current	0 Amps

A photograph of the Local charger is given below in Fig. 2.



Fig. 2. : Photograph of the Local charger

The specification of the UBT charger used for charging the battery is given in Table 3 below.

TABLE 3. : SPECIFICATIONS OF UNIVERSAL BATTERY TESTER

Brand and country	Digatron, Germany.
Software	BTS600
Input	400V, 3 phase, 50/60Hz
Maximum Output (Charging) Voltage	18 Volts
Charging mode	Constant voltage, constant current, constant power.
Voltage rating of each battery	12 Volts
Number of charging circuits at same time	10 no.
Maximum Charging Current	100Amperes
Min Charging Current	0.5 Amps

A photograph of universal battery tester is given below in Fig. 3



Fig. 3. : Photograph of the Universal Battery tester

III. CHARGING AND DISCHARGING METHODS

The battery is tested through different charging methods as listed in Table 4 below.

TABLE 4. : LIST OF TESTS CONDUCTED ON THE BATTERY

Test No.	Type
1	Charging battery with local charger, both the voltage and currents are variable
2	Constant current charging at 14A.
3	Constant voltage charging at 14.8V, maximum current is limited to 100A.
4	Constant current charging at 21A.
5	Constant voltage charging at 14.8V, maximum current is limited to 28A.
6	Charging with 90A pulse current.
7	Charging with 28A pulse current.
8	Charging with 40A pulse current.

Test no. 1 is done using the local charger, having the output charging voltage of 60V. Therefore 5 numbers of identical batteries of same ratings have been connected in series across the charger. All other tests (test no.2 to test no. 8) were done using the UBT having maximum output charging voltage of

18V, which can be adjusted to different desired voltages through the built-in software. Therefore a single battery, chosen randomly from the row of the batteries used in test 1, is connected across the charger.

Indication of full charge: The indication of full charge of the battery can be ascertained through following measurements, (i) Measurement of specific gravity of the acid in the battery, (ii) Measurement of the terminal voltage and (iii) Measurement of charging current. Battery is full charged if the specific gravity rises to 1.270 [15]. Terminal voltage and current parameters were measured in parallel by BTS600 software (Table 3) and Specific Gravity measured manually in every hour. During constant current charging, the terminal voltage of the battery rises slowly, reaches to a maximum, then remains constant or shows a declination. If the voltage reading remains same for three consecutive measurements or a small declination is observed, the battery is fully charged. On the other hand, in constant voltage charging method, initially the charging current is too high, and then it slowly decreases and finally becomes almost constant when the battery is fully charged [5]. The battery is disconnected from the charger if any of the above indications are observed. The temperature rise of the battery is also monitored and the battery is disconnected for protection if excessive heating is observed. A rise of 50⁰ C is the allowable limit [4,5,6].

Pulse current charging: There are different methods of charging a battery. Constant voltage and constant current charging are very popular and commonly used. In this research pulse current charging has been tested along with constant voltage and constant current charge. A current of a constant magnitude is allowed to flow through the battery for a short period, say for 60 seconds. Then the battery is left at rest for few second. After that the battery is connected to a load to discharge for a short period, thus a negative current pulse is applied. Thereby a Charge-Pause-Discharge cycle is formed which is repeated till the battery is fully charged. The technique is explained in the following Fig. 4. The magnitude and time period of the charging pulse is selected to different values as obtained from standards [6, 16], whereas the magnitude of discharging current is taken 10% to that of charging pulse. The different pulse current charging cycle, as applied in this research, are given in Tables 5, 6 and 7 below.

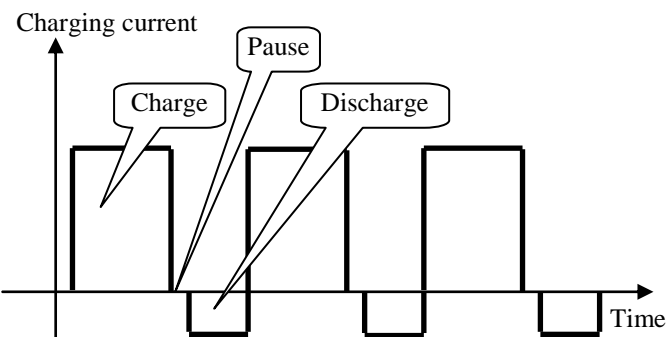


Fig. 4. : Sequence of pulse current charging.

TABLE 5. : 90A PULSE CURRENT CHARGING CYCLE

Program	Current	Time	Ampere-hour
Charge	90A	60 seconds	1.503
Pause	0 Amperes	5 seconds	0
Discharge	9A	10 seconds	-0.025
Total Ampere-hour absorbed			1.498

TABLE 6. : 28A PULSE CURRENT CHARGING CYCLE

Program	Current	Time	Ampere-hour
Charge	28A	60 seconds	0.467
Pause	0 Amperes	5 seconds	0
Discharge	2.8A	10 seconds	-7.78x10 ⁻⁰³
Total Ampere-hour absorbed			0.459

TABLE 7. 40A PULSE CURRENT CHARGING CYCLE

Program	Current	Time	Ampere-hour
Charge	40A	60 seconds	0.668
Pause	0 Amperes	5 seconds	0
Discharge	4A	10 seconds	-0.0033
Total Ampere-hour absorbed			0.6647

Discharging: After each charging test, the battery is discharged at a discharging rate of @C20 [6], a period of 20 hours. UBT discharges the battery by 7A current for continuously 20hours. Then the next test is started. To avoid deep discharge [5], the terminal voltage of the battery is monitored. The battery is disconnected from the load if the terminal voltage goes below 10.5V while discharging.

IV. TEST RESULTS

The results of different tests have been described in the following sections. The parameters measured during the tests are (i) terminal voltage, (ii) charging current (iii) variation of specific gravity and (iv) temperature rise. Test no. 1 was conducted by local charger. From test no. 2 to test no. 8, we have used UBT to complete the tests.

A. Test result of test no. 1

During this test the variation of terminal voltage and charging current with time is shown in Fig.5. It is observed that the terminal voltage does not remain constant during test, rather it increases slowly. The initial current starts from 17A and falls gradually to 7A. The voltage rise in all the 5 batteries (which are connected in series) is almost similar. Although the local charger marked as 30A, it is found during the test it can supply maximum 17A. It is evident from the graph that it took almost 10 hours to full charge of the batteries.

B. Test result of test no. 2

It is a constant current test. The observed results are shown in Fig. 6 below. The Charging current is kept constant at 14A. The terminal voltage is found to increase gradually till full charge. In this test also it is evident from the graph that it took almost 10 - 13 hours to full charge of the battery.

C. Test result of test no. 3

It is a constant voltage charging procedure. While keeping voltage constant at 14.8V, the variation of current is observed. A current of 100A was the maximum charging limit. The obtained result is shown in Fig. 7 below. At beginning the charging current has been 100A. However the current dropped sharply and began to saturate till full charge is obtained. A charging time of 6 – 8 hours is required in this case.

D. Test result of test no. 4

It is a constant current test. In this test a constant current of 21A is being supplied while the terminal voltage is allowed to rise. The result is shown in Fig. 8 below. The charging time is found to be 7 - 8 hours. It is interesting to observe that the terminal voltage rises gradually as charging is going on and reaches to a maximum, and then it comes down, indicating full charge. The battery is disconnected immediately from the charger, because high temperature rise is observed at this condition (Table 8).

E. Test result of test no. 5

Again it is a constant voltage charging at 14.8V but the maximum current limit is reduced to 28A (In a previous test it was 100A). The variation of charging current is shown in Fig. 9 below. It is observed that, the battery was charged by 28A current for 4 hours at the beginning. Then the current fell gradually to a saturation value indicating full charge. 80% of charge was completed in 8 hours. Total charging time required is 10 hours.

F. Test result of test no. 6

This is the said pulse current charging test as explained in Fig.4 above. The sequence of Charge-Pause-Discharge has shown in Table 5. The magnitude of charging pulse current is 90A. The variation of terminal voltage is shown in Fig. 10. It is observed that the voltage rises during charging and falls to a lower value while discharging. However the overall voltage rise gradually reaches to a maximum and then starts to fall down, indicating full charge. The battery is charged fully within a comparatively short time of 3 hours, but the temperature rise is excessive, about 91⁰ C.

G. Test result of test no. 7

Again it is the pulse current charging test, but the magnitude of the charging pulse current is set at a reduced value of 28A. In the previous test the charging current was too high which caused increase in battery temperature. Therefore it was decided to charge the battery at a lower current. The sequence of Charge-Pause-Discharge is shown in Table 6. The variation of terminal voltage is shown in Fig. 11. It is observed that the voltage rises in a similar way, as in the previous test and falls to a lower value while discharging. However the overall voltage rises gradually and reaches to a maximum and then starts fall down, indicating full charge. However a charging time 7.5 of hours is observed in this case, which is a bit longer

compared to the previous test. The temperature rise is 54⁰ C only, which is not too high, as expected.

H. Test result of test no. 8

It is a pulse charging process. In the previous test the charging current was too low which causes the temperature rise within safe value. But comparatively longer charging time was required. Therefore it was decided to repeat the same test with an increased value of charging current, set at 40A. Similar variation of voltage is observed here as shown in Fig.12 below. As expected, the charging time required is reduced to 4 hours with a temperature rise of 55⁰ C, which is within acceptable limit.

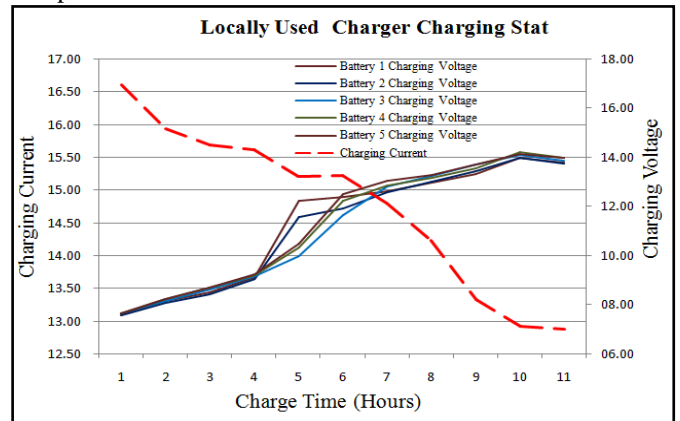


Fig. 5. Variation of voltage and current with time in test no.1

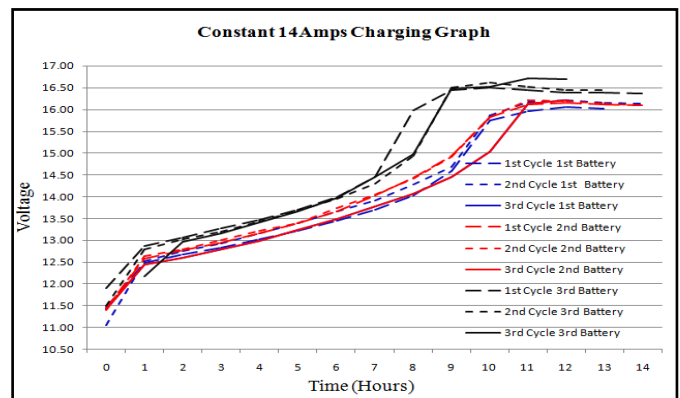


Fig. 6. Variation of voltage with time in test no. 2

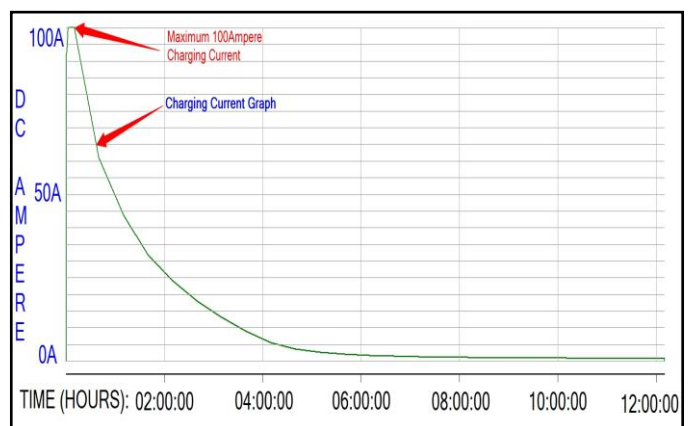


Fig. 7. Variation of current with time in test no.3.

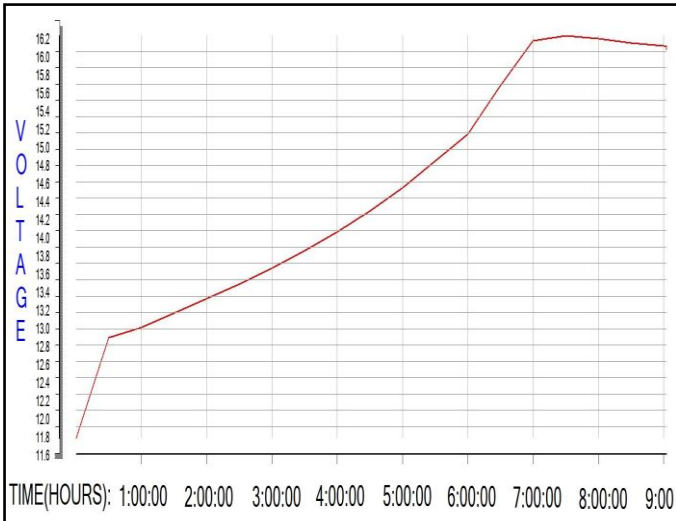


Fig. 8. Variation of voltage with time in test no.4

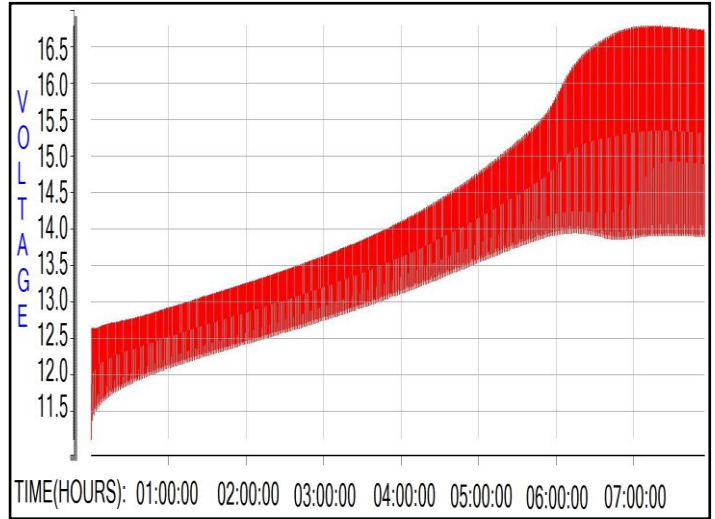


Fig. 11. Variation of voltage with time in test no.7

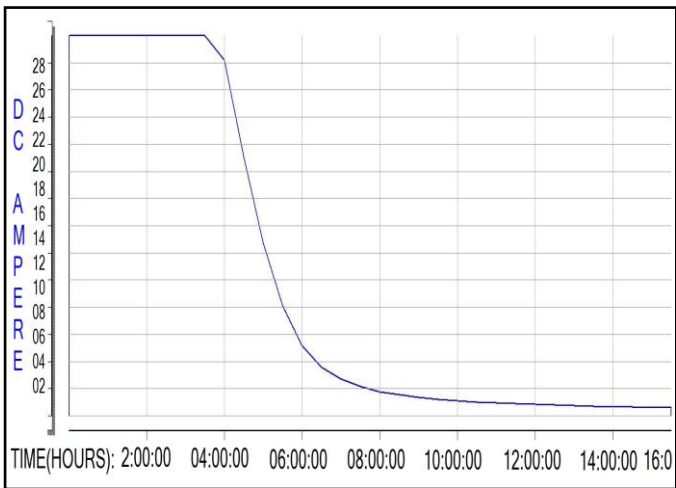


Fig. 9. Variation of current with time in test no.5

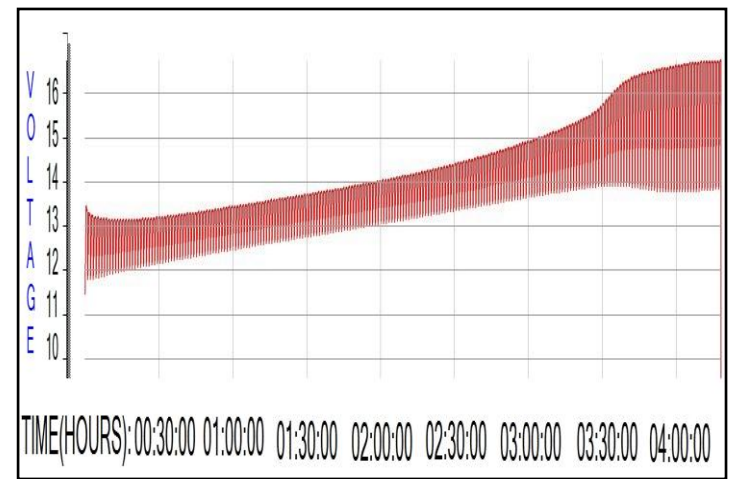


Fig. 12. Variation of voltage with time in test no.8.

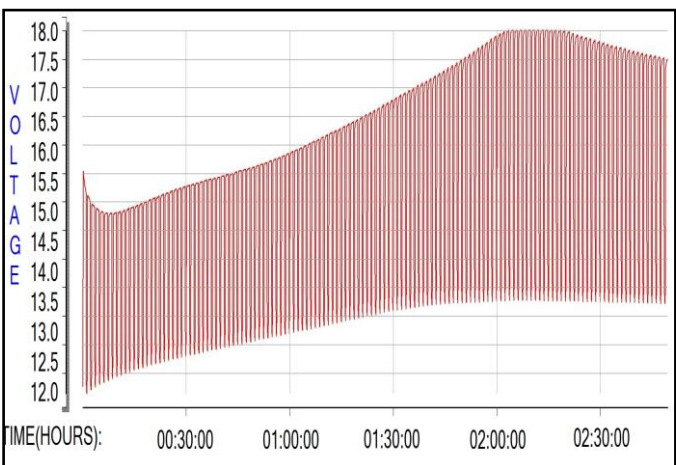


Fig. 10. Variation of voltage with time in test no.6.

V. DISCUSSION

The findings from all the above mentioned tests are summarized in the Table 8 below. It is observed from the table that the maximum charging time is 13 hours with a temperature rise of 44⁰ C. On the other hand the quickest charging is possible within 3 hours but the temperature rise is 91⁰ C, which is too high and harmful for the battery life. As a compromise between these two extreme values, an optimum charging scheme could be found which correspond to test no.8. Therefore Constant voltage charging at 14.8V with a maximum current limit to 100A charging scheme is recommended for moderate charging and Pulse 40A charging scheme is recommended for fast charging for 140AH@C20 battery.

TABLE 8: Summary of all tests

Test No.	1	2	3	4	5	6	7	8
Charging Current in Amperes	Variable	14	Variable	21	Variable	Pulse	Pulse	Pulse
Charging Voltage in Volt	Variable	Variable	14.8	Variable	14.8	Variable	Variable	Variable
Charging AH and Sp. Gr.	(Haven't Calculated) and 1.285 - 1.295	170-180 and 1.275 - 1.285	150-155 and 1.275 - 1.285	155-160 and 1.270 - 1.280	130-150 and 1.275 - 1.270	200 and 1.270	155-175 and 1.250	140-150 and 1.225
Max Amps and Volt.	16.92A and 15.49V	16.71V	100A	16.62V	28A	90A and 18V	28A and 16.5V	40A and 16.5V
Discharge Time(Hours) / Mileage (Km)	120Km with 220Kg load	20Hrs.	19.5Hrs.	Around 20 Hrs.	19.5 Hrs.	20 Hrs.	Around 20 Hrs.	19.25 Hrs.
Charging Time (Hours)	10	12-13	6-8	8-9	9-11	2.5-3	7-8	4
Max Temp °C	53	44	50	55	37	91	54	55

VI. CONCLUSION

Different charging methods have been tested on EV140AH battery to find the most suitable charging scheme. It has been clearly observed from the test results that both the constant voltage and constant current charging require very long charging time of around 10 hours, indicating that overnight charging is needed. Whereas pulse current charging methods require comparatively shorter charging time, ranging from 3 to 6 hours and if the peak value of pulse current reduces, it keeps the charging temperature within range. However very high pulse current charging causes excessive temperature rise of as high as 91°C, which is undesirable. A moderate pulse current of 40A is found to be suitable for the said battery; the temperature rise is 55°C, which is within permissible limit. Only three pulse current, 90A, 40A and 28A, have been tested in this research. Further research can be done by testing with other values of pulse currents. Thereby in the future work, one can find the best suitable pulse charging profile to charge the battery in the shortest possible time without increasing the temperature and affecting the other parameters.

ACKNOWLEDGEMENT

This work is supported by SAIF POWERTEC BATTERY LTD.

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