International Journal of Sustainable and Green Energy
2021; 10(4): 121-128
http://www.sciencepublishinggroup.com/j/ijsge
doi: 10.11648/j.ijrse.20211004.12
ISSN: 2575-2189 (Print); ISSN: 2575-1549 (Online)

Fast Charger for Lead Acid Motive Power Batteries for E-Rickshaw

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To cite this article:

Rajarshi Sen, Harsh Thacker, Anindita Roy, Rupesh Shete, Anil Jadhav, Calvin raj, Mithilesh Sawant, Vinay Patil. Fast Charger for Lead Acid Motive Power Batteries for E-Rickshaw. *International Journal of Sustainable and Green Energy*. Vol. 10, No. 4, 2021, pp. 121-128. doi: 10.11648/j.ijrse.20211004.12

Received: August 9, 2021; **Accepted**: October 5, 2021; **Published**: October 21, 2021

Abstract: Electric 3-wheeler Rickshaws are the most economical among battery powered electric vehicles. They cost INR 1,20,000 (USD 1615) to buy, including the price of a 48V100Ah deep cycle battery @ INR 20,000 (USD 270) and run around 80 KM on a single charge. No wonder there are already 15,00,000 E Rickshaws in India alone. These E-Rickshaws use Lead acid tubular or flat plate batteries, which cost less than half the price of an equivalent Lithium Battery & have a service life of around 600-800 cycles of 80% discharge & recharge if maintained properly. However, with conventional chargers, the Lead Acid Batteries require 6-7 hours for 80% recharge and 10 hours for a full recharge after a discharge of 80% of rated capacity. Faster recharge increases battery temperature, copious gas evolution & reduces its life. This has been a disadvantage for lead acid batteries in EVs. Lithium-Ion battery requires 2 hours for 80% recharge and 3 hours for a full or recharge. The objective of the research work was to try out and develop a charger, which can fast recharge E Rickshaw battery up to 80% of capacity in lesser charging time without increasing battery temperature or gassing, avoiding battery service life reduction. Method of fast charging was to continuously explore the charge acceptance limits of battery and feed it with optimum charging current so as not to increase temperature & gassing. The unique fast charger requires only 3 hours & 30 minutes to recharge the battery to 80% of its capacity, while temperature rises by 3°C to 4°C, less than half of that in normal charging process. In addition, a super-fast "opportunity charge" during one-hour lunchtime, injects 35% energy in 65 minutes, giving E Rickshaws an extra 35 KM run each time. It is proven that service life is same or more. The fast charger prototypes were successfully field tested on 40 vehicles each at Kolkata & Baharampur in West Bengal, India, to the entire satisfaction of the E Rickshaw drivers. It is now in mass production & sales. Lead Acid batteries in E-Rickshaws, E- Bikes, golf carts & electric trucks are discharged and recharged daily or more. A safe & fast charger increases productivity & revenue.

Keywords: Lead Acid Battery Fast Charger, Motive Power Battery Fast Charger, Quick Charge, Opportunity Charge, E-Rickshaw Fast Charger, EV Charging Station, Rapid Charger, Ampere-hour Law

1. Introduction

Lead acid batteries require around 8 to 10 hours for recharging after a full discharge of 80% of their rated capacity, which is the maximum discharge allowed [9]. Any faster recharge drastically increases the battery temperature with copious release of gases, which not only reduces battery life but also can lead to explosion in extreme situation [5].

The unique fast charging system requires only 3 hours & 30 minutes to recharge the battery to 80% of its capacity or alternatively, inject 35% opportunity charge in 1 hour & 5 minutes. The fast charging raises battery temperature only by 3°C to 4°C, less than half of the temperature rise in normal charging process & battery service life is not at all affected [18].

Motive power batteries for E-Rickshaws & E-two wheelers, golf carts, forklifts, tow & platform trucks are discharged and recharged daily and sometimes twice a day. Hence, a faster mode of recharge reduces their idle time, increases productive time & revenue. [7]

The fast charger has primarily been developed for quick & efficient charging of 48V100Ah (4 numbers 12V100Ah @ C20 / 12V90Ah @ C10 lead acid) Electric Rickshaw batteries. These low cost 3 wheelers, providing economical mass transportation, number over 15,00,000 in India alone & constitute 83% of the Indian electric vehicle market [1].

Methods for Battery Charging:

Prevalent procedures for Re Charging of Lead Acid Motive Power / Traction Batteries used in Electric Vehicles and Material Handling Equipment [8].

The current research & development process involves 4 methods of recharging of lead acid traction battery which are “slow”, “boost” and “taper” charging for flooded batteries and “constant current-constant voltage” charging for Gel or VRLA batteries. [13]

1. Slow charging is done at a constant current of 6%-7% of battery capacity in amperes from start to finish and takes around 17 to 18 hours to recharge a fully discharged battery.
2. Boost charging is done initially by a constant current of 12%-13% of rated AH capacity of battery in amperes, also known as starting rate which is reduced to 6%-7% or finishing rate, when battery is 80% charged. It takes approximately 7-8 hours to charge from 0% to 80% S.O.C (state of charge) & 10 hours to fully recharge battery. The diagram below depicts the boost charging current versus voltage profile. [12]
3. Taper charging is started at higher than boost charge current with constant voltage DC supply where the charge current tapers down as the potential difference between the charger and battery decreases. Charging current is stepped down to permissible levels of 7% at 2.35 Volts/Cell and voltage is then allowed to increase to 2.7/2.75 VPC (volts per cell) at reduced current, which also tapers down as the battery voltage increases. Taper charging takes 8 – 9 hours and is faster than boost charge. [6] However, the temperature increase during this type of charge is higher and forced cooling arrangements are made in the battery charging room. The diagram shown above depicts the voltage and current profile during taper charging.
4. CC-CV (Constant Current-Constant Voltage) Charging is used for Gel type of sealed traction/ motive power batteries. [4] A constant charging current is applied to the battery by constantly increasing the applied charging voltage till it reaches 2.35 volts per cell on charge. Then the charging voltage is kept constant and due to the increasing battery voltage, the charging current tapers down to almost NIL when the battery is considered fully charged. The diagram below shows the charge current and voltage profile in CC-CV mode. [2]

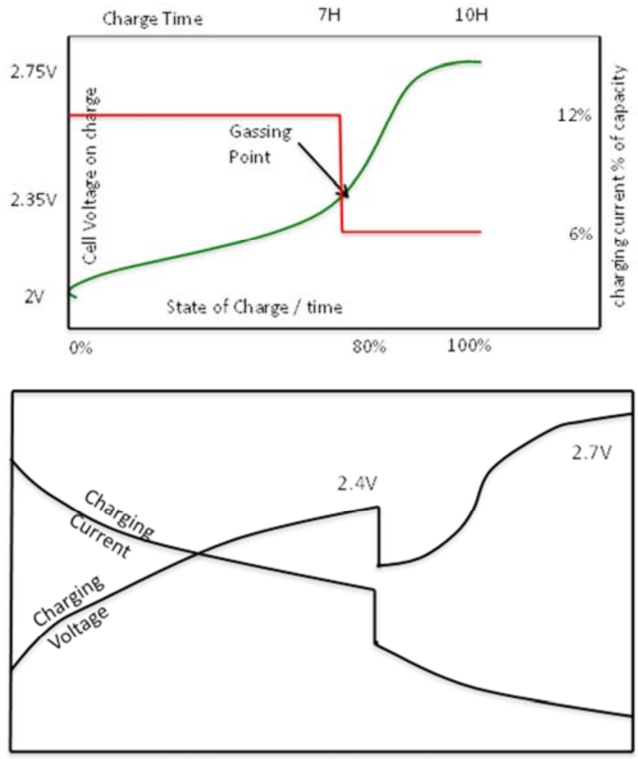

Figure 1. *Charging voltage/current profile of lead acid battery.*

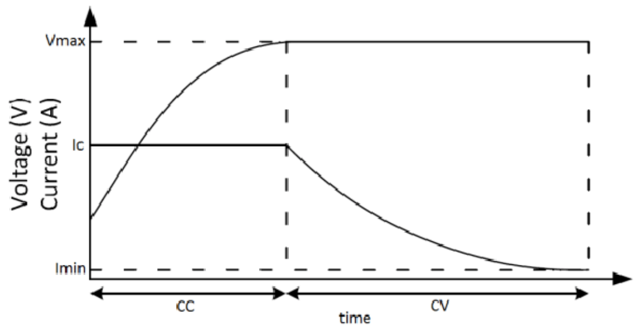

Figure 2. *Voltage & current profile in CC-CV charging.*

Factors in Battery Charging:

a) Charge Acceptance of battery is measured by ampere-hour or watt-hour efficiency. AH efficiency up to 95% is achieved by slow or finishing rate charging, while boost charging allows 90% or a little higher efficiency. Taper charging offers even lower efficiency. Lower charge acceptance causes higher temperature to rise in battery [16].
b) Temperature increase during charge has a direct bearing on the life of the battery. Higher than recommended temperature of battery during charge, lower its service life [3, 11].

Discussion (On development of Fast Charger for Lead Acid Battery):

The newly developed fast charger recharges the battery from fully discharged state or 20% SOC to 80% of its capacity in 3.5 hours as against 7 to 8 hours required by other battery chargers. It can also inject up to 35% charge in 65 minutes as against 3 hours by other charging modes.

Temperature rise in battery during this process is around 3-4°C only [17].

The process is based on the phenomenon that battery accepts higher charging currents efficiently at low SOC/ high DOD (Depth of Discharge) and accepts lower charging currents as the SOC increases progressively [14, 10]. If optimum amount of charge current is controlled as per the SOC/DOD, the battery will accept almost all of it with minimal temperature rise. [15]

It's to be noted that the charging current gradually gets reduced in other modes of charging also, as the battery voltage increases, but the current always remains above optimum limits, leading to rapid rise in battery temperature.

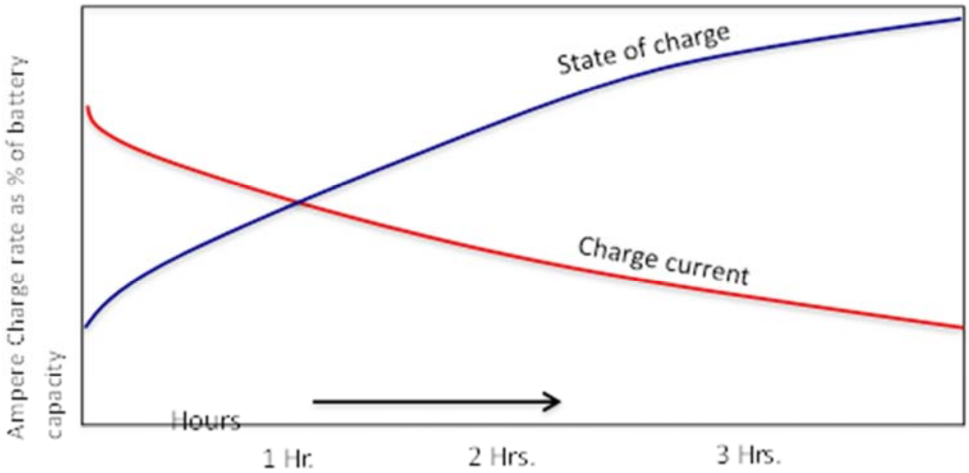

Figure 3. *Charge acceptance Vs SOC of battery.*

Fast Charging Algorithm has been developed for quick recharging of the 48V100Ah @ C20 / 90Ah @ C10 E Rickshaw battery in 3½ hours from 20% SOC (state of charge) to 80% SOC. This algorithm with some modification can be used for similar motive power batteries of other voltages and AH capacities as used in Golf Carts, Electric Forklifts, Tow and Platform trucks. Using the same process for stationary / standby batteries in UPS, Inverters, Solar, Power Grid support and other applications for both flooded and Gel/VRLA batteries are also contemplated to be possible.

However, as in boost or taper charge, the last 20% (80% to 100% SOC) of the battery has to be charged at slow/finishing rate of 7% of battery capacity in Amps & will take another 2-3 hours and this is true for Fast charger as well. We have observed that none of the E Rickshaws are charged more than 80% by their existing home chargers with lower efficiency, considering the 7-8 hours of charging time (from 11pm/12AM to 7AM) available during the night. Hence, the fast charge to 80% in 3.5 hours with 95% AH efficiency provides similar vehicle range during the day and hence adequate.

Details of the fast charging process are under an Intellectual Property right for the investors of the project. However, in general, the process can be described, involving accurate measurement of state of charge of battery before the start of fast charge followed by selection of the highest current that the battery can absorb fully at that SOC. This is followed by continuous monitoring of the changing SOC of the battery and control of charging current to optimum levels all through the charging process till the end. The process also involves periodic charge level change in order to increase the charge absorbing efficiency of the battery.

The above process is converted to an algorithm built into a micro controller in the charger, incorporating the SOC and corresponding charge current levels and periodic charge control impulses to increase absorption. There is a separate algorithm for the measurement of the SOC of the battery, built into the same micro controller.

Opportunity Charge, historically, have been used by electric forklift operators, using 1 hour lunch break as an opportunity to partially recharge the traction battery by 12-15% & increase the run duration. The E-Rickshaw operators similarly use their 1 hour lunch break to add around 12% or a little more extra charge to their battery which translates to 12 or 13 KM extra run for the day.

In the fast charger, Opportunity Charge mode injects up to 35% charge in 1 hour & 5 minutes at charging currents, even higher than the 3.5-hour fast charge mode and at different rate of current reduction control as well as a higher magnitude of periodic charge level change. This has proved to add up to 35 KMs of extra run in a day. The charger micro controller has a separate algorithm for the Opportunity Charge.

The Algorithm has been proven to work for both new and old batteries as well as both flooded Tubular and Flat plate batteries yielding same performance level.

2. Results (Performance of Fast Charger)

Alpha Testing Results for Laboratory Model on Electric Rickshaw Traction Battery of 48V90AH @ C10 or 48V100Ah @ C20.

Six repeated cycles of 3.5 hours fast charge and C10 discharges were carried out on the 48V90Ah @ C10 battery.

The target was to ensure that end of charge maximum voltage does not exceed 2.45 volts per cell for extended duration, thus ensuring minimal gassing and temperature rise. This limit is exceeded after 6 cycles & hence, after 6 cycles, equalizing charge at low current and high voltage was carried to fully recharge the 48V battery, after which another six cycles of fast charging can be imparted efficiently. It suits both E Rickshaw and Forklift operations since a few extra hours can be spared for equalizing charge on every Sunday and Holiday.

After freshening up the batteries, similar 6 cycles were repeated 2 more times, that is, a total of 18 cycles were carried out with absolutely similar result. The cycle wise AH efficiency, temperature & voltage rise during charge are as under:

AH output Versus Ah input, AH efficiency, temperature & voltage rise during 3 hours 30 minutes Fast Charge from 20% to 80% capacity of 90Ah @ C10 Battery.

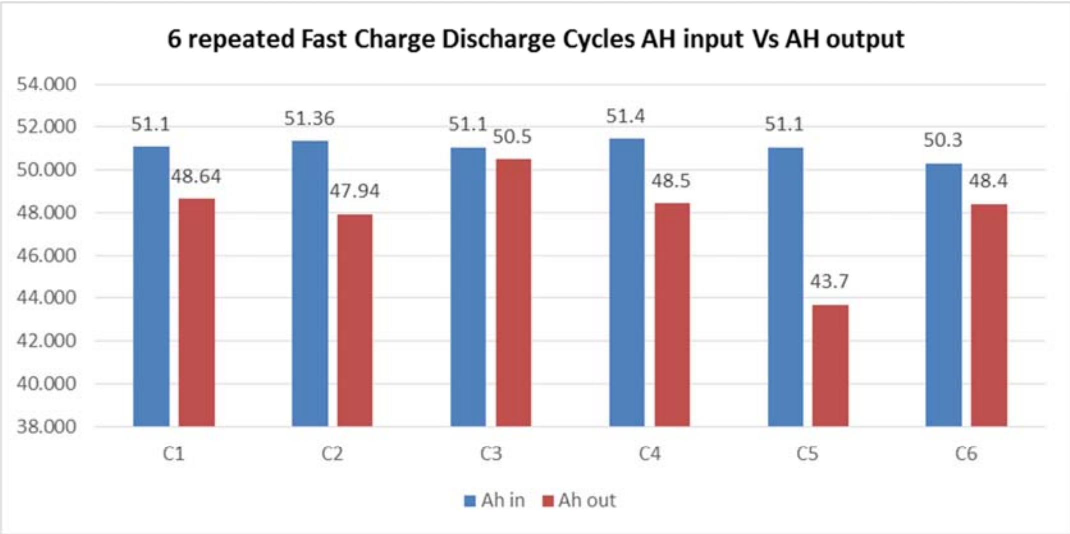

Figure 4. *6 repeated charge discharge cycles Ah input Vs Ah output.*

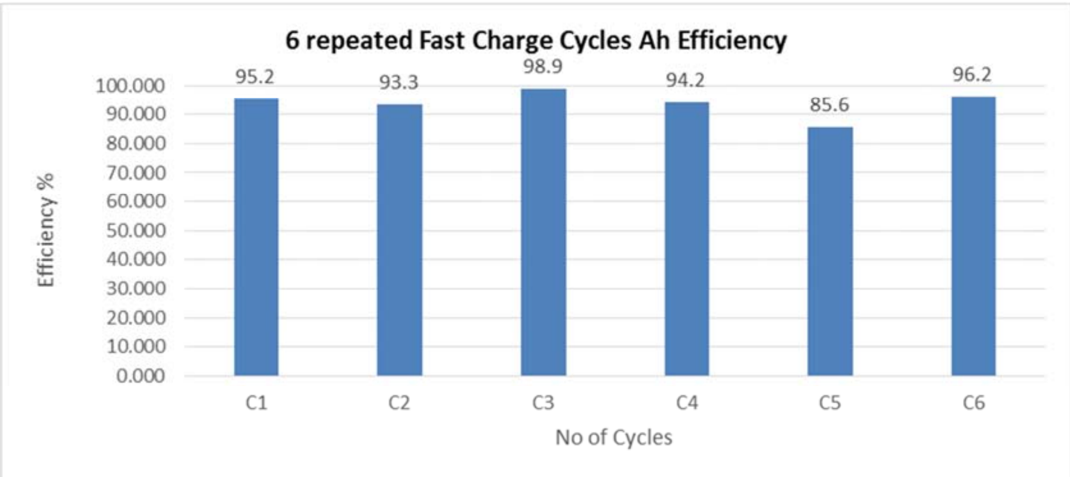

Figure 5. *6 repeated fast charge cycles Ah efficiency.*

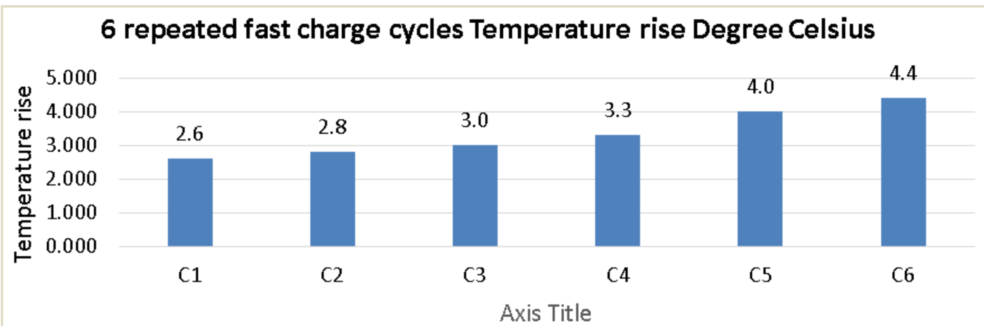

Figure 6. *6 repeated fast charge cycles temperature rise degree Celsius.*

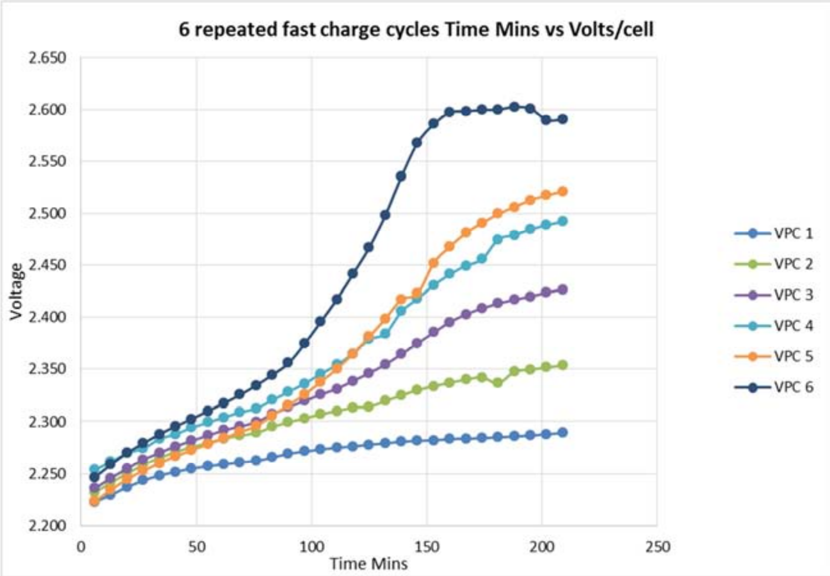

Figure 7. *Per cell charging voltage profile during 6 consecutive cycles.*

AH output Versus Ah input, AH efficiency, temperature & voltage rise for 1 hour 5 minutes Opportunity Charge injecting 35% capacity of 90Ah @ C10 Battery.

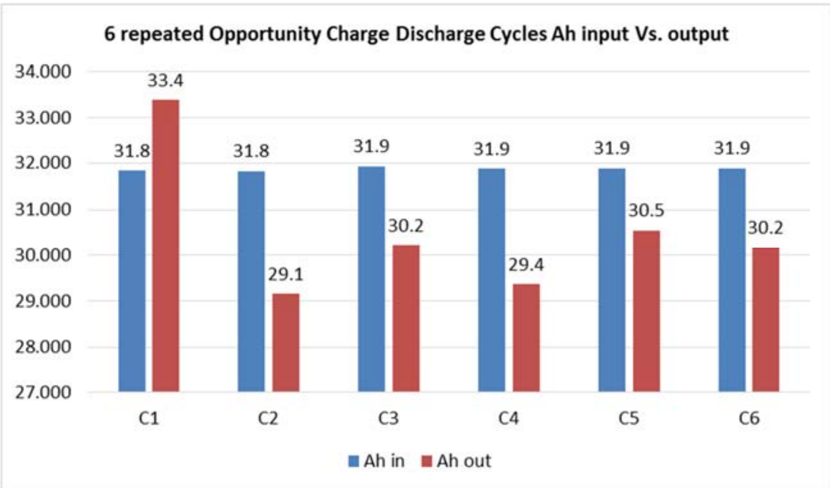

Figure 8. *Ah in Vs. Ah out in 6 consecutive opportunity charge cycles.*

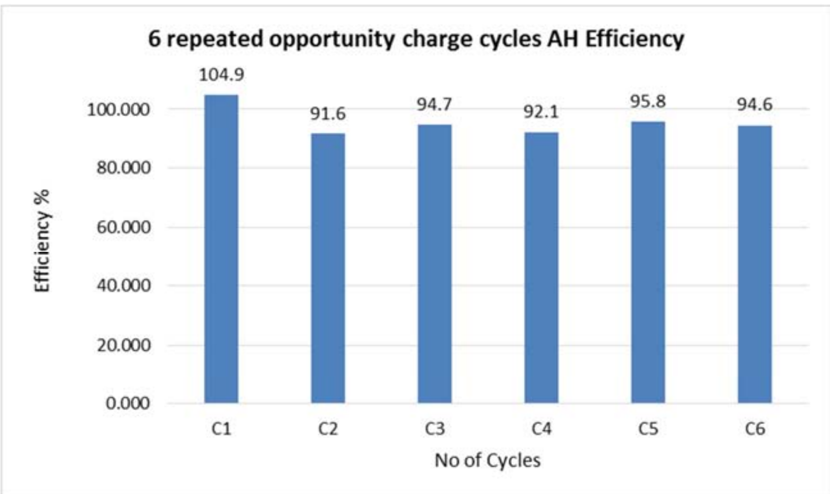

Figure 9. *6 repeated opportunity charge cycles Ah efficiency.*

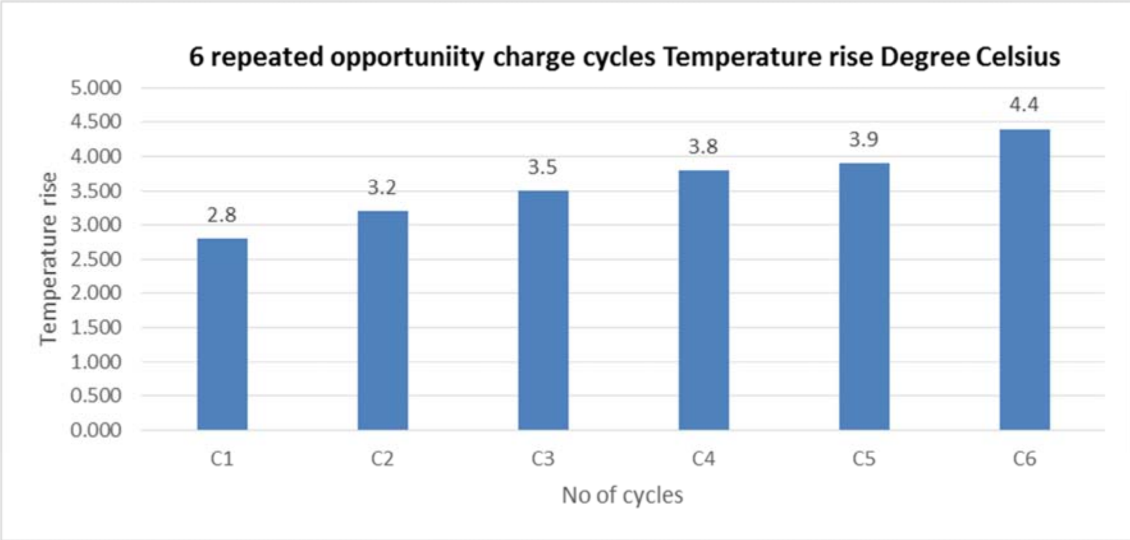

Figure 10. *6 repeated opportunity charge cycles temperature rise degree Celsius.*

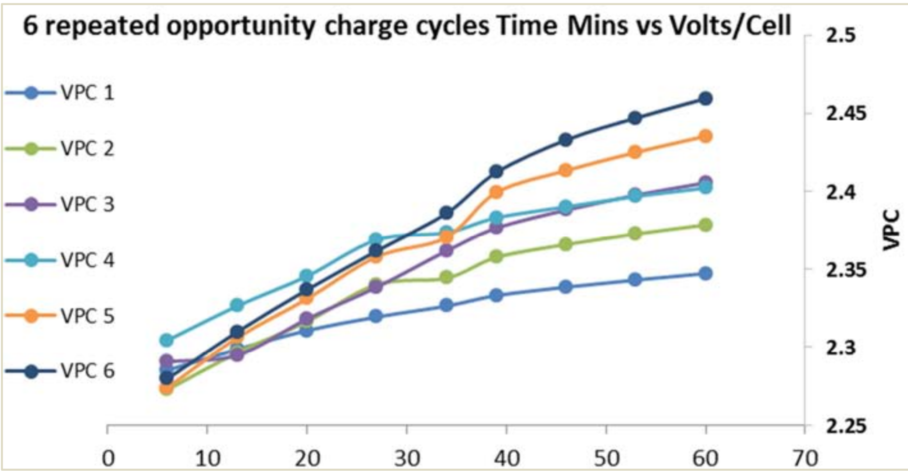

Figure 11. *6 repeated opportunity charge time mins Vs. volts/cell.*

Life Cycle Trend Test under Fast & Opportunity Charging Regime.

160 cycles comprising of fast charge & discharge as well as opportunity charge & discharge were carried out with the Fast charger and the test results are as hereunder. The blue and red bars denote charge and discharge respectively.

Denotes fast charge AH output;

Denotes opportunity charge AH output;

Denotes Maximum AH capacity of battery after periodic equalizing.

It is seen that the 48V90Ah @ C10 battery has retained almost same capacity from 19th to 160th cycle of fast charge/ opportunity charge cycles. Hence it is proved that the fast charging regime does not cause any damage to the battery & tends to yield the normal service life.

Test results for 160 Fast Charge, Opportunity Charge, Equalizing Charge & periodic capacity tests. Blue & Red Bars denote charge & discharge respectively.

Table 1. *Beta/Field Testing Results for Fast Charger Prototype Models on Electric Rickshaw Traction Battery of 48V90AH @ C10 or 48V100Ah @ C20 at Baharampur, West Bengal, India.*

Test Date	Time Min Duration	Total AH input	Extra Run Km/ charge	E Rickshaw Vehicle No.	Driver Name	Driver Mobile No.
12/12/20	100	29.85	30km	NA	Sajibul Shaikh	8116681877
12/12/20	72	31.56	32km	WB 57 C6922	Subroto karmakar	9614950691
13/12/2020	70	31.56	35km	WB 57 D3146	Ratan Pramanik	8172079425
13/12/2020	70	31.56	29 km	WB 57 C6922	Subro karmakar	9614950691
13/12/2020	44	15.55	19Km	NA	Kapildeep Paswan	9635241434
13/12/2020	2	NA	NA	NA	Rajesh SK	7719148392
13/12/2020	80	23.5	22km	NA	Tapan Saha	6297065281
14/12/2020	37	16.15	20km	NA	Ashok Bagdi	9641681833
14/12/2020	40	31.56	32km	NA	P Rakshit	9609382395

Test Date	Time Min Duration	Total AH input	Extra Run Km/ charge	E Rickshaw Vehicle No.	Driver Name	Driver Mobile No.
14/12/2020	80	23.5	26km	NA	Tarun Ghosh	7865121649
14/12/2020	37	16.15	18km	NA	Sajibul Shaikh	8116681877
15/12/20	22	9	12km	NA	Ranjan Das	9046147169
15/12/20	13	8.07	NA	NA	Pravinkumar Rakshit	9609382395
15/12/20	77	17.21	30km	NA	Pravinkumar Rakshit	9609382395
15/12/20	40	18.82	20 km	NA	Rohit SK	7924061430
15/12/20	53	25.16	28km	WB 57 E 0078	Sanjit Pramanik	7908442778
16/12/20	58	28.1	30km	NA	Samor Mandal	6297014302
16/12/20	70	31.56	35km	NA	Sameer Mandol	No Contact/Mobile
16/12/20	70	31.56	35km	NA	Manab Mandal	8609149602
17/12/20	46	22.07	23km	NA	Samor Mandal	6297014302
17/12/20	5	4	NA	NA	Salabuddin	No Contact/Mobile
17/12/20	51	25.16	22km	NA	Sajibul Shaikh	8116681877
17/12/20	46	22.07	26km	NA	Eliyas Sarkar	7431892947
18/12/20	80	23.5	25km	NA	Pintu Mandal	9153799909
18/12/20	23	15	20km	NA	Bakul Ghosh	6296914956
18/12/20	70	31.56	32km	NA	Eliyas Sarkar	7431892947
18/12/20	80	23.5	25km	NA	Samor Mandal	6297014302
19/12/20	46	22.07	25km	NA	Milap ghosh	No Contact/Mobile
19/12/20	80	23.5	20km	NA	Tapan Saha	6297065281
19/12/20	66	21.67	20km	NA	Rajesh SK	7719148392
20/12/20	70	31.56	pending	NA	Vicky Sen	7063044497
20/12/20	66	21.67	pending	NA	Anikul sheikh	9004624024
20/12/20	46	15.55	pending	NA	Tushar Saha	8346808981
20/12/20	90	4.5	pending	WB 57 D3766	Ganesh Hari	8972579219

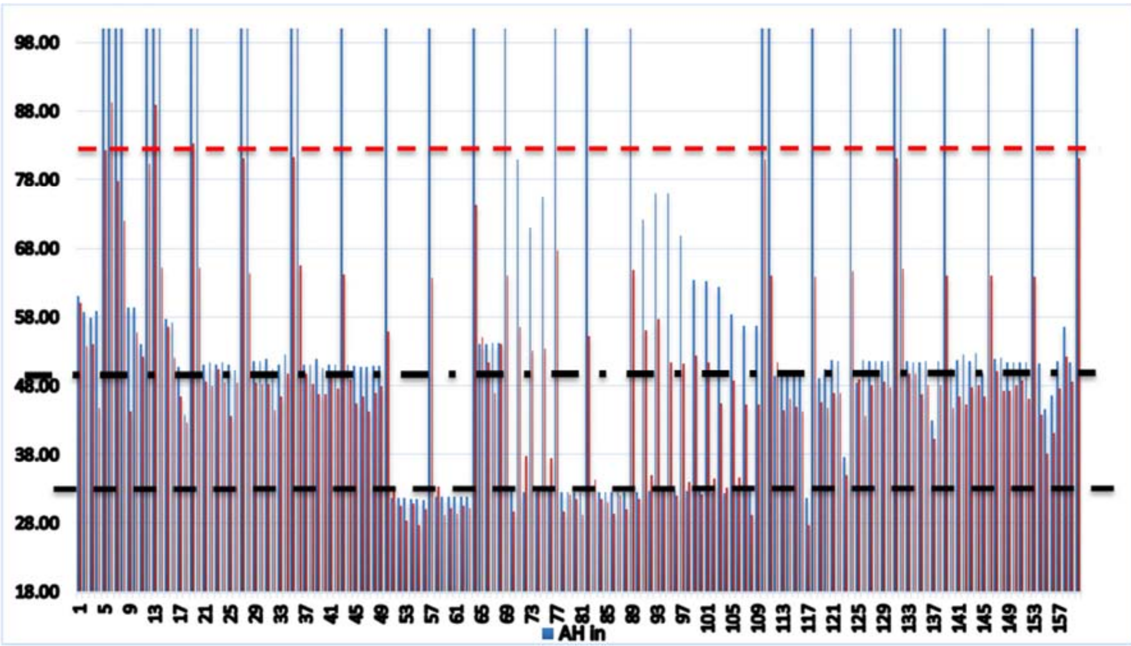

Figure 12. *Battery retained same capacity even after 160 cycles of high current-fast charging.*

3. Conclusion

The performance of the E-Rickshaw fast charger has been proven in the laboratory model, the field level prototype model as well as the mass production model. It not only reduces charging time for the Electric vehicles but also increases the revenue of Rickshaw drivers by giving them more running time. It is also proven that the fast charging at high rates does not affect the battery life at all.

Figure 13. *The Laboratory Model Fast Charger for development of Algorithm & Design.*

Figure 14. *The Prototype Charger & E Rickshaw at Baharampur Beta Testing.*

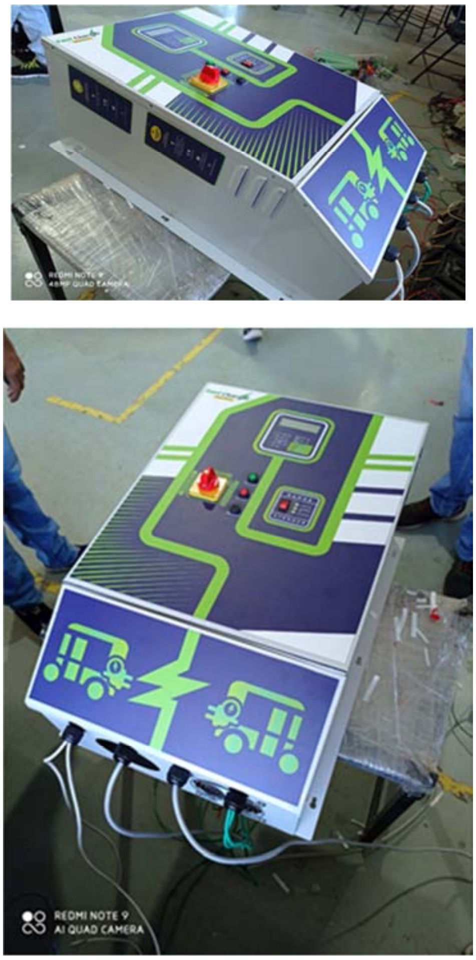

Figure 15. *Final Production Model of E Rickshaw Fast Charger – Launched.*

While the market demand for this E Rickshaw fast charger is increasing, we are now looking for applying this technology in other applications like battery operated forklift trucks, material handling equipment, golf carts, UPS systems and solar charging.

4. Scope for Future

This rapid charging procedure, with modification can be used for recharging all types of lead acid batteries in electric vehicles, forklift & tow trucks, golf carts, UPS & invertors. Charging time will reduce by 60% without adverse effects.

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