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Original scientific paper

PV-BASED RAPID CHARGING AND BATTERY SWAPPING STATION FOR SMALL TRANSPORT EVS IN RURAL AREAS OF WEST BENGAL

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***Abstract**. The widespread adoption of electric vehicles (EVs) necessitates innovative solutions for fast, efficient, and scalable charging infrastructure. The present research work aims to integrate Battery Swapping Stations (BSS) with renewable-power source (Photo voltaic system), and proposes enhanced financial models to achieve advancements in charger technology. The present approach focuses on the development of optimized LLC resonant converters with energy recovery cell (ERC) that offer high efficiency, reduced electromagnetic interference, and improved power transfer capabilities. These converters ensure compatibility with various battery chemistries while enhancing energy conversion and thermal management. Simulation and experimental results ascertain their ability to meet the fast-charging requirement of high-power EVs and reduce energy losses. The sole power source of battery operated electric vehicle (BEV) is the battery packs that are installed in the vehicle itself, thus battery depletion with progression of working duration is a critical limitation of BEV. Charging time of batteries primarily depends upon capacity and application of the battery. Longer time compels the EV to become inoperative for the time duration and consequently hinders its operational efficiency. Battery swapping provides a practical solution to address these lacunae. By quick replacement of depleted batteries with fully charged ones and consequently reduce EV downtime, economic losses, and offering a*

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sustainable, affordable alternative to traditional fuel stations. It represents a transformative step towards more accessible and eco-friendly mobility solutions.

Key words: *BSS, Energy Recovery Cell. LLC, ZVS, EV*

1. INTRODUCTION

Off late surge in usage of private vehicle along with conventional gasoline based transport vehicle have alarmingly increased the rate of carbon emission. Immediate measuring actions are essential to rescue the environment from this greenhouse gas emission. Deployment of EV [1] in the transportation system is considered as quintessential alternative that can replace gasoline based cars. Valve regulated Lead acid (VRLA) battery is the main power source for EVs the electricity required to drive this car is stored in a pack of batteries. This battery unit provides the required driving power of brushless DC (BLDC) motor associated with the vehicle. However, the batteries get depleted after giving service for hours, then the charging of battery becomes critical to run the vehicle further by maintaining the state of charge (SOC). On the other hand, to meet the escalating power demand, the power networks mostly operate very near to its rated power delivery capacity. Thus, electric energy required to charge the EV imposes additional load to the existing loaded power network. Prolonged battery charging time (7 to 8 hours) makes EV inadmissible in the transportation system, as the vehicle becomes dormant during this charging time span. This is the main limitation of EV. To overcome this limiting issue, a viable technical solution and its deployment is required that can forgo the down time of EV and can escalate the operational efficiency with a pragmatic, scalable, and commercially feasible infrastructure device. There are several state-of-the-art approaches observed which primarily deals with the progress in electric vehicle battery charging stations.

The literature reviewed underscores the advancements and refinements in electric vehicle (EV) charging systems, highlighting key contributions across various domains.

In 2010, Sortomme and colleagues analyzed the interplay between losses, load factor, and variance within coordinated Plug-in Hybrid Electric Vehicle (PHEV) charging systems. They developed convex objective functions that streamline real-time dispatch and enable integration into broader optimization frameworks. These methods, being topology-independent, outperform traditional loss minimization techniques in daily load profile predictions. Zakariazadeh et al. (2014) introduced a multi-objective scheduling framework for EV charging and discharging, aiming to lower costs and emissions. Their approach utilized Vehicle-to-Grid (V2G) capabilities, the augmented e-constraint method, and Benders decomposition to deliver Pareto-optimal solutions, achieving notable reductions in emissions and operational expenses. Tan and collaborators (2016) examined the dual advantages of V2G technology, which offers grid services like power regulation and peak load management. Despite challenges in battery development, their work highlighted V2G potential for environmental and operational benefits, contingent on effective policies and stakeholder collaboration. Yang et al. (2014) developed an EV charging model that integrated optimal power flow, statistical data, user satisfaction, and grid cost considerations. Using an advanced particle swarm optimization (PSO) algorithm, their model achieved significant cost reductions while meeting user requirements. Gan et al. (2012) advocated for decentralized algorithms to optimize EV charging, focusing on demand valley filling with minimal communication and computational requirements. They proposed synchronous and asynchronous methods to establish effective charging patterns. Dong et al. (2018) designed a pricing model for fast charging stations, aligning user travel patterns with demand forecasts to enhance voltage control. Their double-layer optimization model balanced station income with user response, improving voltage profiles effectively. Fachrizal et al. (2020) reviewed the integration of smart EV charging with photovoltaic (PV) systems, discussing centralized and distributed configurations, objectives, and algorithms. They identified optimization techniques and highlighted research gaps for future exploration.

Spiazzi et al. (2020) and Medina-Garcia et al. (2021) explored asymmetrical half-bridge flyback converters for compact, high-speed charging solutions. Their innovative control methods, including zero-voltage resonant valley switching, advanced voltage control and efficiency. In most of the reviewed works, application of optimization techniques, involvement of electrical power grid or application of half bridge converter are observed. But amid the emerging energy crisis, the involvement of renewable energy sources gives more viable and energy efficient solution. Moreover energy recovery cell with full bridge resonant converter in the present research work gives better solution to the problem related too long battery charging time. Hardware implementation of the proposed prototype can harness the practical constraints and viability of the scheme, which is not possible in optimization based techniques to the full extent.

So, the present research work aims to reduce the charging time by incorporating an energy recovery cell with the available LLC resonant converter [2] technology. This modification of the resonant converter enables the circuit to reuse the output ripple ac voltage of the rectifier and resend the same back to the Bus capacitor (C_B) present at the beginning of the MOSFET based full bridge inverter. This feedback path ensures the saving of power to a considerable extent, reduces the power loss due to zero voltage switching (ZVS) technique of the circuit and significantly enhances the overall efficiency.

Although the above mentioned prototype circuit substantially reduces the battery charging time from 8 hours to 4 hours approximately [3][4]. However, this time span is also long for EV operator as the functioning of EV ceases for this charging time duration. This is reflected as an economical loss which is indeed a practical hindrance in deployment of EVs in small scale transportation sector in rural Bengal.

As EV requires high power and fast charging mechanism, efficient power conversion and proper thermal management are two fundamental criteria for flawless EV operation. Thus, modifications in LLC converter are made to achieve these goals as far as possible. This research contributes the integration of ERC with LLC based resonant converter topology powered by solar PV system. Moreover, in this work the deployment of BSS technology along with above mentioned fast charger development in rural Bengal is executed. The presented charging topology is found to address not only the limitation of long charging hours but simultaneously reduces the dormant period of EVs to only 10 minutes by incorporating BSS schemes.

A battery swapping station [5] is a junction where quick replacement of depleted battery associated with electric vehicle can be replaced by a fresh fully charged battery [6]. The scheme of battery exchange can be considered as a temporary solution to recharge the electric vehicle quickly such that the overall run time of the vehicle can be enhanced to considerable time extent. Battery swapping technique compensates the loss of EV owner as they do not need to wait until the depleted battery gets fully charged. The BSS owns the batteries whereas the EV operator borrows the battery according to their requirement. Since the battery swapping includes mechanical interchange of the discharged battery [7] with the charged one, the process can also be termed as mechanical refueling. The innovation of BSS technology has the potential to revolutionize the future of electric based transportation.

The rest of the paper is organized as follows: Section 2 proposes BSS integrated fast charging prototype, section 3 discusses about the result and analysis of the proposed scheme, where economic analysis, field survey report, cost estimation and a detail of the payback period are presented. Section 4 concludes the present research work followed by the discussion about the future scopes of the present work. Table 1 provides the abbreviations used in this article.

Table1 Annex: List of Abbreviations

Abbreviation	Full Form
EV	Electric Vehicles
BSS	Battery Swapping Stations
BEV	Battery operated Electric Vehicle
VRLA	Valve regulated Lead Acid
BLDC	Brushless DC
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
C_B	Bus Capacitor
ERC	Energy Recovery Cell
SPV	Solar Photovoltaic
ZVS	Zero Voltage Switching
ZCS	Zero Current Switching
BS	Battery Swapping
USD	United States Dollar
$V_{P1}(s)$	Primary-side voltage in the Laplace domain
V_{ac}	AC voltage across the resonant tank
L_m	Magnetizing inductance
L_r	Resonant inductance
C_r	Resonant capacitance
R_{ac}	Equivalent AC resistance
R	Load resistance factor
V_{in}	Input voltage

The present research work focuses on the development and integration of modified LLC resonant converter with ERC that aims to reduce the charging time of the EV batteries. The work explores the potential of adopting BSS technology so that the EV can undergo a quick recharging process and effectively can increase the working duration of the vehicle.

Solar photovoltaic plant is integrated with the converter circuit to supply the required driving power of the circuit. Integration of renewable energy to the present technology is much required amid present conventional energy crisis scenario. Fig. 1 shows schematic representation of the proposed PV powered LLC based Fast charging technology with ERC.

The series parallel combination 75 Watt, 12 volt solar modules comprises the solar array in this scheme. It acts as a solar power system as well as the primary source of energy, converting sunlight into direct current (DC) electricity.

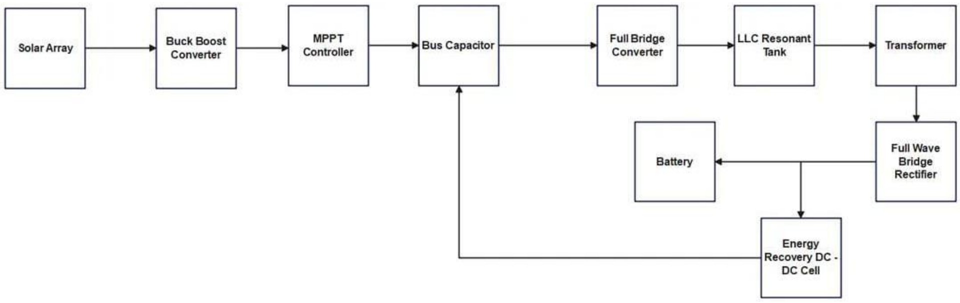

Fig. 1 A schematic representation of the proposed PV powered LLC based Fast charging technology with ERC.

The generated DC power is then processed by the buck-boost converter, which adjusts the voltage levels to align with the requirements of subsequent components. To ensure maximum energy utilization, the MPPT (Maximum Power Point Tracking) controller continuously optimizes the power output of the solar array, adapting to varying sunlight conditions. The full-bridge converter performs the critical task of converting DC power into alternating current (AC), which is then directed to the LLC resonant tank. This resonant tank facilitates efficient energy transfer by creating oscillatory waveforms. The transformer further adjusts the voltage to the desired level, ensuring it meets the load specifications. The AC output from the transformer is converted back into DC by the full-wave bridge rectifier for direct utilization. An energy recovery DC-DC cell [6] captures the ripple ac from the inductive filter placed at the output of the rectifier. The output of the rectifier consists of both DC and ripple ac parts. The DC output part is fetched as input to the battery for charging purpose. And the remaining ripple ac is fed back to the input section of the full bridge converter circuit and stored in the bus capacitor for future use. Lastly, the battery stores excess energy for future use, ensuring a reliable and stable power supply even during fluctuations in input or demand.

2. Resonant LLC Converter: Structure and Functionality

The resonant converter serves as a critical component in the system, composed of an inductor (L_r) and a capacitor (C_r) that together form the resonant tank circuit. This circuit is designed to enable efficient energy transfer to the load via a transformer. By facilitating smooth current flow within the circuit, the resonant tank enhances stability and performance.

The system begins by converting the DC input into a square wave through a switching bridge network. This network uses a full-bridge design, employing four Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) to efficiently produce the square wave signal. The square wave is then passed through the resonant LLC tank, which acts as a harmonic filter. The primary purpose of the resonant LLC tank is to remove unwanted harmonics from the square wave signal, delivering nearly sinusoidal voltage and current. The LLC resonant converter is distinguished by its high efficiency and reduced switching losses, achieved through the implementation of ZVS. The technique ZVS ensures that switching transitions occur when the voltage across the switch is zero, significantly minimizing energy losses [5, 6].

By integrating the resonant converter, switching bridge network, and transformer, the system achieves an efficient DC-to-AC conversion process. The resonant LLC tank not only filters harmonics but also generates high-quality AC signals. The transformer ensures both voltage adjustment and electrical isolation, making the system safer and more reliable. This architecture is well-suited for applications that demand efficient power conversion, such as renewable energy systems, industrial equipment, and high-power electronic devices [7, 8].

2.1. The Rectifier Stage in the LLC Resonant Converter

The rectifier stage in the LLC resonant converter utilizes a full-bridge diode configuration to convert the high-frequency AC signal from the transformer into a unidirectional DC voltage. This arrangement comprises four diodes (D1, D2, D3, and D4), strategically connected to handle both positive and negative half-cycles of the AC waveform [9] [10] [11] [12] [13].

The rectifier thus converts the bipolar AC waveform into a pulsating DC output, which contains significant ripple components that require further filtering [14]. The output capacitor (C_0) is positioned downstream of the rectifier to smooth the pulsating DC signal into a stable DC output voltage. The capacitor plays two key roles: Ripple Filtering [15][16][17]. Load Stabilization: [18] [19].

2.2. ZVS Technique

ZVS [20] [21] represents a significant advancement in the domain of power electronics, aimed at minimizing energy losses during the switching processes. This innovative technique ensures that switching devices, such as Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs), are activated precisely when the voltage across them approaches zero. Through precise timing and synchronization ZVS effectively mitigates power dissipation during switching events, a prevalent drawback in conventional hard-switching methodologies. Fig. 2 shows Circuit Diagram of prototype LLC based fast charging system with ERC.

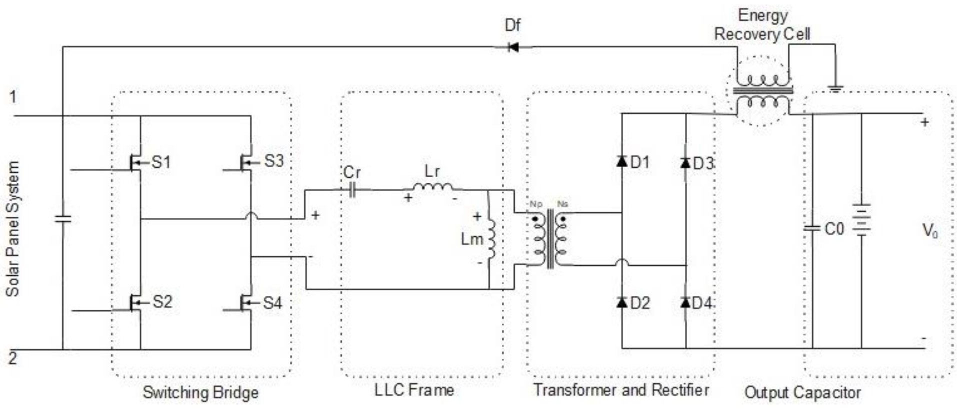

Fig. 2 Circuit Diagram of prototype LLC based fast charging system with ERC

The principle of ZVS operation relies on the synchronization of the MOSFET's activation with the instant at which the voltage across its terminals naturally falls to zero. This phenomenon is realized through the exploitation of circuit resonance, particularly in LLC resonant converters [22]. These converters employ a resonant tank, typically comprising an inductor (L_r) and a capacitor (C_r), to generate oscillatory waveforms. The resonance induced by the tank circuit ensures periodic fluctuations in the voltage across the MOSFET, facilitating moments where the voltage reaches zero. The switching mechanism is strategically triggered during these intervals, thereby minimizing energy losses and enhancing system efficiency.

2.3. LLC based Converter

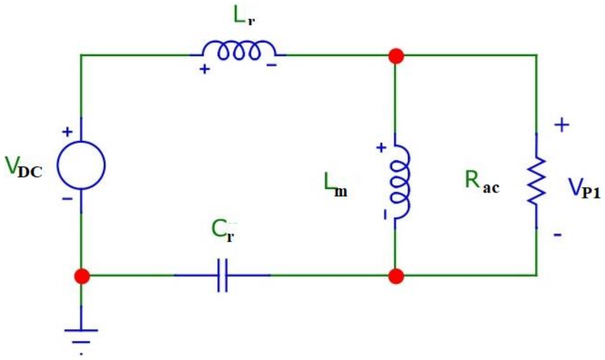

Fig. 3 Output voltage of LLC resonant convertor

$$f_{r_1} = \frac{1}{2\pi\sqrt{L_r C_r}} \tag{1}$$

Equation (3), (4), (5), (6) & (7) indicates different parameters of a LLC resonant convertor.

$$f_{r_2} = \frac{1}{2\pi\sqrt{L_m + L_r C_r}} \tag{2}$$

$$V_{P1}(s) = V_{ac}\frac{\frac{L_{mx} * R_{ac}}{L_{mx} + R_{ac}}}{L_{rx} + \frac{1}{C_{rx}} + \frac{L_{mx} * R_{ac}}{L_{mx} + R_{ac}}} \tag{3}$$

$$V_{P1}(s) = V_{ac}\frac{L_{mx} * C_r * R_{ac} * S^2}{L_m * L_r * C_r * S^2 + (L_m + L_r)C_r * R_{ac} * S^2 + L_m * S + R_{ac}} \tag{4}$$

$$R_{ac} = \frac{8r^2}{\Pi^2} \tag{5}$$

$$V_{P1} = \frac{2\sqrt{2} * r}{\Pi}V_{in} \tag{6}$$

$$V_{ac} = \frac{\sqrt{2}}{\Pi}V_{in} \tag{7}$$

V_{ac} is the output voltage of the secondary winding of the transformer, V_{p1} is the output of the LCC resonant converter

2.4. ERC in LLC Resonant Converters

The Energy Recovery Cell (ERC), as an integral component in LLC resonant converters, plays a pivotal role in enhancing energy efficiency by recovering and reutilizing energy that would otherwise be dissipated as losses. This feature is particularly critical in high-power conversion systems, where energy wastage can significantly impact performance and operational reliability [23],[24]. Fig. 4 shows the Hardware experimental set up of the proposed prototype system.

Fig. 4 Hardware experimental set up of the proposed prototype system

3. BATTERY SWAPPING STATION

3.1. Stages of BSS Operation

The operation of battery swapping station follows certain rules. The BSS should be stocked with sufficient numbers of fully charged battery, such that it can replace the newly entered discharged vehicles at any random time instant.

Initially, each EV drives the required power from its fully charged battery pack. Once the battery gets depleted after providing service for the expected time span, it is queued in the charging section of BSS. The batteries under charge get ready to serve the new entries of discharged EVs. Although the depleted batteries of a candidate discharged EV can be immediately replaced by freshly charged battery, the momentary charging of the fully discharged battery is not practically feasible as it requires considerable time as discussed earlier. This is the actual hindrance in deployment of EV in mostly rural as well as urban areas. This necessitated the researcher to look for a practical and economically viable solution of reducing battery charging time.

To avoid the out-of-stock scenario, the stock of the charged battery in any BSS [25] should be greater than the numbers of entry of candidate discharged vehicles at any random time frame. The fully depleted batteries during charging time interval can also be employed in energy management system [26] [27]. Charge scheduling of the batteries are executed in such a fashion that they can be incorporated as a source to inject power to the electric microgrid during peak load period. For sound operation of BSS, a robust communication interface is critical between information system, EV and the BSS [28].

Usually wave communication establishes the bidirectional link between vehicles and information system. The information system accumulates the current location of the incoming vehicle and estimates their expected time of arrival. Thus, information is shared with the BSS through local internet. Station prepared the new charged batteries to be added to the newly entered depleted EV [29]. As the vehicle reaches the BDS, the depleted battery specification undergoes verification and then the vehicles are allowed to swap the battery. With aid of a robotic arm the battery replacement procedure is executed without delay. An accurate record of the user's payment , battery details, charge level, next probable scheduled charging time are stored in the cloud system for ease of tracking system. Mobile App can help the EV user to track the nearest BSS, raise requests etc. [30][31].

At the peak load condition, the charging batteries are utilized as an alternative power source to inject power to the grid. This generates additional revenue. For congestion-free operation of BSS, First in first out (FIFO) service is employed.

3.2. Merits of BSS

1. Compared to other existing EV charging process, the BSS assures uninterruptible service of EV and helps the user to give service without distraction, cost effective solution [32][33].
2. Charging of battery in off load period and injection of power during peak load enhances the load curve of the grid. As a result the electric system become much more efficient [33][34].
3. Sufficient stock of batteries in BSS satisfies the customer's need by reducing the waiting time [34][35].

3.3. Classification of Battery Swapping Technology

Depending upon the battery position, the BS technology is classified into Side swap, Top swap, Bottom swap, and Rear swap. Table 2 shows the Vehicle & their swap position and any one or more than one number of techniques are used in a BSS.

Table 2 Vehicle & their swap position

Vehicle	Swap position
Car with large space	Rear
Bus	Top
Car	Bottom
Van, Truck	Side ways

4. Layout of Swap Station and Cost Analysis

A battery swapping station for a specific number of electric vehicles is a facility where discharged batteries in electric vehicles can be quickly replaced with fully charged ones. Instead of waiting for a vehicle's battery to recharge, the driver swaps the depleted battery with a charged one, allowing for faster turnaround. The term "n electric vehicles" simply refers to the number of EVs the station is designed to serve.

Fig. 5 shows the Layout of a BSS unit where charging and discharging of battery swapping fast charging station clearly visible with the help of a block diagram power by solar energy and system is totally off grid solar system.

Total Estimated Investment for a single charging unit of a BSS is 8790 USD. The cost of establishing an EV charging station in India depends on several factors. One of the primary variables is the type of EV charger, as different chargers vary in price. Another significant factor is the cost of land. If you already own the land, this expense is eliminated [36][37]. However, if you choose to lease land, the cost will vary depending on the location. Additionally, obtaining an electricity connection for the charging station is necessary, and this cost differs across states. Currently, many states in India offer subsidies to encourage the development of EV charging infrastructure. These subsidies help lower both the cost of acquiring an electricity connection and the overall expenses of setting up the EV charging station. This makes it an advantageous time to invest in EV charging infrastructure [38][39]. The costs associated with establishing an EV charging station are currently stable, primarily due to government initiatives providing substantial subsidies. These subsidies help offset the expenses of key high-cost components, making the setup process more affordable [40][41]. A significant factor influencing the overall cost is the price of land, which varies widely depending on location. Fluctuations in land prices can significantly affect the total investment required for an EV charging station. Additionally, electricity tariffs play a critical role in the operational and setup costs. Variations in electricity rates can impact the overall expenditure and profitability of the charging station.

Manufacturers can generate revenue from your EV charging station through several methods:

Charging Fees: The primary source of income will come from the fees customers pay to charge their electric vehicles at your station [42] [43].

Advertising Collaborations: Partnering with outdoor advertising agencies can provide additional revenue by leasing space at your station for advertisements [44].

Retail Opportunities: Establishing a convenience store, cafe, or other retail outlets near the charging station can attract customers who want to shop or relax while waiting for their EVs to charge [45][46].

These strategies are widely adopted by EV charging station operators across the country. In summary, your revenue streams can be categorized into three main areas: fees from charging services, income from advertising, and earnings from ancillary spending opportunities created for customers during their wait times [47][48].

5. Result and Analysis

In the result and analysis section, variation of Open circuit voltage of the 12V battery used in the present case, standard open circuit voltage of battery bank and measured open circuit voltage from the battery unit with respect to quantity of the charge are shown in table 3. Table 4 depicts the comparative analysis of charging time of prototype fast charging method with the conventional charging method. The state of charge (SOC) of a VRLA battery is determined using the battery unit's specified open-circuit voltage and the measured voltage after charging by using prototype charging system**.**

Table 3 Variation of Open circuit voltage of single unit 12 V battery, Standard open circuit voltage and measured open circuit voltage from the battery unit with SOC

Quantity of Charge (%)	Open Circuit Voltage (V) of 12 volt battery	Standard Open Circuit Voltage (V) of Battery Bank as per specified value	Measured Open Circuit Voltage (V) from battery unit
100	12.51	48	49.55
90	12.33	48	49. 23
80	12.27	48	49.11
70	12.19	48	48.76
60	12.08	48	48.62
50	11.83	48	48.25

From the above table it is observed that the single battery with 50 % SOC can give 11.83V output voltage. The output voltage rises upto 12.51V with full charging level. Fig. 6 shows Plot of Standard open circuit voltage of battery bank versus quantity of charge (%). The standard open circuit voltage of the battery bank consisting of 4 units of 12 V battery (VRLA) is 48V. The measured value of open circuit voltage of the battery bank is found to vary from 48.25 volt to 49.55 volt with the corresponding variation in charging level from 50 % to 100 %. Figure 6 indicates Plot of Standard open circuit voltage of battery bank versus quantity of charge (%). Fig. 7 shows Plot of Measured open circuit voltage versus quantity of charge (%) quantity of charge (%). Fig 8 shows the plot of open circuit voltage of 12 V battery versus quantity of charge.

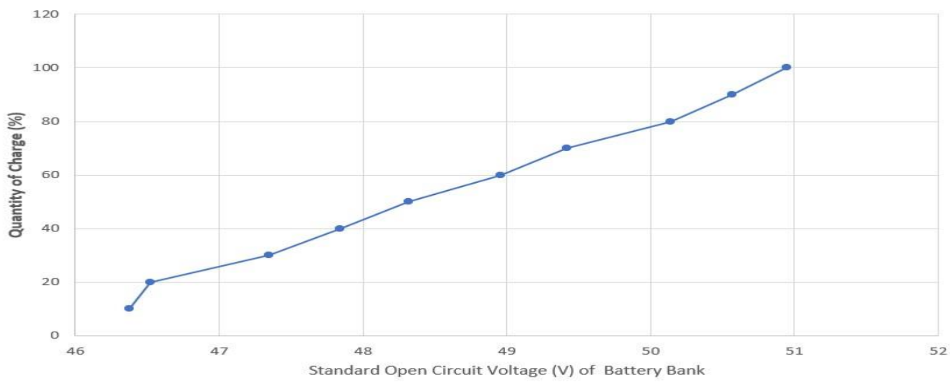

Fig. 6 Plot of Standard open circuit voltage of battery bank versus quantity of charge (%).

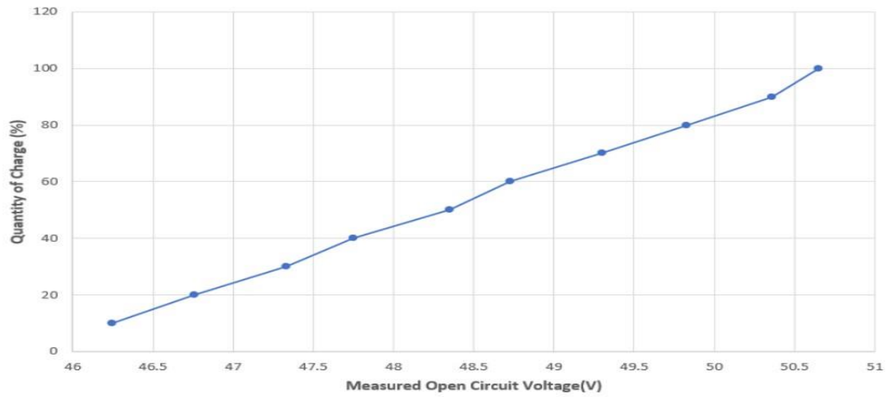

Fig. 7 Plot of Measured open circuit voltage versus quantity of charge (%) quantity of charge (%).

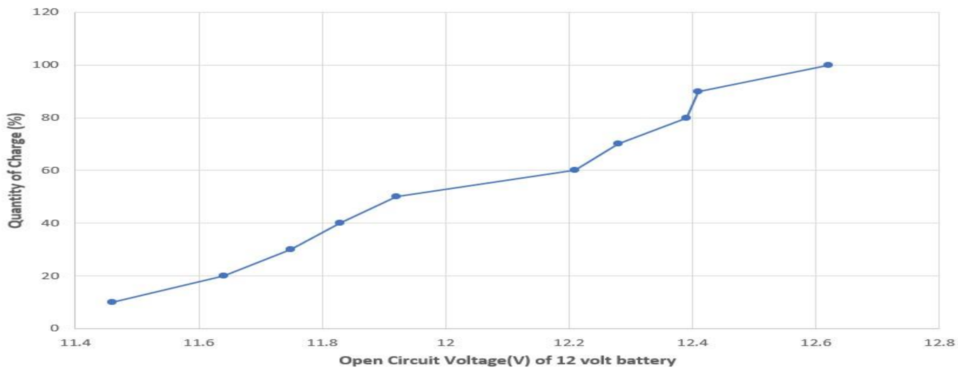

Fig. 8 Plot of open circuit voltage of 12 V battery versus quantity of charge

The charging time of a VRLA battery is evaluated using both the traditional charging method and the proposed prototype fast charging technique.

Table 4 Comparative analysis of charging time of prototype fast charging method with the conventional charging method.

VRLA battery Charging level (%)	Charging time with conventional method (hours)	Charging time with prototype fast charging method (hours)
50	4.0	2.5
60	4.5	3
70	5.0	3.5
80	5.5	4
90	6.5	4.5
100	7.5	5

From Table 4 it is observed that the time required to charge the battery with 100 % charge is 5 hours, whereas the time taken by the conventional charging system is 7.5 hours. Thus, it can be concluded that the present prototype system can save up to 2.5 hours' time duration to fully charge the battery. Fig. 10 shows Plot of VRLA battery charging level (%) versus charging time (hours)

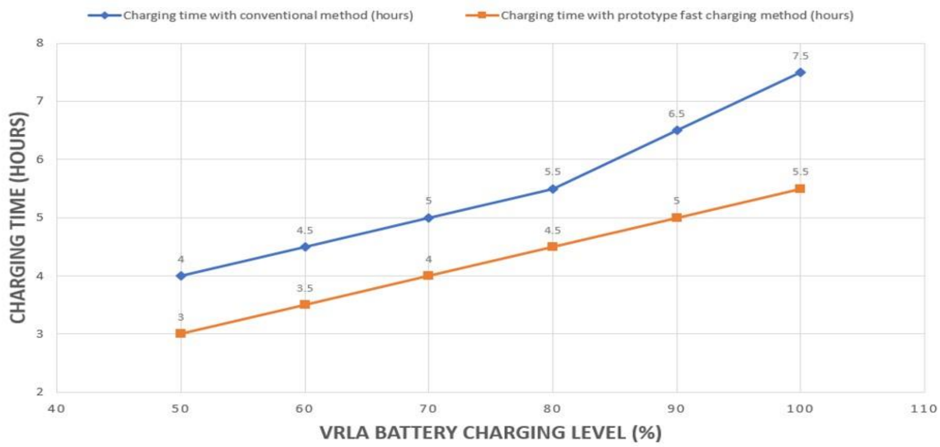

Fig. 9 Plot of VRLA battery charging level (%) versus charging time (hours)

5.1. Economic Analysis and Savings

A field survey is conducted to evaluate the present scenario of EV deployment in rural Bengal (mention area). The survey report gives an estimation of the revenue earned by each EV operator. It is evident from the survey report that the high charging time and scarcity of proper battery charging infrastructure in these areas suppresses the chance of the maximum earning of the EV operator.

A sample economic analysis of the revenue earned by each EV operator is given below:

Each EV operator earns RS 70 per hour. Approximate working day per month can be 25 days. With the existing battery charging infrastructure, the total battery charging duration is 7 to 8 hours.

If the existing technology is upgraded with PV powered LLC full bridge resonant converter system, the charging time is considerably reduced to 4.5 hours approximately. However, this time-span is still high as the EV owner has to remain idle for this duration of time. The vehicle dormant time is directly reflected in the economic loss of the EV owner. Thus, integration of the BSS with the converter based charging technology fills up the gap of the system by providing a quick replacement of the depleted batteries with fully charged stored batteries already present in the station. Thus, the dormant period drastically reduces to few minutes. This mechanical refueling of battery by screwing and unscrewing of mechanical nuts and bolts merely takes 10 minutes to complete the whole task. So, it is evident that the downtime of the EV can upgrade significantly and can save at least 7 working hours. Therefore 70 INR /hr x 7 hours = 490 INR can be saved per day. Savings per month will be 490 x 25(INR) working days =12, 250(INR) per month. Moreover, utilization of solar energy in the proposed fast charging technology makes it more compatible with rural environment.

5.2. Tabulation of Cost Analysis of Single Unit BSS

Table 5 shows the cost analysis of a single unit BSS.

Table 5 Cost analysis of a single unit BSS

Cost Component	Description	Estimated Cost Range (INR)
Infrastructure Costs	Land acquisition, civil works, construction, and permits.	1,50000
Battery Unit Costs	Initial purchase of swappable batteries (varies with type/capacity).	70,000
Charging Equipment	Battery chargers, power electronics, and transformers.	12,000
Battery Swapping System	Robotic arms/mechanisms for automated battery swapping.	45,000
Energy Storage System	Optional on-site energy storage (e.g., lithium-ion battery packs).	10,000
Solar Power plant cost	Solar panels or wind turbines for renewable power generation (optional).	1,25000
Maintenance Equipment	Tools and spare parts for regular station upkeep.	30,000
Miscellaneous Costs	Marketing, legal fees, and other administrative expenses.	10,000

The overall cost of this proposed plant; 4,52000 (INR)

6. Conclusion

In this present research work, a fast charging technology powered from PV source is proposed. The main objective of this present work is to reduce the battery charging time and upgrade the total active-duty period of each EV. It has been observed in the result and analysis section that to attain 100% SOC, the time required by the proposed technology is 5 hours, whereas the conventional method takes 7.5 hours duration to do the same. Thus, saving charging duration by 2.25 hours is a considerable advancement in the charging technology. However, 5 hours waiting period to fully charge the battery is yet another limitation of the charging technology, as it is reflected as an economic loss of the EV operator. Thus to provide an immediate solution, BSS is incorporated with the present proposed scheme. This BSS mechanically refuels the batteries within 10 minutes and helps to maintain the uninterrupted EV service.

As discussed in section 3.2, an EV operator can save up to INR 12,250 per month by availing the BSS technology. Integration of PV energy and BSS technology with LLC based full bridge resonant converter with ERC can be considered as an advancement in the overall performance of the EV battery charging technology in rural Bengal.

However, IOT based implementation of the proposed technique remains unexplored. The exploration of the proposed technology with the aid of IOT will further upgrade the technology to an advanced edge. Simultaneous monitoring and control of the SOC and battery replacement of large numbers of EV will become more convenient by incorporating IOT with the present scheme.

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