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Battery Swapping Stations- A Viable Option for Faster Adoption of EVs in India

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Abstract

Total electrification of road transport has its own major constraints. The industry struggles to reduce the plug-in charging times and impact on the grid of battery-powered electric vehicles. Battery swapping is one of the best concepts to overcome the constraints where Vehicles swap low state charge batteries for charged ones at Battery Swapping Stations (BSS). A Battery Swapping Stations (BSS) is a charging place/fuelling station equipped with number of standards and certified charging units and battery swapping robots. A BSS has a certain amount of battery inventory of fully charged batteries of different sizes and types thus providing a faster and intermediate service to the customer looking for recharging their batteries. This paper studies the challenges and opportunities for the use of BSS in India.

Keywords: Battery Swapping, Charging Station, Electric Vehicles, G2V, V2G

1. Introduction

India is currently having certain issues like having to depend on import fuel (both oil and coal), having less skilled manpower and jobs, to meet climate change goals in the automobile and energy landscape, Research and Development (R&D), etc. E-mobility matters most important for India as the adoption towards Electric Vehicles (EVs) shall solve the problems faced by India. The entire shift in the automobile sector to E-mobility can reduce the dependency on fuel imports leading to the promotion of energy security and climate change goals, creation of new jobs, reduction of carbon emissions (increases clean kilometres), spurs innovation in local R&D and manufacturing and also promotes entrepreneurship. Post-COVID pandemic, the adoption rate of Electric Vehicles (EV's) is expected to increase in India given the existing policies of the Government of India (GoI). Currently, batteries of EVs around the globe are mainly recharged through two charging methods viz. slow charging at home and fast charging at public stations. The present market in the world revolves around the use of two-wheelers (2W) and four-wheelers (4W) covering mopeds, motorcycles, cars, passenger vehicles, buses, trucks, etc. The main reason for the slower adoption of EVs in the world and India is due to two reasons viz. cost and recharging time. In 2018-2019, the battery cost has dropped down to more than 85% since 2010. With the slow increase in the adoption and better policy and regulations for e-mobility will make the cost of the battery decrease rapidly in the coming years[1].

Since 2013, the Indian government had taken ambitious steps to promote the use of EVs through schemes such as NEMMP, FAME-I, FAME-II, etc. which indicates that EVs are the future of the automobile sector for the next 50 years or more. Along with the government of India, 50% of Indian states have also taken initiatives to put proper policies and regulations in place to promote the use of EVs. A few of the states are Karnataka, New Delhi, Andhra Pradesh, Maharashtra, etc. As far as Indian EV market segments are considered, Three wheelers (3W) dominate more than 2W and 4W market segments. India is the world's largest market for Three wheelers. These 3-Wheelers or Auto- Rickshaws are being used seamlessly

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in tandem with public transportation and for intra-city good movement. The majority (78%) of the Passenger 3Ws are configured for less than 4 seats and another 21% have more than 4 seat configurations. For 3-wheelers in India, battery swapping may be encouraged to strengthen the possibility of overcoming range limitations in inner cities[2]. Battery swapping is doable and will be much more efficient if started in India for faster adoption of EVs. As the 2W and 3W category of vehicles falls under small vehicles, battery swapping solutions are the best option for this kind of vehicle as the battery sizes are less, less weight of the battery and less time is involved in the swapping process.

2. Battery Swapping Station

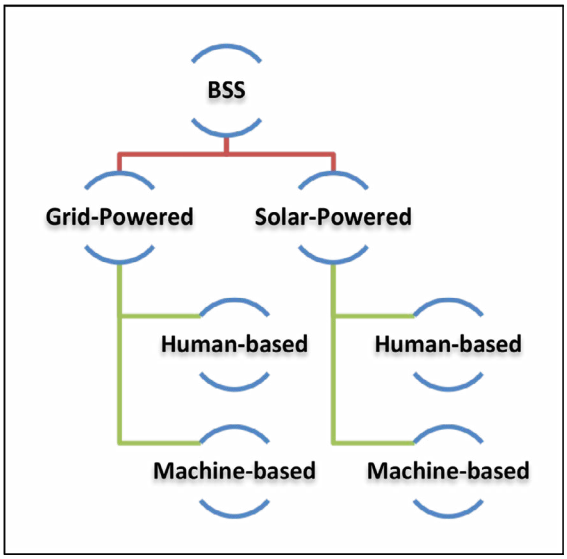

Figure 1. Types of BSS (Source: *Author*).

Battery Swapping Station (BSS) shall mean a station where any electric vehicle can get its discharged battery or partially charged battery replaced by a standard and fully charged battery. A BSS has a certain amount of battery inventory of fully charged batteries of different sizes and types thus providing a faster and intermediate service to the customer looking for recharging their batteries. There are basically two types of BSS viz. grid powered and solar-powered. The operation involved in the replacement of the battery (full charge) in BSS shall be either by use of an automated battery replacement machine or by hand (human-based). Figure 1 provides the different types of BSS which are available presently in the world. In the future, the possibility of using wind power or other renewable energy-based power source for BSS and Battery-Based Energy Storage System (BESS) for BSS is highly likely.

The main function of BSS is to provide a full charge to the depleted or low-charge battery by replacing it with a new, standard and fully charged battery. Batteries in general which are used in EVs are of two types viz. low weight (small-scale batteries used in 2W) or heavy weight (high-capacity batteries used in 3W and 4 W). Figure 2 provides the block diagram of BSS operation. In general, 2W EV batteries and to some extent 3W EV batteries are having low weight and therefore can be lifted by hand easily to replace them with the new battery at the BSS. This operation in BSS will not involve the high cost of machinery in automating the replacement process.

There are four different swapping techniques that could be implemented based on the position of the battery in the EV and the point of application of the robotic arm and are given as follows[3]:

- Sideways swapping: This is mostly employed in the case of e-buses, e-trucks, e-autos, etc. where the EV batteries are located on the side of the EV and are convenient to remove.
- Rear swapping: This is utilized for EVs in which the battery is placed in the rear end. Usually, this type is present in e-cars (E-4W).
- Bottom swapping: This is used for EVs whose battery is placed at the bottom. The swapping station is built in such a manner that the car is placed on an elevated platform and the batteries get swapped from the bottom using a robotic arm and other accessories generally, placed below the ground level or manually like in repair/service centres.
- Top swapping: This is most commonly used for the e-buses wherein the batteries are placed at the top and upon the arrival of the bus, the rooftop opens and the swapping is completed by means of the robotic arm.

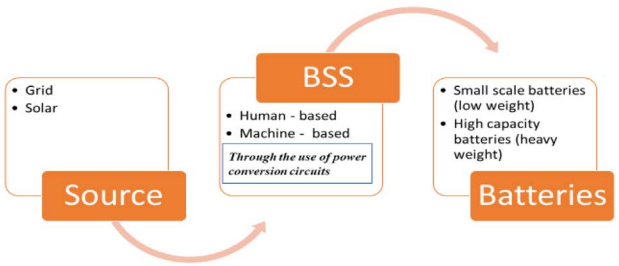

Figure 2. Block diagram of BSS *(Source: Author).*

3. Merits and Challenges of BSS

Battery Swapping is largely being considered as a trade-off between high battery sizes for meeting range requirements and lowering the vehicle costs as they can be sold without the battery largely for 2W and 3W. Battery Swapping will require a higher stock of batteries, detailed safety and charging protocol and require land for storage of battery stocks. Swapping does not do away with the additional grid/wiring infrastructure costs which will be similar to requirements for conventional DC/AC charging stations (EVSE). The charging infrastructure of EV i.e., EVSE has to satisfy extensive requirements before it is introduced to the market. Apart from faultless communication, power is a prime consideration. The challenges consist of the required compatibility with different vehicles (EV), charging interfaces and power grids[4].

Regulatory issues remain around battery swapping stations integrating with the grid, providing grid balancing, charging at off-peak hours, and the tariff rate applicable. It will require a strong synergy between energy and automotive applications for swapping to be successful. The main issues are around standardization, commercial viability and reliability which are provided below:

- Standardization of EV Lithium-Ion Battery Packs has not happened globally. Majority of the auto OEMs prefer to control their design strategies for battery packs as their core technology.
- Commercially Viable Business Models, with the FAME subsidies not recognising vehicle independent of battery it is difficult to create business models.

The reliability of Leased/Rented Battery Packs is questionable, given poor handling protocols, causing potential safety risks and sub-optimal service to customers.

Major advantages and challenges of BSS are provided in Table 1. Speed is the main attraction to the BSS model and does not need to leave the vehicle while BSS operation occurs (like in a conventional petrol/diesel station). In the case of a normal EV charging station, EV owners need to operate the EV plug for them to charge their batteries. With advancing charging technologies, EV owners need to get updated with new versions of chargers to satisfy their daily activities. In the case of BSS, EV owners need not worry about the upgradation as it is taken care of by the BSS itself. BSS can help the power system by providing power to the grid during peak demand. BSS along with BESS can help regulate the frequency, and load smoothening, and act as a reserve for the power system. BSS infrastructure is complex and costly in the case of automated or robotic-based operations. As the EV market is at the nascent stage, the use of BSS can be promoted for E-2W, E-3W, and taxi fleets for faster adoption and better usage of BSS. Access to the location is a major challenge in India. With different types of batteries, brands, and less cross-platform features, the success of BSS model in EV market is difficult. The battery will degrade at a faster rate over time. New battery packs are generally favoured by the customers and the old batteries will offer low energy storage and thus reflect in the mileage of EVs. Availability of adequate electricity connections to suitable locations is another major challenge. Smart BSS (SBSS) can help make the BSS model very successful. Some of the components which are implemented in smart BSS are smart charging,

Table 1. Advantages and challenges of BSS

Advantages of BSS	Challenges of BSS
1. Mimics the experience of exiting fuel pumps (petrol/ diesel station)	1. Upfront cost (high cost of robotic-based battery swapping)
2. Eliminates the waiting time for charging	2. Utilization (only compatible batteries)
3. Increases run-time.	3. Operational cost
4. Improves remunerative opportunities for shared e-mobility drivers	4. Provision of land space
5. EVs could be sold without batteries as batteries constitute 40 to 50% of the cost of EV	5. Parking space
6. Improves demand	6. Load availability
7. Improves battery life and reduces the anxiety of the user	7. Civil works
8. Provides grid–balancing solutions by balancing the demand load and providing energy storage opportunities (The system can be used as renewable energy storage)	8. Range anxiety
9. Improves the utilization of land and reduces the fiscal burden	9. Longer charging time
10. Creates new jobs, business models, and entrepreneurial opportunities	10. Less business models
11. Promotes innovation in research and development	11. Battery ownership
	12. Battery degradation
	13. Not standardized

cloud-based data transmission, the internet of things, location tracking system, and time-based charges, etc. The international standards for BSS are IEC TS 62840-1 and IEC 62840-2 which provide the general requirements and safety requirements respectively. There are no Indian standards (BIS) as of today for BSS[5].

Due to a lack of involvement in supporting the development and usage of BSS, these standards have not been made mandatory for any country across the world.

Being the most attractive developing nation in the world, India provides a huge market opportunity for the EV sector (e-mobility). Also, with the depletion of fossil fuels and the incorporation of the renewable sector and alternative fuels for the transportation sector, EV Charging can help or acts as an enabler in grid reliability improvement for India. Privately owned BSS could be encouraged thereby utility or its distribution franchise or any other third party can aggregate the demand for batteries and set up BSS. Battery swapping will not amount to electricity rescale and hence third parties can set up the stations with intimation to the distribution licensee to avail of special category tariff. The BSS can receive electricity in bulk at a single point from a distribution licensee or through open access to charge the batteries as per the provision of the Act. The bulk supply tariff or single point supply tariff shall be determined by the State Electricity Regulatory Commission (SERC) of the respective states of India.

Despite not being a major per capita polluter, India has committed itself to COP-21 to bring down the pollution levels in the country. To scale up the business of battery swapping in India, three things need to be covered viz. encouraging automotive use of batteries not sold along with vehicles, extending incentives to battery swapping business models and offering GST subvention on swapping services. One of the successful models of BSS is the example of Gogoro BSS in Taiwan. Gogoro is a Taiwan company in the business of selling E-2W and BSS infrastructure in Taiwan. It has set up GoStations along with ATM-sized vending machines where the discharged battery can be readily swapped for fully charged batteries. The BSS is integrated with the cloud system of E-2W to transmit data on vehicle and battery status. Similarly, Better Place BSS stations in Israel are an example of the failure model of BSS. Their idea was to separate car ownership from battery ownership, which would make the cost of an EV comparable to the cost of an Internal Combustion Engine (ICE) vehicle since battery cost would be excluded from the initial car purchase. The EV customers using this BSS were paying for the electricity charges based on per-mile usage under a subscription model. These BSS were compatible with only applicable for a few EVs and not for all. Also, the BSS infrastructure is robotic (automated) based, has lower market penetration, and is a high cost[6-7].

4. Operations of BSS

Battery swapping stations are also becoming a popular concept for countries like India which are having dense populations. BSS is a business model wherein by separating batteries from vehicles, you can bring down the cost of an electric vehicle to that of an Internal Combustion Engine (ICE), the cost of energy becomes cheaper than gasoline, and the cost of maintenance becomes 40% lower. The total cost of acquisition thus becomes lower and the total cost of usage also lessens. By making a battery swap within one minute, which is possible, we can address both range anxiety and refuelling time. It is faster to swap batteries than to refuel with gasoline today, which takes about 10 minutes. Providing a battery as a service removes those anxieties because consumers will always get a battery that works. It is like a gas cylinder that gets changed and guarantees you the same amount of energy. The BSS can be installed at existing petrol stations, similar to petrol pumps, or public parking lots enabling the establishment of a cost-efficient infrastructure.

Carrying a 200 kg battery is a huge challenge for us humans, but for a machine, it is a simple task. BSS will find the location of the battery compartment through an optical search system, extract the discharged battery and send it to the battery storage for charging, replacing it with a fully charged one. In the storage, the batteries are charged under harmonious conditions- minimizing stress on the battery and the grid. Payment is handled through an app or an RFID system, enabling fast and easy transactions. The BSS functions as a distribution system for batteries and is equipped with multiple sensors, motors and computer systems if automatic. BSS swaps the batteries from the side of a vehicle -reducing the unit's complexity, size and cost.

Battery-swapping stations require flat or plane areas for proper installation. Cites from China such as Shenzhen and Hangzhou have flat areas, they had adopted BSS whereas cities like Chongqing (China) with most mountain areas and very few flat areas, the adoption of

BSS is difficult and they can go for fast charging stations[7]. Whereas, a few cities in India have mountainous areas and some flat areas. Hence, not all places or cities in India could go for BSS. The Ministry of Power, Govt. of India has amended the charging station guidelines issued in October 2018. They have now limited the tariff, for the supply of electricity to EV public charging stations, to be no more than 15% of the average cost of power supply. Another change is that for all practical purposes, the Battery Charging Station (BCS) will be treated at par with the Public Charging Station (PCS). The tariff for electricity supply will also be the same for PCS and BCS.

BSS consists of 3 major components viz. source, charging circuit or power conversion circuit and load. The power flow can be either from source to load or from load to the source which depends on the usage or requirement of the user/ customer. The input power source can either be from a grid supply or solar energy or a Battery Energy Storage System (BESS). The grid supply provides Alternating Current (AC) in nature with a 50 Hz frequency whereas the solar energy from solar photovoltaic modules is installed in rooftop or decentralized power plants and BESS provides Direct Current (DC). The main component in BSS is the charging or power conversion circuit which can either be a rectifier (AC to DC) or chopper (DC to DC) or inverter (DC to AC) depending on the power flow direction. The actual output power (DC) of the PV system is mainly affected by solar irradiance and ambient temperature. To improve the service availability of solar-based BSS without increasing the charging cost, the use of BESS-based BSS would be a good solution to the problem[8]. If the power supply input is from the grid, then a rectifier is used whereas in the case of power supply input from solar energy or BESS, then a chopper or linear switching regulator is used. The load can be either battery or solar energy. The power flow process from source to load through the power conversion circuit is called "Grid to Vehicle (G2V)". In the process of G2V, the load is the discharged battery from EVs. Similarly, the reverse flow process from the load (acting as a source) to the source (acting as a load) through the power conversion circuit is called "Vehicle to Grid (V2G)". The load in the V2G process is either grid supply or BESS.

Figure 3 provides different types of usages of BSS and their direction of power flow. It can be observed that there are 7 ways of using BSS out of which 3 power flow processes are G2V and 4 other power flow processes are V2G. For a better balance of power flow between the BSS and grid, a bi-directional inverter can help maintain stable voltage for the DC bus of BSS and the distribution grid through a distribution transformer. An Energy Management System (EMS) for BSS can help monitor and control the operations of the BSS. Many theoretical optimization strategies to run the BSS are yet to be implemented in practice. Much more research work is needed to study the battery-swapping service model which is necessary to improve service availability and reduce charging costs. To promote the use of EVs in India, the BSS with G2V process capability is sufficient and then, later on, could be advanced to implement V2G process.

Advanced BSS (ABSS) are involved in communicating with the power distribution grid to participate in the market activities. There are three ways of doing business involving BSS and the distribution grid as follows:

- Supply power to the grid from the batteries (B2G).
- Charging the battery from the grid (G2B).
- Charge the battery from another battery (B2B).

The BSS must own the batteries, and perform maintenance, labour costs, and degradation aspects in order for the business models to succeed. For the replaced battery with a full charge, the EV owners shall pay a fixed fee. Figure 4 provides different types of interactions of the BSS with EV owners, market and power systems. Figure 5 provides an overall perspective of BSS. Researchers indicate that BSS is more suitable for public transportation in distribution systems. The charging and the logistics of depleted batteries and well-charged batteries must be optimally managed to maximize the revenue of BSS. A closed-loop supply chain-based model of BSS could be better for optimal operation. BSS could be integrated with appropriate control software or techniques for optimal scheduling of an aggregate number of EV batteries that are charged centrally to power local EVs or could also act as and then shipped via vans to other Battery Swap Stations (BSSs) stationed remotely or in a mobile van/ truck systems. BSS must be having the capability to determine optimal schedules for battery charging, battery replacement and truck routing. BSS along with day-ahead dynamic scheduling of EV battering charging could help the owners get a profit margin of more than 25%. A flexible decision structure for BSS is needed including the BSS operation time and intelligent control system for V2G and G2V operations[10-14].

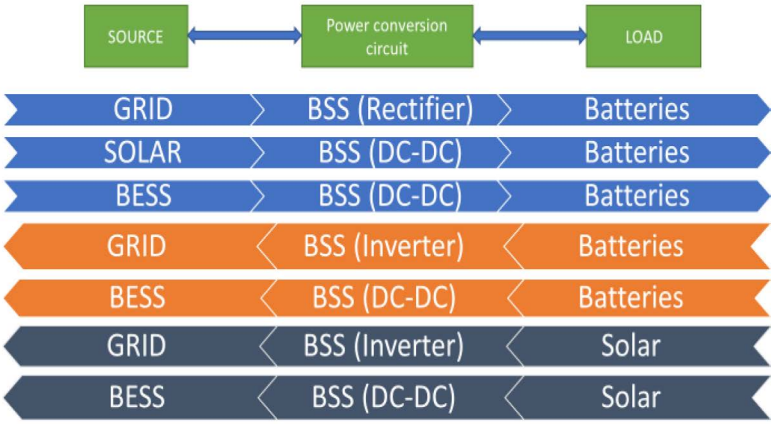

Figure 3. Operations of BSS (Source: *Author*).

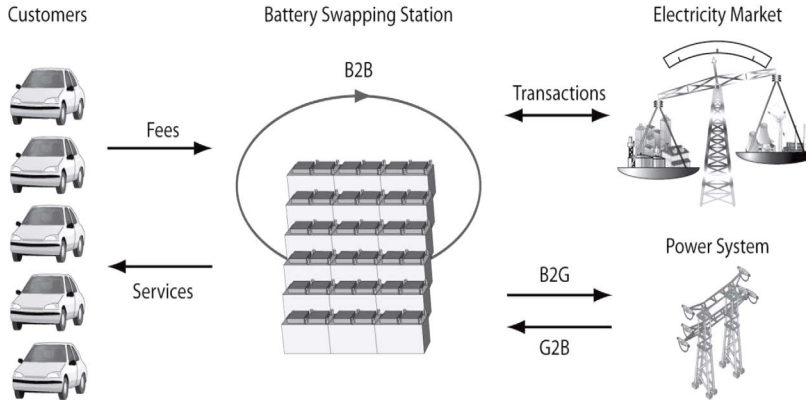

Figure 4. BSS interactions with EV owners, market, and power system[9].

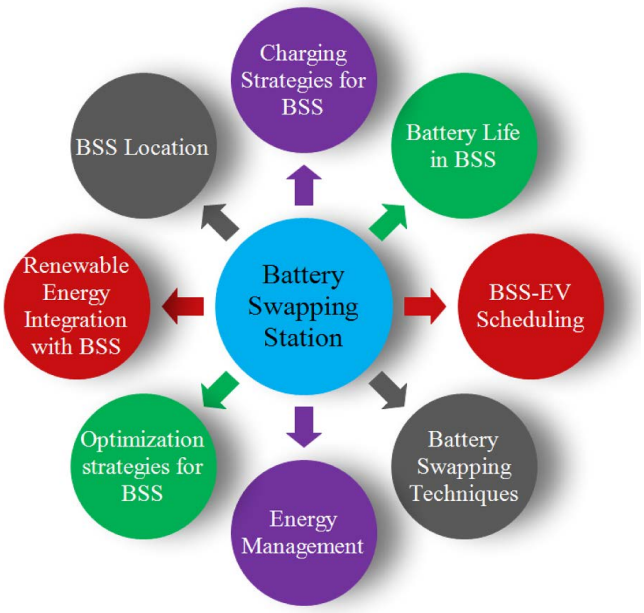

Figure 5. Overall picture of battery swapping station.

5. Conclusion

Presently in India, over 90% of vehicles are 2W; electric 2W batteries can be charged from any single-phase plug point. Battery swapping on 3-Wheelers may be successful- a new business model of 3W sold without batteries and a battery leasing agency owning and renting charged batteries in a city is worth exploring. Battery swapping is not yet feasible for cars and buses (although trials are in progress). Innovative models for BSS are to be explored to make it successful. This paper provides a brief introduction to the BSS, its advantages, challenges and usages thus making it viable for faster adoption of EVs in India.

With the present scenario of the EV landscape in India, EV consumers will like the idea of BSS since it is far easier to swap the battery than to charge it. However, with the quick charging technology advancing each day, the range of EVs increasing and the quicker charging of the EV batteries getting lesser, Battery swapping might be a good idea in the long run or it might get obsolete over the years. Ultimately, there is a potential of battery swapping to become a successful business model for commercial electric vehicles. Fleet operators like buses, taxis etc. would swap their battery packs at their own facilities and distribute battery swaps among various electric vehicles. International cooperation is essential to the faster adoption of EVs in India.

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