Fast Charging Station Planning Framework with Battery Swapping Facilities: a Techno-Economic Approach

Shakti Vashisth, Praveen Kumar Agrawal, Nikhil Gupta, Bhuvan Sharma, Anil Swarnkar and Khaleequr Niazi

January 27, 2025

Fast Charging Station Planning Framework with Battery Swapping Facilities: A Techno-Economic Approach

Shakti Vashisth
Dept. of Electrical & Electronics Engineering
NIT Sikkim
Sikkim, India
shaktivashisth@nitsikkim.ac.in

Praveen Kumar Agrawal
Dept. of Electrical Engineering
MNIT Jaipur
Jaipur, India
pkagarwal.ee@mnit.ac.in

Nikhil Gupta
Dept. of Electrical Engineering
MNIT Jaipur
Jaipur, India
nikhilgupta.ee@mnit.ac.in

Bhuvan Sharma
Smart and Resilient Power Mobility
AEEE Delhi
Delhi, India
bhuvansharma27@gmail.com

Anil Swarnkar
Dept. of Electrical Engineering
MNIT Jaipur
Jaipur, India
aswarnkar.ee@mnit.ac.in

K.R.Niazi
Dept. of Electrical Engineering
MNIT Jaipur
Jaipur, India
krniazi.ee@mnit.ac.in

***Abstract*—Fast charging infrastructure is widely accredited as obligatory for the market success of plug-in electric vehicles (PEVs). However, a fast-charging station (FCS) necessitates capital-intensive infrastructure and network connections, although fast-charging infrastructure might be profitable in long-term multi-stage planning. In addition, the demand for fast charging of EVs varies significantly and the maximum power required for charging stations may only be for a short duration in a day. Therefore, the profitability of stationary energy storage and the demand for fast charging have gained broad attention. This paper aims to provide a framework for FCS planning to consider energy storage systems. It has been assumed that the FCS is equipped with a battery bank (BB) of suitable capacity to enhance the profit of the FCS considering the dynamic price signal of electricity. A definite portion of BB is utilized to facilitate battery swapping (BS) for EV drivers. A highly simplified algorithm is proposed to coordinate the charging/discharging of BB and BS considering concurrent EV traffic and dynamic price signal to optimize techno-economic advantages. The simulation results reveal that the integration BB and BS increases the NPV and the net profit of the FCS owner by 50.56% and 54% respectively along with 26% reduction in waiting time of the EV users. The technical studies are carried out on the 33 standard bus distribution systems.**

***Index Terms*—Plug-in EVs, FCS planning, Battery bank, Battery swapping, waiting time, net present value**

NOMENCLATURE

i/j	index for PEV/charging outlet
b/s	index for battery bank/ swapping battery
t/y	index for times (minute/year)
$BC(i,j)$	battery capacity of ith EV at jth charging outlet (kWh)
$BC_{k,b}(b)$	capacity of kth battery in BB (kWh)
$BC_b(s)$	battery capacity of SB (kWh)
$C_{I,FCS}(y)$	total investment cost at FCS in yth year($)
C_L/C_B	cost of land/building
$C_{CO}(y)/C_{EN}(y)$	cost of charging outlet/electrician $)
$C_{OMT}(y)/C_{I,b}(y)$	Other materials/BB ($)
$C_O(y)/C_{SS}(y)$	cost of installment/substation($)
C_{bat}	cost of the battery ($)
$C_{O\&M,FCS}(y)$	O&M cost of FCS ($)
$C_{O\&M,b}(y)$	O&M cost of BB ($)
C_{deg}	battery degradation cost $
C_l	labour cost for battery replacement ($)
DOD	depth of discharge of battery
ς	base PEV traffic
$E_b(t)$	energy purchased from the grid to charge BB (kWh)
$E_d(t)$	energy sold to charge EVs (kWh)
$\eta(i,j)$	charging efficiency of ith EV at jth CO
η_b/η_d	charging/discharging efficiency of BB
F_A	floor area required for FCS (m^2)
IC	installed capacity of substation (kVA)
k_{PEV}	PEV base traffic conversion coefficient
λ	total number of days in a year
l_{bb}	life cycle of battery
m	total number of batteries in BB
m_s	total number of batteries used in swapping from BB
m_b	total number of batteries used as BB
N_i/n_{co}	total number of PEVs/COs

P_c	charger rating(kW)
P_G	purchasing cost of electricity($/kWh)
P_{sb}	selling price of electricity at FCS using BB and SB to EVs ($/kWh)
R_y	Revenue obtained in yth year ($/kWh)
$soc_i(i,j)/soc_f(i,j)$	initial/final SOC of battery of ith PEVs at jth CO
$soc_i(b,t)/soc_f(b,t)$	initial/final SOC of bb at tth instant
$soc_i(s,t)/soc_f(s,t)$	initial/final SOC of battery used in SB at tth instant
$soc_i(b,t_1)/soc_f(b,t_1)$	initial/final SOC of BB at t_1th instant
$soc_i(b,t_2)/soc_f(b,t_2)$	initial/final SOC of SB at t_2th instant
$s/\wp$	AMC ratio/inflation rate
x/Z^+	a/real positive integer

I. INTRODUCTION

Conventional vehicles are gradually being replaced by electric vehicles (EVs) due to their reduced maintenance and running cost, better drivability, and environmental friendliness. However, the major hurdle to flourish PEVs at large charging time [1]. FCS aims to recharge PEV batteries within a short period similar to that for gasoline refueling of conventional vehicles. For the successful deployment of FCS, proper planning is needed considering various techno-economic concerns. The high penetration of FCS accumulates various challenges in front of the FCS owner, and the utility. One of the major challenges is high grid connection cost due to high power demand. Which exceeds the power limit of many conventional distribution grid transformers when combined with the conventional load. However, the grid goes under more stressed conditions when the peak demand of the FCS surges up with the peak demand of the conventional load. Consequently, an FCS operates at peak power only for a limited period of time i.e., twice a day [2]. This will create significant stress on the local distribution system. The increased power demand needs grid up-gradation which is a very costly and time-consuming process. Therefore, to reduce the effect of peak demand, the FCS planner may be interested in alternative solutions. The coordinated charging and discharging of PEV with an energy storage system (ESS) can be a preferred solution. The battery can provide high power output for a short period of time and respond nearly instantaneously to a control signal. Even though, PEVs still take a long charging time as compared to traditional internal combustion engine (ICE) vehicles powered by gasoline [3]. This may lead to the formation of queues and long delays. To reduce PEV driver's waiting time and peak loading on the FCS, the forthcoming technology is battery swapping [4].

Battery swapping technology facilitates PEV drivers to swap their empty batteries with the fully charged battery. It takes less than 5 minutes to swap the empty battery with a fully charged battery [5]. The battery swapping station (BSS) can provide massive flexibility to grid operators for performing critical tasks such as balancing the grid [6]. In the existing literature, some of the work is done by considering the BESS with FCS and some work considers battery swapping charging stations (BSCS) to gain several techno-economic benefits. However, no one used the collaborative effect of BESS and swapping facilities with FCS in the multi-stage planning of FCS.

This paper presents a framework for FCS planning with DER integration. It has been suggested that the FCS is equipped with a battery bank (BB) of suitable capacity to enhance the profit of the FCS considering the dynamic price system of electricity. A definite portion of BB is kept spare to facilitate battery swapping to PEV drivers. A highly simplified algorithm is proposed to coordinate the charging/discharging of BB and swapping of batteries considering concurrent PEV traffic and dynamic price signal to optimize techno-economic advantages. The simulation results on a benchmark test distribution system highlight the importance of the proposed method considering financial benefits to FCS owners and techno-economic advantages to utility.

A. Literature review and contribution of the paper

Energy storage devices are used to regulate the services at FCS to maximize the various techno-economic benefits. The majority of the planning papers only focus on the technical aspect of sizing and siting of FCS [7]. In [7] ESS is coordinated with the PEV charging station via communication and control system to reduce the peak shaving in respect of the main distribution system. In [8] the idea of installation of BESS in the basement of FCS is proposed where the electric energy is stored during low peak power and supplies power to the grid during high peak hours. However, in [9] authors have studied its economic aspects also. These works have been carried out as an economic analysis. However, do not consider a precise model of battery degradation in the analyses. Although fast charging provides a great deal of promise. However, authors are still deterred from purchasing PEVs on account of limited driving range, long charging times, and high battery replacement cost. An efficient solution to these issues involves the deployment of battery swapping stations (BSS). In these stations, PEV drivers can exchange their discharged battery with a charged one. This service is comparable to the service that gasoline stations provide to ICE [10]. In [10] an optimized BSS has been presented. However, the proposed methodology is based on the assumption that consumers are willing to take a battery on lease instead of purchasing the battery for cost effectiveness. This paper presented a novel solution for a battery-sharing station (BShS) and a battery-sharing network (BShN) to mitigate the negative impact of the PEVs' scale and enhance the reliability/stability of the grid. However, BShS and BShN both are connected via telecommunications which may suffer from security hacks and several interruptions. In ref. [11] optimal battery charging schedule is formulated as a stochastic control problem. Ref. [12] developed a robust optimization model that aids the planning process for deploying battery-swapping infrastructure. However, these papers do not consider the battery degradation cost. In [13] developed a dynamic programming model to assist in making optimal charging and purchasing decisions. But battery swapping has been placed in which during the swapping fully charged battery is replaced by a nearly empty battery instead on customers arrival preferences i.e., first-in first-out (FIFO). This may create dissatisfaction among to the customers. Therefore adding ESS might increase the profitability of FCS in two ways. It can be used as a battery bank which will encounter the peak demand of the FCS as well a fully charged battery can be swapped with the empty battery at a higher price. BESS increases the financial benefits to the FCS owner, PEV driver, and the utility altogether. The salient contribution of this paper is as follows.

1) From the FCS owner's perspective, it increases the NPV of the FCS planning project.

2) From the PEV driver perspective, batteries are given at lease to EV users so that the cost of the EV will drop dramatically. In addition, it reduces the service time of the EVs thus addresses two major concerns of the EVs' driver.

3) From the utility perspective, the battery swapping load can be preserved as a huge flexible load. By coordinating the charging/discharging time of the batteries, the potential peak demand or overloading, caused by increasing penetration of EVs, can be reduced.

The paper is organized as follows: section II presents the proposed methodology, and section III presents the simulation results. Finally, conclusions are described in section IV.

II. Proposed Methodology

In this section, methodology to plan FCS using BB and BS facility has been described. Initially, FCS is assumed to have 500 as base PEV traffic. PEV traffic varies dynamically in every year of planning. Therefore, all the investments have been made in multi-stages to relieve the initial burden of the FCS owner. The BB is integrated with the FCS to reduce the peak loading at the FCS. Different standards for PEV batteries have been explored by several organizations around the world. Therefore, all the batteries are taken in different sizes to make this planning project more realistic. A highly simplified algorithm is proposed to coordinate the charging/discharging of BB and swapping of batteries considering concurrent PEV traffic and dynamic price signal to optimize various techno-economic advantages. Coordination between the charging/discharging of BB leads to various techno-economic benefits to the FCS owner, PEV driver, and the utility altogether. This problem addresses these techno-economic benefits. Primarily, for the technical aspects the simulation is carried out at 33 bus standard distribution system. Furthermore, load flow analysis is performed and determined considering various concerns of the utility such as peak demand, voltage profile, and power losses at the distribution system. Moreover, for the economic aspects, an analytical approach is developed for estimating the net present value (NPV) of the FCS planning project. In the proposed methodology number of charging outlets (NCO) is taken as the decision variable constraint by realistic mean waiting time and installed capacity. The load profile curve is simulated based on Waterloo TTS data [2]. The simulation has been carried out for 100 trials to achieve better accuracy in the load profile at FCS and it has been found that the load profile curve for the FCS two have peaks in 24 hours. The economic assessment study of real-time pricing signal is also performed and it has been concluded that the load profile at FCS is quite different than RTP. In the case of FCS, the majority of the people charge their PEVs in the morning and evening (office timings) [13]. However, in the case of RTP signal electricity price is high at the time of evening (when demand for all types of loads is high). In this work, both the profiles (load profile of FCS and RTP signal) are taken into consideration. Therefore, BB (about 17% of the total load) is charged when RTP is low as well as PEV traffic is also low at the FCS in G2B mode and discharge for the period in B2V mode when high load and high RTP signal coincide i.e. at the time of evening to get more profit. All the PEVs are charged in B2V mode until all the batteries of BB are exhausted. Moreover, the NPV of the FCS is determined. Furthermore, One-third part of the BB is reserved to provide the swapping facility to the PEV driver. Battery swapping takes a few minutes to do which increases PEV driver comfort that's why, batteries are swapped at a higher price than the charging price thereby FCS owner get more benefits. Moreover, NPV is calculated. Multi-stage planning for the N years has been performed. Revenue has been calculated till the 2N-1 years (total life span of each CO which is installed in the last year of planning horizon). Finally, a comparison study is carried out for multi-stage planning of FCS for all three cases when only FCS is considered, FCS with BB, and FCS with BB and BS.

A. Local load on FCS

Local load on the FCS is taken from the use of the large database of mobility statistics available from the Waterloo Region TTS [24]. PEV traffic over a sample day is

$$N_{PEV} = k_{PEV}\varsigma; k_{PEV} \in Z^{+} \tag{1}$$

B. Charging model of PEVs

The charging model of PEV at FCS is calculated using the FIFO queuing model. The charging/Service/departure time of i PEV at jth CO is formulated in (2), (3), and (4) as

$$T_c(i,j) = (soc_f(i,j) - soc_i(i,j))BC(i,j)/P_c\eta(i,j) \tag{2}$$

$$T_s(i,j) = T_c(i,j) + T_w(i,j) \tag{3}$$

$$T_d(i,j) = T_a(i,j) + T_s(i,j) \tag{4}$$

Constraints are

$$T_s(i,j) \leq T_s^{max} \tag{5}$$

$$IC \leq IC^{max} \tag{6}$$

C. Charging and discharging models of the BB

One-third of the BB is used for swapping purposes during the peak demand at FCS, at the highest price. Equation (7) shows the energy required to charge the BB. The first term shows the charging energy for the battery storage and the second term shows the charging energy for the BS. Minimum/maximum bounds of SOC levels of the EV batteries are formulated in (8) & (9).

$$E_b(t) = \sum_{b=1}^{mb} (soc_f(b,t) - soc_i(b,t)) BC_b(b)/\eta_b + \sum_{s=1}^{ms} (soc_f(s,t) - soc_i(s,t)) BC_b(s)/\eta_b \forall t \in \Delta t_{chg} \quad (7)$$

$$soc_i^{min} < soc_i(b,t) < soc_i^{max} \quad (8)$$

$$soc_f^{min} < soc_f(b,t) < soc_f^{max} \quad (9)$$

The total batteries are denoted by (10). Equations (11) & (12) represent the battery capacities of all batteries. Discharging energy for the BB is shown by using (13).
Let,

$$m = m_b + m_s \quad (10)$$

$$m_b BC_b(b) = (1-x) BC_b; 0 < x < 1 \quad (11)$$

$$m_s BC_b(s) = x BC_b; 0 < x < 1 \quad (12)$$

$$E_d(t) = \sum_{b=1}^{mb} (soc_f(b,t_1) - soc_i(b,t_1)) * BC_b(b) * \eta_d + \sum_{s=1}^{ms} (soc_f(s,t_2) - soc_i(s,t_2)) * BC_b(s) * \eta_d; \forall t_1 \in \Delta t_{bb}, t_2 \in \Delta t_{bs}. \quad (13)$$

The battery degradation cost due to B2V operation is taken from ref. [14] and formulated as

$$C_{deg} = \frac{C_{bat}\, BC_b(k,b) + C_l}{BC_b(k,b)\, l_{bb}\, DOD} E_d \quad (14)$$

D. Capital Cost

FCS has massive capital cost which considers the initial investment cost and O&M cost. Initial investment cost includes the land, building, substation, charging outlets, electrician, and other material cost which is represented by equation (14). Land requirement is calculated based on the number of charging outlets installed in the yth year. Therefore cost of the land is calculated in (15). Equations (16) & (17) shows the operational and maintenance cost of FCS and BB respectively

$$C_{I,FCS}(y) = C_L + C_B + \sum_{y=1}^{N} (1+s)^{y-1} (C_{SS}(y) + n(C_{CO}(y) + C_O(y)) + C_{EN}(y) + C_{OMT}(y)) \quad (15)$$

$$C_L = n_i * F_A \quad (16)$$

$$C_{I,b}(y) = m(y) C_b \quad (17)$$

$$C_{O\&M,FCS}(y) = n \sum_y \wp (1+s)^{y-1} C_{CO}(y) \quad (18)$$

$$C_{O\&M,b}(y) = m \sum_y \wp (1+s)^{y-1} C_b(y) \quad (19)$$

E. Operational revenue

The operational revenue obtained in the total planning horizon is given in (19). Revenue obtained by charging the PEV from the grid and using a battery bank in a year at FCS is represented by (20). Equation (21) denotes the selling energy which is the fraction of energy obtained from the grid.

$$R_t(y) = \sum_{y=1}^{2N-1} (1+r)^{y-1} R(y) \quad (20)$$

$$R(y) = \lambda((\sum_j \sum_i \Delta E_s(i,j) P_s(y)) + E_b * P_{sb}(y)); \forall y \leq (2N-1) \quad (21)$$

$$\Delta E_s(i,j) = \eta(i,j) \Delta E(i,j) \quad (22)$$

The energy required to charge the PEV and battery bank is taken from the grid. The total energy purchased in a year is formulated as

$$C_E(y) = \lambda \sum_j \sum_i \sum_k \Delta E(i,j) P_G(y) + E_b * P_G(y); \forall y \leq (2N-1) \quad (23)$$

F. NPV of the project

To evaluate the economic feasibility of the FCS planning project during the entire life cycle, the NPV criterion is adopted for estimating the life cycle benefit. NPV of the planning project is given by (24). Where $Z(y)$ is the profit obtained during the planning horizon and formulated in (25)/(26)

$$NPV = \sum_{y=1}^{2N-1} (Z(y)/(1+d)^y) \quad (24)$$

$$Z(y) = R(y) - C_{I,FCS}(y) - C_{I,b}(y) - C_{O\&M,FCS}(y) - C_{O\&M,Bat}(y); \forall 1 < y < N \quad (25)$$

$$Z(y) = R(y) - C_{O\&M,FCS}(y) - C_{O\&M,b}(y); \forall (N+1) < y < (2N-1) \quad (26)$$

III. SIMULATION RESULTS

Simulations are carried out on a standard 33-bus test distribution system referred from [15]. This is a 12.66 kV three-phase balanced distribution system that consists of 33 nodes and 37 lines including 32 sectionalizing (normally closed) and 5 tie-lines (normally open). The base configuration consists of a radial topology by opening all the five tie-lines. The nominal active and reactive loading of the system are 3.715 MW and 2.30 MVAr, respectively. FCS is installed assuming traffic at FCS is 500 PEV and 6 charging outlets. The considered real-time pricing signal is taken from [15]. PEV traffic growth rate is considered 10% in each year of planning. The input parameters are presented in TABLE I.

Fig. 1 illustrates the minute-wise FCS demand profile in all three cases, FCS without DERs, FCS with BB, and FCS

TABLE I
INPUT PARAMETERS

Parameters	Value
BC_b^{min}/BC_b^{max} (kWh)	30/50
$BC_b(s)$ (kWh)	30
$\varsigma/\wp(\%)$	500/5
C_{CO} ($/charging outlet)	$23,500 [16]
C_L ($\$/m^2$)	407 [16]
C_b ($/kWh)	100
C_B ($/charging outlet)	1000 [17]
C_{SS} ($/KVA)	106.5 [17]
C_O ($/charging outlet)	500 [16]
C_{EN} ($/Substation)	2000 [16]
C_{OMT} ($)	300 [17]
d (%)	8 [11]
η_b/η_d (%)	92/90
F_A (m^2)	20 [17]
$N(year)/r(\%)$	10/6
soc_i^{min}/soc_i^{max}	0.20/0.40
soc_f^{min}/soc_f^{max}	0.10/0.45

with BB + BS over the 24 hours. The figure indicates that the energy demand during the peak hours reduced using DERs, whereas, off-peak demand hours are utilized by charging BB and BS.

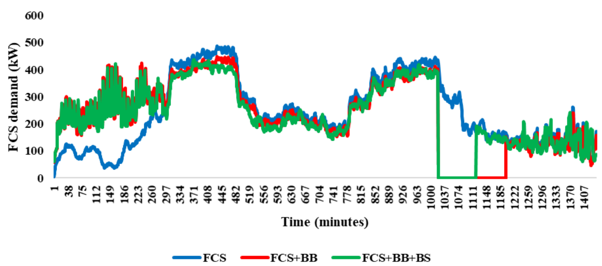

Fig. 1. FCS demand profile over a day

TABLE II compares the impact of three scenarios FCS, FCS with BB, and FCS with BB+BS on grid performance metrics: minimum voltage, peak demand, and power losses. The results show that integrating BB and BS enhances grid stability by increasing the minimum voltage from 0.95 p.u. to FCS to 0.96 p.u. in FCS with BB+BS. Additionally, these integrations reduce peak demand from 487.86 kW to 435.78 kW, indicating improved demand management. Furthermore, power losses decrease slightly from 242.48 kW to 240.63 kW.

TABLE II
COMPARISON OF FCS, FCS+BB, AND FCS+BB+BS

	FCS	FCS+BB	FCS+BB+BS
Peak demand at FCS (kW)	487.86	449.40	435.78
System minimum voltage (p.u.)	0.95	0.9505	0.96
System power losses (kW)	242.49	240.80	240.63

TABLE III illustrates the year-wise PEV traffic and related attributes. It can be observed from the table that CO retirement increases with the growth of PEVs each year in order to maintain the mean waiting time and service time around 1 minute and 8 minute respectively. This consequentially increases the peak demand of the FCS. TABLE IV details the

TABLE III
YEAR-WISE PEV TRAFFIC AND RELATED ATTRIBUTES

Years	NEV	Charging outlets	Mean waiting time (min)	Mean service time (min)	Peak demand (kW)
I	500	6	1.08	8.47	710.31
II	551	7	0.63	8.01	806.80
III	605	8	0.40	7.79	903.32
IV	668	8	0.84	8.23	900.84
V	735	9	0.64	8.03	1001.93
VI	809	9	1.52	8.90	997.40
VII	890	11	0.49	7.89	1190.80
VIII	980	12	0.53	7.92	1276.85
IX	1078	13	0.54	7.92	1371.29
X	1185	14	0.62	8.01	1465.82

financial parameters for FCS planning without DERs over 19 years. As the PEVs and NCOs increase, the initial cost rises, particularly from 7th year onward. The cumulative earnings, revenue yield, and present value (PV) show a gradual increase, with the PV transitioning from negative to positive, indicating an eventual return on investment. This table highlights the financial progression of FCS planning, showing how profitability improves as the network expands and matures.

TABLE IV
YEAR-WISE FINANCIAL PARAMETERS FOR FCS PLANNING WITHOUT DERS

Year	NPEVs	NCOs	IC (kVA)	Without DERs ($)			
				Total investment	Energy purchased cost	Revenue	Present value
1	500	6	1000	0.388	0.441	0.487	-0.326
2	551	7	1000	0.032	0.498	0.549	0.019
3	605	8	1000	0.033	0.547	0.603	0.023
4	668	8	1000	0.009	0.590	0.651	0.051
5	735	9	1000	0.035	0.649	0.717	0.033
6	809	9	1000	0.011	0.699	0.772	0.062
7	890	11	1500	0.061	0.782	0.863	0.021
8	980	12	1500	0.067	0.859	0.948	0.023
9	1078	13	1500	0.039	0.934	1.032	0.059
10	1185	14	1500	0.040	1.031	1.138	0.069
11	1185	8	1500	0.009	0.589	0.651	0.054
12	1185	7	1500	0.008	0.516	0.569	0.048
13	1185	6	1500	0.007	0.442	0.488	0.042
14	1185	6	1500	0.007	0.442	0.488	0.042
15	1185	5	1500	0.006	0.368	0.407	0.035
16	1185	5	1500	0.006	0.368	0.407	0.036
17	1185	3	1500	0.004	0.221	0.244	0.022
18	1185	2	1500	0.002	0.147	0.163	0.015
19	1185	1	1500	0.001	0.074	0.081	0.007

TABLE V compares the financial performance of FCS with BB and BB+BS over 19 years. The data shows that incorporating BB and BS leads to higher cumulative earnings, revenue yield, and PV compared to BB alone, with the BB+BS scenario consistently outperforming the BB-only setup. This indicates that the addition of BS to the charging infrastructure not only enhances financial returns but also shortens the payback period, making it a more profitable investment in the long term.

TABLE V
YEAR-WISE FINANCIAL PARAMETERS FOR FCS PLANNING WITH BB AND BB+BS

Year	Total investment ($)	With BB ($)			With BB+BS ($)		
		Energy purchased cost	Revenue	Present value	Energy purchased cost	Revenue	Present value
1	0.482	0.416	0.487	-0.392	0.428	0.522	-0.370
2	0.037	0.473	0.549	0.038	0.476	0.575	0.060
3	0.038	0.536	0.603	0.028	0.478	0.577	0.059
4	0.014	0.565	0.651	0.071	0.571	0.680	0.093
5	0.039	0.625	0.717	0.052	0.633	0.748	0.075
6	0.015	0.675	0.772	0.082	0.683	0.803	0.105
7	0.065	0.758	0.863	0.040	0.766	0.895	0.064
8	0.072	0.835	0.948	0.042	0.842	0.979	0.066
9	0.044	0.910	1.032	0.080	0.929	1.075	0.105
10	0.045	1.007	1.138	0.089	1.012	1.167	0.113
11	0.014	0.576	0.651	0.064	0.579	0.667	0.078
12	0.013	0.504	0.569	0.056	0.506	0.583	0.068
13	0.012	0.432	0.488	0.048	0.434	0.500	0.058
14	0.012	0.432	0.488	0.048	0.434	0.500	0.059
15	0.010	0.360	0.407	0.040	0.362	0.417	0.049
16	0.010	0.360	0.407	0.040	0.362	0.417	0.049
17	0.008	0.216	0.244	0.022	0.217	0.250	0.028
18	0.007	0.144	0.163	0.013	0.145	0.167	0.017
19	0.006	0.072	0.081	0.004	0.072	0.083	0.006

TABLE VI demonstrates that integrating BB and BS into FCS significantly enhances both operational efficiency and financial performance over time. The inclusion of BB and BS reduces mean WT by 26.56% and increases NPV and net profit by 50.51% and 54.00% respectively compared to FCS without DERs. The results indicate that the integration of BB and BS enhances all the techno-economical parameters significantly.

TABLE VI
COMPARISON OF FCS, FCS+BB, AND FCS+BB+BS

	FCS	FCS+BB	FCS+BB+BS
Mean WT (min)	1.026059	1.026059 (0%)	0.7535 (26.56%)
NPV ($)	333376.8	466414.86 (39.9%)	783351.6 (50.51%)
Net Profit ($)	295668.5	423243.1 (43%)	8987498 (54%)

IV. CONCLUSIONS

This work proposes an FCS planning framework, effectively integrating Battery Banks (BB) and Battery Swapping (BS) systems to address the concerns of utilities, FCS planners, and PEV drivers. The results highlight significant improvements in voltage profiles, reductions in peak demand, and decreased power losses, making it a beneficial approach for utilities. For FCS planners, the model offers reduced initial investments and increased net present value while PEV drivers benefit from reduced waiting times. Moreover, the implementation of battery bank and battery swapping increases the NPV and net profit of FCS owner with the significant amounts i.e., 50.51% and 54% respectively along with reduction in waiting time by 26%. Hence, the systems provides considerable advantages for operators, ensuring a more efficient and economically viable infrastructure.

REFERENCES

[1] S. Vashisth, P. K. Agrawal, N. Gupta, K. Naizi, and A. Swarnkar, "Integration and co-ordinated operation of stationary batteries with fast charging stations," in *2022 22nd National Power Systems Conference (NPSC)*, 2022, pp. 560–565.

[2] O. Hafez and K. Bhattacharya, "Queuing analysis based pev load modeling considering battery charging behavior and their impact on distribution system operation," *IEEE Transactions on Smart Grid*, vol. 9, no. 1, pp. 261–273, 2016.

[3] L. Hua, J. Wang, and C. Zhou, "Adaptive electric vehicle charging coordination on distribution network," *IEEE Transactions on Smart Grid*, vol. 5, no. 6, pp. 2666–2675, 2014.

[4] M. T. Hussain, A. B. Afzal, A. H. Thakurai, A. Azim, R. A. khan, H. Alrajhi, M. R. Khalid, and S. Hameed, "A comprehensive review on electric vehicle battery swapping stations," in *International Conference on Electrical and Electronics Engineering*. Springer, 2023, pp. 317–332.

[5] A. Vallera, P. Nunes, and M. Brito, "Why we need battery swapping technology," *Energy Policy*, vol. 157, p. 112481, 2021.

[6] S. R. Revankar, V. N. Kalkhambkar, P. P. Gupta, and G. B. Kumbhar, "Economic operation scheduling of microgrid integrated with battery swapping station," *Arabian Journal for Science and Engineering*, vol. 47, no. 11, pp. 13 979–13 993, 2022.

[7] D. Sbordone, I. Bertini, B. Di Pietra, M. C. Falvo, A. Genovese, and L. Martirano, "Ev fast charging stations and energy storage technologies: A real implementation in the smart micro grid paradigm," *Electric Power Systems Research*, vol. 120, pp. 96–108, 2015.

[8] W.-D. Xie and W. Luan, "Modeling and simulation of public ev charging station with power storage system," in *2011 International Conference on Electric Information and Control Engineering*. IEEE, 2011, pp. 2346–2350.

[9] M. Gjelaj, S. Hashemi, P. B. Andersen, and C. Træholt, "Optimal infrastructure planning for ev fast-charging stations based on prediction of user behaviour," *IET Electrical Systems in Transportation*, vol. 10, no. 1, pp. 1–12, 2019.

[10] M. R. Sarker, H. Pandžić, and M. A. Ortega-Vazquez, "Optimal operation and services scheduling for an electric vehicle battery swapping station," *IEEE transactions on power systems*, vol. 30, no. 2, pp. 901–910, 2014.

[11] Y. Zheng, Z. Y. Dong, Y. Xu, K. Meng, J. H. Zhao, and J. Qiu, "Electric vehicle battery charging/swap stations in distribution systems: comparison study and optimal planning," *IEEE transactions on Power Systems*, vol. 29, no. 1, pp. 221–229, 2013.

[12] H.-Y. Mak, Y. Rong, and Z.-J. M. Shen, "Infrastructure planning for electric vehicles with battery swapping," *Management science*, vol. 59, no. 7, pp. 1557–1575, 2013.

[13] O. Worley and D. Klabjan, "Optimization of battery charging and purchasing at electric vehicle battery swap stations," in *2011 IEEE vehicle power and propulsion conference*. IEEE, 2011, pp. 1–4.

[14] J. Singh and R. Tiwari, "Cost benefit analysis for v2g implementation of electric vehicles in distribution system," *IEEE Transactions on Industry Applications*, vol. 56, no. 5, pp. 5963–5973, 2020.

[15] B. Sharma, N. Gupta, K. Niazi, and A. Swarnkar, "Estimating impact of price-based demand response in contemporary distribution systems," *International Journal of Electrical Power & Energy Systems*, vol. 135, p. 107549, 2022.

[16] H. Zhang, Z. Hu, Z. Xu, and Y. Song, "An integrated planning framework for different types of pev charging facilities in urban area," *IEEE Transactions on Smart Grid*, vol. 7, no. 5, pp. 2273–2284, 2015.

[17] S. Vashisth, P. K. Agrawal, N. Gupta, K. Niazi, and A. Swarnkar, "Multi-stage planning of fast charging stations for pevs using traffic-based approach," *Sustainable Energy, Grids and Networks*, vol. 30, p. 100662, 2022.