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Optimal Cost Strategy of Electric Vehicle Charging Station for Grid Load Balance

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Abstract: The growth of Electric Vehicle (EV) users is expected to rise in the future. The driving behavior of EV users is inherently unpredictable, necessitating the development of a scheduling framework for EV charging stations, particularly when the number of EVs exceeds one. The substantial load imposed on the grid by a large number of EVs charging concurrently can impact the grid during peak hours. The integration of solar panels into Electric Vehicle Charging Stations offers a viable priority to mitigate the grid impact resulting from EV charging events. In light of the expanding adoption of EVs, there is a critical need to address peak load technological challenges associated with EV charging management. This paper introduces effective solutions and strategies to overcome the problems. The results give a comprehensive solution to EVCS, considering the profit for both EV users and the grid by providing the Time of charging (TOC) based cost for scheduled charging priorities. The effectiveness of the implemented system by analyzing the load shifting of 12.7 Kwh for 100% acceptance, based on EV user responsiveness to the priority. This provides a cost reduction benefit of 22.63 Rs for off-peak hours to EV users, with the additional benefit of fast charging at off-peak hours by selecting a proper strategy for charging according to the requirements of EV users.

Keywords: Electric Vehicle Charging; Charging Scheduling; Solar Integration; Grid Impact; Sustainable Mobility Infrastructure

1. Introduction

The accelerating demand for Electric Vehicle (EV) charging in India is on a constant rise. The concurrent emergence of a multi-source energy system is pivotal for the efficient management of the inherently disordered EV charging[1,2)]. Utilizing renewable energy sources is a crucial and essential step in reducing greenhouse gas emissions and encouraging the electrification of some forms of transportation[3,4)]. Many policies are designed to raise awareness about energy conservation and to reduce air pollution[5,6)], have contributed to the surge in EV numbers. However, this commendable trend has introduced a concomitant challenge by placing an augmented burden on the grid and especially given the random nature of charging loads. Several studies have been undertaken from the perspective of Electric Vehicle Charging Stations (EVCS). In[7)], it is asserted that the charging efficiency of EVs can be substantially enhanced through the implementation of a well-structured charging service infrastructure. The complexity of maximizing profits in an EVCS for a single user amplifies the significantly with a high volume of EVs entering public charging systems, thereby complicating the system and increasing peak loads[8)]. The application of the game theory-based concepts for the charging and discharging of EVs is expounded in[9,10)]. Furthermore, a strategic algorithm for energy management in the context of vehicle-to-vehicle cooperative charging introduces in[11,12)]. [13)]explores the integration of a Photovoltaic (PV) solar system with EVCS, and [14)]proposes a multi-source EVCS incorporating groups of wind and thermal energy sources to enhance profitability. Many studies have been carried out to comprehend the benefits and difficulties connected with the broad adoption of EVs[15,16)]. The economic benefits of the power grid were examined in and the power grid's interests were taken into consideration when determining the charging and discharging costs for EVs[17)].

Problem’s like disorderly charging in residential area mentioned in[18)], where orderly charging proposed based on TOC tariff, valley period charging strategy.

The problem statement addressed in this paper by the collective findings emphasizes the essential need for a well-coordinated infrastructure as the number of EVs continues to rise. The inclusion of multi-source add a layer of complexity, emphasizing the necessity for a meticulously scheduled charging and discharging framework within the EVCS to maximize system profitability. Most of the previous researches are address over the load equalization of grid by scheduling the EV charging, but the EV user priority acceptance is very important to take into consideration.

This paper introduces a novel priority strategy designed to optimize Electric Vehicle (EV) charging rates, while simultaneously addressing their impact on grid load variations. Utilizing Monte Carlo simulation to analyses EV user charging patterns, the study presents priority strategies that aim to achieve optimal charging rates for EV users and mitigate fluctuations in peak grid loads through a game theory-based model. Acknowledging the inherent uncertainty in EV user profile[19,20], the Fechner law[21] is employed to characterize and account for this uncertainty. The key contributions of the paper include showcasing the benefits of optimal charging costs for Electric Vehicles within a multisource energy system, coupled with a priority scheduling approach. The implemented method not only identifies optimal time slots for EV charging at lower prices, aligning with Time-of-Charging (TOC) cost rates, but also strategically sets EV charging priorities to shift grid loads from peak to off-peak periods, contributing to effective load management. Rooted in TOC rates, the proposed multisource EV charging station priorities form a game theory-based optimized model, offering benefits for both the grid and EV users. Moreover, the application of the Shapely value method, based on priority strategies, illustrates the attainment of optimal subsidies. The outlined priority strategies demonstrate efficacy in minimizing grid peak loads, reducing costs, and enhancing user satisfaction. The consideration of EV user acceptance factors in determining optimal charging costs, along with the Shapely value method's insights into specific costs, positions this research as a comprehensive approach that aligns economic and operational objectives, paving the way for sustainable and cost-effective EV charging solutions. The Objectives of this paper given below:

1. Propose a comprehensive solution EVCS, taking into account the profit for both EV user as well as Grid.
2. To explain the structure of the EVCS model, incorporating with the solar energy, also exploring the upcoming trend of V2G integration.
3. To analyses the acceptance factor of EV user in correlation with the priority selection and its benefits for the EV user.

2. The framework of priority strategy basis EVCS model.

At a charging station, the presence of 'N' vehicles is observed, each with distinct charging requirements based on their State of Charge (SOC) and available charging time. Game theory based strategy for both EV users as well as grid is considered with respect to renewable energy sources[22,23]. The management of these charging requirements is fulfill through a combination of grid, solar, and energy storage systems, complemented by Vehicle-to-Grid (V2G) capabilities. In an aggregator-based system, comprehensive data is collected encompassing various parameters such as grid peak hours, EV user arrival times with their respective state of the charge (SOC), and the charging priorities set by the EV users[24,25].The aggregator leverages this information to determine charging costs in a prioritized manner, employing historical charging load data to anticipate and capitalize on periods of low charging costs[26]. The game theory based EVCS is a advantageous system in terms of dynamic and equitable in nature which emphasis the interaction between EV user and aggregator on real data time. This approach creates more efficient and strategic charging performance. This system works on a individual responses and perform collective benefits for EV user and Grid in terms of load minimization and optimal cost benefit.

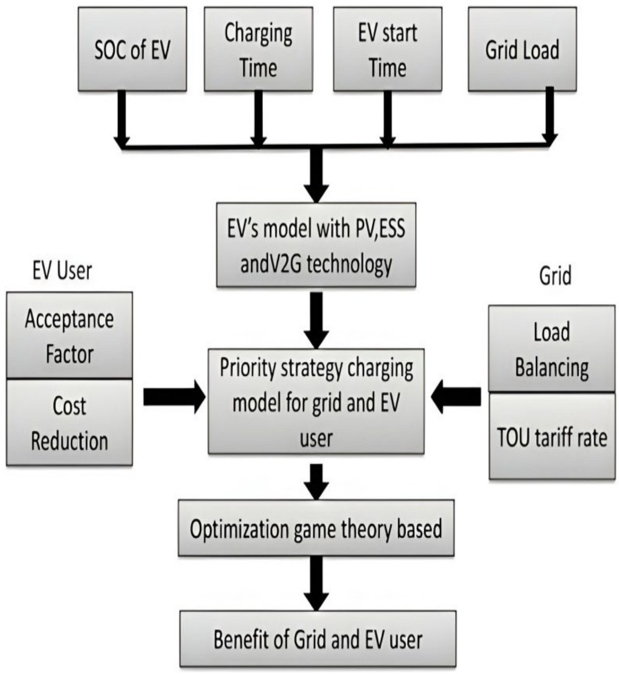

Fig. 1: The structure of a charging station of Electric Vehicles.

Figure 1, illustrates the Electric Vehicle Charging Station (EVCS) model, with the initial factors considered for EV user charging loads being 1) Present SOC 2) Charging time 3) Priority selected by the EV user. Simultaneously, additional factors, including EV driving patterns, travel charging prices, battery charging characteristics, and the number of EVs in the vicinity, contribute to the overall load model. Figure 1, explains the frame work for game theory based EVCS model which depend upon the game priorities. This model proposed for optimal results for load balancing and cost benefit of EV user. It is important to note that the efficiency of this load model varies across different areas[27,28].

2.1 Grid Load parameters

In this session for peak hour load consideration for both daily load and EV charging load. EV charging load is vary with time it's depend upon the requirement of EV charging and their current SOC. Total charging station capacity assumed as total charging socket present at charging station so we considered total 7 charging socket 4 of slow and moderate charging and 3 of fast charging, total 100kw capacity. In this scenario we assumed that EV charging station is with solar rooftop and ESS system, also integrated with V2G system. So, total charging station load can be calculated as N number of EVs charge.[29,30] Total load of charging station can be calculated as

$$E_{dem}^{t}=\sum_{a=1}^{N} E_{a}^{ch,t},\ \forall\ a \in N, \forall\ t \in T \quad (1)$$

The energy load demand and supply variance can be calculated as (2)

$$E_{v}^{t} = E_{cs}^{t} - E_{dem}^{t} \quad (2)$$

Power balance equation can be written as

$$P_{cs(t)}=P_{grid(t)}+P_{PV,Ess(t)}+P_{V2G(t)} \quad (3)$$

Where, $P_{cs(t)}$ is the total power drawn from the $P_{grid(t)}$,$P_{PV,Ess(t)}$ and $P_{V2G(t)}$ power sources. In this solar power can be considered as below,

The output power of PV panel for the rth day at any instant of time (t) is calculated by using below equation

$$P_{PV,Ess(t)} = V * I * \text{efficiency} \quad (4)$$

$$P_{PV(t)} = N s \cdot N p \cdot P pv \cdot (G (t)/G), \quad \forall t \in T \quad (5)$$

$P_{PV(t)}$ Total energy by solar source whereas, Ns and Np are the modules of PV cell and G is irradiant power.

For V2G power calculation,

$$P_{v2g,(t)}= \sum_{EV=1}^{Nv2g} P_{v2g}\ (t)\ (EV) \quad (6)$$

Pavg is the average load of grid for a day with respect to EV user load[31,32]. The average power required can be calculated as equation no (7) Where, $P^{t}$is the electricity load (except EVs user load) for particular area at time t; P_{N}^{t} is the load with considering the EVs user load for t time period. Pavg is the average of total load with EV of a day. N, number of user.

$$\text{Pavg} = \frac{1}{Tn}\sum_{Tn=1}^{Tn}(P^{t} + \sum_{P_N^t}^{t} E_{dem\ N}^{t})^{2} \quad (7)$$

$$\sigma^{2}= \frac{1}{Tn}\sum_{Tn=1}^{Tn}(P^{t} + \sum_{N}^{t} E_{dem\ N}^{t} - \text{Pavg})^{2} \quad (8)$$

Equation no (8), The grid load stability it is necessary to find out grid load variance is σ^2. The Peak hour grid load can be minimizes by reducing the Lf, grid load variance according to equation (9)

$$Lf = 1- \frac{\sigma_{o}^{2} - \sigma_{min}^{2}}{\sigma_{max}^{2}- \sigma_{min}^{2}} \quad (9)$$

$\sigma_{max}^{2} - \sigma_{min}^{2}$ is the maximum to minimum grid load variance for the time index

$\sum_{t=1}^{T} | \sigma_{max}^{2} - \sigma_{min}^{2} | \leq$ Pavg.

2.2 EV user charging parameter

This section gives the EV user parameter as follows:

2.2.1 EV user travel parameter

EV Users travel distance is different from initial point to destination[33]. So, it is required to considered EV user travel characteristics. It is explain for the time period of 24 hrs. Time period is considered as T for i trip so, T-i. At initial point T-0 and at stop point T-i+1, as number of trip increases T-i+n.

EV user acceptance factor is depend upon many parameters like travel range, EV penetration ration, type of charging, time of charging and charging cost[34,35]. The static data is considered from data published on switch Delhi website[36]. The daily travel distance for EV user given the form of probability density function is

$$(x)= \frac{1}{\sqrt{2\pi d\sigma.}} \exp\left(- \frac{(\ln x-\mu)\ \hat{}2}{2\sigma.\hat{}2}\right), \quad x > 0$$

For 0, x < 0 (10)

The x is a user function; μ is normal distribution 12.6, and σ is the standard deviation of normal distribution is 6.5.

The charging time and charging rate is based on the state of charge (SOC) of the battery. This SOC is depending upon the daily driving range of the EV user[37].

$$Esoc = (dev -1 / Dev) * 100\% \quad (11)$$

Where EV battery SOC is considered as Esoc; Dev is the maximum driving range of an electric vehicle. EV charging time depends upon the travel range dev, power required to full charge E_{dem}^{t} for Km (kilometer).

$$Tf = \frac{devW_{km}}{km\ E_{dem}^{t}} \quad (12)$$

Where Tf is the charging time length is estimated as (12) let considered the charging power of EVs is set at 15kW,

$$Tf=\sum_{n=1}^{nf}\left(\frac{V(n)-SOC(n)}{Pnf}\right) \quad (13)$$

Above equation is considered for fast charging Tf in which nf denotes the number of vehicles supposed to charge by fast charging for the V (n) rated capacity of EV.

$$Ts=\sum_{n=1}^{ns}\left(\frac{V(n)-SOC(n)}{Pnf}\right) \quad (14)$$

Above equation is for the slow charging at peak hour and, if EV user in emergency then that user can charge with fast changing by paying high tariff rate.

2.2.2 EV user strategy acceptance factor

In the priority charging strategy to consider the response of EV owners is important. The total number of EVs is considered as N, the number of EV user to be charged with respect to charging priorities P , and EV user approach towards selecting an priority to be η. for EVs priority charging strategy to be Nr , then shown as

$$Nr = \eta N \quad (15)$$

The EV user acceptance factor is depending upon individual EV user energy consumption routine with respect to time. EV user may charge randomly, before the implementation of a priority strategy charging without any change in routine.

If EV user respond to priority strategy then its acceptance factor increases as EV user convenience factor decreases. The user priority strategy acceptance factor define as ε,

$$\varepsilon = 1 - \frac{\int_1^{24}(F_{TOC\ (t0)} - F_{T\ (t1)})\, dT}{\int_1^{24} F_T(to)\, dT} \quad (16)$$

EV user priority strategy acceptance increase its results into change in its charging routine with respect to time which shifts the EV load from peak time to off peak time.

$$\int_1^{24}(F_{TOC\ (t0)} - F_{T\ (t1)})\, dT \quad (17)$$

$F_{T\ (t1)} and\ F_{T\ (t0)}$, are function of time of charging t0 to t1.above equation gives the idea of shift the EV user load time after selecting the priority. User acceptance factor is ε, which is depend upon the priority selection, if user changes its charging habit according to priority group without any adjustment then it is acceptance factor is 1 otherwise it will be 0.

2.2.3 EV user charging cost parameter

For TOC pricing for EV user, analysis of previous 30 day energy consumption is need to consider planning energy consumption to take an advance benefit of TOC[38]. Hence the objective function is stated as, C (t) is the cost for charging per hour. For all vehicles at each time period (t) the total charging cost C(t) in rs, P is the priority selected by EV user, the cost required for charging EV with respect to priority can be calculated by CP(t) can be obtained as equation (18)

$$CP(t) = \sum_{t=1}^{Tev} (CP(t) * Tev\ P) \quad (18)$$

EV user selects the priority strategy P, after choosing the preferred priority by user it affects into charging cost up to some extent, that can be calculated by equation no(19).

$$\Theta = 1 - \frac{C(_{t0}) - Cp(_{t1})}{C(_{t0})} \quad (19)$$

In the formula, θ is the cost acceptance factor. $C(_{t0})$ is the cost for user before selecting the strategy and $Cp(_{t1})$ after opt the strategy.

EV user priority strategic charging acceptance factor is depending upon the Ur, priority acceptance factor and cost acceptance factor. γ1, γ2 and γ3 are the weight of priority acceptance and cost acceptance factor of EV user and γ3 is grid load variance.

$$Ur = \gamma 1\ \varepsilon + \gamma 2\ \theta + \gamma 3 Lf \quad (20)$$

γ is weight function are considered for EV user and grid optimized parameter, $0<t0<24$, t is the time to get optimal parameter. Ur value is a EV user priority strategic charging acceptance factor, we can get by algorithm by solving the ε and θ variables.

The cost of charging is depending upon the TOC of EV user. As the cost of charging decrease its results into change in user acceptance index toward the priority strategy selection it also reflects into grid load variance.

3.1 Optimal Priority EV Charging Scheduling Model

The game theory based EVCS advantageous system in terms of dynamic and equitable in nature which emphasis the interaction between EV user and aggregator on real data time. This approach creates more efficient and strategic charging performance. This system works on a individual responses and perform collective benefits for EV user and Grid in terms of load minimization and cost benefit.

3.1.1 Peak load minimization

The goal of grid load balancing for electric vehicle (EV) users is to optimally balance the charging load across various power sources or charging points. In this situation, Particle Swarm Optimization (PSO) can be used to determine the best load balancing strategy. Usually, the fitness function is decreasing the imbalance in load or optimizing the charging stations overall efficiency[39].

For optimal model, PSO is population based optimization technic which gives the particle velocity for minimum to maximum value of user function. Algorithm performs repetitively among the population to find out the optimal solution.

The PSO equation for EV user grid load balancing:

Step 1

Particle locations and velocities should be initialized. Define the objective function (fitness function) in order

to assess the load balance.
Step 2
Particle Position update:

$$Xk\ (t+1) = X(k) + V(t+1) \qquad (21)$$

Step 3
Particle velocity update

$$V(t+1) = w.\ V(t) + (A(t) - (Bt(t) - xi(t))) \qquad (22)$$

Where xi(t), presents charging slot for EV with i particle for time t. The V(t) velocity of particle for w is the inertia weight, a variable that regulates how much the particle's prior velocity affects its current velocity.

$$A(t) = \sigma_o^2 - \sigma_{min}^2 \qquad (23)$$

$$B(t) = \sigma_{max}^2 - \sigma_{min}^2 \qquad (24)$$

A (t) and B (t) is the fitness function by repetitive iterations it gives the best particle solution for EV user charging strategy time for grid load balancing. σ_o^2 Values from equation (8)

3.1.2 EV user cost parameter

In this section Priority distribution for EV charging load is discuss for EV user charging cost parameter. Cost is dependent of off peak hours 12am to 6 am, average load hours are 6am to 12 pm and peak hours are 1pm to 11pm. And which varies according to weather condition of India.
The n number of vehicles is considered arriving at charging station. Let considered EVs are uniformly distributed priority level from 20% SOC to 90% SOC[40]. Optimal priority strategy EV charging, charging is scheduled based on priority strategies. The priority level are distributed over the EVCS, distribution is depend upon the source allocation to the highest priority EV user with respect to time of day. Priority probabilistic control strategy is evaluated to solve the determine scenario. At every t the sampling interval the aggregator determines the optimal control strategy to obtain the optimal value Cv. for this time variant system is $v(t)$ is the control unit for ($P_{grid}[t]$,$P_{PV[t]}$,$P_{V2G[t]}$) and optimal cost function is Cop (t) is represent as the sum of the t-th operating cost C(t). Figure No 2, algorithm explains the priority strategies are explained below for optimal cost benefit. Cop is the shapely based optimal cost which can be calculated by equation number 26, for each priority condition for its v value. Assume that when EV comes at EVCS, user will check for the priority according to its requirement then user checks the cost for charging.Table.1, gives the optimal values for each priority strategy P1,P2 and P3 according to that EV user get the benefit from the priority strategy. Details priority strategies are explain in below section.

Table 1. Specifications for EV user charging

Sr No	Specifications	Details
1	Type of Vehicle	Battery Electric vehicle (Range from 2 Kwh to 55 Kwh) under consideration
2	Number of EVs	165(sample of 25 EVs)
3	Type of charging	Level 1- 120v, output power >3kw Level 2- 240v, output power 3kw to 22kw Level 3- DC fast charging 480v output power,>50kw
4	No of charging socket	7
5	Solar panel capacity +ESS	150kwh

Priority Strategy-1
The PV and ESS energy sources are in priority 1 to decrease the load on grid, best usage time for this priority is 8am to 5 pm. The surplus Solar energy can store in ESS could reduce the C value. Cπ is an optional cost which is continuously updated for next time slot according to EV approach to EVCS. Total cost can be calculated as Optimization cost function of solar+ ESS is v(PV,ESS)=C1 So,

$$C1v = \min \sum_{t=1}^{T} Cg\,[t] \qquad (25)$$

From above equation we considered the optimal cost for the charging priority strategy 1.
Priority Strategy-2
For the function of peak hour grid,
v (Grid pk t) = C2, EV user assign to the priority strategy- 2 ,who wants to charge EV by level 1 and level 2, or level 3 chargers in(Grid pk t)peak hours applied with high tariff rate (1pm to 11pm). This optimize function allocate PV and ESS energy for charging. High tariff rate is applied if emergency level 3 charging is required.
Priority Strategy-3
Provide charging strategy at night with low tariff rate opk (off peak hours 12pm to 6am) for optimal strategy function of off peak hour grid is define as, v (Gridopk t) = C3
V2G facility available for that EV user who's SOC above 80%, EV user can discharge EV at peak hours timing by getting cost benefit, this is quite inconvenient from the view of EV user response. Battery degradation and economic Viability are the limitations of this technology. But combines with the game theory based priority strategies based optimization, to find out correctness of strategies implementation. According to priority chosen, cost will be calculated. But key point from strategic priorities the peak hour cost of charging is setting for high value so indirectly EV user will shift to another scheduled charging. Equation (26) gives, Shapely value probable best cost at which EV user can charge EV.

Optimal cost , *Opi* can be given by equation as

$$Opi = \frac{1}{|N|!}\sum_{v \subseteq N\setminus\{i\}} [C(v \cup \{i\}) - C(v)] \quad (26)$$

The EV's Shapley value is the average marginal contribution of i'th EV for possible optimal priority strategy group. Let considered N is set of EV and C (v) is the cost for different priority group of EVs.

This $v \subseteq N \setminus \{i\}$ indicates that the summing covers all subsets v that are subsets of N, with the exception of element i. For a given term [C (v ∪ {i})−C(v)], gives the difference between the function C on the set v and for value i. This feature would rely on the particular elements that affect the cost of charging, like the amount of time needed to charge an EV, the cost of power, and the needs of each individual EV. A Shapely value characteristic function C(v) for different priority condition with the source given in Table 1,

$$\min C\ v = Cop \quad (27)$$

Table 2. Priority based optimal cost for EV user

Source	Priority	Variables for cost Function	Optimal cost
PV,ESS	P1	v(PV,ESS)=C1	$C1v = min\sum_{t=1}^{T}$ Cg [t]
Grid peak hour)	P2	v(Grid pk t) = C2	$C2v = min\sum_{t=1}^{T}$ Cgpk [t]
Grid off peak hour)	P3	v(Grid opk t) = C3	$C3v = min\sum_{t=1}^{T}$ Cg off peak [t]

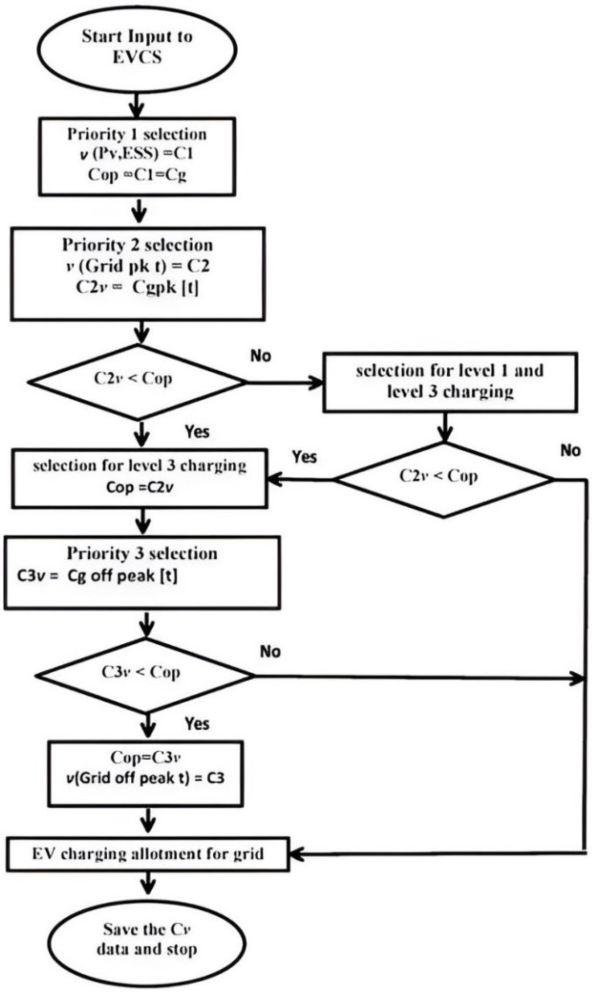

Fig.-2: Flowchart of the proposed optimal Priority EV Charging Scheduling Model

Problem Formation for EVCS considered a charging Station where total 7 EV charging points for EV charging at 3 kW to 45 KW controllable charge points. Total EVCS capacities assume is 100kw. In this paper we considered 24hrs time pattern, 3 levels charging[41].EVCS charging load curve is shown in diagram. Let considered grid connected charging station of 150kw, PV capacity is 120kw and energy storage system 250kw, for N=20 let considered EV load is 110kw 20% of its holding capacity. Numerical Analysis for EVCS parameters are considered as per above section. For ESS and V2G let considered discharging SOC up to 80% to 20% to maintain the life cycle[42]. The time line is fixed consider for 24hr pattern, in EV sampling is considered N=165.

To represent the daily optimized strategy grid charging cost index is considered i=5.6 Rs per kwh that is for Cv. For priority 2 tariff rate is i=6.6Rs per kwh, depend on EV SOC unit if charge from grid for level 2 and level 3.for Priority 3 off peak hour Tariff rate are i= 4.1Rs per kwh[43].

In this paper 165 EV are under analysis with the help of Monte Carlo simulation. Load curve and acceptance factor curve are shown in Figure 3, shows the optimal results for the parameter of grid load changes from high value to low value. EV user load with respect to time and its acceptance factor shown in Fig. 3.

Table 3.Time sharing EV load data and EV user cost

Time	Required Battery power Kwh	Strategic Cost	Before strategy Cost	Cost Benefit	User Strategy Acceptance
Off Peak Hours	15.75	64.57	88.2	0.62	0.86
6am	19.06	106.73	106.73	0.51	0.83
9am	24.01	134.45	134.45	0.24	0.74
1pm	27.61	182.22	154.61	0.21	0.6
7pm	11.78	77.74	65.96	0.37	0.75
9pm	11.81	77.94	66.13	0.50	0.68

Table 2, provides strategic values of EV user; the user cost acceptance factor can be the difference of electricity consumption cost before priority charging and after selecting priority charging. From above table 2, at peak hour cost benefit is less as compare to off peak hours. At off peak hour EV user get a cost benefit of 0.62 by comparing the strategic cost and before strategic cost. Same at peak hour strategic cost is high to manage the peak hour load so, here user strategy acceptance factor decreases.

Overall decrease in charging cost will increase the cost acceptance factor as at 9am strategy acceptance factor is 0.74 which is 0.09 increases at 6am(off peak hour).at It is clear that Charging acceptance index decrease as cost increases at peak hour time(7pm). The EV user acceptance factor calculated by analyzing Ur, given in above section 2.2

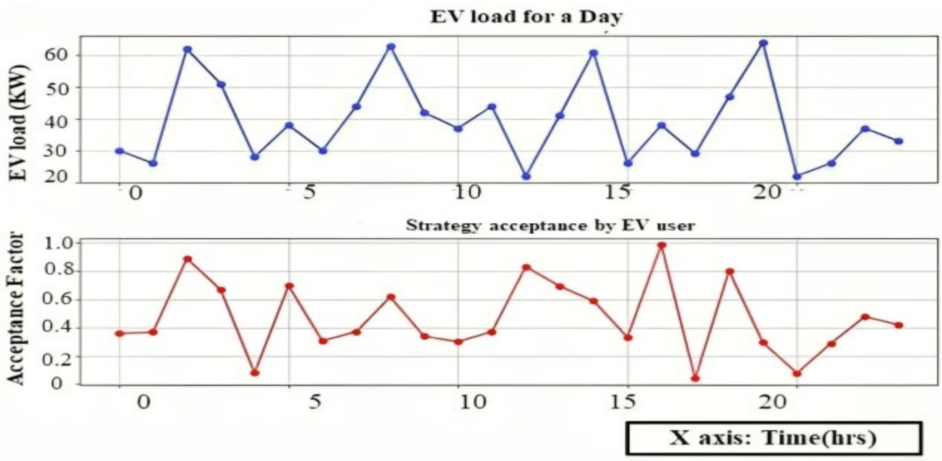

Fig. 3: EV user load with its acceptance factor.

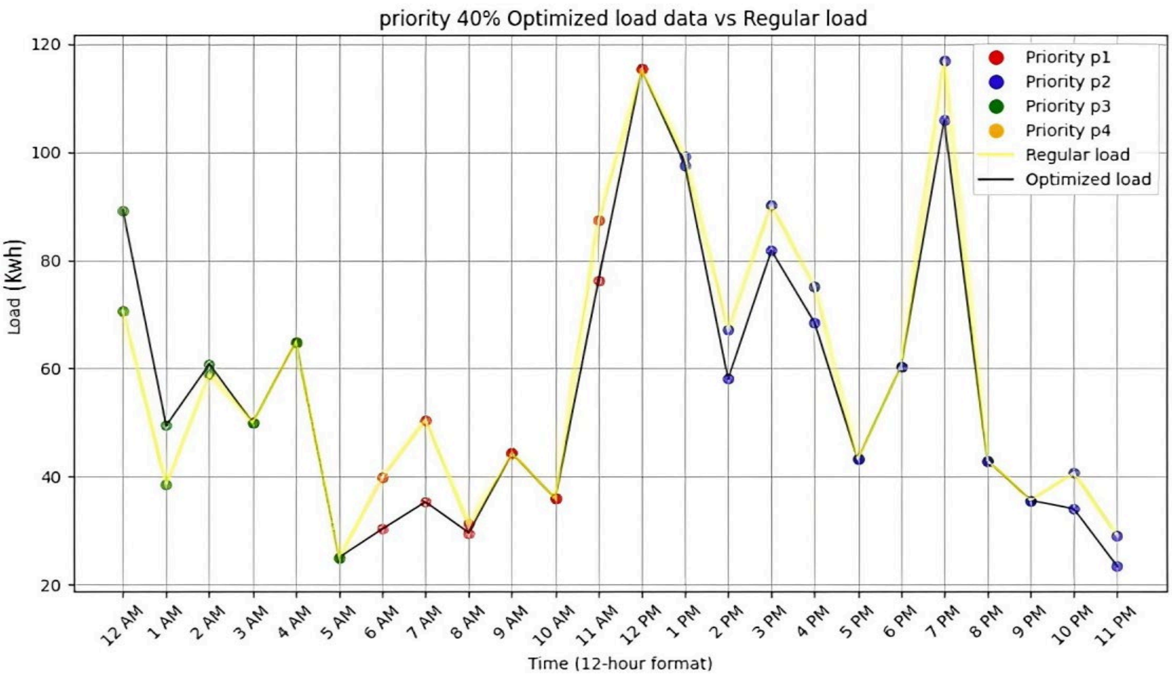

Fig. 4: Effect of 40% priority acceptance on EVCS load curve

From above Figure 4 is the effect load shifting due to 40% of EV user accepted strategic charging. Figure 6 is addition of solar+ESS and v2g in EVCS to compensate the peak load as Figure 7 shows the percentage of user for priority strategy acceptance of 100%. This percentage depends upon the how many EV users adopted the strategy and shifted their charging load from peak hour to off peak hour which is depend upon Ur as discuss in 2.1.3. In Table 3,For 100% user acceptance load value is 78.6 kwh at 11pm and for 40% of user acceptance load value is

91.3kwh at 11pm. If Ur, Priority acceptance value Increases will reduces the Peak time's system load.

Table 4. EVCS load minimization in %

Sr No	Load for 40% priority acceptance	Load for 100% priority acceptance
1	91.3 Kwh	91.3 Kwh
2	83 Kwh	78.6 Kwh
load minimization %	9.1 %	13.91%

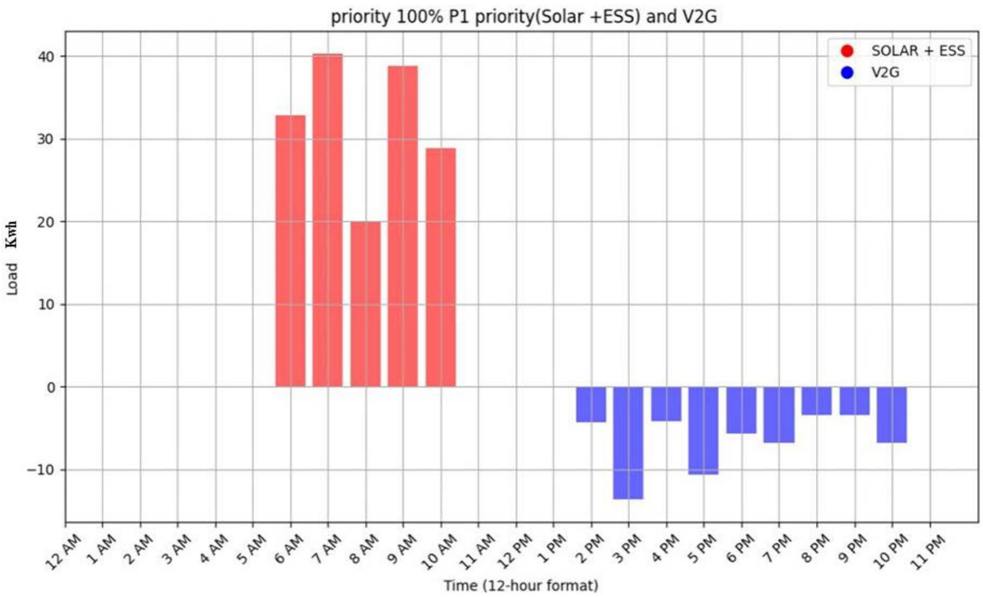

Fig. 5: Effect of Solar +ESS and V2G on EVCS

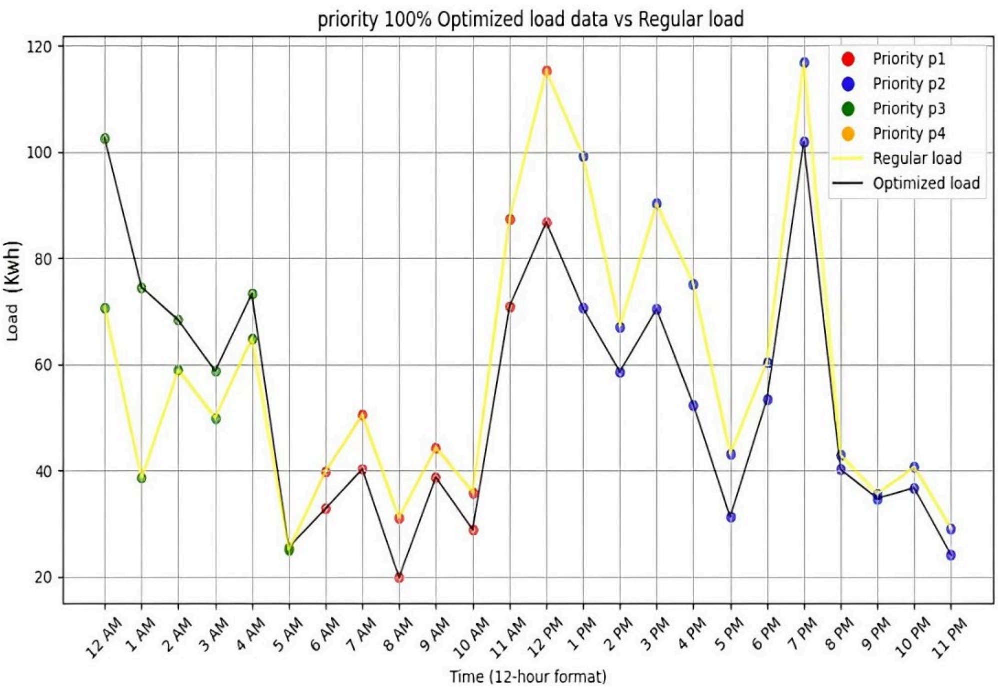

Fig. 6: Effect of 100% priority acceptance on EVCS

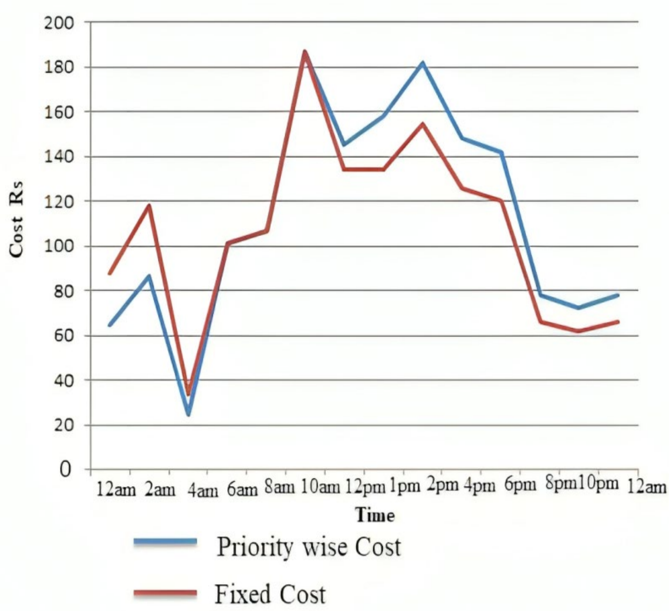

Fig. 7: EV charging cost before and after and before optimal strategy implementation

User response modes begin to change compared to before optimal strategy. From table 2 and Figure 7 this shows the results for EV user charging cost for before and after optimal strategy shows the best results as for average % of user acceptance. We can observe that for 12hour pattern time period in off peak hours(12pm to 6am) the total cost reduces and profit of 22.63Rs for required charging EV power decrease by using proposed strategy. The tariff rate is dependent of TOC index for different priority strategy.

Conclusion:

This paper presents a strategic approach to Electric Vehicle (EV) charging prioritization that delivers benefits for both the grid and EV users. Utilizing a game theory-based optimization algorithm, the study aims to determine the most effective output for priority strategies, coupled with a comprehensive response analysis. The optimization process incorporates a cost acceptance factor through a TOC strategy to calculate costs. The EV user responsiveness has been considered for checking the correctness of priority strategies. Simulation results are employed to analyze the daily load curve both before and after the implementation of priority settings. Moreover, employing a probability method to calculate the specific cost of charging, the paper proposes optimal user priorities, aiming to minimize the overall charging cost. In the context of future developments, priority strategic-based charging is anticipated to consider additional parameters for Vehicle-to-Grid (V2G) integration to further enhance optimization processes.

Nomenclature

EV	Electric Vehicle.
EVCS	Electric Vehicle Charging Station.
TOC	Time of charging.
V2G	Vehicle to Grid.
ESS	Energy Storage System.
E_{dem}^{t}	Energy demand by EV at 't' time.
N	Number of EV users.
a	Individual EV user.
t	Individual time of EV charging/discharging at charging station.
T	total time charging/discharging for an individual EV.
E_{cs}^{t}	Total Energy demand by EVCS at 't' time.
E_{v}^{t}	Supply difference.
$P_{grid(t)}$	Grid power.
$P_{PV,Ess(t)}$	Photovoltaic system and ESS power.
$P_{V2G(t)}$	V2G power.
r	Day number.
Pnf	Power required by n EV fast charging.
Xk(t)	Position of particle.
(t+1)	Time slot.
V	Velocity of particle.
A	Particle previous start position.
B	Particle previous end position.
C1	Cost for priority strategy 1.
C2	Cost for priority strategy 2.
C3	Cost for priority strategy 3.
Cg	Grid energy cost.
Gridopk	Grid Off peak hour.
i	Tariff Rate
v	Voltage
kw	Killowatt
Kwh	Kilowatt hour
Rs	Ruppes

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