# Chapter 28
# Performance Analysis of Controlled Vehicle-To-Grid Charging in 30 Bus Power System for Electric Vehicle

**Gourab Bhuyan and Bani Kanta Talukdar**

**Abstract** Electric vehicles (EVs) are making an impact on vehicle markets sooner than we expected. Due to its widespread popularity of being environment friendly, it brings some solutions to the highly debated environmental problem of carbon emission. As the EVs promote green energy, it can be completely run without burning any fossil fuels. However, the actual challenge lies in charging the same. Charging an electric vehicle has highlighted some of the potential impacts on grids. To make EVs popular, companies are trying to reduce its battery charging time by introducing fast chargers. With decreasing the charging time, charging power is increasing for a fast charger. Using high power load can cause immediate impact on power system stability and voltage regulation. The problem of high power requirements can be controlled with a charging strategy. This paper focuses on the study of impacts on grid by a high power EV charging load and providing a controlled charging method supporting vehicle-to-grid (V2G) technology. In this paper, study on different cases taken during a day with respect to available charging power in a power system is presented in this report to improve overall performance of the charging strategy.

**Keywords** Electric vehicle · Vehicle-to-grid (V2G)

## 1 Introduction

The modern-day world is rapidly increasing population and developing technologies, and the usage of individual vehicles and public vehicles is increased to provide the mobility. IC engine vehicles dominate the field of transportation by fair and square, but due to increasing environmental concerns, rising petroleum prices, the uncertainty of fossil fuel is enhancing the popularity of electric vehicles (EV) [1]. The EVs are fueled by the rechargeable battery pack, which powers the electric motor during the

---

G. Bhuyan (✉)
Assam Engineering College, Guwahati, India

B. K. Talukdar
Department of Electrical Engineering, Assam Engineering College, Guwahati, India

G. Panda et al. (eds.), *Sustainable Energy and Technological Advancements*,
Advances in Sustainability Science and Technology,
https://doi.org/10.1007/978-981-16-9033-4_28

drive. To get the attention of customers, advancement in the fields of battery technologies such as fast-charging infrastructure and battery capacity must be developed [2]. In the Indian scenario, large EV penetration will solve problems like air pollutions, energy savings, noise-level reduction, energy efficiency, and emissions of greenhouse gases [3]. The mass adoption of fast-charging may degrade power systems though the EV brings one of the most welcomed greener options for transportation. To ease the mode of driving fast-chargeable batteries with high-density charge would increase the battery capacity and driving range [2]. Literature also suggested bidirectional communication-enabled smart grid infrastructure for less impact on a power system. The bidirectional energy flow is proved efficient to provide power back to the grid. A discussion on EV charging infrastructure is carried out by NTPC [3] and highlighted potential marketplace for EVs. It was shown that it would increase as high as 50% of all vehicles on Indian roads by 2030. In [4], a study emphasizes on charging time to be less to cope up with the popularities of conventional vehicles.

A study on stability was carried in [5], where the EV load model was suggested to stabilize the system was also shown. A reliability study was carried by [6] showed that considerable losses occur during charging EV. A high voltage (HV) system study carried out in the city of Perth, Western Australia, is presented in [7]. The study assumes all vehicles in Perth metropolitan area to be plug-in electric vehicles (PEV) and carried out an analysis to find the impact of charging them in the grid. The uncontrolled charging of PEV fleet has caused a peak demand which exceeded the forecasted generation. EV charging load is modeled in [8] and showed that it has constant power behavior or a combination of constant power and exponential load behavior. In a park and charge model with scheduling to minimize EV battery degradation cost [9]. Another study [10] showed limited V2G application where discharging mode is only applied when high demand arises. The system load study with respect to the very dynamic load curve has not been operated in details in any of the studies. This work is to improve the voltage profiles of a system with a V2G-enabled control strategy, which will monitor charging limit and V2G support during different cases. This work is to highlight the improvement made by V2G charging during different periods of the day which reflects upon practical scenario.

### 1.1 Objective of This Study

The objective of this study is to provide round the clock analysis of charging of EVs in a power system. The system study was performed taking three different cases of charging in different periods of the day. The end result shows how effective V2G control charging method would be than an uncontrolled one. Advantages of pre-define charging limit and V2G support would effectively improve the voltage profiles. The rest of this paper is organized as follows: A review of existing approaches is presented in introduction section. Section 2 describes the modeling of V2G charging with detailed modeling of loads along with 30 bus power system. Load flow calculations are defined in this part. Section 3 consists of daily load and different test cases and parameters for the study. Results of the simulations are discussed in Sect. 4 followed by detailed conclusions.

## 2 Modellıng V2G Envıronment

### 2.1 Modeling of V2G Load

EV charging loads are the most crucial component to this analysis. Building an V2G-enabled charging load is crucial to this work. A universal input EV charger consists of an active rectifier front end, and a buck converter at the battery end is modeled here. It is capable of providing unity power factor and regulated voltage, despite grid voltage variations and supply point voltage. It enables vehicle-to-grid

(V2G) mode of operation by allowing bidirectional power flows. Further, it has become an attractive solution for medium power applications above several kW [8].

The number of EVs in area is taken as n, which are set of all the charging and V2G support operations. A parking data probability curve is used to predict number of vehicles will available at parking. These vehicles will be the source which will draw powers during the charging mode and provide power during V2G mode. The charging and V2G power levels are been taken as constant for all the n vehicles. The total power at the system at any time t would be

$$\sum \mathrm{P} = \sum \mathrm{PGEN} + \sum \mathrm{P\ V2G} - \left(\sum \mathrm{P\,DEM} + \sum \mathrm{P\,EV}\right) - \sum \mathrm{P\,LOSS}$$

### 2.2 Newton Raphson Load Flow with 30 Bus System

The case study on IEEE 30 bus system is carried out for calculating the effects on power system. Output parameters like voltage magnitude and system losses are observed. For the calculation of real and reactive power drawn by bus in power system, it is necessary to define bus voltages and bus admittances of buses present in the system. For the *i*th bus, equation of the bus voltage is denoted in Eq. (1).

$$V_i = |V_i|\angle\delta_i = |V_i|(\cos\partial_i + j\ \sin\partial_i) \tag{1}$$

Admittance of the *i*th bus represented by Eq. (2)

$$Y_{ij} = \left|Y_{ij}\right|\angle\theta_{ij} = \left|Y_{ij}\right|(\cos\theta_{ij} + j\sin\theta_{ij}) = G_{ij} + jB_{ij} \tag{2}$$

For a system consisting of *n* buses, the current at bus i can be expressed in the form of Eq. (3)

$$I = Y_{11}V_1 + Y_{12}V_2 + \cdots + Y_{in}V_n = \sum_{k=1}^{n} Y_{ik}V_k \tag{3}$$

Complex power Eq. (4) can be simplified further to find real and reactive powers of individual buses.

$$\begin{aligned} P_i - jQ_i &= V_i^* I_i = V_i^* \sum_{k=1}^{n} Y_{ik}V_k \\ &= \sum_{k=1}^{n} |Y_{ik}V_iV_k|[\cos(\theta_{ik} + \delta_k - \delta_i) + j\ \sin(\theta_{ik} + \delta_k - \delta_i)] \end{aligned} \tag{4}$$

Comparing the real and imaginary parts, two equations are formed for the calculations of real and reactive power for each buses of the system.

$$P_i = \sum_{k=1}^{n} |Y_{ik}V_iV_k| \cos(\theta_{ik} + \delta_k - \delta_i) \tag{5}$$

$$Q_i = -\sum_{k=1}^{n} |Y_{ik}V_iV_k| \sin(\theta_{ik} + \delta_k - \delta_i) \tag{6}$$

### 2.3 Load Flow Analysis by Newton–Raphson Method

If the *n*-bus power system will contain a total *np* number of P–Q (load bus) buses while the number of P–V (generator bus) buses be *ng* such that $n = np + ng + 1$. Addition of 1 is assumed to be the slack or reference bus. The technique of Newton–Raphson load flow is similar to that of solving a system of nonlinear equations using the Newton–Raphson method. Each iteration is to form a Jacobian matrix and to solve for the corrections.

$$\begin{bmatrix} \Delta\delta_2 \\ \vdots \\ \Delta\delta_n \\ \frac{\Delta V}{V} \\ \vdots \\ \frac{\Delta|V_{1+n_0}|}{|V_{1+n_0}|} \end{bmatrix} [J] = \begin{bmatrix} \Delta P_2 \\ \vdots \\ \Delta P_n \\ \Delta Q \\ \vdots \\ \Delta Q_{1+n_0} \end{bmatrix} \tag{7}$$

$$J = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \tag{8}$$

With the voltage and angle at slack bus fixed at $V_1\angle\delta_1$, all PQ buses are at $|V|$, $\angle\delta$ and all PV buses assumed to have $\delta$ at all the buses. For the $r$th iteration, power mismatch equations are checked

$$\Delta P_i^r = P_{iInj}^r - P_{iCalc}^r$$
$$\Delta Q_i^r = Q_{iInj}^r - Q_{iCalc}^r$$

Power mismatch values are checked for minimum, the iteration stops if found less than the prescribed tolerance. If the convergence criteria are not fulfilled, the voltage magnitudes and angles are updated.

$$|V|^{(r+1)} = |V|^r + |\Delta V|^r$$

This process is continued until the convergence is less than the prescribed value of tolerance, once found entire solution is printed. This solution technique is used to calculate output parameters (Fig. 1).

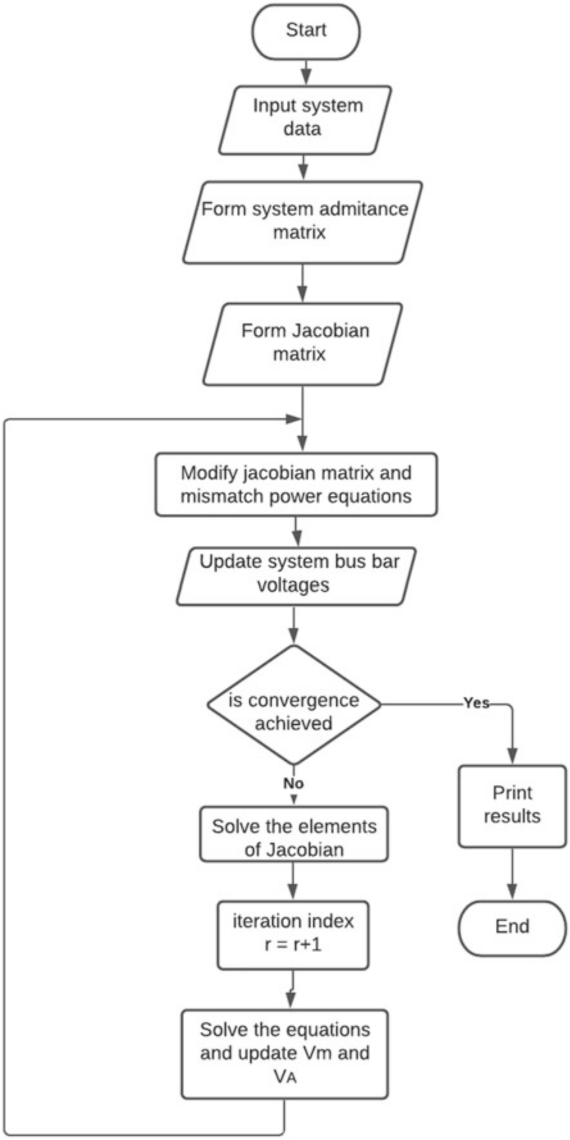
## 3 Daily Load Curve Situation, Parameters, and Charging Limits

For case study on 30 bus system, different types of EV charging loads are modeled. Different constraints of time like early morning, mid-day, afternoon, and night are taken into consideration. Load demand patterns are identified for different time of the day. While working on these data, practical situation-based data were preferred. Data were collected from IEEE and other official websites [11].

### *3.1 Case Study*

This case study of EV charging load has taken consideration of four period of time in a day. The daily load curve has four significant changes of load during a day. These periods are named *night lean*, *morning peak*, *day lean,* and *evening peak;* four different load patterns can be seen from Indian daily load curves. The changes of loads during intermediate periods and load characteristics are almost similar for each period [12]. With the addition of EV charging loads into the account, the load curve will show characteristics as that of the old one. The dynamic behavior of EV charging load will bring unpredictability to the load requirement. This behavior or unpredictability is studied with simulations, named as *uncontrolled EV charging*. The uncontrolled charging will affect on the voltage level and stability of the system. To overcome this problem, a control charging method is adapted which comes with vehicle-to-grid support. The analysis emphasizes on three states of EV charging on

**Fig. 1** Newton–Raphson load flow algorithm



four different periods of the day. The states are named as ‘no EV load,’ ‘uncontrolled EV charging,’ and V2G controlled charging. Voltage magnitude and voltage angles are calculated from all the cases.

**Fig. 2** Arrival of EVs in home and workplace

### 3.2 Parking Pattern Throughout the day

The amount of time that EV charging station takes is quite higher than a conventional fuel station. The convenient method for charging an EV would be in parking spaces of offices, housing complexes, commercial hubs, etc., to be equipped with charging facilities [10]. Figure 2 explains parking behavior or the electric vehicles arrival at home and office.

### 3.3 Allowed Charging Levels and V2G Support During Controlled Charging

During control charging method, charging powers were made available for EV charging according to the load demand in the system. During the night lean period, charging power was made available up to. The V2G support of highest was supported for the duration of peak demand. This V2G support was crucial to improve stability during the periods of high load demands (Fig. 3).

The total available charging power is taken as 50 MW for this project work. The penetration of EV is considered as very low to have minimum effect on the case system.

## 4 Results and Discussions

In uncontrolled charging state, the charging loads are increasing in uncontrolled manner. However, one key highlights of the state are that it increases the system peak

**Fig. 3** Control charging strategy

voltage, which provides an important analysis on voltage variation. On controlled V2G support state, the charging loads are modeled with V2G support and also restricted with limited charging power during the time of peak demand of the region (Table 1; Fig. 4).

As the loading on EV loads has increased, bus voltage in the respective buses shows decrease in magnitudes. When the controlled V2G charging method is used,

**Table 1** Total loads in different cases and different periods of the day

| Load case | Time period | No EV load | | Uncontrolled charging | | Controlled V2G support | |
|---|---|---|---|---|---|---|---|
| | | MW | MVAR | MW | MVAR | MW | MVAR |
| Night lean | 1:00–5:00 | 185.2 | 64.8 | 197.2 | 66.1 | 224 | 72.1 |
| Morning peak | 8:00–11:00 | 220.2 | 72.3 | 248.3 | 74.6 | 232 | 70.7 |
| Day lean | 13:00–16:00 | 202 | 66.6 | 230.2 | 68.5 | 229 | 69.8 |
| Evening peak | 18:00–21:00 | 232.3 | 75.4 | 276.2 | 78.5 | 241 | 69.4 |

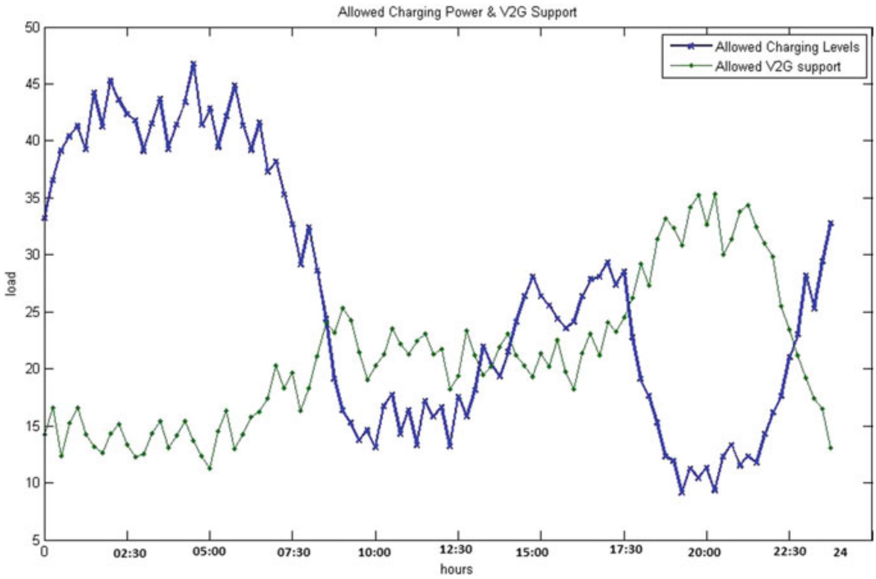


**Fig. 4** Allowed charging and V2G power (MW)

the system showed improvement in voltage magnitudes. Index for voltage magnitude variations from no EV load ($VM_{NL}$) to uncontrolled charging is $(VM_{UC} - VM_{NL}) = \Delta VM_{UCNL}$ and index for variations in voltage magnitude from uncontrolled charging ($VM_{UC}$) to V2G charging $(VM_{V2G} - VM_{UC}) = \Delta\ VM_{V2GUC}$.. These indices are used in Table 2.

From Table 1, test cases are taken and results were plotted in Fig. 5.

Figure 5 represents all the voltage buses in different periods of the day. From the above periods, morning peak and evening peak were most affected among all.

During night period all the buses were under 0.95 pu limits, as more EVs are putting into charging during this period. During the night lean period, simulation was done as the maximum number of EV users is putting their vehicles to charge. At bus 30, lowest 0.965 pu was recorded. At morning peak duration, bus 26 and bus 30 are recorded 0.926 pu and 0.952 pu. During day lean period, worst-affected buses were bus 26 (0.945 pu) and bus 30 (0.953 pu). During evening peak, bus 26 (0.899 pu), bus 29(0.948pu), and bus 30 (0.932 pu) were affected the most. The $\Delta VM_{UCNL}$ value is significantly high in bus no 26 for all the noted cases comparing to other cases. The V2G support was provided the most in the evening peak duration, as all the affected buses are showing great improvement during this period. The control strategy for coordinated charging is as per in Fig. 3.

**Table 2** Voltage magnitudes during different periods

| EV load bus | Night lean | | | Morning peak | | | Day lean | | | Evening peak | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $VM_{NEVL}$ | $VM_{UC}$ | $VM_{V2G}$ | $VM_{NEVL}$ | $VM_{UC}$ | $VM_{V2G}$ | $VM_{NEVL}$ | $VM_{UC}$ | $VM_{V2G}$ | $VM_{NEVL}$ | $VM_{UC}$ | $VM_{V2G}$ |
| 4 | 0.987 | 0.986 | 0.982 | 0.982 | 0.977 | 0.983 | 0.984 | 0.980 | 0.983 | 0.980 | 0.973 | 0.983 |
| 8 | 0.976 | 0.974 | 0.970 | 0.971 | 0.966 | 0.972 | 0.973 | 0.969 | 0.971 | 0.969 | 0.960 | 0.972 |
| 9 | 0.987 | 0.986 | 0.984 | 0.984 | 0.982 | 0.984 | 0.985 | 0.983 | 0.984 | 0.983 | 0.973 | 0.985 |
| 18 | 0.977 | 0.975 | 0.970 | 0.968 | 0.964 | 0.971 | 0.974 | 0.970 | 0.974 | 0.967 | 0.960 | 0.975 |
| 19 | 0.976 | 0.974 | 0.969 | 0.967 | 0.963 | 0.969 | 0.974 | 0.970 | 0.972 | 0.966 | 0.959 | 0.972 |
| 25 | 0.993 | 0.989 | 0.983 | 0.990 | 0.981 | 0.993 | 0.991 | 0.983 | 0.992 | 0.989 | 0.973 | 0.995 |
| 26 | 0.972 | 0.967 | 0.957 | 0.957 | **0.926** | ***0.988*** | 0.963 | **0.945** | ***0.991*** | 0.951 | **0.899** | ***0.994*** |
| 28 | 0.985 | 0.983 | 0.977 | 0.979 | 0.972 | 0.980 | 0.982 | 0.976 | 0.980 | 0.977 | 0.966 | 0.981 |
| 29 | 0.980 | 0.977 | 0.968 | 0.973 | 0.964 | 0.975 | 0.974 | 0.968 | 0.974 | 0.970 | **0.948** | ***0.975*** |
| 30 | 0.968 | 0.965 | 0.960 | 0.962 | 0.952 | 0.971 | 0.962 | 0.953 | 0.966 | 0.959 | **0.932** | ***0.971*** |

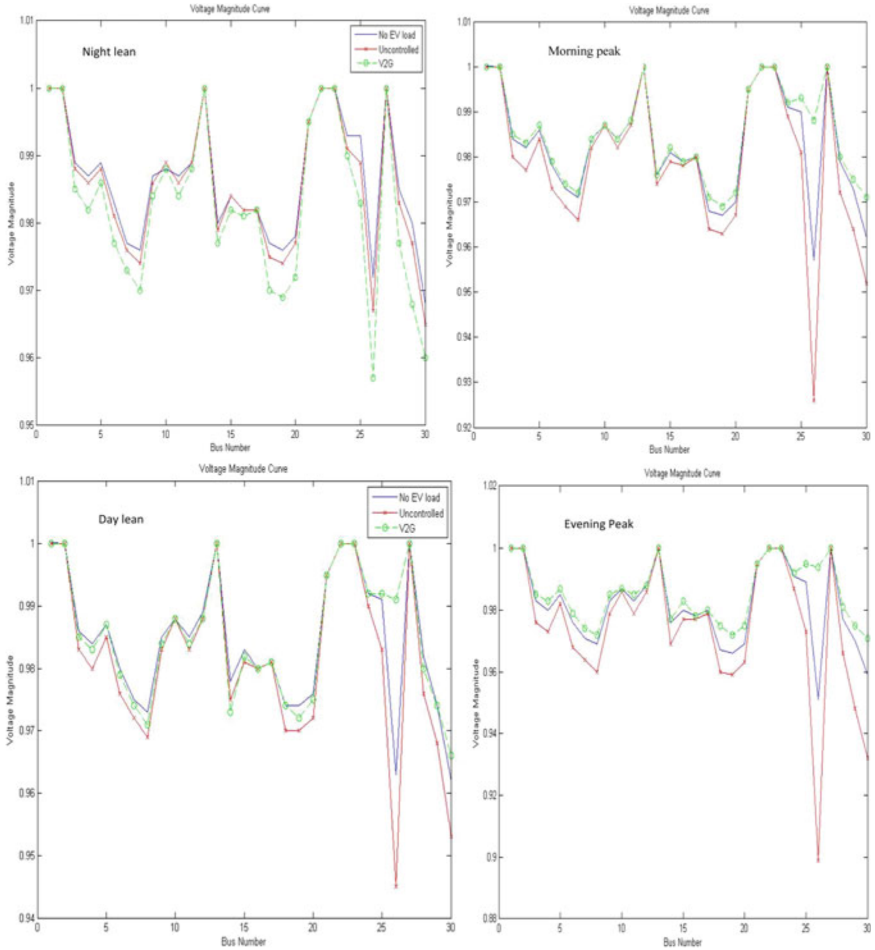


**Fig. 5** Voltage magnitude during different periods, i.e., night, morning, day, and evening

## 5 Conclusion

This paper is focused on the analysis of the control charging method to improve power system performance during a day. Simulation was carried on IEEE 30 bus system, and results were discussed. It was seen that increasing the EV loads on specific bus resulted in a decrease in voltage profiles. Implementation of V2G controlled charging throughout the day drastically improves the scenario. The penetration of EV was taken as very low considering the present scenario of low popularity of EV. It is confirmed from the study that an increase in EV charging would have an impact on the power system if it is not controlled and grid operators should focus on improving the same. Improvement in power quality devices will minimize the system losses and well-equipped V2G support with battery packs, and renewable sources will help grid operators to balance the power demands during the daily operations. Further, improvisation of the controlled charging method can be done with better-trained algorithms.

## References

1. Dharmakeerthi CH, Mithulananthan N, Saha TK (2011) Overview of the impacts of plug-in electric vehicles on the power grid. In: 2011 IEEE PES innovative smart grid technologies, Perth, WA, pp 1–8. https://doi.org/10.1109/ISGT-Asia.2011.6167115
2. Bora Y, Önen UB, Umurkan N (2017) A review of electric vehicles and their ımpacts on grid. Int J Sci Technol Res 6(10). ISSN 2277-8616
3. Busıness of chargıng ınfrastructure for electrıc vehıcles & energy storage and ıts ımpact on power market ııt, NTPC, Kanpur 27.07.2019
4. Collin R, Miao Y, Yokochi A, Enjeti P, von Jouanne A (2019) Advanced electric vehicle fast-charging technologies. Energies 12:1839
5. Dharmakeerthi CH, Mithulananthan N, Saha TK (2014) Impact of electric vehicle fast charging on power system voltage stability. Electr Power Energy Syst 57:241–249
6. Deb S, Tammi K, Kalita K, Mahanta P (2018) Impact of electric vehicle charging station load on distribution network. Energies 11:178
7. McCarthy D, Wolfs P (2010) The HV system impacts of large scale electric vehicle deployments in a metropolitan area. In: Universities power engineering conference (AUPEC), 2010 20th Australasian, pp 1–6
8. Dharmakeerthi CH, Mithulananthan N, Saha TK (2012) "Modeling and planning of EV fast charging station in power grid. In: 2012 IEEE power and energy society general meeting, San Diego, CA, pp 1–8. https://doi.org/10.1109/PESGM.2012.6345008
9. Tae-Hoon K, Seung-Jun L, Woojin C (2011) Design and control of the phase shift full bridge converter for the on-board battery charger of the electric forklift. In: IEEE 8th international conference on power electronics and ECCE Asia (ICPE & ECCE), pp 2709–16
10. Chtioui H, Boukettaya G (2020) Vehicle-to-grid management strategy for smart grid power regulation. In: 2020 6th IEEE ınternational energy conference (ENERGYCon), pp 988–993. https://doi.org/10.1109/ENERGYCon48941.2020.9236530
11. Song N, Kwak B (2019) International standard trend of vehicle to grid (V2G) communication ınterface for wireless communication and RPT. In: 2019 IEEE transportation electrification conference and Expo, Asia-Pacific (ITEC Asia-Pacific), pp 1–5. https://doi.org/10.1109/ITEC-AP.2019.8903797
12. Hassan Mohamed T, Ahmed Hassan H (2018) Terminal voltage and power regulation using vehicle-to-grid (V2G) schemes connected to a two-area power system. In: 2018 20th ınternational middle east power systems conference (MEPCON), 2018, pp 203–208. https://doi.org/10.1109/MEPCON.2018.8635159