Modeling the Impact of Vehicle-to-Grid System on Electric Power Quality

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ABSTRACT: The transition toward Smart Grids concept promoted the increased reliance on renewable energy sources and Electric Vehicles (EV). Through such concept, and with the help of EVs, it becomes possible to enhance the Power Quality (PQ) of the grid by delivering the energy stored in batteries on-board EVs into the electrical network through Vehicle to Grid (V2G) functions. V2G technology's aim is to provide the electrical grid with the surplus of energy stored in EV batteries in order to stabilize the grid, and to compensate for the PQ disturbances that occur in the network and may damage the appropriate function of the loads connected to the electrical network. This paper presents Modeling the Impact of Vehicle-to-Grid System on Electric Power Quality. The paper analyzes how Vehicle-to-Grid (V2G) technology can balance the grid and regulate power quality issues caused by EV charging, ensuring stable system operation. On the basis of the study results, the impact of electric car chargers on electric power quality was assessed, and attention was given to the opportunities offered by the development of charging systems with vehicle-to-grid (V2G) functionality.

KEYWORDS: Vehicle to Grid (V2G), Power Quality (PQ), Electric Vehicles, EV batteries, charging systems.

I. INTRODUCTION

Recently, Electric Vehicles (EVs) have received an increasing attention, as the rapid development of EVs technologies is regarded as a trigger to rely on EVs in the near future [1]. Environmental and social issues such as pollution and harmful CO2 emissions caused by the excessive use of ICE cars are the main key factors leading to the adoption of Electric cars as the most appropriate, sustainable and clean alternative for ICE driven vehicles in the near future [2]. This is driven mainly by the improvement in battery cell technologies that certainly will lead to enhance the performance of the Electric Vehicles in terms of long periods of driving with only one charge a day, as well as the capability of the battery to withstand extreme hot or cold weathers [3]. In addition, the increase reliance on Renewable energy sources to provide energy to the electrical grid is a key factor leading to adopt more sustainable and green vehicles fully powered by clean energy. Therefore, the aim to eliminate harmful pollutants as well as reducing CO2 (Carbon dioxide) and greenhouse emissions will certainly be reached effectively relying on e-mobility as well as powering the grid with renewable energy sources [4].

Establishing more charging stations aiming to serve the high demand of energy from Electric cars connected to the grid will definitely enhance and facilitate the charging process within the charging stations and mitigate the traffic congestions caused by the long waiting times inside the charging stations [5]. The penetration level of EV fast charging affects the voltage of the distribution grid, and as more EVs connect to the grid, harmonic pollution becomes more severe, negatively impacting EV charging [6]. Additionally, uncontrolled charging of EVs for prolonged periods increases the load on the distribution grid and can result in a decline in power quality [7].

Moreover, due to the unprecedented renewable energy sources penetration in smart grid, Power Quality (PQ) has received in an increased attention, as it considered an important key factor in the power systems engineering domain [8]. PQ events such as voltage dips, although they are characterized with short durations, they are capable of degrading the continuity of the service either for affected loads or in the utility mains, and may cost the operators a loss of high amount of money [9]. Therefore, it is mandatory to assess the severity of the occurred PQ events in order to know the exact origin of different voltage dips and then create a mitigation plan performing immediately after the occurrence of an undesired event [10]. With a feasible method to reduce the hazards on the grid due to PQ events, the electrical grid will be able to guarantee a good quality of power delivered to end-users.

Currently, the application of V2G and V2X technologies, which utilize EVs as energy storage systems, is gaining traction [11]. V2G technology provides reliable energy storage without compromising battery life and offers significant advantages for industrial frequency regulation services. Using V2G technology, EVs can serve as energy storage systems to reduce the gap between peak and off-peak electricity demand on the grid [12]. Some researchers propose using direct current control strategies to provide bidirectional chargers for V2G EV batteries, enabling fast charging, fast discharging, slow charging, and slow discharging.

Through Vehicle-to-Grid (V2G) technology, EVs can interact with the grid and feed the electrical network with the surplus of energy stored in their batteries in order to help the grid withstanding additional peak demand of energy as well as mitigating severe power interruptions, outages, and avoiding blackouts [13]. Through V2G, a bi-directional flow of energy between the electric grid and the electric car is made possible. The ancillary services provided by EVs are able to compensate for the PQ events occurring continuously in the grid, i.e., stabilizing the active power and compensating the reactive power of the electrical network.

Simultaneously, optimizing intelligent charging stations and enabling vehicle-grid interaction are crucial development directions in the field. To enhance user convenience, the optimal number and location of charging stations can be determined. Intelligent charging stations can automatically adjust the charging power based on the number of vehicles, maximizing the utilization of station resources. One key technology involves using load prediction to calculate the required number of charging stations, correcting the estimated demand and designing charging station locations and capacity. Vehicle-grid interaction is also a current research focus, where scholars propose an EV charging route strategy based on prospect theory to achieve coordination and optimization among charging stations, networks, and road infrastructure. Therefore this paper presents Modeling the Impact of Vehicle-to-Grid System on Electric Power Quality. Rest of the paper is organized as follows: section II presents the literature survey, section III explains the Vehicle-to-Grid System. Results and discussions are elaborated in section IV, and finally paper is concluded with section V.

II. LITERATURE SURVEY

In [14] investigates the role of electric vehicles (EVs) contributing to frequency response was investigated. A dynamic frequency control strategy which considers the comfort level of vehicle owners was developed for EVs to regulate their power consumption according to the deviation of system frequency. The case study showed that using EVs as a demand response resource can greatly reduce the frequency deviations. And the rapid response from EVs can help reduce the operation cost of conventional generators.

In [15] an energy management and optimization system is designed and modeled. By using the wavelet packet decomposition method, the target grid-connected wind power, the required electric vehicle (EV) power, and supercapacitor power are determined. A case study demonstrates that the energy management and optimization method for V2G systems achieves noticeable performance improvements over benchmark techniques. In [16] a novel decentralised control approach is proposed to coordinate numerous EVs in a computationally efficient manner with privacy perseverance. Case studies on a 14-node GB (Great Britain) power network with a large population of 556,733 EVs are conducted to validate its efficacy in simultaneously maximising the EVs' carbon service provision and decarbonising the GB power system by intelligently linking local behaviours with global interest. Finally, the proposed control approach shows its generalisation performance for various day and season scenarios as well as evidence for realising the GB's decarbonisation ambitions by 2030 and 2050.

In [17] have suggested that the EV charging stations should be supported by a direct current microgrid algorithm for real-time, regulatory-based charging stations. This paper focuses on an EV charge station for power management strategy under power constraints and considers most drivers' choices. This article examines an EV charge station's real-time management strategy with power limitations. combining theory and practice in which driver choices, disconnecting, standby, shedding, and restoration are included. The arrival time for the electricity transmitters, the original State of Charge EV, and the drivers' choice is random, emphasizing an uncertainty concerning EV charging behavior. Smart shedding and restore operations are suggested according to the same theory as the computer stack.

In [18] An integrated power conversion system is proposed for electric vehicles (EVs), which consists of a dual active bridge (DAB) dc-dc converter cascaded by a three-phase four-leg (TPFL) dc-ac converter. The integrated power conversion system can realize both vehicle-to-grid (V2G) operation and traction operation for EVs. By designing the phase-shifting control for the primary H-bridge of DAB, a high-frequency pulsating dc-link voltage with zero portions is generated. Setting switching actions of the secondary H-bridge of DAB and TPFL during zero portions of the dc link, the zero-voltage-switching (ZVS) operation is achieved, and the system efficiency can be improved consequently. Detailed analysis of different switch states within one half operating cycle is presented. Both simulation and experiment are conducted to verify the effectiveness of the proposed system and control schemes.

In [19] describes a model of an electric vehicle storage system integrated with a standardized power system. Applying empirical data, the benefits to the network in terms of load balancing and the energy and cost savings available to the vehicle owner are analyzed. The results show that for the case under study, the EVs have only a minor impact on the network in terms of distribution system losses and voltage regulation but more importantly the vehicle owner's costs are roughly halved.

In [20], aggregated electric vehicle (EV)-based battery storage representing a V2G system is modeled for the use in long-term dynamic power system simulations. Further, it is analyzed for power system regulation services for typical days with high and low wind production in the Western Danish power system. The results show that the regulation needs from conventional generators and the power deviations between West Denmark and Union for the Coordination of Electricity Transmission (UCTE) control areas are significantly minimized by the faster up and down regulation characteristics of the EV battery storage. In [21] present the transient stability analysis of a power grid, which integrates both superconducting magnetic energy storage (SMES) and grid able vehicles (GVs). Simulations of various faults are carried out under different penetration proportions of SMES and V2G power. The results of load angle response and system voltage response are given to illustrate that both SMES and GVs can enhance transient stability of the power grid. Moreover, the simultaneous use of SMES and GVs can further improve the system dynamic performances.

In [22] presents a framework for analyzing V2G service development from a coevolutionary perspective in which the interactive relation between the diffusion of EVs and the upgrade of the distribution grid system is considered. A V2G service development logic and its management formulation are put forward. The physical trade structures and corresponding management hierarchies, management relations as well as management measures, are proposed. This paper provides a new perspective of V2G service development, answers the core question on how to make the V2G vision come true in synergy with the development of EVs, and gives some advice on future V2G management paradigms.

In [23] Charging cost functions suitable for charger- and utility-controlled power scheduling are presented. Ancillary service levels possible with unidirectional vehicle-to-grid are quantified using sample charging scenarios from published data. Impacts of various power schedules and vehicle participation as a flexibility resource on electricity locational prices are evaluated. These include benefits to both owners and load-serving entities. Frequency regulation is considered in the context of unidirectional charging.

In [24], our attention is on bringing a large number of EVs into the centralized supplementary frequency regulation (SFR) of interconnected power systems. The aggregator calculates the total frequency regulation capacity (FRC) and expected V2G (EV2G) power of EVs based on the data communicated between the aggregator and individual EVs or EV charging stations. Besides, V2G control strategies are developed to distribute regulation requirements to each EV. Simulations on an interconnected power grid based on a practical power grid in China have demonstrated the effectiveness of the proposed strategies.

In [25] Plug-in electric vehicle (PEV) is an emerging vehicle that can be directly charged from the power grid via properly designed vehicle-to-grid (V2G) interfaces that coordinate the energy flow between the grid and the connected PEV. Bidirectional dc/dc converters are used as controlled power interfaces between the HESS (Hybrid energy storage system) part and the common dc-side connection point. The proposed scheme is verified by simulating the complete nonlinear plant and controller system, while a further validation is conducted through a hardware-in-the-loop (HIL) real-time dSpace-based emulation.

III. Vehicle-to-Grid System

Now a days, the power demand is increasing vigorously this demand can't be controlled that's why we need to produce more energy to meet this demand we have one more solution else than producing more power we can withdraw power from that batteries of the vehicle. When the grid is supplied with the batteries of the vehicle this concept is called as Vehicle to Grid. Though it cannot provide power that can meet that requirement but still this is also the one more way to provide the power.

Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or its life expectancy. Any power problem in Voltage, Current or Frequency deviations that results in mis-operation of consumer equipment or failure is power quality problem.

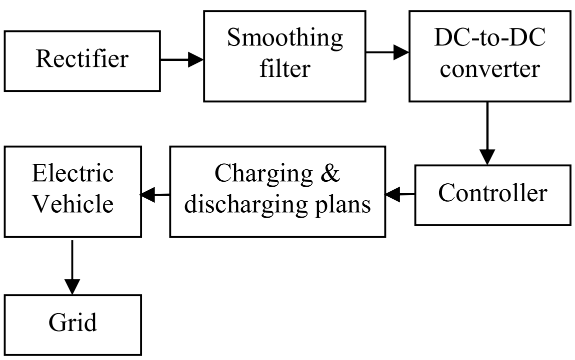

Figure 1. Block diagram of V2G **system**

V2G Charger Model:
The V2G concept is all about the vehicle connected to grid. When the vehicle is connected to grid when it is fully discharged to get energized with the help of grid this can also feed the grid its power when the energy demand of the vehicle is mate this cycle is shown in the block diagram below. When the vehicle is connected to grid, it will affects grid performance factors the reason behind this is the grid has its own load before this charging of vehicle and the grid is designed to meet its load demand but the electrical vehicles are new in market to adopt this change grid will require more time so this is at its first step so there will be excess load on the grid in the form of these electrical vehicles. The effects on grid due to this load are observed with the help of this prototype.

The grid has large capacity but for the battery charging it has to be step-down at 230-0-12V after this the battery is supplied with 12V. All the blocks are connected to microcontroller (PIC18F4550). The battery is connected to the inverting circuit to feed back to the supply. The effect can be observed at different stages that is 1. Supply at initial stage (nothing at the output)
2. When battery is connected (regulated supply)
3. When battery is connected (unregulated supply)
4. When V2G is ready
5. V2G is ON and feeding back to the supply.

A 220V AC primary to 15V-0-15V secondary transformer, two high power (1N5408) rectifier diodes, and a filter capacitor (C1 = 2200F) make up the step-down and rectifier. This setup resembles a full-wave rectifier with a filter circuit. The AC input voltage is reduced by transformer X1 to 30V AC, which is rectified by two diodes D1 and D1 and filtered by capacitor C1. This DC output has ripple, and the DC volt magnitude is around 28.5V (30V-0.7V-0.7V = 28.5V). The voltage drop across diodes D1 and D2 combined is approximately 1.5V.

The charger circuit is built around a voltage regulator IC that may be adjusted (LM317T). The input pin of IC1 receives filtered DC voltage (LM317T). This IC can deliver a controlled voltage of 1.2V to 32V at a current of more than 5A. The protective diodes D3 and D4 safeguard against reverse polarity voltage sources. The voltage at the output is controlled by transistors Q1 and Q2. When the battery is completely charged, the output is set to float charging, and when the battery is charging, the output is set to bulk charging.

When the battery charging status is showed full on the LCD the V2G shows ready i.e. V2G is ready to operate and can provide supply to input side.

- For V2G the battery voltage must exceed 13.9 volt otherwise it won't start.
- It operates up till the battery voltage reaches to 11 volt after it reaches to 11 volt it doesn't operate.
- For V2G one switch is provided which is operated manually but only after the V2G status on LCD is READY.
- Two MOSFETs (Q1 & Q2) are used in this inverting circuit for providing oscillations to the inverting circuit.

IV. RESULT ANALYSIS

Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or its life expectancy. Any power problem in Voltage, Current or Frequency deviations that results in mis-operation of consumer equipment or failure is power quality problem. Power quality issues observed in this project are as follows;

Impact on voltage fluctuations:

The use of unsafe chargers can result in load-induced fluctuations in direct current (DC) voltage and power factor reduction. The voltage of uncontrolled rectifier chargers fluctuates greatly during the charging process, but when pulse width modulation (PWM) rectifiers are used, the voltage variation in the distribution grid is minimal. Voltage fluctuations are methodical varieties of the voltage envelope or a progression of irregular voltage changes, the size of which doesn't regularly surpass the voltage range 0.9 to 1.1 Pu.

- Voltage fluctuations are portrayed as a progression of irregular or ceaseless voltage fluctuations.
- Loads that can display ceaseless, fast varieties in the heap current size can cause voltage varieties that are frequently alluded to as glint.
- The term glint is gotten from the effect of the voltage fluctuation on lights to such an extent that they are seen by the natural eye to gleam. To be in fact right, voltage fluctuation is an electromagnetic peculiarity while flash is an unfortunate aftereffect of the voltage fluctuation in certain heaps.

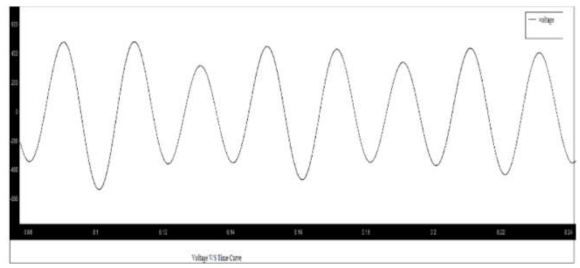

Figure 2. Voltage Fluctuation

Notching:

Notching is an intermittent voltage aggravation brought about by the ordinary activity of force electronic gadgets when current is commutated starting with one stage then onto the next.

Voltage unbalance:

On the off chance that the single-stage homes are drawing equivalent current and are appropriately circulated across the three stages, than voltages will be adjusted. Practically speaking this is difficult to accomplish and the downstream voltages will in general be different in the three guides. This is called as voltage unbalance and may cause heating of machine.

DC Offset:

The presence of a dc voltage or current in an air conditioner power framework is named dc offset. Impacts:

- It might immerse the transformer internal winding causing extra warming and loss of transformer life.

- Direct current may likewise cause the electrolytic disintegration of establishing terminals and different connectors.

Impact on harmonics of power grid:
In addition to voltage fluctuations, EV charging also has a notable impact on harmonics in the power distribution grid. Harmonics not only affect voltage variations but also compromise the compatibility of the grid. The presence of harmonics constitutes a form of pollution in the power distribution grid, degrading the operating environment of electrical equipment, generating excessive harmonics, and potentially causing line short circuits and even power outages.

Impact on power grid's load capacity:
The rapid development of electric vehicles (EVs) presents significant challenges to the planning and construction of urban power distribution grids due to the substantial increase in charging load. The types of charging in the distribution grid have also changed, with the introduction of new loads such as electric heating and EVs connecting to the grid, leading to increased demand. If the structure of the distribution grid is incompatible with the penetration rate, the connection of these loads poses a significant risk to the safe operation of the distribution grid. To address the issue of limited load capacity in the distribution grid, measures such as timely adjustment of grid load or grid upgrading are needed to ensure the safe operation of the distribution grid. Methods such as network transformation, power capacity expansion, and double-fed line power supply can be employed to enhance the load capacity of charging stations in the grid.

Simulation Results:
Simulation studies were conducted for the developed models of chargers and networks. In each case, a low-voltage network powered by a 630 kVA transformer station was modeled. For chargers with smaller power (22 and 40 kW), the power line was a reproduction of an aluminum cable with a cross-section of 150 mm^2. On the other hand, the 200 kW chargers were modeled on a 240 mm^2 aluminum cable due to the higher rated current. Two cases where the low-voltage grid has been loaded with several chargers operating in one circuit were investigated. For both situations, the worst conditions for the network were modeled in terms of load. It was calculated that a 200 m long line made with a 150 mm^2 aluminum cable can be loaded with up to seven 22 kW chargers or four 40 kW chargers.

Simulation of 200 kW Chargers:
Due to the value of the rated current, for 200 kW chargers, the line made with a 240 mm^2 aluminum cable is used in the model of the mains supply. It is assumed that the maximum length of the line is 250 m. In all the simulations, the following elements were taken into account: loads, current-carrying capacity, permissible voltage drops, requirements for protection against electric shock, and network typology. The worst case was when the length of the cable reached 250 m and yet the requirements of technical standards were met. As mentioned in the previous experiment, the most unfavorable conditions of network operation in terms of load and line length were modeled. The results of the simulation tests are presented in Figure 3.

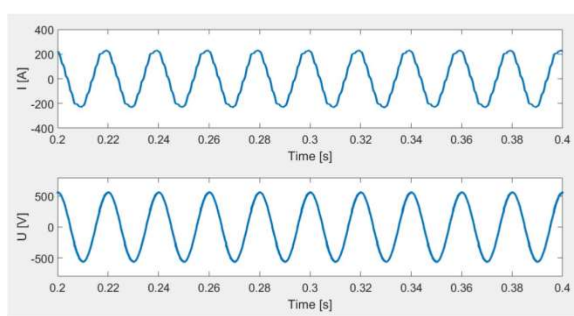

Figure3.Current and voltage of the transformer supplying a 200 kW charger

As in previous cases, for a high-power charger, the current and voltage waveforms are not deformed.

Simulation of 40 kW V2G Chargers:

The following simulations show a case in which four 40 kW chargers worked in a V2G configuration and transferred energy from batteries in electric vehicles charged to 80% to the mains. The grid model was additionally loaded with a load of 10 kvar. The results of the simulation tests are shown in below Figure 4.

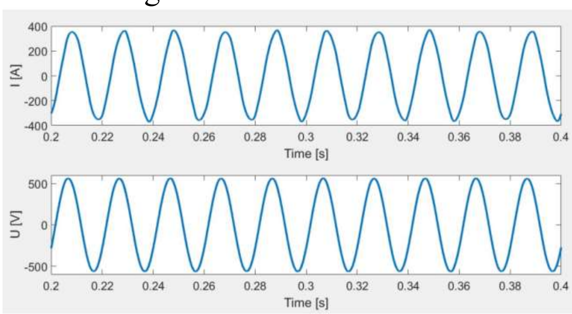

Figure 4. Current and voltage recorded at the point of connection of four 40 kW vehicle-to-grid (V2G) DC chargers

The simulations showed that the maximum load on the mains with chargers operating in the V2G mode also had no negative impact on the voltage deformation.

V. CONCLUSION

In this paper, modeling the Impact of Vehicle-to-Grid System on Electric Power Quality is described. Electric vehicles will gradually become main stream in the automotive market. By employing appropriate methods and technologies, the shortcomings of EVs in terms of charging and energy storage can be optimized. The case for V2G and sustainable energy production in the long run boils down to a decision. Separate the electric system from the car fleet. As a result, the cost of renewable energy will rise since we will need to create storage to match intermittent capacity. Alternatively, to intelligently integrate the vehicle and electric power networks by utilising the large untapped storage capacity of an emerging electric-drive car fleet to serve the electric grid. Impact of Vehicle-to-Grid System on Electric Power Quality is analyzed in result section. In order to analyze the charging process in more depth, it is possible to establish a simulation model to effectively reduce errors. Delayed current control can suppress and regulate a portion of the harmonic generation at the source, while series harmonic compensation can effectively eliminate third-order harmonics.

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