Vehicular to Grid Technologies– A Survey on Architectures and Solutions

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Abstract—**Nowadays, the novel Vehicle to Grid (V2G) technology is becoming of high interest in the domain of Electric Vehicles (EVs). In the context of many EVs connected to the power grid, the V2G technology has as its primary objective to control and assure a necessary balance between the consumption of the energy by some EVs and possible energy delivery into the power grid by other EVs. The V2G applications potentially help to increase the supply grid performance, concerning system stability, efficiency, and reliability. Given the novelty of V2G networking, this paper exposes a short survey on the V2G technology, focusing on identifying the challenges and open research issues for our future work. Also, some solutions and not yet solved problems in V2G are discussed. The approach of using a Software Defined Network (SDN) type of control is briefly introduced. The advantages of SDN-Based Smart Grid (SG) are identified, as well as some challenges, especially related to the centralised concept of the SDN.**

Keywords-V2G; Electric Vehicles; SDN-Based Smart Grid; Software Defined-V2G.

I. INTRODUCTION

The Vehicle to Grid (V2G) technology has recently received increased interest from researchers because of its advantages for both the environment and for power systems. From the environmental perspective, Electric Vehicles (EVs) are nature-friendly because of their reduced pollution when compared with conventional vehicles (fuel and gasoline). From the power system perspective, by exploiting the battery of the EV, it can act as power storage that can be used based on demand. The Smart Grid (SG) is a comprehensive innovation proposed for managing and monitoring the traditional power grid. The SG introduces a bidirectional communication (two-way) between service companies, and consumers and has sensors over the transmission lines that why it is called "Smart Grid". Therefore, the main objective of the V2G technology is to provide available distributed power to serve the EVs connected to the SG.

Figure 1 illustrates the bidirectional connection between EVs and the SG. The power can flow in two directions: from the power generator, over the SG to reach EVs or back, from the EVs to the SG. Usually, the EVs are supposed to have appropriate resources in order to benefit from the advantages the V2G technology has to offer [1]. Software, processing power, and power electronics devices should be included in the design of EVs. The EVs can be attached to Distributed Networks (DNs) [2], to deliver power to a grid at peak hours of load and thus enhance the overall system efficiency and reliability. Moreover, the EVs must have three essential elements:

- A connection to the SG for power flow.
- Physical and logical communication connections to the grid operator, used for control purposes.
- Onboard metering capabilities and controls of the EVs.

The power grid arranges the vehicles in a group called an aggregator. Also, it coordinates the charging and discharging processing in order to provide reliable operation.

SDN offers flexible control by separating the control plane from the data plane. The control plane has programmable controllers and logical centralisation. Controllers can have access to the entire network information, so it is easy to configure the network and deploy new protocols. Switches in the data plane provide only simple data forwarding function, thus matching packets can be processed rapidly to adjust the growing traffic.

As a novel technology, the V2G is facing challenges, and therefore, several open research issues exist. This work identifies several open problems, some of which have solutions and some are still unresolved.

The structure of this paper is the following: Section II describes some relevant work in the field. Section III presents the features of SDN control integration into the SG. In Section IV, we address EVs charging issues in the SG and we outline the usage of SDN as a control solution in the V2G environment. In Section V, we describe a general SDN-Based V2G framework. Section VI identifies some open research challenges. The conclusion is summarised in Section VII.

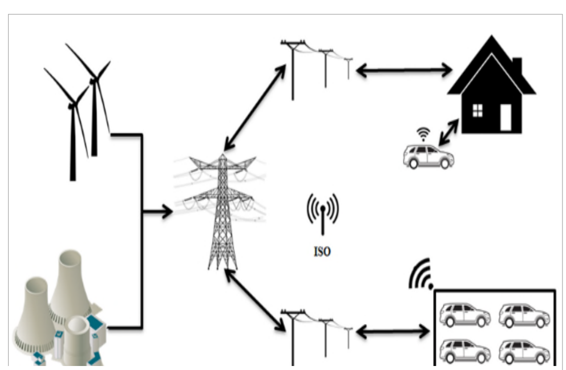

Figure 1. The connection between EVs and the power grid.

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II. Summary Of Related Work

Wang et al. [3] introduce a novel architecture of distributed energy management for the integration of V2G networks with EV aggregator, aiming to achieve energy balancing between the grid side and the EVs side. The paper analyses theoretically what are the constraints of charging, incorporated in the form of *Willingness To Pay* (WTP) and proposes a distributed framework to coordinate the system behaviour during charging and discharging.

According to SDN features as mentioned above, SDN can solve two problems of V2G. First, V2G have the problem of complex network configuration and management due to the dynamic of V2G. Second, unbalanced the energy distribution in V2G, so the importance of communication data is different. The SDN can accelerate forwarding time and achieve traffic control.

Zhang et al. [4] proposed for V2G communication model, software-defined V2G (SD-V2G), aiming to apply SDN in V2G. This proposal deals with the dynamic communication and security for the V2G system. Also, a security communication mechanism (SCM) is proposed to ensure non-repudiation, confidentiality, integrity, and authentication.

Sun et al. [5] proposed a software-defined charging network architecture for hybrid EVs having three architectural planes: physical, control and application plane. Some more details are provided in Section IV.

Li et al. [6] exploit the multicast communication to collect information on the battery status and *State of Charge* (SOC) from EVs. They propose a battery status sensing by a software-defined multicast (BSS-SDM) scheme, where the battery status of each EV is identified during SOC transitions and maintained by a centralised controller. Additionally, a battery-status-based multicast scheduling algorithm is proposed to implement the V2G regulation optimisation. The work presented simulation results that verified the effectiveness of the proposed schemes. The BSS-SDM is shown to be more adaptive than to achieve optimal costs of the V2G regulation delay time in IEC 61850 advanced for V2G. Li et al. [6] also propose the coordination of EVs during charging/discharging sessions.

Integration benefits of the SDN with the SG in terms of improving the system operations are proposed by Chen et al. [7].They introduce a ‘‘two-tier SDN based framework’’. The results have shown that it is easier to upgrade and configure the SG. However, there are other open issues (e.g., request balance between tiers) required to be solved.

Rehmani et al. [8] presented a comprehensive survey on the SDN-controlled SG, including a taxonomy of the advantages and the architectures. Also, this work identifies some challenges, open research issues, and future directions.

Considering the recent developments in Fog computing, technology, Tao et al. [9] proposed a new hybrid computing model for V2G networks, to integrate Fog and Cloud for 5G-Enabled V2G networks, (called Foud).

III. Major Advantages of Software Defined Networking In Smart Grids Context

The SDN technology can successfully be used to manage in a centralised way the communication entities in the SG system and also to improve the efficiency, scalability, and resiliency. By deploying the SDN in SG technology, one can reduce the system cost and management complexity, making easier the system upgrades. In particular, this solution is appropriate to satisfy the demands of charging operation.

The SDN controller can offer (Rehmani et al. [8]):

- <u>*Programmability:*</u> this feature is an added value that SDN brings to SG. For instance, appropriate decisions (dynamically changeable) can be taken, in situations when a specific link should be used, based on differences in SG communication traffic. However, an open research issue is related to the fact that different SG components might use different protocols and are based on different standards. Therefore, the SDN controller should be able to handle diverse communication technologies. This issue can be solved by taking benefit from the abstraction capability of the SDN architecture (data plane is abstracted at the control plane level). This separation can also be exploited in SG, in terms of management and communication support.
- <u>*SDN independence on vendor specific data plane solutions:*</u> *SG* can implement and run diverse applications, networking technologies, and protocols.
- <u>*Powerful traffic management*</u>: SDN controller can naturally identify data flows, i.e., it can install appropriate flow tables in the forwarding nodes. The traffic flows are treated accordingly to their particular requirements; this allows the SG to meet some specific *Quality of Service* (QoS) requirements (in terms of reliability, delay, and throughput).

The SG operates on different types of traffic. The SDN controller can simultaneously identify the traffic types, and set priorities to the traffic flow by dynamically programming the SDN switches. However, there is an open issue on horizontal scalability, in terms of the number of devices in the vehicular network that can be managed by a single SDN controller.

IV. V2G Charging/Discharging Solutions

A. Charging Coordination

A critical issue faced by V2G technology is how to coordinate a large number of EVs via the aggregator to perform charging or discharging actions, in order to offer an efficient service. This problem is a challenging one because it is hard for the aggregator to directly control the charging/discharging activities of each EV individually. Moreover, the privacy of the EVs owners should be met

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(some of them would not want to disclose their personal activities).

To solve this problem, Wang et al. [3] defined for an EV a parameter named WTP (Fan et al. [10]). They formulated the V2G adjuvant services and applied methods of the contract theory (Laffont et al. [11]). A framework has been developed for distributed coordination of the EVs activities (charging/ discharging). The aggregator can coordinate the EVs and also can increase EVs revenue. One main objective is to reach a balance between power supplier and consumer. Some numerical results of their framework show that this solution can make a higher income to the aggregator.

From our point of view, the work in [3] can further continue in our future work by simulating the model and make a comparison between practical and theoretical results. Also, the location awareness of the EVs by the SG is required to apply in this model. Therefore, the SG will be able to send a request to the EVs based on demand.

B. Multicast

In multicast communication, the information is sent to multiple receivers (e.g. users) in the network. In term of SG, multicasting has been used to distribute time-critical information such as control instructions or measurement data from the Phasor Measurement Units (PMUs). Generally, one PMU is deployed on a substation. Where, PMUs are responsible for monitoring the level of voltage and phasor angle of the transmission lines. Then, this information is collected by different PMUs and sent to a Phasor Data Concentrator (PDC). Then, this collected measurement data forwarded by the PDC to the control centre of the service [8].

In wide area monitoring systems, the PMUs measure information of current and voltage current and this measured information is multicasted to the control centre for immediate actions. Also, multicast can be used to inform a large number of consumers to turn-off their appliances at peak time, in order to manage and control the power level in the SG. In the substation, the multicast communication can distribute an emergency alert across substation Local Area Networks (LANs). In SDN-Based SG, multicast has been applied to V2G networks, PMUs, and substation communication.

The EVs can be considered as moving power storage which may support to supply power to entities where is energy is required. In a functional of V2G network, several sensors are installed at *Charging Stations* (CSs) as well on the EVs itself. These sensors help the EVs owners to monitor the charging situations of their vehicles. Consequently, by sharing this information of sensing to the V2G network, the global power grid can be stabilised. For example, the SG can schedule the charging/discharging at EVs, based on the power grid demand. This makes necessary that the V2G knows the battery status of EVs and their SOC. Through multicasting, the V2G can instruct the EVs and implement the regulations relating SOC.

Li et al. [6] proposed a battery status sensing by a software-defined multicast (BSS-SDM) scheme, the EVs access to the SG system for charging or discharging operation, controlled by the SD-V2G controller. During the power transition, the SD-V2G controller directly communicates via *Southbound Interface* (SBI) with data plane. The data plane is distributed devices and contains different devices: routers, Road Side Units (RSUs), smart meters, EVs, smart sensors, etc.).

The central SD-V2G controller includes functions of monitoring and controlling the EVs sensors. SD It supports the V2G multicast in order to support EVs mobility, as well to provide a capability for dynamic configuration. The simulation results show that the BSS-SDM scheme could reduce the average delay time of the V2G operation.

C. Type of Charging

Management of the regulation charging is required for the SG (especially when the number of EVs is high), in order to avoid unregulated charging that could lead to grid overload and even provoke SG breakdown. A solution to this problem is to design EVs to support the SG aiming to achieve a balance for the SG (Wang et al. [12]). Another problem is how to balance between the charging demand and the capability of service while a large number of EVs are onboard.

There are two types of charging; wired and wireless charging technologies. These two technologies have advantages of increasing the efficiency of charging and provide a bidirectional power transition. Wang et al. [13] introduced a Demand-Side Management (DSM) scheme for the wireless charging, showing that in this way the process of wireless charging can be easier and economical. Integrating both of wired and wireless charging technology into the SG required an extensive communication network to implement the DSM scheme for the EVs keeping the stability of the grid in the real time.

By investigating the advantages of SDN, Sun et al. [5] proposed a framework of Software-defined Green (SD-G), which provides both wired and wireless charging and efficient charging management. The objective is to evaluate the SD-Based EVs charging network. The architecture of SD-G framework contains three planes: physical, control, and application plane. The EVs and SG networks have both elements in the physical plane while the control plane is responsible for control, of the data and power flow. The centre of intelligent decision is served by the application plane. The EV owner will get specific information about the SG to practice the charging decision.

The simulations performed by Sun et al. [5] attempted a comparison between two cases: with SDN and without SDN control. The result shows that the demand setting time and the cost of SG operation for nodes can also be controlled.

V. A General SDN-Based V2G Framework

The increasing number of EVs or Plug-in Electric Vehicles (PEVs) and Internet of Thing (IoT) devices, and their interaction with the SG need further study to improve the efficiency, reliability, and stability of the system operation. The integration of EVs and SG has a feature of increasing the power storage through V2G technology and corporate the SG with *Renewable Energy Source-*

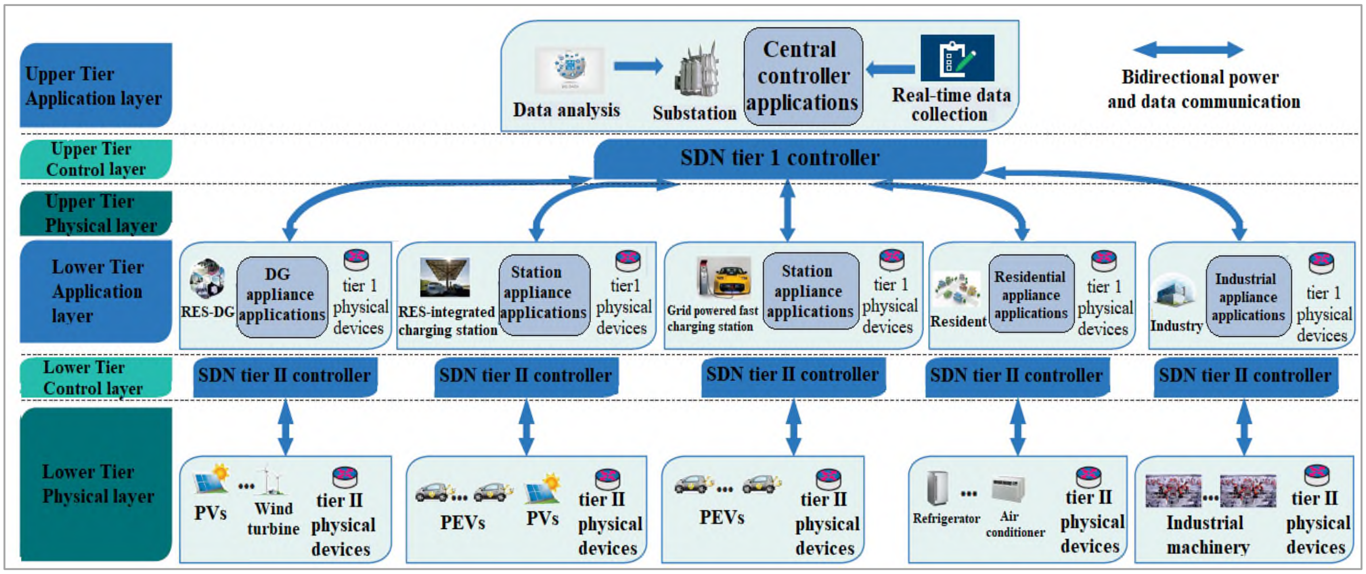

Figure 2.The SDN Framework for the distribution system in the PEV integrated SG [7].

Distributed Generations (RES-DGs). Moreover, with the integration of EVs with RES-DG into the power system, SG faces the challenges of increasing large numbers of EVs and IoT, which will affect the system scalability. Also, the connection of EV, RES-DG, IoT, sensors, etc. to the network require a hard/effort to configure the devices and maintain a convenient cost at the same time.

To address the challenges mentioned above, many contributions proposed general solutions, to cover any gaps and satisfy the consumers. The approach adopted in [7] (see Figure 2) comprises a two-tier SDN based framework for the integration of EV with SG, aiming to provide a scalable and stable system. The distribution system power flow has two tiers. First, the power flows from sub-stations to primary feeders to provide power for large-size commercial and industrial loads. Then, the power flows from primary feeders to secondary feeders to supply the small-size resident loads.

Consequently, the SDN framework also has two tiers. The tier-1 controller is located in the substation to have a global system view, while the tier-2 controller is managed by every aggregator in primary feeders to perform the power and data operations. SDN controllers on each tier collect the information frequently. This information is analysed by the application layer to achieve optimal operation then, the application layer sends new instructions to the devices in the physical layer to update their commands.

A case study [7] based on PEVs and RES-DGs can contribute to identifying the requirement of applying SDN into the SG. Three fast charging stations (A B and C) are deployed along a highway and distance between each one is 50 miles, (figure 3). The stations A and C get power generated from solar radiation, while B is a powered by the It has been supposed that PEVs arrive at each station following a Poisson process through hourly variant arrival rates. The charging stations send requests to the passing PEVs for power supplement.

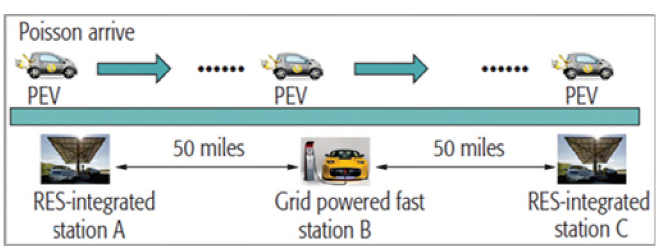

Figure 3. The layout of fast charging stations [7].

The first case considers 15 per cent of PEVs entering the station, following a uniform distribution. In this hypothesis, most PEV resources are wasted. The arrival rate of PEV in the stations (A and C) are increases, while the grid powered station (B) does not require any PEV, because the grid powered station is stable and consistent source for the V2G services. Note that the cloudy station would require more PEVs than the sunny station.

The second case applies the SDN lower-tier operation. The passing PEVs can be fully used to help the stations to complete their V2G services. The SDN coordinated performance is improved, while the PEV arrival rate increases. The cloudy station requires far more PEVs than the other two stations. The SDN-based system can analyse the service requests depending on weather conditions; it is able to direct more PEVs to the most needed station to help the V2G service.

VI. OPEN RESEARCH ISSUE AND CHALLENGES

Given that V2G is a new technology, many frameworks have been proposed; however, some of them have not yet been implemented, given many open issues. In this section, we identify the challenges of the V2G technology from the communication side in order to guide for our future work investigations.

A. Wired and Wireless Charging

In practice, many different charging standards have been adopted (in single wireless or wired charging technology). A unified charging standard would be necessary to be studied

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and defined. Wireless EVs charging may have two significant behaviours; static and dynamic charging. By applying the dynamic charging in the road, one can reduce the traffic in the SG. If both of wireless/wired charging are supported by EVs/SG, a selection decision is required to get optimal charging operations.

B. Synchronising Between Tiers

The aggregators in primary-feeders [7] obtain and implement the instructions from the upper-tier. On the other hand, they obtain requests from the physical devices in the lower-tier, and provide suitable responses. Unsynchronised data transmission of instructions from upper-tier and the lower-tier requests may cause a lack of consistency at the controllers in lower-tier. In some situation, the analysis process at controllers in the lower-tier possibly will meet different operation circumstances so that the controller will be confused. The problem of balancing and evaluating process between the instructions in upper-tier and requests in the lower-tier, will be study and simulate in our future work. Additionally, we will apply a simulation for the charging and discharging decision and control process using the tools of OMNET++.

C. SDN-Based V2G and Energy Internet (EI)

A novel concept has been proposed recently called Energy Internet (EI), aiming to connect numbers of SG devices for the purpose of management of the power flows. Similar to traditional internet, the EI has routers and the idea is to find the optimal routs and/or paths. That approach will achieve high efficiency in the power distribution. Also, EI has Local Area Networks (LAN), called (e-LAN) in the Energy Internet standard. The power routers are responsible for power flows management between various SG devices and, in this regard, Wang et al. [14] proposed different algorithms of energy routing. Chelmis et al. [15], Zhang et al. [16], and Hou et al. [17] presented some results about the integrating EI and SDN; this novel concept still requires hard efforts in order to achieve an efficient and reliable system operation of SDN-Based Energy internet. For instance, it is hard for a single power router to have the information of the entire network status at a short time. Therefore, the real global smart control is not achieved yet.

D. Integrating Fog and Cloud (Foud) For 5G-Enabled V2G Networks

To deal with the high mobility of EV, the computing resources provided by mobile computing devices are integrated with the provisional Fog dynamically. So, the performance of the V2G applications and services in Foud computing is affected by the mobility of EVs. Efficient *resource management* can be implemented by dynamically integrating the mobile computing resources with provisional fog, and integrating cloud computing with temporary fog (Foud), which is constitute a significant open issue needs to study further. Also, integrating between Foud and two-tiers framework could be a useful solution to reduce the large data in the SDN controller.

E. Failures Detection

A central SDN controller may face failure issues, such as breakdown, resource limitation by a malicious switch, and so on, that is could be causing a loss of SDN controller service. Therefore, solution for this problem is required. Also, fast failure detection and recovery using the OpenFlow should be analysed; in the situation of communication link failure, the packets should be routed to additional rout with/without asking the SDN controller.

VII. CONCLUSION

The novel V2G technology is still facing many problems and challenges, especially from the communication perspective. The SDN is a powerful solution to have a global view on the network. It can also solve problems management and control for V2G service. The EVs represent an available power storage distribution to the grid based on the demand, integrating the SDN in the SG; one can control the EVs onboard and coordinate their charging status. In this paper, we have discussed some open research issues concerning the integrations of SDN in SG. Multicasting and scheme of SDN-Based V2G will be considered in our future work. Finally, we have identified and discussed some challenges, open research issues, and future research directions related to SDN-based V2G.

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