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A Concept of V2G Battery Charging Station as the Implementation of IoT and Cyber Physical Network System

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Abstract—**The integration of the internet of things (IoT) and cyber physical network into the battery charging station system is critical to the success and long-term viability of the vehicle to grid (V2G) trend for future automobiles in terms of environmental and energy sustainability. The goal of this article is to create a V2G battery charging station concept using the internet of things (IoT) and a cyber physical network system. The V2G charging station concept was developed with the idea that every charging electric vehicle (EV) can communicate and coordinate with the charging station's control center, which includes a cyber physical system that addresses privacy and security concerns. The communication protocol must also be considered by the charging station. The preliminary test has been taken into consideration. Normal hours (for case one), peak hours (for case two), and valley hours (for case three), respectively, were created as charging circumstances for EVs at charging stations. Simulations were run for each of the three case scenarios. Each EV's battery state of charge (SoC) is provided a 50 percent initial charge and user-defined SoC restrictions. The MATLAB/SIMULINK platform was used to run the case simulations. The grid frequency, charging station output power, and the EV's battery SoC were all observed during the 24-hour simulation. As a result, the developed V2G charging station concept can regulate its input and output power depending on the battery status of the EVs inside the charging station, as well as provide frequency regulation service to the grid while meeting the energy demand of EV customers.**

Keywords—**IoT; cyber physical network; V2G; EV; SoC; Charging Station**

Introduction

THE demand for appropriate charging infrastructure arose during the first golden age of the electric vehicle, in the early twentieth century. The charging plug was the first ever standard produced for electric vehicles, with a standard sheet being presented in 1913 [1, 2], which would later be adopted on an international basis as British Standard 74 [2]. Infrastructure requirements had an impact on vehicle design as well. Standard battery voltages have been chosen to allow direct charging from a 110 V DC supply. This is the ultimate charging voltage for a 40-cell lead–acid battery with a nominal voltage of 80 V [1], which has been the standard for battery-electric industrial vehicles till now [2]. Alongside the development of compact and efficient power electronic converters, electric vehicles might be equipped with on-board chargers and connected directly to the AC distribution network, substantially increasing the vehicle's flexibility of usage. Vehicle-to-grid (V2G) is a technology that allows energy from an electric car's battery to be transmitted back to the power grid for the benefit of the grid. An automobile can be charged and discharged based on different signals using V2G technology. Electric vehicles and their batteries are thought to represent a transportable power source from which electricity can be extracted while the vehicle is not in use for transportation. The fluctuating power demand causes enormous loads that the power plant's generator cannot handle and must be balanced by the public power grid [3].

V2G emphasizes the concept of bilateral use of electric vehicles and hybrids, which entails connecting the vehicle to the general power grid for charging and returning excess electric power. Owners of cars equipped with V2G technology which has the ability to sell electric power to power engineering specialists during hours when the car is when not being used, and load the car during hours when the electric power is cheaper, as the price of electric power in many countries varies depending on the time of day.

In recent years, a study trend toward the adoption of electric vehicles (EVs) in smart cities has been comprehended, as EVs enable urban carbon dioxide (CO_2) reduction plans to be reduced. As a result, few researches have been conducted in order to increase the flexible and efficient mainstream integration of EVs by citizens. As in reference [4], the author used an enterprise architecture strategy to support the digital transformation of EVs for electro mobility toward sustainable mobility in one of these studies. The author aspired to integrate data from many stakeholders and systems involved in urban mobility services in order to accomplish data integration of electric mobility solutions. Another study as in reference [5] used a modeling approach for plug-in hybrid EVs to evaluate the best electricity trading policy for solar-powered microgrids. The study found that battery management is critical for promoting the widespread integration of microgrid-connected EVs. The grid energy storage capacity made available by V2G helps operators handle demand changes more effectively at the network level. It can help absorb a spike in demand without depending on a selective power cut or correct for micro-disturbances that may occur when energy output shifts from one source to another. Operators pay customers who make their batteries available as part of this model.

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In reference [6], it states that the EV managed through smart chargers or V2G chargers can provide services to the building/home (behind the meter services); the neighborhood electricity networks (distribution system operator (DSO) services) and to the whole system/region (transmission system operator (TSO) services). Smart charging and vehicle-to-grid (V2G) charging technologies use a charging device with a data connection to connect an EV to the electricity grid, allowing for the exchange of data and control commands between various entities in the EV ecosystem, such as charge points, charge point operators, and grid network operators, among others.

According to reference [7], the location of charging stations must consider the readiness of city infrastructure for development of V2G technology. The following daily basic data (weekdays and weekend) such as the charging set, the average power capacity of batteries of the electric vehicle, the total number of parking spaces, and the attitude of number of cars towards available energy and also the relation of number of cars to peak generating loading is identical (linear dependence).

The involvement of the internet network and cyber physical network into the battery charging station system plays a strong role in the accomplishment and sustainability of the V2G trend for future automobiles in its role for clean environment and clean energy.

OBJECTIVE

This paper aims to develop a concept of V2G battery charging station by implementing internet of thing (IoT) and cyber physical network system. The structure of this paper is as follow, the developed concept of V2G battery charging station, which include the use of IoT and cyber physical network system. In the results and discussion section, the analyzing of the developed concept as for its communication technologies and algorithms is provided. Then for overall developed concept and its results are concluded in the conclusion section.

METHODS

Here we provide some basic information regarding the architecture of the IoT-based management system, and the communication protocols. Moreover, it details how V2G works toward the electric grid. In addition, we also provide the cyber physical network system of the V2G technology that covers the privacy and security challenges of the V2G battery charging station management system.

A. Internet of Things (IoT)

IoT makes smart grid to contribute the information between multiple users and thus amplifies connectivity by the help of infrastructures. Cloud storage is used for the data storage where the data is sent through Internet gateway. The advantages of involving IoT in the V2G's battery charging station are listed in Table I.

The V2G system necessitates widespread involvement and a centralized mechanism for scheduling EV charging and discharging activities. Fig. 1 illustrates the proposed V2G management system. according to reference [8], it is a level 5 IoT solution. Multiple end nodes or client devices communicate data to and receive actuation signals from a single coordinator node in an IoT level 5 system. The data collected from the end nodes is sent to the cloud by the coordination node. The data is processed and stored in the cloud's database, which end users can access via a cloud-based application. Users choose how they want to participate in the operation and utilize a software application to keep track of their EV.

TABLE I
IoT ADVANTAGES IN V2G CHARGING STATION

Observed issues	Advantages
Customer engagement	IoT undergoes a complete transformation to gain greater and better engagement with audiences, reducing defects and blind spots that impair the system's accuracy.
Optimization	The same technology that improves and sharpens client interaction also increases device utilization and aids in more robust automation technology development. IoT provides a demanding functional and data area in which multiple users can participate at the same time.
Minimal waste	Current data analytics provide external insight, conversely IoT provides true information that leads to resource management that is both secure and perfect.

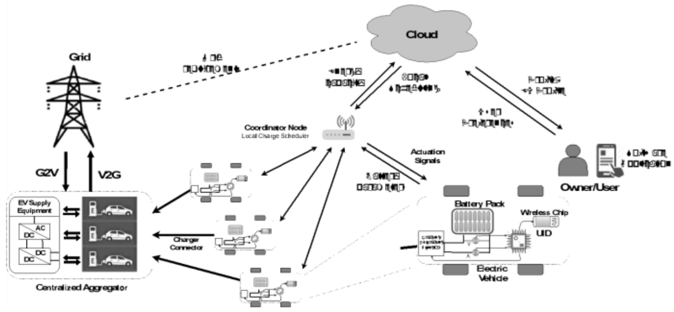


Fig. 1 Architecture of IoT-based management system [7]

Each EV is considered to be able to communicate with the centralized aggregator in both directions. A client device is also assumed to be connected to each EV. A cluster of client devices connects to a single coordinator node, which acts as a cloud access point. Since the client devices measure the parameters of the vehicle's battery and send them to their corresponding coordinator node (wirelessly) together with some user metadata unique to the EV user, they act like a battery management system. After receiving actuation signals from their respective coordinator node, they also control the charging and discharging of the EV's battery, as well as the EV's involvement in the V2G operation.

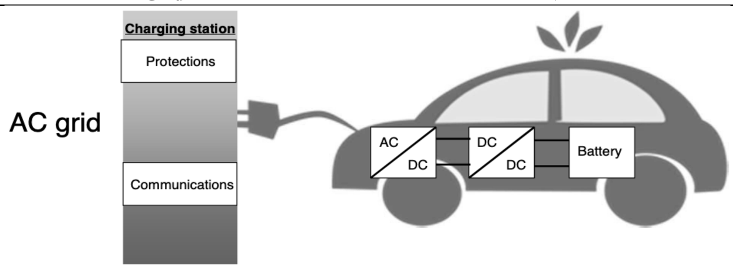
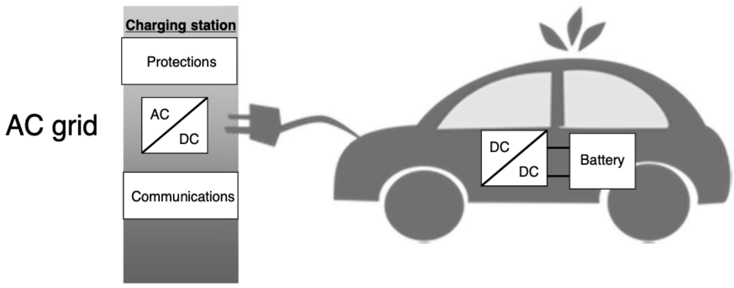
The coordinator node develops battery parameters from the EV's client device and calculates the change in the state of charge (SoC) of the battery in real time. The coordinator nodes perform as edge devices for the SoC change computation technique to reduce latency and lower the computational load on the cloud. The cloud server, on the other hand, schedules V2G processes. The coordinator node sends the computed change in SoC and user metadata to the cloud, which maintains a database of users, EVs, grids, and stations, and determines the best charging schedules for all EVs depending on power costs. It sends device-specific actuation signals, namely charging and discharging to the coordinator node depending on this schedule, which then forwards them the EVs they operate.

B. *Design of V2G's Charging Station*

Designed of the V2G's battery charging station must consider the communication protocol. The author chose the IEC 15118 protocol since this protocol is the ISO communication protocol that mostly used. The IEC 15118 protocol makes two-way communication between electric vehicles and charging stations simple. It also has a feature that allows it to identify itself automatically. As a result, as a user, you have the option of employing external identifying means (EIM) such as radio-frequency identification (RFID) cards or the automatic identification system to be identified based on your original data. In addition, the central system can set constraints to the amount of power during a charge transaction for smart charging. The infrastructure of the charging station that allows this protocol to run well can be determined as seen in Table II.

When electricity usage rises, the electrical grid in that area may become overloaded. The ability of a building to balance its electricity use with V2G charging stations benefits the power system in the long run. As the result, it useful when the amount of renewable energy produced by wind and solar in the grid grows. Renewable energy sources are inherently volatile, posing problems for places that rely on wind and solar energy. These conditions result in grid overcapacity, or bottlenecks, which can prevent electricity from reaching its intended destination. Fortunately, intelligently operated EVs can alleviate grid congestion while avoiding the need for costly grid infrastructure changes.

TABLE II
V2G TYPE OF CHARGING STATION

Connection type	Grid	EV
Contact-less charging		
	• Real insulated solution • Can be used for static and dynamic charging	• Complexity of magnet coupler design
Fast charging		
	• Charging station has to adapt to battery's characteristic • Charging station is sized to maximum power • Less efficiency	• Charger located outside of vehicle • Less constraints regarding weight and volume • Vehicles are cheap

C. *Cyber Physical Network System*

We also consider security concerns, which are crucial when creating any IoT system. For these reasons, this section discusses the privacy and security issues that V2G networks face, such as link-ability, the risk of security attacks, identity tracing, obtaining position data, extracting vehicle preferences, and compromising message information. For this developed concept, the cyber physical system of the network must have features, namely 1) Anonymous authentication and fine-grained access control; 2) Anonymous signatures; 3) Information confidentiality and message integrity; 4) Remote attestation; 5) Payment system in the V2G network.

The block diagram of the developed cyber physical system, which included security and privacy of the end-users (customers) is described in Fig. 2. While, the designed is illustrated in Fig. 3. It can be seen from the illustration in Fig. 3 that the communication occurred between an aggregator (LAG) and a communication server (ComS). Similarly, many aggregators and communication servers can be added to the situation. Owners of EVs link their vehicles to the charging stations to charge their batteries. The owners specify their input preferences (SoC), then waits for the system to process the data. The aggregator, deployed over the wireless network (i.e., DSRC), concentrates vehicle information and forwards that information to the communication server over the wide area network, i.e., long term evolution (LTE). The communication servers are responsible for securely receiving the vehicles' information, communicating with the authentication server, and billing generation and payment management centre.

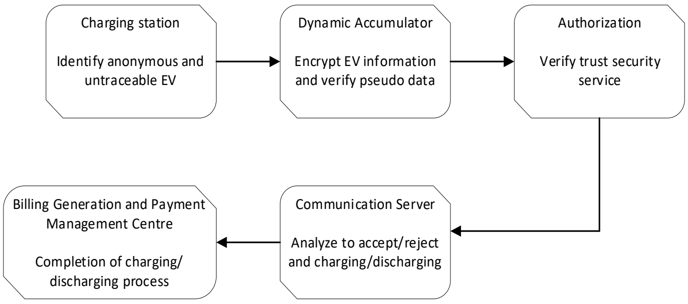


Fig. 2. Block diagram of cyber physical system on charging station

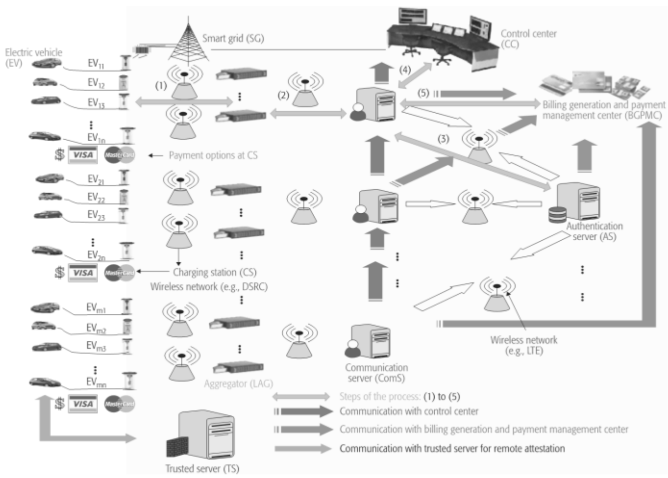


Fig. 3. Illustration process of charging/discharging V2G at the charging station

RESULTS AND DISCUSSION

Before we used the concept for advance purposes, preliminary test must put into account. Assume the initiate grid voltage is 220V AC – 24V DC. The rest of the step for the preliminary test is described in flowchart in Fig. 4. The control strategy for V2G charging station is synchronverter-based and the parameters of the simulation circuit are provided in reference [9].

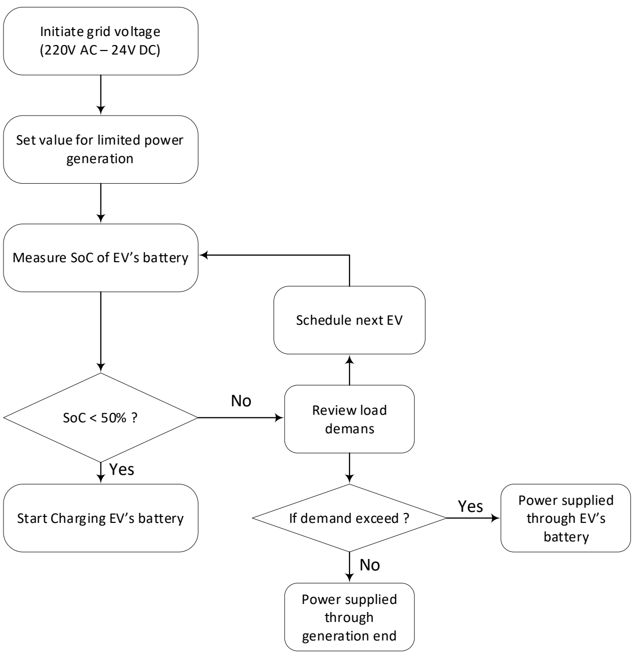


Fig 4. Flowchart of preliminary test for developed concept

A. Case Scenario of Charging Station

As the need for the preliminary test to be run, three case scenarios are built. The condition of the charging EVs are normal hours (for case one), peak hours (for case two), and valley hours (for case three), respectively. Simulations for the three case scenarios were performed considering a V2G charging station as several EVs are charging. The different initial of SoC and user defined SoC limits of each EV are given < 50%. The cases simulations were carried out in the MATLAB/SIMULINK platform.

In case one we assume that EV batteries with a different initial SoC are connected during normal hours, and that the grid frequency is 50 Hz at first, then drops or rises to 0.01 Hz every 10s, and that the grid voltage is 220V. (line-neutral). In case two, EV batteries with a different initial SoC are connected during peak hours, with the grid frequency starting at 49.8 Hz and increasing to 49.9 Hz at t = 10 s. Finally, in case three we assume that EV batteries with a different initial SoC are connected during valley hours, and that the grid frequency is 51.2 Hz at first, then drops to 51 Hz at t = 10 s.

B. Observed Parameters of Charging Station

Parameters that observed as EV's connected to the grid as their batteries assumed to be in different initials of SoC during case one, two and three, respectively. The observation of those mentioned parameters has been conducted for 24 hours. Figure 5, Figure 6, and Figure 7, respectively, illustrate the trends for grid frequency, charging station output power, and EV's battery SoC, respectively.

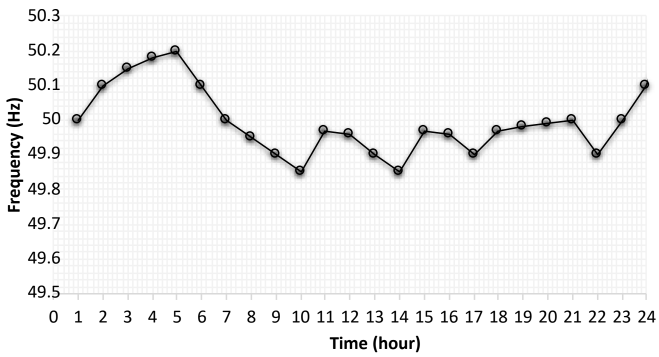


Fig. 5. Grid frequency for 24 hours preliminary test

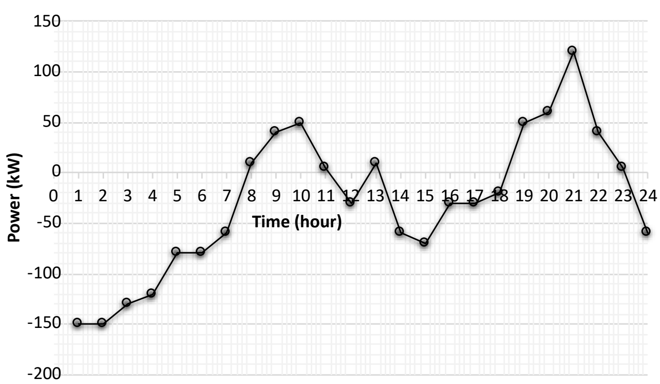


Fig. 6. Charging station output power for 24 hours preliminary test

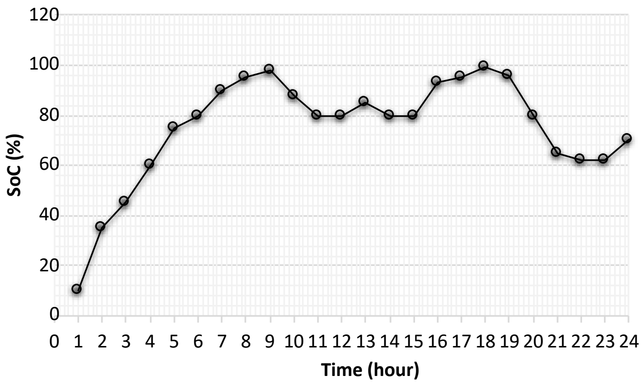


Fig. 7. SoC of EV's battery for 24 hours preliminary test

Figures 5 and 6 show that when the grid frequency is high during valley hours, at the time of 0:00–6:00, the charging station is controlled to absorb excess energy from the grid. When the grid frequency is low during peak hours, at the time of 7:00–21:00, the charging station is controlled to feed energy back to the grid. When the grid frequency is low during peak hours, at the time of 7:00–21:00, the charging station is controlled to feed energy back to the grid. It's worth noting that the charging or discharging power at the charging station is influenced not only by grid frequency but also by EVs' battery level of charge.

Due to the fact that the EVs' battery level at 4:00 is relatively high after a 4-hour high-power charge, the charging power is reduced as the energy required is reduced. It's also worth noting that the grid frequencies at 9:00 and 18:00 are the same, indicating that they're lower than the nominal grid frequency. However, since the EVs' battery levels at 18:00 are higher than those at 9:00, the former's output power is higher. In Figure 7, it can be seen that the discharging power spiked at 19:00 due to a dramatic drop in grid frequency, whereas the EVs' battery SoC were lowered at 20:00 due to a large amount of energy discharged to the grid, and their discharging power was reduced as well.

CONCLUSION

By setting three case scenarios, the developed concept of V2G charging station can manage its input and output power based on the battery status of the EVs internal the charging station, and it can also provide frequency regulation service to the grid while fulfilling the energy demand of the EV users. All of this, we may say, is inseparable from the important role of IoT and cyber physical systems in the V2G network of battery charging stations. This plays a crucial role in the ancillary services market, which addresses power grids' continual need for stabilization. V2G has an upper hand because it can stabilize the grid closer to the demand endpoints. V2G thus helps end-users save money on electricity. Without V2G technology, energy must be purchased from reserve power plants, which raises electricity costs during peak hours due to the high cost of setting up these additional power plants.

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