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A Comparative Study of Vehicle to Grid Application of Electric Vehicles on a Microgrid

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ABSTRACT- Vehicle to Grid (V2G) technology is becoming a promising application for Electric Vehicles (EVs) in modern grids. This manuscript describes the potential benefits of V2G, its functions, the scheme of V2G and demonstrates its applicability on a microgrid. We explain how EVs can act as a spinning reserve to store excess grid power in the vehicle batteries and feed the power back to the grid if the demand arises. This helps to regulate the grid's frequency within its nominal ratings. We demonstrate this on a microgrid system with a fleet of EVs connected with solar, wind, and a Diesel generator.

KEYWORDS- Electrical Vehicles (EVs), Internal Combustion Engine (ICE), Vehicle to Grid (V2G)

I. INTRODUCTION

The global population is projected to increase from 7 to 10 billion in 2050 (42.8% increase) [1], and the number of vehicles is also estimated to increase from 700 million to 2.5 billion by 2050 (257.2% increase). In India alone, the number of private vehicles is projected to be 662 million and 994 million under cautious and aggressive expansion, respectively, in the same period [2]. This large number of vehicles will require vast amounts of fossil fuel annually, which in itself, at the current rate, are set to exhaust [3] in around 50 – 100 years. Additionally, burning fossil fuels releases lots of byproducts into the atmosphere, polluting and degrading the air. Research by WHO referring to the year 2016 reports that around 7 million people die of air pollution annually around the world [4]. These problems can be addressed by using Electric Vehicles (EVs), which make them an apt alternative to conventional internal combustion vehicles. Moreover, they are more efficient than ICE vehicles, and features like regenerative braking can only be found in EVs [5] [6].

An Electric Vehicle stores around 4 KWh to 80 KWh of energy depending upon the capacity of the batteries or the size and type of vehicle [7], and it is also estimated that the vehicle is vacant 90% of the time [8]. So, a technology called Vehicle to Grid (V2G) is employed, which broadly describes the regulation and management of Electric Vehicles when connected to the grid (loads or source) by the power company or aggregators through communication between vehicles and the electric grid to charge the vehicle or offer ancillary services such as active and reactive power regulation, frequency regulation, peak load shaving, [9] load balancing through valley filling (e.g., charging the vehicle at night when the demand is low) [10], and current harmonic filtering to the grid.

The behavior of the V2G operation is dynamic and random. Optimization techniques are used to efficiently use V2G technology and address several conflicting objectives involving uncertainties and nonlinearities. Some optimization goals for the V2G implementation include minimizing operation costs, minimizing power losses, and maximizing profits. Several approaches are used, out of which Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are the most popular and easily implemented methods. [11] [12] [13]. GA uses an iterative approach to search for a globally optimal solution with limits imposed on execution time [11], while PSO looks for a globally optimal solution within a set of the random solution by updating the generations [12] [14].

Charging EVs isn't as straightforward as refilling at a gas station; in fact, due to many battery chemistries and different models of vehicles, an EV charger can be either Onboard or Off-Board. Onboard chargers have slow charging rates and are installed on the car, whereas Off-Board chargers are fast chargers usually installed at commercial charging stations. Table 1 gives the industry-defined charging rates.

Table 1: Charging Levels

Level	Category	Primary Use	Usual Power	Charging Time
1	On-board	Home	1.4 KW (12 A) -1.9 KW (20 A)	4-11 hrs
2	On-board	Work, Parking	4 KW (17 A) -19.2 KW (80 A)	1-4 hrs
3	Off-Board	Commercial fast charging	100KW	Less than 30 min

Certain topologies are used in realizing the onboard chargers, these are two-stage, single-stage, integrated and multistage chargers. They generally are comprised of two stages; an AC-DC stage followed by a DC-DC stage. In the case of Off-Board chargers, it becomes necessary to provide isolation between the AC supply and DC output due to the high-power ratings. It is of four types: Unidirectional AC/DC Converter, Bidirectional AC/DC Converter, Unidirectional DC/DC Converter, and Bidirectional DC/DC Converter [15].

This manuscript provides a holistic analysis of V2G technologies in microgrids and discusses the advantages and disadvantages. We demonstrate how V2G can help to regulate the frequency of an isolated microgrid with intermittent sources via a numerical simulation. We provide analyses of the model under regulation and non-regulation conditions. The remainder of this paper is sectioned as follows: in section II, we describe the V2G technology along with its types. In section III, we present a numerical simulation using SIMULINK. Finally, in section IV, we discuss the conclusion along with some future perspectives on this technology.

II. VEHICLE TO GRID TECHNOLOGY

V2G is the term used to describe the regulation and management of Electric Vehicles when connected to the grid (loads or source) by the power company or aggregators through communication between vehicles and the electric grid. In addition to V2G, other new grid-connected EV technologies are Vehicle to Home (V2H) and Vehicle to Vehicle (V2V) [16]. The power transfer between a home power network and an EV battery falls under the V2H framework. In this situation, EV batteries can serve as energy storage devices, providing backup power for home electric appliances and renewable energy sources in case of a sudden blackout [17]. On the other hand, vehicle to Vehicle or V2V is like a local electric vehicle community that can trade the power between themselves. Then the combined lot operated and controlled by a local aggregator can trade the power with the electric utility as well [14]. Thus, EV owners aren't mere consumers but would be referred to as prosumers as they both consume electricity and sell it to the grid.

V2G allows for successful coordination with intermittent power generating renewable energy sources like wind and solar energy to support them by filling in the demand during their low or no generation phases [18] [11] [19] [20]. A vehicle that can be used for V2G mode can provide opportunities for active power regulation, reactive power assistance, peak shaving [9], load balancing through valley filling (e.g., charging the vehicle at night when the demand is low), [10], and current harmonic filtering. These systems are capable of enabling supplementary services, including spinning reserves and primary, secondary, and tertiary frequency control [21] [22] [11] [23]. Additionally, they can enhance the grid's technical performance in terms of stability, efficiency, reliability [24], and generation dispatch [25]. They cut back on electrical operational expenses and may even bring in money [26].

A general layout of the V2G system [27] can be seen in Figure 1.

A. *Types of V2G*

V2G can be broadly classified into two types: Unidirectional V2G and Bidirectional V2G.

In the Unidirectional V2G method, power flows in only one direction, i.e., from the grid to the vehicle [28] [29]. The point is to regulate the rate of battery charging so that the grid is prevented from overload, system instability, and voltage drops [30] [31]. For unidirectional V2G to be implemented, there must be an effective energy trading policy between EV owners and the power utility [32] [33]. To promote more EV participation in this policy, it should ensure that EV owners are renumerated if they charge their vehicles during off-peak hours and restrict the charging during peak demands [34] [35] [11]. This can prevent overloading during peak hours. Additionally, unidirectional V2G can maximize profit and minimize emissions by employing optimization techniques.

In the Bidirectional V2G method, power flows in both directions, i.e., from the grid to the vehicle and vice versa, allowing for several benefits [36]. Typically, a bidirectional EV battery charger will have an AC/DC converter and a DC/DC converter [37] [38]. When the device is charging or discharging, the DC/DC converter functions as a buck converter or boost converter. The bidirectional V2G offers greater flexibility and opportunities to enhance the performance of the power system. The key advantages include the support for incorporating renewable energy resources, active power regulation, reactive power assistance, and support for power factor adjustment. Peak load shaving and load leveling are achievable with active power support from bidirectional V2G [39] [40]. These services are possible only when the charged EVs or those with a good SOC (State of Charge) supply to the grid during peak demands and get charged up only during low demands (off-peak hours). In addition to supporting active power, bidirectional V2G offers the capacity to provide reactive power for voltage regulation of the grid [41]. This reactive power support can be achieved with the proper control switching and suitable charger DC link capacitor sizing. One of the critical services the bidirectional V2G technology provides, which can lower power losses in the power grid, is power factor regulation.

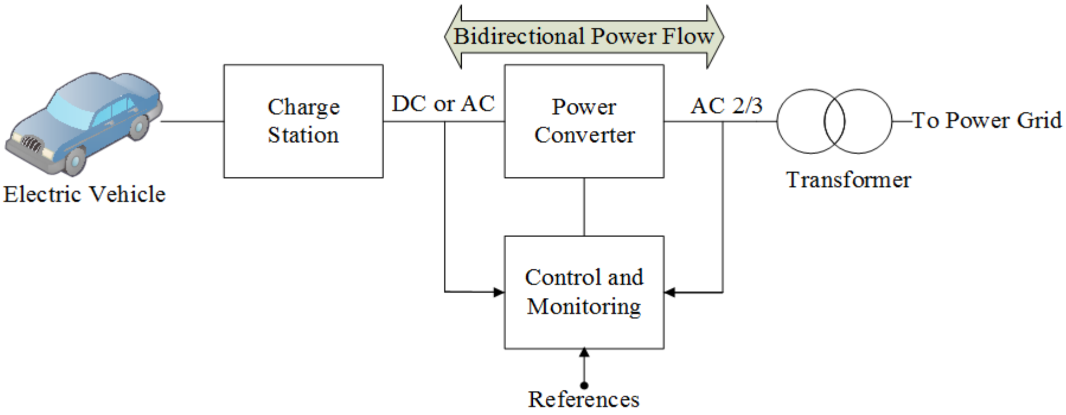

Figure 1: A general layout of the V2G system

A comparative analysis of these two types of V2G power can be seen in Table 2 below:

Table 2: Comparison between Unidirectional and Bidirectional V2G [28] [42] [36] [43]

V2G Type	**Unidirectional V2G**	**Bidirectional V2G**
Power Level	1,2 and 3	1 and 2 (Expected)
Cost	Low	High
H/W infrastructure	Communication System and normal charger	Communication System and bidirectional charger
Services	Power Grid Regulation Spinning Reserve	Improve power system stability Energy backup Frequency regulation Active power support Reactive power assistance Power factor correction Harmonic filter
Benefits	Prevent grid overloading Maximize profit Minimize emission	Prevent grid overloading Maximize profit Minimize emission Reduce grid losses Improve load profile Maintain voltage level Resolves renewable energy intermittent issue Failure Recovery
Drawbacks	Limited service available	Battery degradation Complex hardware Infrastructure High investment cost Social barriers

III. NUMERICAL SIMULATION

This section presents a numerical simulation of a generic Vehicle to Grid (V2G) model using SIMULINK [44]. The model is used to regulate the frequency on a microgrid and is simulated over a period of 24 hours. A block diagram of the complete model, along with all the subsystems, is given in Figure 2.

The block diagram in Figure 2 shows that it is an isolated or a microgrid. The power is supplied to the grid predominantly by three sources: a 15 MW diesel generator, which acts as a base power generator, and two renewable energy sources, i.e., a 4.5 MW wind farm and an 8 MW solar farm. Apart from that, 100 Electric Vehicles, each with a load of 40 KW, are connected to the grid. This accumulates to a total value of 4 MW which can be in charging or may help in grid regulation. Furthermore, an Asynchronous Machine which attributes to an industrial load of 0.16 MVA, is also connected to the system. In addition, a residential load of 10 MW roughly represents a 1000-household community and draws power from the same grid. The load is modeled as a low-consumption day in spring or autumn. Given the specifics, the ratio between cars and households is 1:10, which is a conceivable scenario in the near future.

Five distinct car-user profiles are implemented under the V2G block to represent different usage scenarios. These are:

Profile 1: This profile represents 35% of the cars, or simply 35 cars that are used by people going to work and can charge their vehicles there. These people are assumed to travel for 4 hours (to & fro) and the office timings are taken as 08:00 to 16:00. So, the total time taken is 12 hours.

Profile 2: This profile imitates a fleet of 10 cars driven by people to work but cannot charge them there. The time taken for this profile is the same as profile one i.e., 12 hours.

Profile 3: This profile represents those who commute to work and can charge their vehicles at work but travel longer distances between home and office. A fleet of 25 cars is assigned to this profile. The office timing for this profile is the same as the last two profiles, i.e., 08:00 to 16:00, but the travel time is increased by another 2 hours. So, the total time taken is 14 hours.

Profile 4: This profile represents people who stay at home. A fleet of 20 cars follows this profile.

Profile 5: This profile represents a fleet of 10 cars driven by those who work the night shift. The shift timing is 20:00 to 04:00, and the travel time is included in these 8 hours.

Figure 3 gives five different plots of active power superimposed on each other. The energy generated or consumed by the connected sources or loads has been labelled. It is observed that at three instances along the total simulation period of 24 hours, spikes occur. The spikes in the active power plots at 3 am, 12 pm and around 10 pm. These spikes correspond to three events: starting the induction motor at 3 am partial shading of the solar panels at noon, and stopping the wind farm when the wind speed exceeds its nominal value. Because of their magnitude, these three events have a considerable impact on grid frequency. Since the grid's frequency is directly related to the rotor speeds of the diesel generator, given as:

$$Ns = \frac{120f}{P}$$

Thus, any deviation in the rotor speeds would directly translate to the grid's frequency deviations. These deviations need to be accounted for, and control actions need to be implemented to maintain the stability and dynamics of the grid. This is precisely what the connected EVs in regulation mode does. This can be done by either throttling the charging rate or discharging or recharging the EV batteries fast enough to account for the vast changes.

Figure 4 compares the rotor speeds with and without the EV regulation at three significant events discussed previously. The zoomed-in snips of these events have been placed within the main plot and labelled accordingly. It is observed that the EV regulation not only reduces the peak values of the spikes but also reduces the settling time considerably.

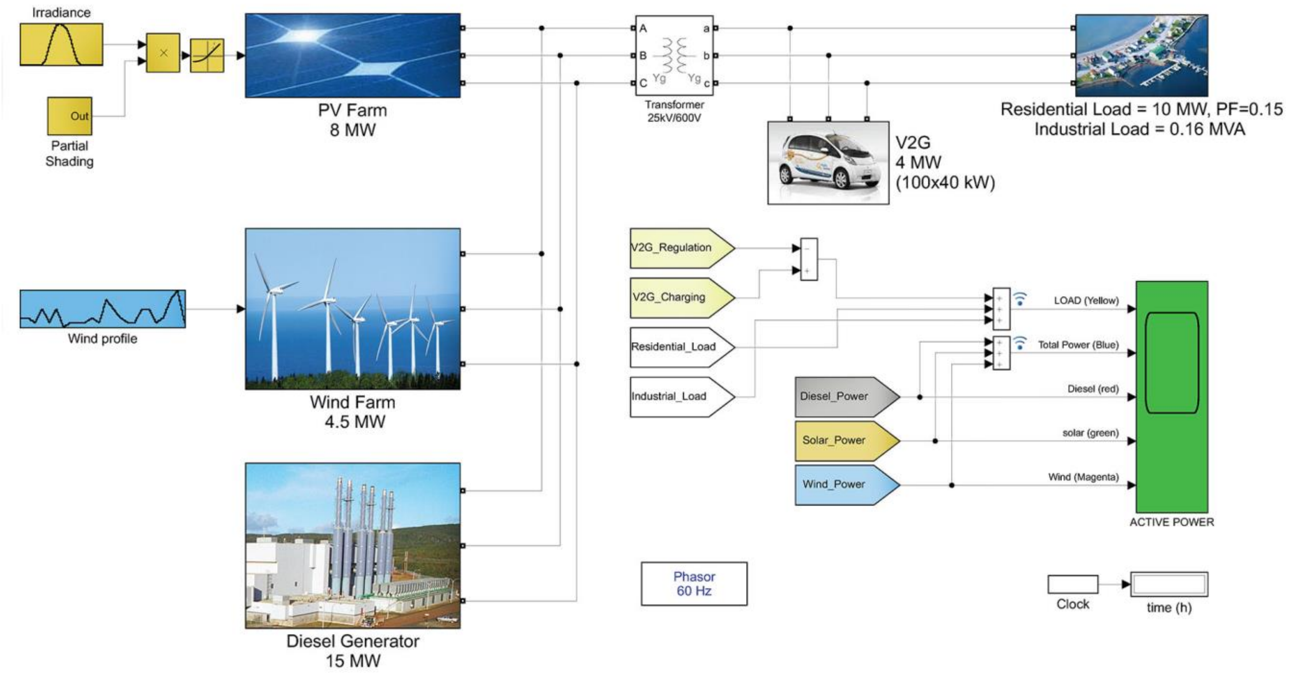

Figure 2: Block diagram of the SIMULINK model

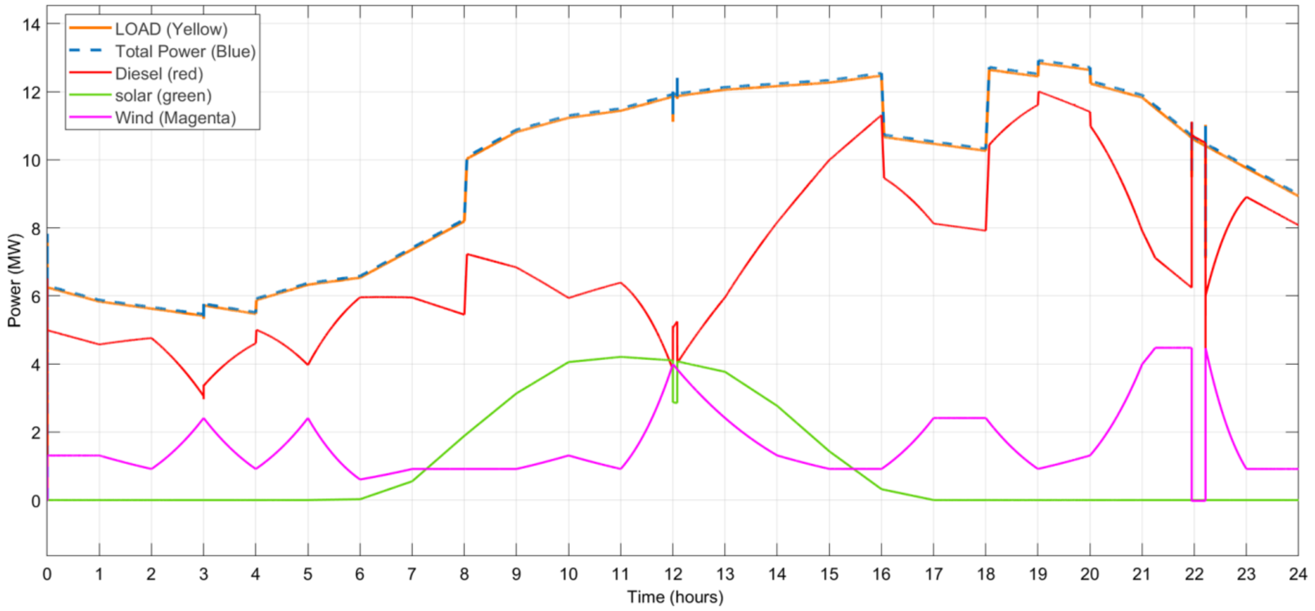

Figure 3: Active power vs time (all sources and loads)

A further zoomed-in snip of the plot at the event of solar shading (beginning only) is compared and presented in Figure 5. The plot shows that a sudden dip in rotor speed is observed when the shading starts and the solar farm generation gets suppressed.

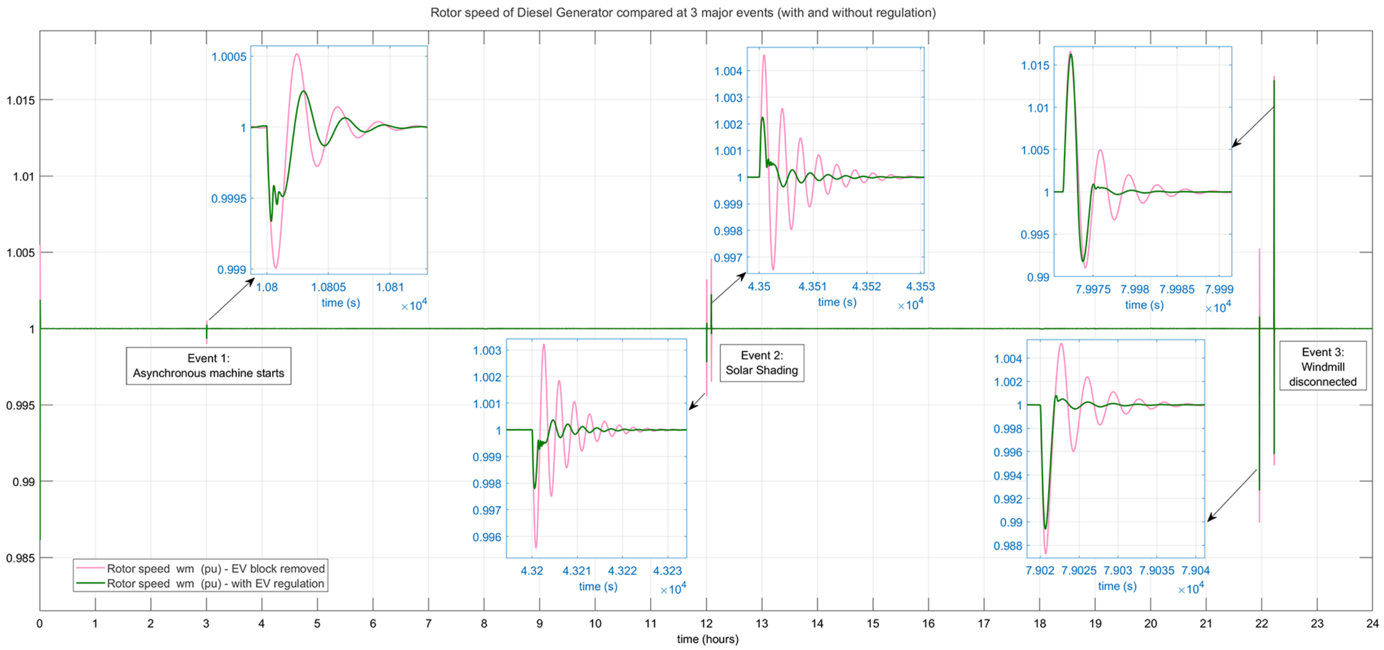

Figure 4: Rotor speed of Diesel Generator compared at three major events (with and without regulation)

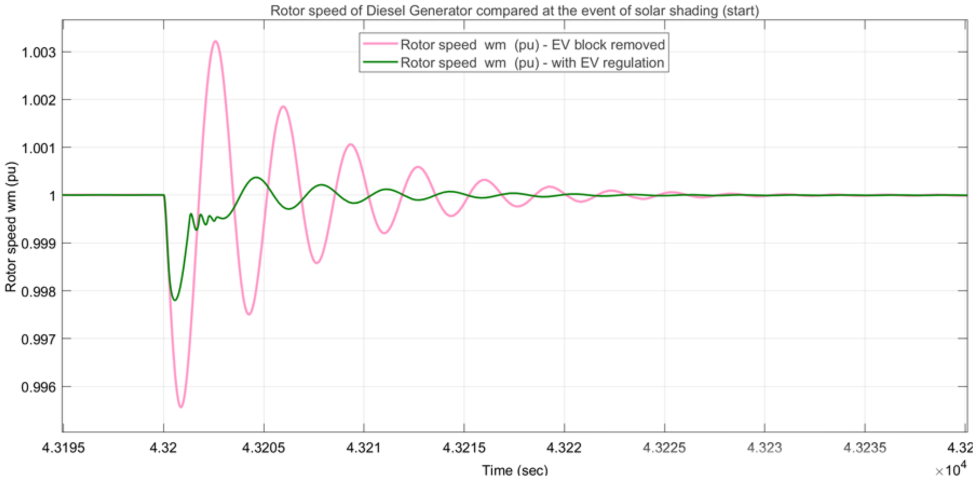

Figure 5: Rotor Speed with and without EV regulation at the beginning of solar shading

The control mechanisms try to regulate the deviation, but it still takes around 25 seconds to settle back to its original value, but with EV regulation, this time is reduced to only 15 sec. Also, the deviation in peak value is reduced by 58%.

IV. CONCLUSION

This paper presented a holistic analysis of the V2G technology of EVs. We discussed the potential of EVs for frequency regulation and peak load reduction. When the vehicle-to-grid (V2G) service is used exclusively for peak reduction, there is a little financial incentive for individuals; however, when the V2G service is used for frequency regulation, there is a significant potential for financial return. This is because frequency regulation is more expensive than peak reduction. We demonstrated both of these applications of EVs on a microgrid and discussed the benefits of EVs for future power systems when more intermittent renewable resources are incorporated.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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