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ELECTRIC VEHICLE FOR FREQUENCY REGULATION OF MICROGRID

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***Abstract*—Electric vehicles (EVs), acts as a distributed load or distributed storage when they are connected to the grid. EVs are able to provide many services like ancillary services, active power control, reactive power compensation and specially frequency regulation. EVs has a novel technology called vehicle-to-grid (V2G). This paper provides analysis of V2G technology for regulating the frequency of a microgrid. The frequency regulation provided by the V2G, due to a mismatch between generation and demand. The microgrid consists of different renewable energy sources, load and EV system. The frequency of microgrid is analyzed with penetration of EVs. The results show that V2G technology is very effective in frequency regulation.**

Keywords—Electric vehicle, Microgrid, Vehicle-to-grid, EV penetration, Frequency regulation.

I. INTRODUCTION

In today's power system coal, natural gas and crude oil are dominantly used as an energy sources. The transport sector and industry are the two area which consumes large amount of energy. The need of global energy is mainly provided by them. With a continuous consumption of these resources world is knocking the door of energy crises. To avoid this problem renewable energy resources has great concern. In all process, the planet’s climate changed in an unnatural manner. So, switching towards renewable energy and electric mobility has a lot of importance. The renewable energy sources are depend on weather conditions and weather conditions are continuously vary. This results in uncertain nature of sources and variable power [1]. The increase in penetration of renewable energy sources imposes the negative impact on the power system due to fluctuating power generated [2]. This is the major issue while integrating the renewable energy sources into the grid. If such renewable energy resources are connected to the grid, it affects the system power quality, reliability and stability. Renewable energy sources like wind and solar are widely integrated into the grid. Specially wind system creates more complications in frequency regulation. When generation and demand are not balanced to each other frequency fluctuates. If a generation is less than demand, then frequency decreases. If a generation is higher than demand then frequency increases. To obtain constant output power, and to reduce such variations energy storage system is used [3].

The frequency in a grid can be controlled in different stages after a large interruption. The First stage, machine having self- inertia, stores kinetic energy into rotating masses. When load increases, the stored kinetic energy opposes the frequency deviation and balances at the standard level. In the second stage, automatic governor control acts to maintain the frequency called primary control. In secondary control, spinning reserves are used [4]. The use of a separate generator for frequency regulation leads to several issues. Even it has a long start-up time, it is not an effective option to restore the frequency. It increases the overall cost and emission also, hence there is a need of another alternative way of frequency control. A lot of studies have been carried out for frequency control with high penetration of renewable energy sources. In this process, battery energy storage system (BESS), is one of the way which can reduce the frequency variations, when there is a sudden change in load.

V2G provides many services like ancillary services, active power support, reactive power compensation and support to renewable energy sources [5]. During an idle state of electric vehicles (EVs), V2G provides sufficient energy to the grid. By this process, EV becomes an effective way of reducing the cost as well as emissions and also EV owner gets revenue for the services [6]. EVs can store the excess amount of energy generated by renewable energy sources in batteries. When generation is higher than demand, energy gets stored in batteries and when generation is low, EVs feed the power to the grid. Thus, EVs are used to stabilize the frequency at standard level [7, 8]. EVs can support the grid in different ways. It supports Valley filling i.e. charging of EVs at low load or at night time, peak load shaving i.e. providing power to the grid to maintain the balance [9].

This paper simulates the microgrid and analyzes the frequency behavior for different cases. Microgrid includes: renewable energy sources, load and EV storage system. For frequency analysis two cases are considered: without V2G operation, 100% V2G power regulation.

This paper is organized as follows, Section II presents the system configuration and the microgrid resources: solar with MPPT and wind system. Section III gives description of MATLAB Simulink model. Section IV discusses two cases and their results. Finally, results are summarized in Section V.

II. SYSTEM CONFIGURATION

This paper provides integration of EVs in a microgrid. The microgrid in proposed configuration consists of solar system, wind energy system, EV storage system and load. All these are connected to the 22 kV transmission line. The system configuration is represented in Fig. 1. PV system consists of a boost converter and MPPT. Perturb and observe algorithm is used to operate a DC to DC boost converter. Pulse Width Modulation (PWM) based IGBT inverter is used for DC to AC conversion in PV and wind system. LC filter is used to reduce current distortion entering into the grid at the wind side. Aggregator acts like independent system operator [10].

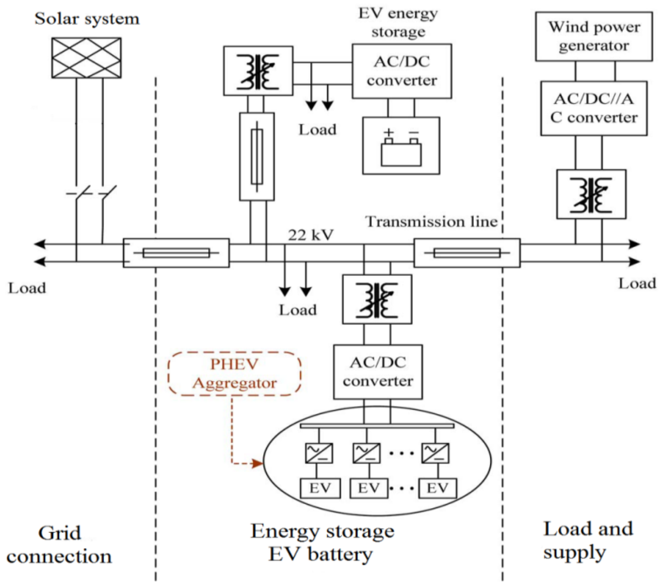

Fig. 1. Representation of V2G regulation model with microgrid

A. WIND GENERATOR

A wind system consists of a wind turbine, electromechanical system and generator. Turbine converts kinetic energy into electrical energy. It extracts kinetic energy of wind and converts it into mechanical energy. The turbines are connected to the rotor of the generator which converts mechanical energy into electrical. There are different types of generators used in wind system. It may be asynchronous or synchronous generator. In asynchronous generator: doubly fed induction generator or squirrel cage induction generator is used. In synchronous generator: wound rotor generator or permanent magnet synchronous generator (PMSG) is used. The induction generator is popular because of low maintenance, low cost, high efficiency, improved power quality and variable speed. For the generation of a magnetic field, reactive power is necessary in wind system. This can be obtained by connecting parallel capacitor bank at the stator side of wind generator.

The output power of the wind turbine is as follows:

$$P_m = C_p(\lambda,\beta)\frac{\rho A}{2}v_{wind}^3 \quad (1)$$

Where,

P_m= Mechanical output power of turbine.

C_p= Power coefficient of the turbine.

λ = Tip speed ratio.

β = Pitch angle.

ρ = Air density (kg/m^3).

A = Area swept by turbine.

v_{wind} = Wind speed (m/s).

The power coefficient can be represented as:

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right) e^{\frac{-C_5}{\lambda_i}} + C_6\lambda \quad (2)$$

Where, C_1 to C_6 are the constants.

The power coefficient is a function of tip speed ratio and pitch angle. In another way, it is function of wind speed and turbine speed. The maximum output power is limited up to C_p. It never exceeds 59.3% and this limit is knows as Betz limit. The output is a torque (Tm), which is applied to the shaft of generator. The data for the evaluation of power coefficient of wind system is in [11]. This subsystem of wind turbine is connected to the asynchronous machine.

B. SOLAR SYSTEM

The solar system is one of the promising solution for the energy crises caused by continuous use of conventional sources. Working of the solar system is based on photovoltaic effect, in which light energy is converted into electric energy. The Solar cell is a basic building block. Combining a number of cells in series and parallel, the output power can be increased. With a lot of benefits, it has few drawbacks: low efficiency and high investment cost. The efficiency of solar system depends on solar irradiance and temperature. In another way, solar power widely varies with environment condition. The modeling and parameter of a solar system is given in [12].

Solar cell has a non-linear characteristics varying continuously with environment. Hence it is very complex to extracts maximum power under such a conditions. To solve above problem maximum power point tracking algorithm is used. There are different algorithms, to tackle this problem. In that perturb and observe (P&O) is one of the popular algorithm. In P&O method, the perturbation is done either in reference current or in reference voltage of solar panel [13]. To obtain MPP, the operating point of a system is changed by employing small perturbation in a reference signal. For each perturbation output power of a panel is measured. If the measured output power is greater than previous power then perturbation is continued in the same direction. In case if measured power is less than previous one then perturbation is employed in opposite direction. This process of perturbation is continued till MPP is achieved [14].

III. MODEL DESCRIPTION

The Simulink model consists of three main subsystems: solar, wind and EV energy storage system. Wind system with squirrel cage asynchronous machine of 275 kVA, 480 V and 50 Hz. The mechanical input to the machine is mechanical torque. To reduce the current distortion entering the grid, capacitor bank is used. The capacitor bank is of 75 kVAr. After converter, power is sent to the step-up transformer, to increases the voltage to 22 kV. There are three loads, each of 150 kW. The EV system contains three main components: Battery, DC-DC converter and electric motor. The electric motor in EV system is of permanent magnet synchronous machine. It is of 50 kW, 500 Vdc. To obtain maximum motor speed, the flux weakening vector control method is used. The maximum motor speed is 6000 rpm.

The electric vehicles which are battery powered, play an important role in the automotive industry. There are different types of batteries used in electric vehicles: Lithium Ion (Li-Ion), Lithium Sulphur (Li-S), Molten salt (Na-NiCl2) and Nickel Metal Hydride (Ni-MH). The battery used in this simulation work is nickel metal hydride. The battery is of 200 Vdc, 6.5 Ah, and 21 kW. The output of the battery is powered by DC-DC boost converter, it acts as a voltage regulator. The low voltage battery i.e. 200 V is adapted by the DC-DC converter. This feeds the motor at 500 V.

To analyze frequency regulation three cases are considered. First, without V2G operation, in which electric vehicle's power is not considered in grid operation. In the second case, 100% EV power is used for the V2G operation. In third case, the EV power supply 75% to the grid operation.

IV. RESULTS AND DISCUSSION

As wind energy sources are weather dependent. At any location wind is not steady. It changes minute by minute. Wind speed has a cubic relation of power. Hence it is very difficult to obtain a constant wind power. The random variation of wind speed is as shown in Fig. 2. The wind speed varies in the range of minimum 9.6 m/s to the maximum 10.3 m/s. The Fig. 3. shows the corresponding fluctuation of wind power.

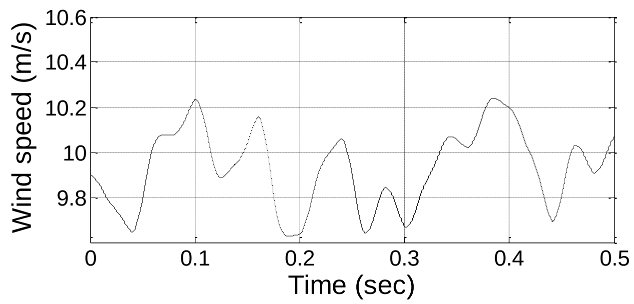

Fig. 2. Speed of wind system

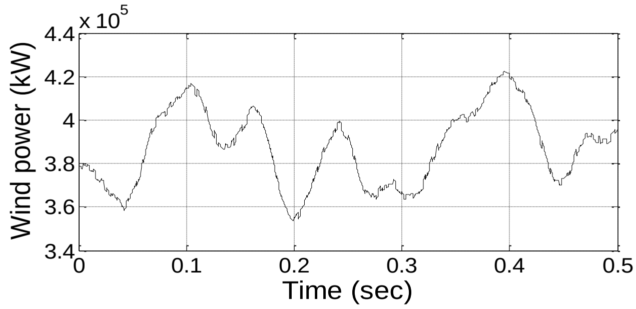

Fig. 3. Wind power

Respective frequency deviation with the wind variation is in Fig. 4. where maximum peak point of frequency is 50.4 Hz. In order to mitigate the frequency deviation, V2G technology is used. Frequency deviation in two different scenario is represented in Fig. 4 and 5. Where Fig. 5 represents the frequency in 100% V2G regulation. By comparing these two frequency waveforms, it is clear that frequency is more stabilized in 100% V2G power regulation than without V2G system.

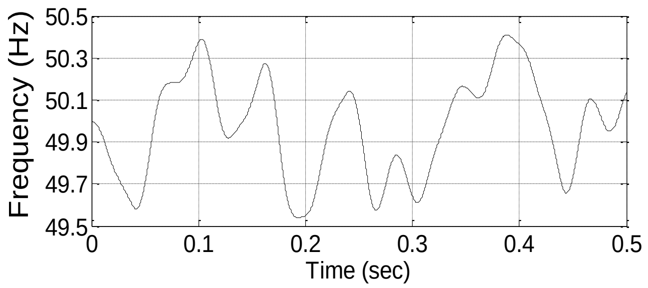

Fig. 4. Frequency without V2G power regulation

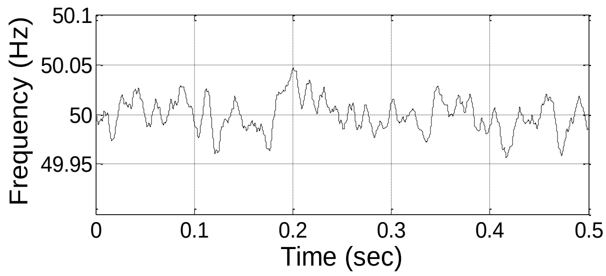

Fig. 5. Frequency in 100% V2G power regulation

Table I

Frequency deviation

Cases	Frequency deviation in Hz	Percentage frequency deviation
Without V2G	50.4	80
100% V2G power regulation	50.04	8

The Table I gives frequency deviation in two cases. The two cases: Without V2G and integrating 100% V2G power. The values of frequency deviations are the peak values of frequency in each case. From these values it shows that when EVs are not used for grid operation, frequency deviates upto 50.4 Hz i.e. with 80% deviation. In second case, total EV power is used for grid operation then frequency deviates upto 50.04 Hz i.e. with 8% deviation. It is clear that frequency deviation is more in first case where EVs are not considered. When 100% EV power is used, frequency deviation is minimized by 72%. Hence, with a higher penetration level of EV frequency is more stabilized to 50 Hz. Fig. 6 shows instantaneous V2G power supplied to the grid.

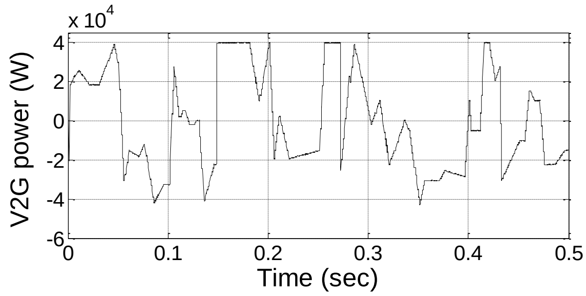

Fig. 6. V2G power in 100% V2G frequency regulation

V. CONCLUSION

In this paper, EVs are integrated in the proposed microgrid for frequency regulation. In microgrid, due to intermittency of solar and wind energy system power fluctuates and frequency deviates. EV with V2G technology is deployed for power regulation. With the fast response V2G is able to reduce the power fluctuation and system frequency is stabilized. At higher EV penetration level, the frequency is more stabilized around the 50 Hz as compared to the with no integration of EV. The simulation results shows that V2G is an effective technology for frequency regulation.

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