“Electric Vehicle Based Battery Storages for Power System Regulation”

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Abstract

The large grid integration of variable wind power adds to the imbalance of a power system. This necessitates the need for additional reserve power for regulation. In Denmark, the growing wind penetration aims for an expedited change of displacing the traditional generators which are currently supplying the reserve power requirements. This limited regulation services from conventional generators in the future power system calls for other new reserve power solutions like Electric Vehicle (EV) based battery storages.

A generic aggregated EV based battery storage for long-term dynamic load frequency simulations is modelled. Further, it is analysed for regulation services using the case of a typical windy day in the West Denmark power system. The power deviations with other control areas in an interconnected system are minimised by the faster up and down regulation characteristics of the EV battery storage

INTRODUCTION

The share of total electricity consumption in Denmark covered by wind power is more than 20%, which is the largest in the world. By 2025, it is planned to integrate 50% of wind power into the Danish electric power system [1]. However, the major constraint of such large scale integration of renewable lies in its variable nature and poor load following characteristics.

This especially is highly challenging for a stable power system operation and control. Many options to negotiate the variable renewable power are studied and explored in the form of heat pumps, demand response, electrolysers and energy storages [1]. The battery energy storages are one of the most efficient and compatible technology for an improved power system operation and control. The operation of storages is complementary to stochastic nature of renewable energy. They can charge whenever there is excess of electricity in the connected system and discharge when required.

The battery storage of electric vehicles is one of the emerging technologies, which can act as a load reacting to the change in power supply. The concept of environmental friendly vehicles has encouraged many car manufacturers to develop clean vehicles, especially vehicles powered from electricity. Electric vehicles when coupled to an electricity network can act as a controllable load and energy storage in power systems with high penetration of renewable energy sources. The reliability of the renewable electricity will be enhanced with the vast untapped storage of electric vehicle fleets when connected to the grid. This could be considered as a large aggregated MW battery storage which is termed as “Vehicle to grid” (V2G) system. With fleets of electric vehicles, the balance between the supply and demand could be achieved by the load reacting to change in generation. Vehicle to grid systems could provide backup electricity storage as well as quick response generation to the changes in power balance of the electricity grid. Now is the time to establish the business models for electric vehicle interaction with the grid, so that the business is developed and ready for rapid expansion as electric vehicles enter the market place in the coming years. AC Propulsion of California has designed an electric drive system using mass-produced 18650 lithium-ion batteries and a patented power electronics unit that is ideally suited for Vehicle-to- Grid (V2G). They have also created electric and plug-in hybrid vehicles by converting existing gasoline vehicles. Other manufacturers, including global auto manufacturers such as Renault/Nissan, Mitsubishi Motors, and BMW, are producing all-electric vehicles for some markets and have announced full-scale production plans for all-electric vehicles.

This paper analyzes the dynamic response of electric vehicle based battery storage to power system regulation signals.

VEHICLE TO GRID SYSTEMS

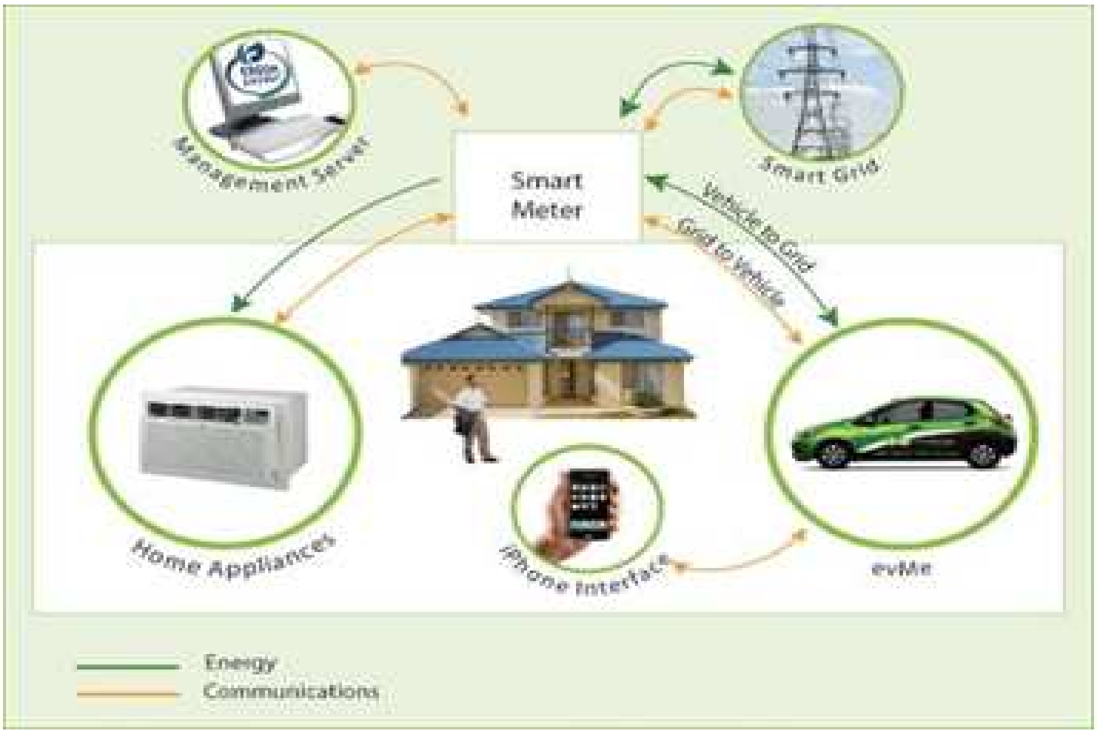

Figure no.2.1

Vehicle to grid (V2G) systems uses the electric vehicle battery storages to transfer power with the grid when the cars are parked and plugged in to the charging stations at parking lots, at offices or at homes, where they will have bidirectional power transfer capability. The electricity supplied by the V2G will reach the consumers through the grid connection and in return, any surplus energy in the grid could be stored in the electric vehicles. The Transmission System Operator (TSO) can request for a power transfer through an aggregator (intermediate entity) who manages the individual vehicle or fleet of vehicles through control signals in the form of a power line carrier, radio signal, internet connection or mobile phone network. The aggregator appears to the TSO as a large battery storage with regulation capabilities.

Energetique specializes in battery-powered energy-efficient electric vehicles as well as vehicle-to-grid (V2G) systems. These vehicle-to-grid systems help in managing peak electricity demand and. Vehicle-to-grid systems include a dedicated electric vehicle (EV) charging circuit, gateway systems that connect the EV to the grid and export-capable meters. Vehicle-to-grid systems can export power up to 7kW to the grid through the smart export meters. V2G power export systems can be enhanced to supply 23kW or the power equivalent to the quantity they draw from the grid systems making the net energy consumption of these vehicles zero. Electric vehicles used in V2G systems have lithium polymer batteries with higher energy densities and higher cycling lives. These energy storage batteries can withstand overcharge, over-discharge and short circuit as well as thermal, vibration, shock, puncture or impact issues. The energy storage batteries are designed for energy storage as well as energy supply The average daily vehicle miles travelled in Denmark is 36km/day. The light motor vehicles are idle almost 90% of the time or for a period 20-22 hours a day.

In general, the utilization factor of the vehicles is less than 10%, compared to an average 40-50% utilization of central power plants. With less than 10% of electric vehicles under V2G mode, it could support grid regulation services in a power system with 50% wind power integration .Many models of electric cars are now commercially available in the market operating with highly efficient lithium-ion batteries. The 2008 model battery electric vehicle, “Tesla Roadster” has a vehicle efficiency of 5.65 miles/kWh and energy storage capacity of 53kWh. From a calculation based in the reference article [7], the net energy available in the battery after the typical daily driving requirements by this battery electric vehicle in the Danish context is approximately 40kWh functions and the EVs act as mobile power stations supplying excess power to the grid

2.1 BATTERY STORAGE MODEL FOR ELECTRIC VEHICLES

Figure no.2.1.1

The Thevenin-based model is the most commonly used electric-circuit based representation of a battery in published research works. This model consists of an ideal voltage source in series with an internal resistance and a parallel RC networks. The inaccurate estimation of the battery state of charge is the drawback in using this model. Figure 2.1.1 shows such a modified Thevenin equivalent representation of a battery. For power system stability and frequency regulation studies, simple transfer functions blocks are also used to represent battery energy storages. The combination of the Thevenin equivalent circuit and converter models are also suggested for dynamic power system stability studies. In this paper, aggregated electrical vehicle based battery storage is modeled for V2G regulation services responding to load frequency control signals. The model is used for long-term power system dynamic simulations in load frequency control (LFC). It is represented by a model equivalent to that in the Figure2.3 which could provide the battery capacity and state of charge capabilities. The block diagram of a generic aggregated battery storage model representing V2G service used in load frequency simulations in this work is shown in the Figure 2.1.1

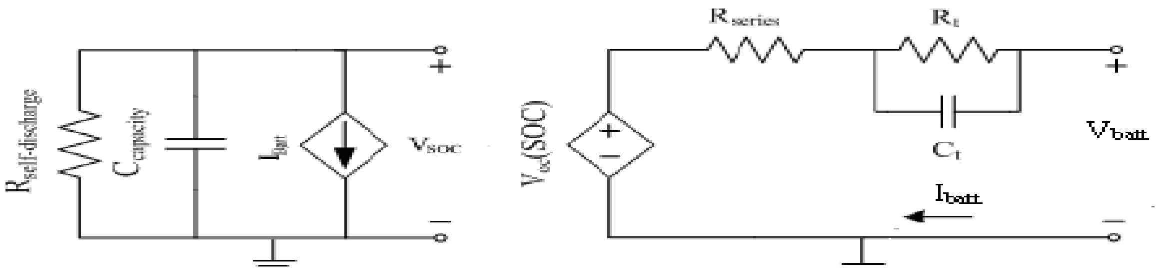

Figure no.2.1.2

The aggregated battery output is controlled based on the load frequency control signal. The input signal is passed through a first-order filter to remove noise and further the signal is applied with an activation and communication delay. From experimental field tests conducted on a V2G system as reported in the wireless communication delay between a vehicle and the aggregator is less than 2 seconds and that between the aggregator and TSO is less than a second. As a worst case a delay of 4 seconds is assumed in this work for simulations.

The electrical parameters for the MW range aggregated battery are adopted from reference where an existing 10MW, 40MWh battery power plant unit is used for frequency regulation. The parameters of the battery model used for simulations in this paper are based from the discharging characteristics and are assumed to be the same for the charging conditions. The model does not include the self discharge resistance as shown in figure 2.1.1, as longer periods of battery characteristics are not taken into account.

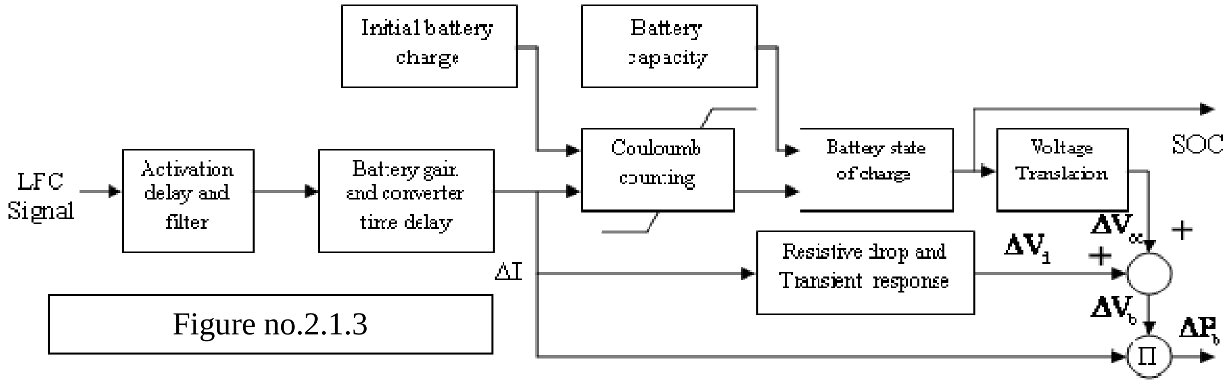

Figure no.2.1.3

VEHICLE TO GRID FOR POWER SYSTEM REGULATION

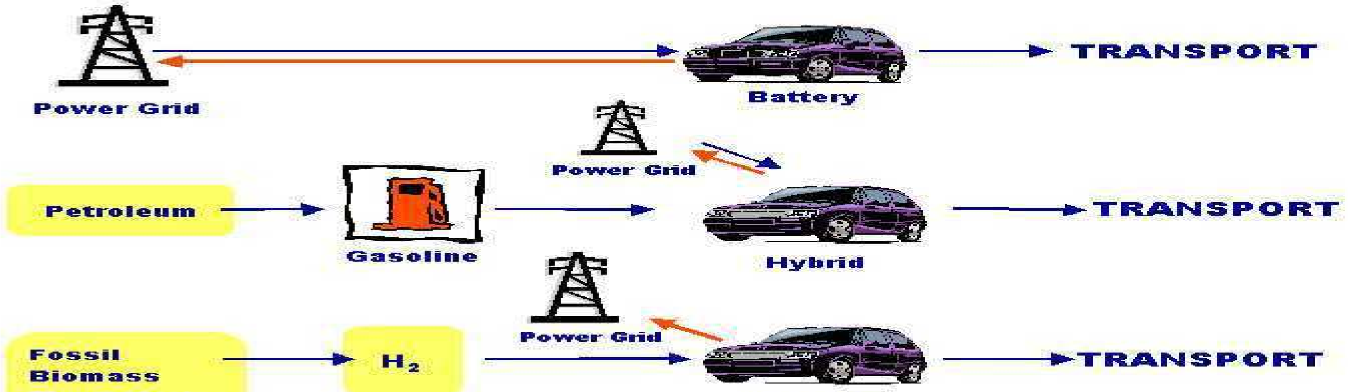

Figure no.3.1

Table3.1.1shows the main power system capacity figures of West Denmark [14]. The larger power plants are either coal or gas based thermal units. More than 50 % of the installed power capacities for electricity generation are from the land based wind turbines and decentralized CHP units. The capacity of the offshore wind farm Horns Rev A is 160MW which is connected to the 150kV HV transmission system. On an average, the wind power supplies more than 20% of electricity consumption in West Denmark. The system is AC connected with Germany which it is dominated by thermal and nuclear power plants and fast growing wind power. To the north, West Denmark is connected to Nordel synchronous area through HVDC links to Norway and Sweden dominated by hydro power plants.

TABLE 3.1.1: WEST DENMARK POWER SYSTEM CAPACITY FIGURES IN MW

Centralized power plant units	3400
Decentralized CHP units	1750
Wind turbines	2400
Offshore Wind - Horns Rev A	160
Maximum demand	3767
Minimum demand	2669
Transmission capacity from Germany to W. Denmark	950
Transmission capacity from W. Denmark to Germany	1500
Transmission capacity with Norway	1040
Transmission capacity with Sweden	740

Today in Denmark, the regulating power to balance the planned generation and unpredictable load are provided by the central and local power plants and from external connections from abroad. The variable nature of the wind power also contributes to the power system imbalance. The wind farms are not often equipped to provide these regulation reserves, as they are not dependable. The “visionary Danish energy policy 2025” plans to double the present wind power capacity in Denmark to 6500MW. However, this aims for an expedited change of replacing the central power stations in the whole of Denmark to about 40% of the present capacity to 4100MW. This future scenario is highly challenging for a reliable operation of the power system as it demands for alternate means of faster and larger regulating reserve power capacity. Table 3.1.1gives the reserve power types in West Denmark. The primary control is used as instantaneous reserve to deal with sudden power imbalances. The droop characteristics of the generators are adjusted to a new operating point by which the frequency deviations are minimized. They are completely activated within 30seconds. The secondary control is a slow process which will replace the primary reserves to restore the nominal frequency and minimize the power exchange deviations. Secondary control makes use of a centralized automatic load frequency control which will be activated fully within 15 minutes. The manual or tertiary reserves are slowest of all the control reserves used in order to restore the secondary reserves.

TABLE 3.1.2 DETAILS OF RESERVE POWER IN WEST DENMARK

Regulation	**reserves**	**Primary Automatic**	**Manual**
Capacity	(MW)	+/- 24 +/- 90 +290/-310	Activation
Time	0 - 30sec 30sec -15min	Contracting	approach
Voluntary	Tender	Voluntary	tender
Regulating	Power	market	Payments Negotiated
capacity and	energy prices	Negotiated	capacity and

Alternate methods to provide future reserve power have been proposed in the form of wind power regulation, increased grid transmission capacities, heat pumps and boilers, electric vehicle storages etc [1]. This paper mainly focuses on the use of electric vehicle based storages (V2G) which is considered to be one of the feasible future regulation reserves in Denmark. The feasibility projects for implementing the same have been initiated in Denmark as mentioned in section II. To analyze how V2G system storage could participate as an automatic regulation reserve in West Denmark, a typical day with large wind production is considered. Figure 4 shows the electricity consumption and production, wind power, load frequency control (LFC) signal (regulation power requirement) and power deviation with UCTE at the German border for a weekday in January 2009. This time series data of five minutes resolution from the West Denmark SCADA system is obtained from the Energinet.dk, the transmission system operator in Denmark. A positive LFC signal indicates regulation up and negative signal gives regulation down values. Similarly a positive power exchange deviation with Germany indicates less planned power being transferred and negative value gives surplus power exchanged. From the data available, the wind power meets an average of 45 % of the total daily electricity consumption, where the total production exceeds the demand. The need for more down regulation during the day is also indicative of high proportion of wind power.

The aggregated battery is assumed to have an initial state of charge of 50%. The aggregated battery capacity is normalized to current secondary regulation capacity of West Denmark which is 90MW as given in table II. A battery storage capacity for four hours (360MWh) and a V2G power line connection of 10kW is considered. The above storage capacity hours of V2G system is based on the “Tesla Roadster” electric vehicle which has approximately 40kWh after the daily driving requirements (Ref Section II). A total of 9000 electrical vehicles are required and it is assumed as 50% of the vehicles are available all the time. The remaining 50% storage is accountable for the uncertainties related to the vehicle availability and management. So, a total of 18,000 electric vehicles must be contracted for V2G regulation which is approximately equivalent to less than 2% of total fleet of vehicles in West Denmark. In Denmark, the total number of cars available is 2 million and the total population is 5.5 million. Approximately one in three persons possess a car in Denmark which accounts to roughly more than 1 million cars in West Denmark, where the population is 3 million.

ELECTRIC POWER SYSTEM BACKGROUND POWER SYSTEM AND REGULATION

The power system infrastructure is essentially a network of wires and sophisticated switches controlled by high-speed computers. Its basic function is to move power from where it is generated to where it is utilized. The power system must balance load and generation, or demand and supply while the energy flow is in the form of real and reactive power.

The system frequency must be kept at, or very near to, its nominal frequency – 60Hz in the United States, or 50Hz in many other countries. Any deviation from this requires action by the system operator. If the frequency is too high, that means there is too much power being generated in relation to load. Therefore, the load must be increased or the generation must be reduced to keep the system in balance. If the frequency is too low, then there is too much load in the system and the generation must be increased or the load reduced. As mentioned previously, these adjustments are called frequency regulation, or simply “regulation.” Regulation is performed at the local level but accomplishes the desired effect on frequency at the grid level. Sufficient accumulation of adjustments to local generators or loads will adjust the frequency of the entire interconnects. A more detailed description of this multi-layer and multilevel hierarchical nature of the power system and load and frequency control can be found.

4.1: THE VALUE OF STORAGE TO THE GRID

With the restructuring of the power system functions, the primary role of the system operator is to balance reliability and cost. Most Americans take power availability for granted, but this must be designed in, at additional cost. Most power system design and operations are engineered with extra margin, to allow for certain loss probability. Large scale inexpensive storage would improve today’s grid, by increasing reliability and reducing power system costs. As the power system develops more renewable generation, the need for electrical storage is likely to increase. Today’s predominant renewable power generation fluctuates with the input (for example, sunlight or wind). At today’s levels, fluctuating renewable generation is adjusted for with existing mechanisms (for example, by adjusting today’s fossil generators up and down to compensate).

At higher levels of renewable generation, storage, transmission, and controllable loads all become useful resources to smooth fluctuating power. Electric vehicles have the ability to provide two of these functions – energy storage and controllable loads.

4.2 THE VALUE OF ELECTRICITY STORAGE IN DOMESTIC HOMES:

Our goal in this research is to assess the value of energy storage for domestic homes in the presence of renewable micro-generation such as small wind turbines and solar collectors. To this end, we propose a unified framework to estimate the value of energy storage for different energy mixes in domestic homes. Specially, we consider a house having of a portfolio of typical energy facilities (such as a boiler and gas and electricity connections) and the potential alternative technologies (such as a solar collector, water tank with auxiliary heater, a small wind turbine and a power battery); see Figure1.

The battery can charge electricity from both the grid and wind turbine and discharge electricity to the auxiliary heater (AH) or meet electricity demand. The water tank can be heated either by the solar collector or the boiler and thus the heat demand is met by the water tank or/and the boiler directly. Given demand profiles, weather conditions (wind speeds and solar radiation levels) and gas and electricity price patterns, the model decides when to charge or discharge the battery and water tank, and when to use the boiler or the hot water tank to meet the heat demand. The objective is to minimize total energy consumption cost over a finite period of time (a typical day).

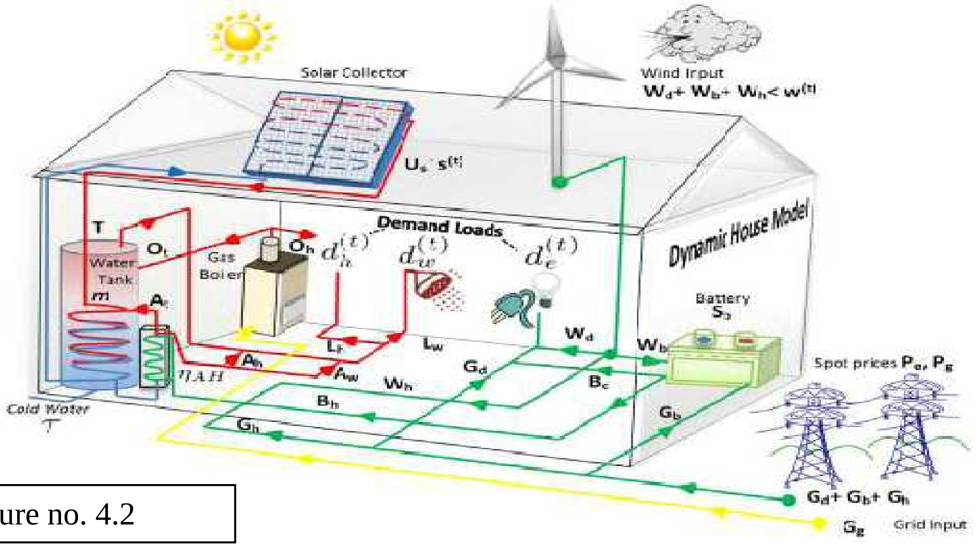

Figure no. 4.2

4.3. VEHICLES AND GRID INTERCONNECTION ELECTRIC

The average US car is driven only one hour a day (in 2001, the average US driver drove 62.3 minutes/day).9 In other words, these cars are parked most of the time doing nothing. Suppose those cars were a source of energy storage the remaining 23 hours? Now, let’s also suppose the car can be driven without gas and can store up the needed energy when the wind is blowing or the sunlight is at maximum. Such cars enable pollution free driving while also providing value, and thus potentially payments, for providing electric services to the electric grid. The above scenario is not far-fetched. The pieces are available today but the cost of storing the energy in the car – through battery technology – is still high. As a transition, we postulated that the regulation market could provide the needed funds to jump-start the process if appropriate public policy is implemented. To prove this, we demonstrate that an electric vehicle can provide regulation. An electric vehicle can be used as both a load and a generating source to balance the system frequency by charging the battery when there is too much generation in the grid and acting as a generator by discharging the battery when there is too much load in the system. In addition to regulation, vehicles can provide other services including: spinning reserve, which contracts for the availability to provide power during unplanned outages of base load generators; back-up service, where one or more vehicles can be connected together to serve as a micro-grid during power outage in a given neighborhood; and peak management, when there are a significant number of V2G cars parked and connected to help reduce system peak. With enough V2G-capable electric vehicles, a truly dispersed storage for electric energy will emerge.

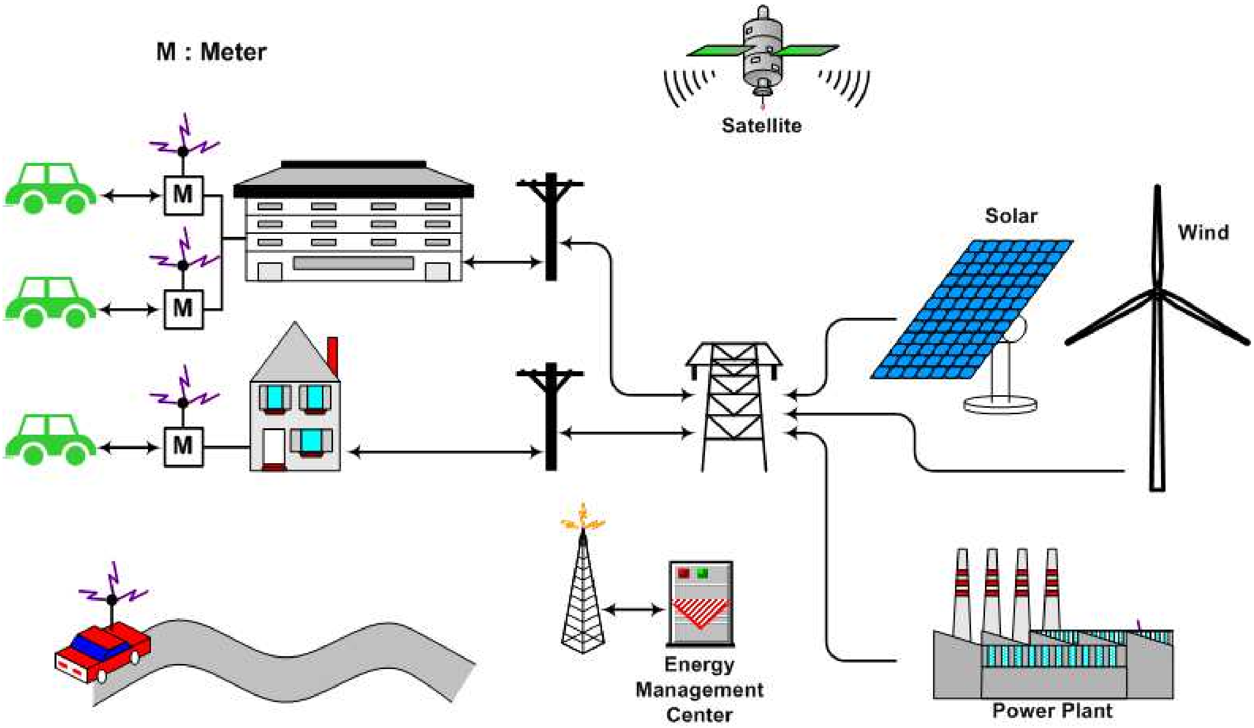

Figure no4.3

VEHICLE TO GRID IN LOAD FREQUENCY CONTROL

Figure5.1 shows the block diagram of a Load frequency control model for West Denmark integrating aggregated models of power plant units and the EV battery storage. The power capacities of generation units use the figures from table 5.1. The LFC models and simulations are performed using Dig SILENT Power factory software. The models of generator units used in the simulations are those **recommended by IEEE and are available in the**

global library of the Power factory. The centralized power plant is modelled based on the steam turbine units and that for the decentralised CHP plant is modelled based on gas turbine units. The wind power units and external connections are modelled as negative loads. The power system model is based on a single bus bar model of the West Denmark system connected with system load, Nordel connections, aggregated model of generation units and the UCTE connection as a slack bus. The transmission line capacities and constraints are neglected in this study as it primarily focuses on the collective performance and regulation capabilities of the generators in the system. For a large variable wind power integrated power system, more power imbalance and power deviations could result.Larger power deviations result in congestions which causes the electricity market and balancing prices to deviate largely from the system prices. If a V2G regulation service is available in the grid, the appropriate charging and discharging of the aggregated battery storage could minimize the wind variations and power congestions thus regulating the price variations. The secondary control operation using the load frequency control model with V2G in West Denmark is shown in figure 5.1. The area control error of an interconnected system due to power imbalance is given by $ACE = B.\Delta f + \Delta Pt$, where B is the frequency bias factor, Δf is the frequency deviation and t ΔP total power deviation with the interconnected system. As the West Denmark power system is interconnected to a larger synchronous UCTE system which could be considered as an infinite bus, the frequency deviations are assumed to be negligible. The LFC operation is accomplished through a tieline control where the inter-tie power must be maintained at the scheduled values. The difference between the planned and actual exchange power gives the power deviations between the two areas. The deviation is passed through a first order filter to eliminate noise.

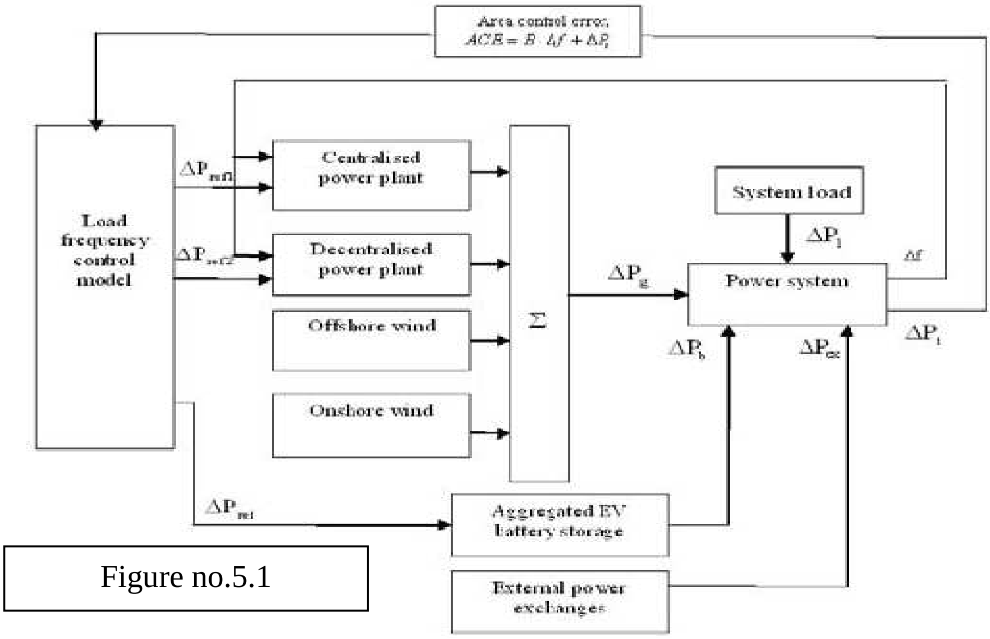

Figure no.5.1

CONCLUSIONS AND FUTURE SCOPE

The vehicle to grid can provide faster reserves unlike conventional generators, by charging and discharging the stored energy during the regulation service. This unique property is well suited and essential to support the integration of large amounts of fluctuating wind power in future Danish power system. The V2G is a feasible solution for a large future reserve power requirement which could substitute the traditional generation resources. The investigation is carried out with a simplified load frequency control model with aggregated V2G system model for the West Denmark power system. The simulated power deviations and regulation.

6.1POSSIBLE FUTURE RESEARCH

This first step in the project shows that a battery powered car can be tied to the grid, power flow in each direction can be controlled, and the output can respond to the PJM Frequency Regulation signal. Several additional questions can be answered with research time but without requiring additional vehicle purchases.

1. Using databases of driving patterns, one could compare V2G resources based on actual patterns of people's vehicle use. This information would give an better insight into limits to charge/discharge which, in turn, would allow an understanding of how many times in a historical year those limits would likely be hit and whether that variability would effect the desirability of providing regulation at certain.

2. To analyze alternative parking scenarios. For example, how would the cost for a large parking lot electrical interface compare with the distributed costs discussed here? Will plug-in parking along streets or roadways be Conducive to V2G participation, or is time parked too short?

3. Modeling a number of typical service drops for thermal capacity as well as for flicker. This could compare one household hooked into a 25 KVA transformer with one car, 31 several sizes of service cable and a typical load mix; two or three households with vehicles on one transformer; different size transformers, and different typical load mixes.

4. Modeling distribution feeder saturation levels and show when multiple installs may affect the feeder. Perhaps a “good” ramp rate could be established – although the rapid response is beneficial to the load balancing exercise, there may be a practical limit so that voltage regulation devices in the distribution system can maintain proper feeder voltage.

5. To avoid non-participation when a battery is charged and the signal requires import of Power to the battery, it might be worth triggering the vehicle heater with a bypass that will blow heat outside the vehicle (in warm weather). In this case it would be important to analyze the cost of electricity consumption not saved into storage versus the benefit of meeting a regulation down contract requirement even when the battery is full.

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