ABSTRACT

A large scale integration of electric vehicles as battery storage devices could be a new alternative to reduce contrary effects on electricity grids by volatile power generation. Mobile storage systems provide fast-response assistance that can be called on a short notice (within ms) and are therefore well suited to counteract fault conditions. Hence, the overall result could be an increased stability and reliability of the electric grid. However, it is not yet fully understood which scale of widely dispersed storage devices could provide efficient ancillary services without stressing the grid or increasing the cost for upgrading of existing infrastructure.

The paper examines and illustrates possible bottlenecks in distribution networks during provision of ancillary services by electric vehicles. In consequence of upcoming electric vehicle deployment in future, investigating the capacity of distribution grids is essential for identification of recommendations for network upgrading. Furthermore, an approach of utilizing fleets as supportive decentralized devices in electricity networks has been implemented in a software simulation in order to demonstrate the potential of geographically distributed fleets as virtual synchronous machines providing additional spinning reserves in case of a fault.

GRID ASSESSMENT

Main aspects and differences of electric vehicles compared to other decentralized sources such as block heating stations can be characterized by an individual pattern of usage and the maximum load or generation capacity installed per unit. Furthermore, electrical installation in houses require different plug-in concepts as the rated power of batteries vary up to 30 kW and more, if fast charging is used at households.

Presuming forms of communication as part of intelligent grid infrastructure in coming years will allow for calling a certain vehicle fleet for an aggregated provision of ancillary services in terms of positive or negative balancing power, thus causing significant changes in load flows. In particular,
dynamic variations in demand and generation pattern are expected, implying voltage and current fluctuations. It therefore is of essence to analyze conditions to which distribution networks are subject of dynamic loading and its resulting consequences for all participants such as customers and electronic devices.

**Grids for vehicles**

Low voltage distribution networks are planned to cope with a simultaneity factor of \( Gl << 1 \) which determines the ratio between the load of maximum demand within a certain region and the sum of non-simultaneous maximum loads. As the index is based on empirical measures and statistical data, it does not cover pooling of large-scale of controlled generating sources or consumers emerging at distribution level, eventually providing power to higher voltage level. Hence, evaluating the impact of electric vehicles whilst providing ancillary services require studies considering a simultaneity factor equal to one in conjunction with an adequate modeling of influence on system reliability. Moreover, geographically distributed vehicle fleets require more complex protection devices as multiple feeding sources and reversed power flows make a location difficult.

**Definition of basic conditions**

A first step in assessing the impact on electricity grids comprises of a worst case scenario where the maximum load or generation power is exceeding the grid capacity. Ancillary services provided by aggregating multiple vehicles at distribution level implying \( Gl \) equal to one and as such a worst case occurrence in demand or generating power in the grid.

Generally, balancing the demand and supply at a high voltage level stabilizes the grid. However, utilizing vehicle fleets for balancing, stresses partly the distribution level which in consequence destabilizes certain areas and increases the potential of islanding.

Comparing several scenarios of ancillary services shows that negative balancing power reveals in the most affecting condition as positive power is partly compensated through the load in this region. Thus, it only makes it necessary to assess the superposition of the current consumption of power and the additional draw of energy during provision of negative ancillary services. A VDEW consumer load profile serves as a typical pattern of a household collective of around 200 households and has been used in order to generate load flows at medium voltage [3].

According to VDEW the period of maximum demand has been estimated to 3pm and 7pm. This time data provide a basis for analysing stress whilst demanding ancillary services during the course of those hours.

However, accurate simulations determining the system status for each households are only possible, if appropriate load profiles are available. Hence, utilizing VDEW profiles only allows for assuming low voltage grids to be implemented in the simulation tool as integrated loads attached to a distribution network with 10kV feeders as shown in Figure 1.

**Exemplary results**

The simulations conducted are based on several real and representative distribution networks topologies taking into account rural, suburban and urban grids. Figure 2 illustrates the results obtained for a suburban distribution grid with a 630 kVA transformer. As shown below, the y-axis points out the percentage of components
overstressed whilst additional balancing power is provided. This parameter is referenced to the battery power and the penetration factor at the x-axis respectively, varying from 0, 25% up to 25% as mentioned above.

Figure 2: Impact on a suburban distribution network

Conclusively it can be observed, that during the startup phase of electric vehicles no upgrades on existing distribution grids are necessary as only small numbers of mobiles are being expected in coming years. Only if 60kW of battery power is connected to grid with a penetration factor of 2,5% will exceed the grid capacity. However, these results are only indicative and do not reflect other network topologies. In fact, individual studies need to be conducted to get an authentic impression on a certain network as these may vary significantly. Nevertheless, a general conclusion can be drawn based on the simulation results obtained. Intelligent management of electric vehicles in conjunction with a real-time status of the grid makes it possible to reduce overloading. As grids are designed and operated up to 40 or 50 years, the existing infrastructure will have to deal with upcoming decentralized sources and only certain regions will be equipped with intelligent communication systems. In order to ensure a safe and reliable operation of future grids it is necessary to assign typical characteristics of high voltage power sources to distribution networks. Hence, further proceeding of this paper briefly illustrates an alternative to implement synchronous generator characteristics to an electric vehicle which helps stabilizing the grid in case of faults.

Improving grid stability

Developing strategies for grid support at distribution level could be achieved by incorporating several characteristics such as providing reactive power as described in regulatory framework for decentralized power sources at low voltage level [4]. However, the features required only consider local grid support as mentioned above and do not require the systems to contribute to faults. Instead, it is requested to disconnect the source from the grid during exceptional conditions. As electric vehicles could be equipped with bi-directionally operated inverters [5] it is possible to emulate synchronous generator characteristics, which act as dynamical loads contributing to a self regulated effect, known from machines in case of a frequency drop or rise. The normal operational grid frequency bandwidth of 49,8Hz - 50,2Hz is implemented as virtual synchronous machine characteristic adopting its demand of load or feeding power according to the frequency. Thus, the power output is proportionally increased in case of a frequency drop such as generators do, hence supporting the grid. Inversing this feature allows for a rise in consumption of charging power in case of an increase of frequency. Thus, the total load is increased which occurs in this period of time and which is done in case of faults where storage pumps etc. are turned on to balance load and generation. As a result, the grid reliability will be increased, if additional virtual synchronous machines are utilized during unstable grid conditions. Figure 3 illustrates the above mentioned characteristic as a linear increase in consumption or decrease in power output at x-axis with respect to the frequency.

Figure 3: Frequency dependant power output of an electric vehicle

The described emulation of rotational spinning reserves has been implemented in a MatLab/Simulink simulation with the affect of contributing to the restoration of outages as shown in Figure 4. A large disturbance as happened during November 4th in 2006 was implemented in a comprehensive model, where the potential of only a small number of electric vehicles stabilizing the grid has become apparent [6]. The occurrence of a frequency drop without vehicles is illustrated as a black curve and the case with vehicles connected to the grid as a black curve. The analysis has shown that 1.000.000 plug-in electric vehicles with a total battery power of 3860MW (3,86 kW each) could have reduced the slope of frequency drop during the fault. Furthermore, the terminal value of the frequency is increased, thus resulting in an improvement of grid stability.
However, on one hand it is required to always limit the depth of discharge in order to provide sufficient capacity to the user and on the other, virtual synchronous characteristics do require a certain charge limit in order to provide sufficient capacity if additional balancing power is necessary as described above.

SUMMARY

Introduction of propulsion systems such as full electric vehicles or plug-in hybrids offer significant CO₂ emissions reduction and could contribute to a more reliable grid due to emulation of characteristics of synchronous machines. However, along with an increase in electric propulsion systems low and medium voltage grids will be subject to higher loading during charging or provision of additional grid support. A scenario analysis has shown that nowadays designed distribution grids are partly able to cope with additional load of mobile storage devices, but may not provide sufficient grid capacity in case of fast recharge if utilized for grid support with a simultaneity factor equal to one. Therefore, further investigations on grid stability are necessary as dynamic changes in load flows do occur during balancing power and demand through decentralized storages. Battery characteristics are essential to be included in simulations as they influence the duration of charging and affect the interval grid components are exposed to additional loading. Considering low voltage grids, it is necessary to include more detailed pattern of demand and user behavior as unfavorable conditions may result in simultaneous charging of multiple vehicles. Nevertheless, considering the fact that only 500,000 propulsion systems such as electric vehicles or plug-in hybrids with a battery power of 4,6kW could stabilize the grid with 1840MW of additional power in case of a fault, an enormous potential becomes evident. Thus, further investigations will analyze the potential of propulsion systems to contribute to voltage stability in grids.

It is also of interest to assess the dynamical impact on low voltage components installed in grids and their ageing behavior as a result of additional stress.

REFERENCES


Figure 4: Frequency drop with and without electric vehicles