USING ELECTRIC VEHICLES TO MITIGATE IMBALANCE REQUIREMENTS ASSOCIATED WITH HIGH PENETRATION LEVEL OF GRID-CONNECTED PHOTOVOLTAIC SYSTEMS

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ABSTRACT

This paper considers the use of electric vehicles as mobile energy storage to mitigate the effects of output power production associated with high penetration level of grid-connected photovoltaic (GCPV) systems. Power flow analysis of a typical the low voltage distribution network is carried out to investigate the voltage level at each busbar along the low voltage feeders. A model of typical UK low voltage distribution network has been developed in the MATLAB program environment. The voltage profile of the network model was investigated with and without GCPV systems connected. Then, electric vehicles are integrated into the network model and the voltage level was investigated when these vehicles are in charging condition while the PV systems remain grid-connected. The paper presents a description of the network model and the results of simulations.

INTRODUCTION

Electrical energy storage technology has the potential to facilitate the high penetration level of variable renewable energy sources, such as wind turbines and grid-connected photovoltaic (GCPV) systems, which are an alternative option for generating the power near the customer load and reducing greenhouse gas emissions from the electric power sector. In the UK, electricity generation is still largely from fossil fuels, which causes the release of harmful gases into the atmosphere [1]. The use of PV systems and other types of renewable energy sources such as wind turbines will help to reduce the gas emissions thereby helping government to achieve 15% of its energy from renewable sources to meet their binding 2020 target [2].

Although PV systems and wind turbines are intermittent electricity sources and their output power varies with sunshine intensity and wind speed respectively, PV power generation may be less challenging for grid integration because sunlight is more predictable than wind. In addition, PV systems have many technical advantages such as flexibility, simplicity to install in any area where the solar irradiation is available, being non-polluting, emitting no noise during electricity generation and requiring little maintenance. However, since operators of the electrical grid must constantly match electricity supply and demand, installing a high penetration level of GCPV systems into low voltage distribution networks within a relatively small area, referred to hereafter as clustered, may have an impact on the power quality and reliability of the existing distribution network.

Normally the direction of power flow is from higher to lower voltage levels in the distribution networks. This system architecture was a technical and economic choice. However, as the amount of locally installed GCPV systems is increasing rapidly, some of the GCPV output power will be consumed locally within the building and any excess will be injected into the grid. Feeding power to the grid could happen during the hours of daylight when the generated power is higher than the load demand due to a high solar irradiation level, especially in sunny weather conditions (summer season). In this case, the main issue to be expected is that the export of active power to the grid could result in reverse power flow and may cause an excessive voltage rise along a distribution network feeder violating the voltage limits. In this paper, the UK low voltage distribution network is taken as a case study to investigate this issue, together with the integration of electric vehicles as a mobile storage system to absorb the surplus power and keep the voltage in the permitted range. Generally, the rated output of a typical UK domestic GCPV system is in the region of a few (1-5) kW [3], based on the average space available on the roof of a residential house and the system efficiency. Figure 1 shows a typical daily load profile [4] and the output power of a 3 kW PV system on a clear summer day in the UK. The summer load profile is considered as it provides a good example of when there is more energy being produced by the PV than is consumed by the local load across the middle of the day.

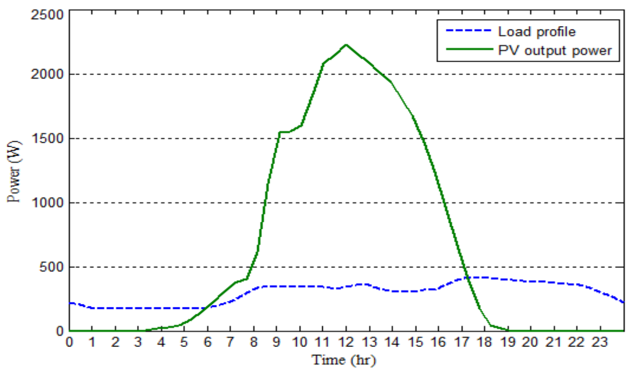

Fig.1. Typical house load profile and PV production for a 24 h period (summer season)

PROBLEM DESCRIPTION

The main issue to be expected with high penetration of grid-connected PV system would lead to export of active power to the grid which could result in overvoltage as the diagram in Figure 2 illustrates.

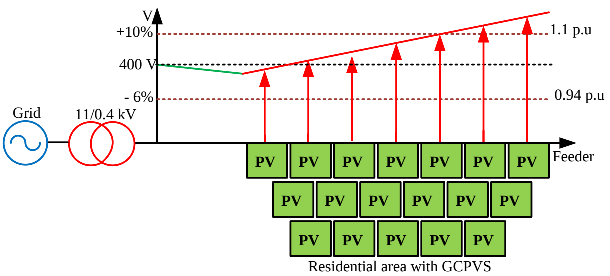

Fig.2. Voltage rise due to clustered PV systems

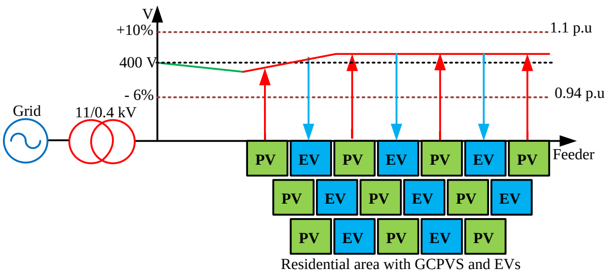

Fig.3. Regulating voltage line by using EVs as storage system

SUGGESTED SOLUTION

Electric vehicles (EVs) could become an integrated part of tomorrow's smart electricity grids as mobile storage systems, especially as their penetration level increases [5]. In the UK there are approximately 28 million cars licensed, with 89% of them privately owned [6]. Most of the time these cars are parked; they are on average being driven for only about 5% of the time. These parked cars could thus provide a valuable second function as load or source to support the grid. This approach could play a key role as a demand-side resource to improve GCPV systems power integration into the low voltage distribution network by keep the voltage within its permitted range as illustrated in Figure 3. In addition, the photovoltaic system owner will gain from the current UK feed-in tariff scheme.

NETWORK MODELLING

Distribution network description

An existing UK low voltage distribution network segment is used to investigate the voltage stability due to a high penetration level of GCPV systems and EVs as a storage system. This network is fed at a primary 500 MVA substation which consists of two 33/11 kV 20 MVA transformers to supply six 11 kV outgoing feeders, with each feeder supplying eight 11/0.4 kV substations. Each 11/0.4 kV substation typically supplies 384 properties which are distributed along four outgoing radial feeders. In total, the network supplies 18,432 properties. In order to simplify the analysis, only one 400 V feeder together with its connected loads and GCPV systems was modeled in detail whilst the rest were simplified as a lumped load. Figure 4 presents a schematic diagram of this network.

Simulink network model

The Matlab/Simulink and Power System Block-set were used to simulate the low voltage distribution network shown in Figure 4 with high penetration levels of GCPV systems. Details of the 400 V feeder with loads and the GCPV systems are illustrated in Figures 5 and 6, respectively. All the feeders use underground cables only. Each 400 V feeder is connected to 384 houses. In order to simplify the model, houses are assumed to be distributed along the feeders and lumped in seven groups. Each house was assumed to have a 3 kW grid-connected PV system. In terms of the energy storage system, electric vehicles were assumed to be connected into the network at different penetration levels and battery state of charge. The Nissan LEAF, with a battery capacity of 24 kWh, is taken as the example since this car is going to be produced and available in the UK.

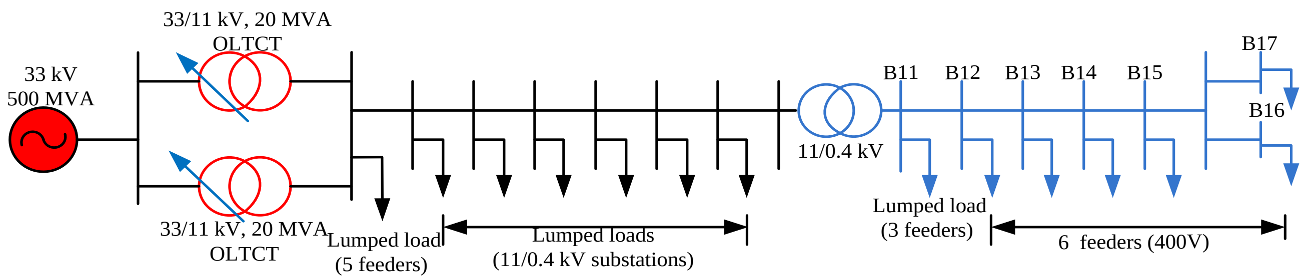

Fig.4. Schematic diagram of distribution network model with one 400 V feeder modeled in detail

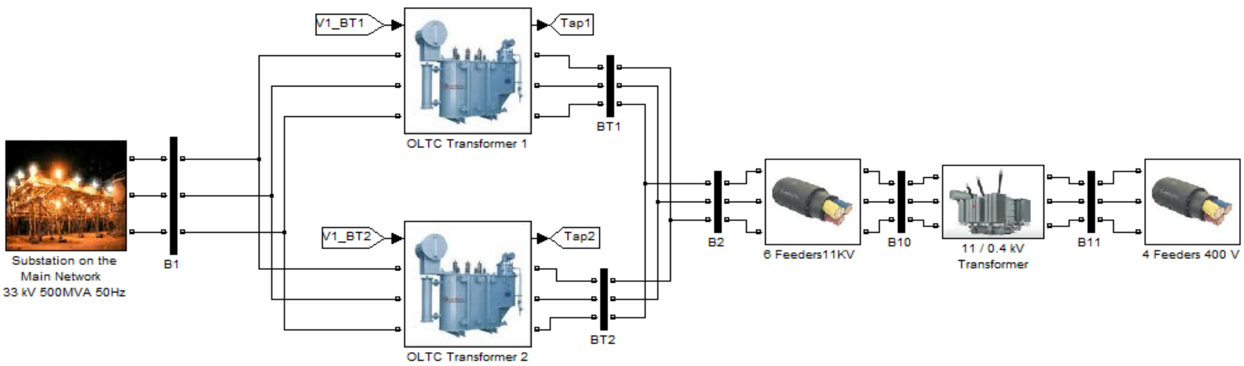

Fig.5. Matlab/Simulink/Sim-Power-Systems model of low voltage distribution network

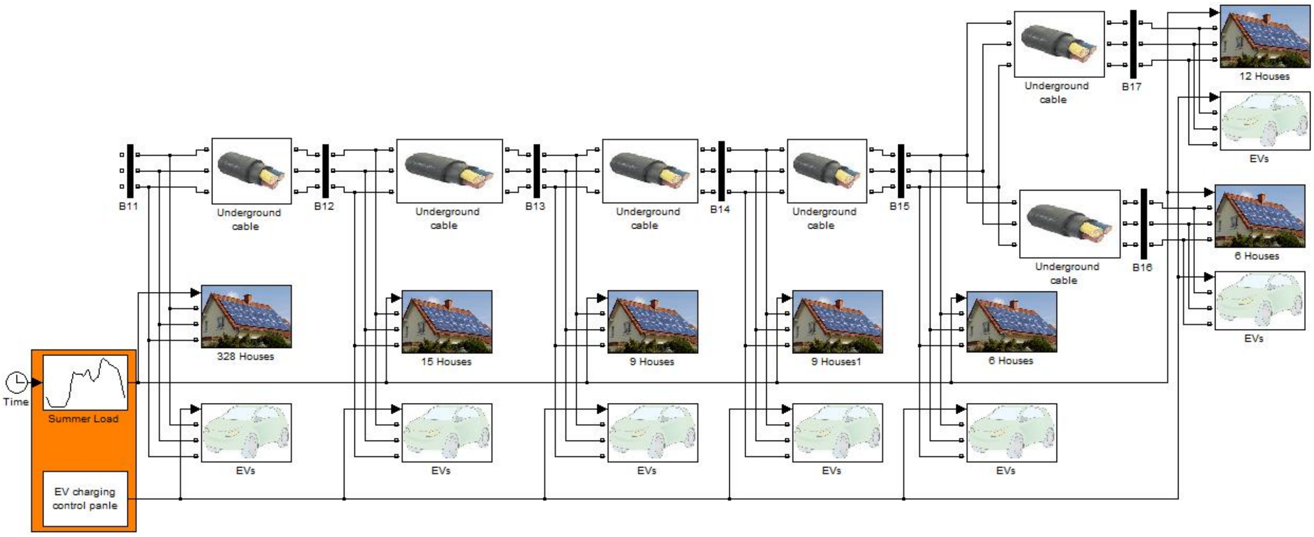

Fig.6. Matlab/Simulink/Sim-Power-Systems model of one 400 V feeder with GCPV system and EVintegration.

SIMULATION RESULTS AND ANALYSIS

<u>Case study 1:</u>

In this case, the network model was simulated with the variation of a typical daily load profile over 24 hours and without PV systems. The voltage at each node along the 400 V feeder (B11 to B17) was measured and the voltage profile is presented in Figure 7. The voltage profile indicates that the voltage level remains within the statutory limits (+1.1 and -0.94 p.u.) of the nominal voltage (400 V) except a small dip at 5.00 pm when most of the people return home.

<u>Case study 2:</u>

Here, the network was simulated over 24 hours with the same summer load profile and three scenarios of GCPV penetration levels (25%, 50% and 75%). The voltage profile indicates that, below 75% penetration, the voltage level remains within the statutory limits. However at 75% penetration level, the end line (B17) voltage level increases above the upper statutory limit (+1.1) as Figure 8 shows.

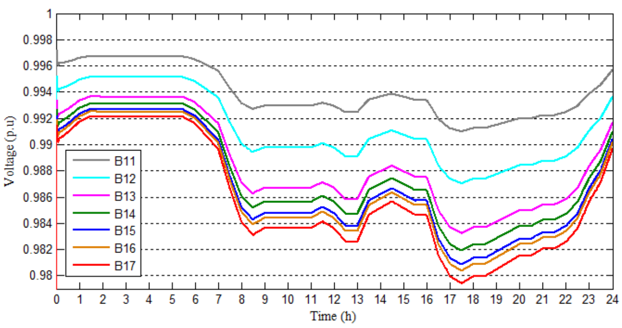

Fig.7. Voltage profile along the 400 V feeder without GCPVS

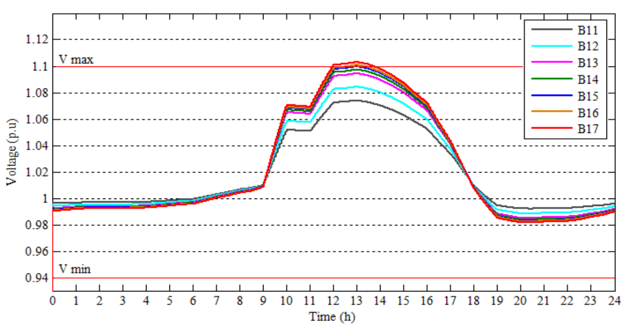

Fig.8. Voltage profile along the 400 V feeder with 75% GCPVS

In the fourth scenario, the penetration level is increased to 100% which is the worst case condition since it assumes maximum penetration of PV (every house has an installed PV system). The voltage level along the 400 V feeder increases further above the statutory limit in the time between 11.00 am to 2.00 pm (midday where load is expected to be low and PV generation is high), although the voltage level at the beginning of the feeder (B11) remained just on or below the statutory limits as Figure 9 shows.

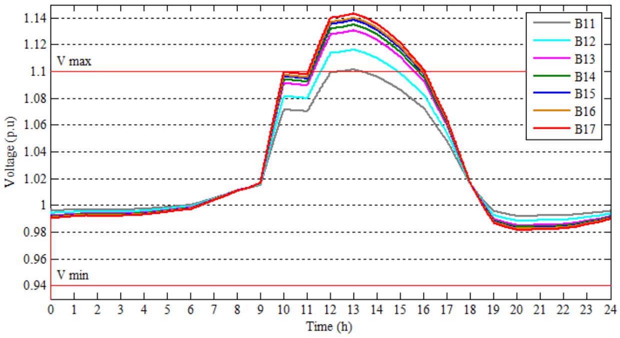

Fig.9. Voltage profile along the 400 V feeder with 100% GCPV systems

Case study 3:

In this case, the network was simulated over 24 hours with typical summer load profile and worst case scenario of GCPV penetration level (100%). In addition, electric vehicles were integrated into the network as a storage system in two different aggregation scenarios (20% and 60%) with 20% battery state of charge assumed at the start of charging. In each scenario, an uncontrolled charging regime from 9:30 to 16:30 was applied and the voltage profile along the 400 V feeder (B11to B17) was measured and plotted as illustrated in Figures 10 and 11.

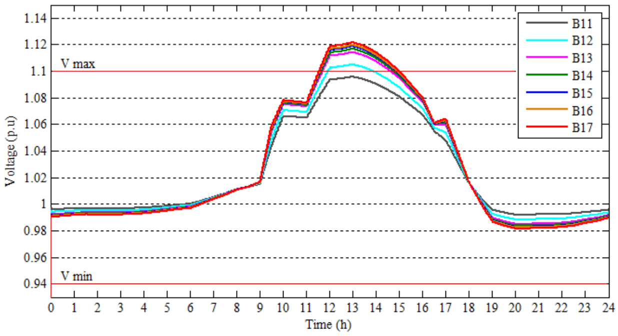

Fig.10. Voltage profile along the 400 V feeder with 100% GCPV systems and 20% EV

From Fig. 10, it is noted that, at 100% and 20% penetration levels of GCPV systems and electric vehicles respectively, the voltage level remains above the permitted level. However, as the penetration level of EVs is increased gradually, the voltage level is improved and remains within the statutory limits for EV penetration levels above 40%.

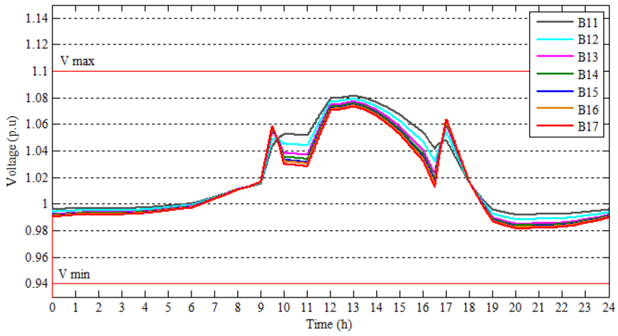

Fig.11. Voltage profile along the 400 V feeder with 100% GCPV systems and 60% EV

CONCLUSION

This paper has investigated the impact of a high penetration level of GCPV systems and the integration of EVs as a storage system on the low voltage distribution network. In the future, EVs will be deployed as part of the smart grid and this will help the network to accommodate more renewable energy sources. Thus, electric vehicles would have the potential capability to participate in the voltage regulation in the distribution network. A smart energy management schemes will need to be implemented to make the best use of the available network resources and therefore gain financial and economic benefits.

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