CUSTOMER LED NETWORK REVOLUTION - INTEGRATING RENEWABLE ENERGY INTO LV NETWORKS USING ENERGY STORAGE

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ABSTRACT

Integrating renewable energy into LV networks brings a number of challenges to existing distribution networks, particularly steady-state voltage rise and in some cases voltage unbalance. Electrical Energy Storage (EES) systems can play an essential role in facilitating renewable energy integration by mitigating voltage rise problems and unbalanced issues. As part of the Customer Led Network Revolution (CLNR) smart grid project, this paper describes research relating to the voltage rise issues arising from large-scale PV integration and presents a solution using EES, based on data analysis from a field trial network, PSCAD simulation and laboratory emulation.

INTRODUCTION

The UK government's policy is expected to lead to a continuous increase in distributed generation, which will affect the operation of distribution networks, and result in new challenges for Distribution Networks Operators (DNOs). With these issues in mind, Ofgem instigated the Low Carbon Network Fund (LCNF) to facilitate investigation into the impact of low carbon technologies (LCTs) on the GB electricity system. The largest project funded by LCNF, thus far, is the Customer Led Network Revolution (CLNR) and is led by Northern Powergrid. One of the main objectives of this project is to investigate network solutions to resolve network constraints driven by the transition to a low carbon economy. In order to achieve this objective, a number of customer propositions, LCTs, including PV generation, and Smart Grid technologies, including six electrical energy storage (EES) systems will be trialled and evaluated [1]. As one of the collaborators in this project, Durham University provides multi-disciplinary support, by undertaking technical modelling and simulation, trial analysis, laboratory emulation and social science research in collaboration with British Gas and EA Technology.

Previous research at Durham University has identified four LV distribution network constraints when large concentrations of micro-generation are installed in LV networks: (a) steady-state voltage limits, (b) voltage unbalance limits, (c) thermal limits, and (d) reverse power flow limits [2, 3]. This paper focuses on steady-state voltage limits since this constraint has been found from simulation and previous research [4, 5], to be the most limiting issue. Previously, voltage control techniques have been developed in order to integrate renewable energy into distribution networks without compromising security of customer supplies [4].

A number of areas have been identified where energy storage systems can be applied effectively within electricity transmission and distribution systems [6]. In this paper, the voltage control capability of EES is illustrated in a PV integration trial network.

This paper initially describes the PV reception network in the CLNR project, and introduces field trial data analysis. Simulation results and emulation results from the Durham University Smart Grid Laboratory are also presented, to demonstrate the voltage control capability of EES in LV networks with PV generation.

PV RECEPTION NETWORK

Within the CLNR project, an area of Northern Powergrid LV network, with a large concentration of PV, has been defined as the PV reception network test cell. This test cell is being used to investigate the impact of PV generation and the voltage control and power flow management capabilities of EES.

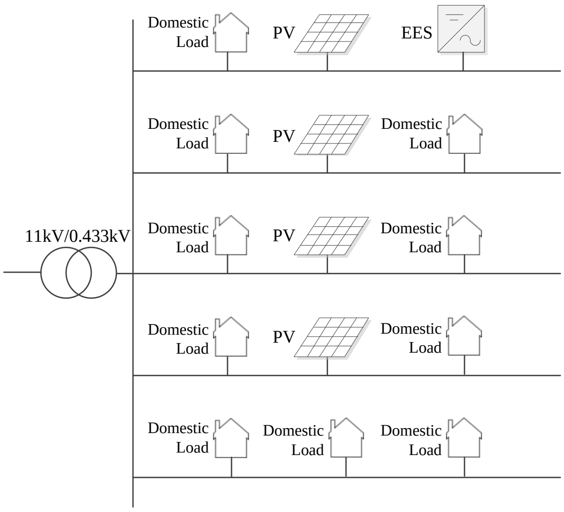

Fig. 1 Topology of Trial Network

The network topology of this test network is shown in Fig. 1. This network consists of five LV feeders emanating from the HV/LV substation. Around 15% PV penetration is deployed on four of these feeders. Here the definition of penetration is the number of households with PV fitted, as a percentage of connected households on that LV distributor or substation. An EES (50kVA/100kWh) is to be installed on one of these feeders. Remote measurement units have been installed in this PV reception network to monitor the voltages and load flow conditions. Fig. 2 illustrates the three phase voltages, based on data measured from midnight to 6 am of the day 2 Jan 2012, at the secondary side of the HV/LV substation.

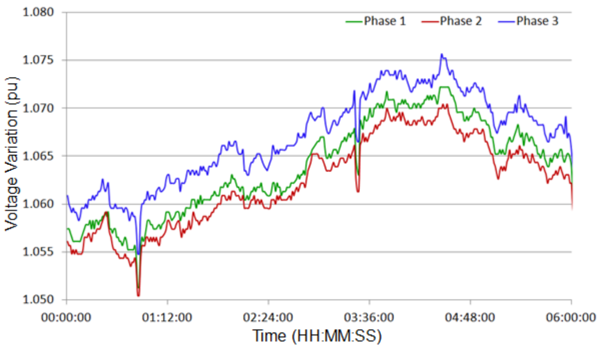

Fig. 2 Measured Three Phase Voltages

It can be seen that the three phase voltages are always higher than rated voltage (1pu), and the maximum voltage reaches 1.075pu, which is close to the 1.1pu statutory voltage limit in the UK and Europe. It can also be seen that the three phase voltages are not balanced, and the maximum unbalanced factor was found to be 0.45% against the limit of 1.3% in the UK.

With current PV penetration, no voltage issue is found in this LV network. However, a number of additional PV generation connection requests in this LV network have been submitted to Northern Powergrid. If all these requests are accepted, this PV reception network will reach approximately 50% PV penetration or above on certain feeders. In this scenario, the voltage is expected to violate the statutory limit, due to the existing voltage bias and underlying voltage unbalance. In this case EES could be used to mitigate this voltage issue. The simulation and emulation work, presented in the following sections, illustrate the effects of high penetration of PV on this network and the feasibility of mitigating voltage issues using EES.

SIMULATION

In order to evaluate EES based voltage control strategies, a PV reception network model, including models of PV generation and an EES system, as well as EES control strategies has been developed in PSCAD.

Network Model Development

The simulation network model is based on the trial LV network and UK generic distribution network [5]. Network information (topology and line impedances etc.) and measurement data from Northern Powergrid are applied to establish and validate this network model. Fig. 3 represents the LV section of this network model.

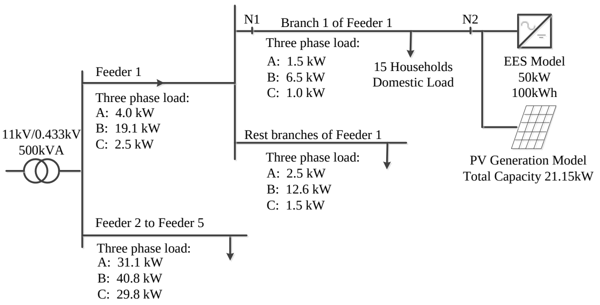

Fig. 3 LV Section of Simulation Network

As shown in Fig. 3, the domestic loads on the first branch of Feeder 1, to which a total of 15 households are connected, are modelled in detail, while the loads on the remaining branches of this feeder and other feeders are modelled as aggregated load. All these load models are determined based on actual field measurements at midday, when PV output is typically at its maximum level.

PV and EES Modelling

The PV generation model and EES model have been developed in PSCAD to represent the PV generation system and EES system. The PV generation model is able to inject current into a single phase of the network. Similarly, the three phases of the EES model can also be controlled independently to absorb or inject real power and reactive power.

The maximum output of PV generation in the network is 21.15kW. This would represent a 60% PV penetration of the 15 households on this branch, with a rated power of 2.35kW per household. Furthermore, this 21.15kW of PV generation is deployed in an unbalanced fashioned across the three phases which exacerbates the voltage rise problems [5]. The rated power and capacity of the EES model are 50kW and 100kWh as per the EES system, which is to be installed in this LV network.

Voltage Control Strategies

Two EES voltage control strategies have been evaluated in this analysis, namely balanced power exchange control strategy (BPECS) and unbalanced power exchange control strategy (UPECS). In BPECS, the power flows on each of the phases of the EES are the same. In UPECS, the power flow on each phase of the EES can be controlled independently.

Simulation Results

Simulation results demonstrating the operation of the EES with UPECS are shown in Fig. 4. Three-phase voltages at N2, which is the remote end of the feeder, are illustrated in section a) of Fig. 4. The power import/export of the PV generation system and EES system are illustrated in section b) of Fig. 4.

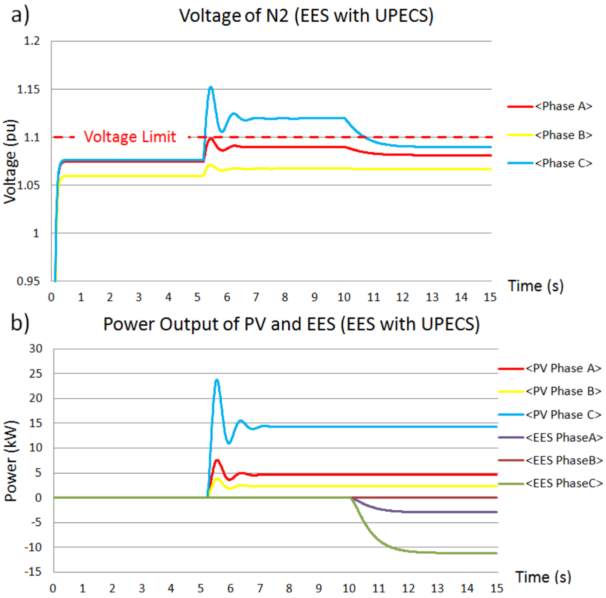

Fig. 4 Simulation Results in PSCAD

It can be seen that the three-phase voltages increase after the PV generation starts injecting its maximum output power into the network at time t=5s and the voltage of Phase C rises above the statutory voltage limit. At time t=10s, the EES starts importing power from the network which decreases the voltage below the limit. This indicates that the EES can mitigate the violation of the voltage limit effectively.

Table 1 indicates the required EES converter power rating using each of the voltage control strategies. It was found that the EES converter with UPECS requires a lower three-phase power rating than that with BPECS.

Table 1 Required EES Converter Power Rating

	Phase A	Phase B	Phase C
EES with BPECS	11kW	11kW	11kW
EES with UPECS	3kW	0kW	11kW

In the area of the trial network, Yorkshire, UK, peak solar hours in summer are around 5 hours, which means it is possible that the EES may need to import power for 5 hours, with the power ratings shown in Table 1. To keep the voltage within limits, the EES utilising BPECS would require an energy capacity greater than 165kWh, while that of the EES utilising UPECS would only require an energy capacity greater than 70kWh. The EES deployed as part of this project, has the capability to control each phase independently with an energy capacity of 100kWh, which means it is a feasible voltage control solution.

LABORATORY EMULATION

In addition to the simulation work in PSCAD, emulation in hardware in the Smart Grid Lab of Durham University has also been conducted to further investigate EES's capability of voltage control in an LV network with large concentrations of PV generation.

Smart Grid Laboratory in Durham University

The Smart Grid Laboratory in Durham University, shown in Fig. 5, hosts a low-voltage network and a wide range of low carbon technologies, including Electrical Energy Storage (EES), Air Source Heat Pump (ASHP), wind and solar PV emulators, electric vehicle and a Real Time Digital Simulation system (RTDS). The laboratory is fully instrumented with a central workstation that monitors and controls the equipment via high-speed data acquisition network throughout the laboratory. It is designed for investigating the solutions to network constraints in electrical networks.

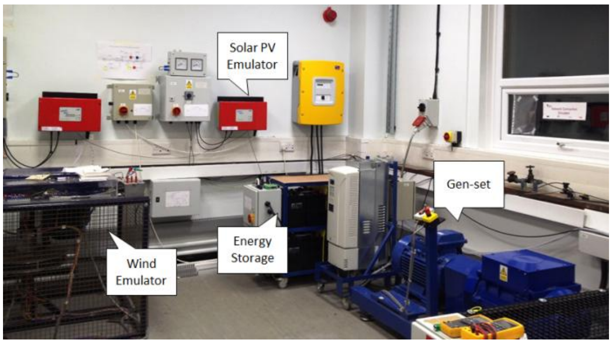

Fig. 5 Smart Grid Laboratory in Durham University

Emulation

A control system, with the purpose of overcoming steady-state voltage rise/drop issues has been developed in this Smart Grid laboratory. With this control system, steady state voltage rise can be mitigated by: (i) reducing the power output of the PV generation, (ii) diverting power into the EES and/or (iii) increasing the load in the locally affected area. These interventions can be performed individually or collectively. In this research the EES was applied to mitigate voltage rise. The EES system in the laboratory is single phase, which is different from the one applied in the simulation work.

The Smart Grid laboratory is operated so that the voltage exceeds the steady-state voltage rise limit, which is defined as 229V, as shown in Fig. 6, due to the increase of PV generation. Specifically, the PV emulator was initially instructed to output 0.6kW into the LV network after the inverter's synchronisation process. At time t=120s the PV emulator was instructed to increase its output power to 1.2kW, which pushed the voltage above the defined limit. The EES control system detected voltage limit violation and instructed the EES to import real power, which brought the voltage back below the limit, which in this case was set at 229V.

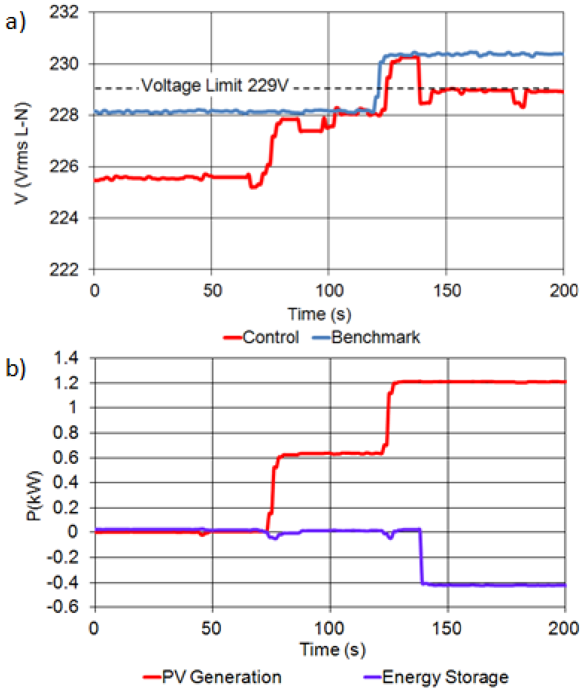

Fig. 6 Emulation Results

In section a) of Fig.6, the effect of the operation of the PV emulator on the remote end network voltage, without any control deployed in the system (*Benchmark*) and with the EES based voltage control system in operation (*Control*) is illustrated. In the *Benchmark* voltage trace the voltage exceeds the defined voltage rise limit of 229V following the increase in generation. However, in the *Control* trace it can be seen that the remote end voltage is controlled below the defined voltage limit, following application of the control action. The corresponding power flows of PV emulator and EES are shown in section b) of Fig. 6. This emulation result further demonstrates that EES can effectively mitigate the voltage rise problem arising from PV integration.

CONCLUSION

Field measurements and simulation results are used to demonstrate that high PV penetrations are likely to cause voltage rise issues in LV networks. In response to this, voltage control strategies were developed to mitigate the voltage rise resulting from high, unbalanced, penetrations of PV generation in these networks. The simulation and laboratory results demonstrate that EES can be used to mitigate these types of voltage rise problems. Furthermore, it is found that the ability to control power exchange, independently on each of the phases, of the storage device reduces the required energy storage capacity and converter power rating of the EES.

FUTURE WORK

Further work in simulation and in the laboratory will be conducted to investigate the voltage control capability of EES, in cooperation with other voltage control techniques, such as On Load Tap Changer (OLTC) and voltage regulators. Field trials on the PV reception network will also be carried out to demonstrate EES based voltage control, using the EES units deployed as part of CLNR project, in collaboration with other voltage control techniques as per simulation and laboratory work.

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