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Real and reactive power control of distributed PV inverters for overvoltage prevention and increased renewable generation hosting capacity

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ABSTRACT

Australia has seen a strong uptake of residential PV systems over the last five years, with small scale distributed generation systems now accounting for around 10% of peak capacity within the Australian National Electricity Market. As uptake further increases, there is concern about the ability of distribution networks to maintain reliability and power quality without requiring substantial additional infrastructure investment, and in some locations PV installations are no longer being allowed.

This paper evaluates the effectiveness of real and reactive power control of distributed PV inverter systems, to maintain and improve network power quality. High resolution PV output data has been collected at a number of trial sites in Newcastle, Australia and network impact simulations undertaken for an example long rural feeder gathered from the Australian National Feeder Taxonomy Study. These show how localised PV inverter controls can regulate distribution network voltages, reduce network losses, increase the network hosting capacity and hence the uptake of distributed renewable energy.

1. Introduction

Australia's energy sector is in the midst of a fundamental transformation. On the generation side, renewable energy is expected to provide 20% of Australia's electricity needs by 2020 and low emissions technologies are expected to have replaced almost all conventional generation by 2050. Energy usage patterns are also changing, particularly with the widespread uptake of residential air-conditioning – which has driven growth in peak demand relative to energy consumption and consequently undermined existing energy based revenue structures.

Responding to changing energy usage patterns and the intermittency of renewable (particularly PV) generation, means transitioning the electricity network from a one-way bulk transport system, to a transactional system with controllable generation and loads throughout. Fortunately, there are a number of technology and market changes taking place that combine to make this a realisable, if ambitious goal:

- Community awareness and engagement in the management of the electricity system is increasing, partly due to considerable pricing increases;
- Off-grid and local generation systems are becoming viable in their own right – PV module prices have plummeted and battery and balance of system costs have been steadily dropping;
- The technologies for consumers to participate in demand management are maturing – HAN (Home Area Network) controllers are now being included in smart meters, while standards are becoming available for appliance demand and inverter advanced power quality responses;
- Smart meters that not only measure consumer energy usage, but also network conditions, have been extensively trialled and are suited to main-stream deployment;
- New sensing technologies allow for easier monitoring of HV (high voltage) transmission systems, giving a clearer picture of network conditions and behaviour;

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- Data storage capabilities and communications speeds have increased substantially, making it possible to measure and store better information than ever before; and
- Algorithms are being developed to manage 'big data', providing network control system optimisation and taking advantage of improvements in communications and computational power to rigorously evaluate alternate control scenarios before committing to a particular action.

The challenge is to now build the social, technical and regulatory systems to support this transformation. One aspect of this, and the focus of this paper, is the technical challenge of increasing the PV hosting capacity of distribution networks. With PV installations in Australia now nearing 10% of the peak capacity of the National Electricity Market (NEM), concern over the potential impacts that this may have, has led some electricity companies to begin restricting PV installations in particular geographical areas. Such restrictions have been attributed to concerns over power quality, specifically voltage rise problems ([1], pg. 75). The voltage rise problem is well established as occurring, though its significance in determining limits of PV adoption is not.

To help make this assessment, high resolution PV output data and network voltages have been collected at a number of trial sites in Newcastle, Australia and network impact simulations undertaken for an example feeder from the Australian National Feeder Taxonomy Study (NTFS). The NFTS was conducted by the CSIRO as part of the Ausgrid Smart Grid Smart City trial (see www.smartgridsmartcity.com.au), with input from electricity distribution companies from across Australia, and has created a classification of feeder types in Australia and a representative set of example feeders. A similar study of US feeders was undertaken by the PNNL (Pacific Northwest National Laboratory) [2]. The NFTS allows the applicability of experimental results on a particular feeder to be understood in terms of their significance across Australia and hence build the business case for specific network management and control approaches.

This paper compares and reports the effectiveness, using experimentally obtained data in combination with network simulations, of a variety of inverter control strategies to reduce voltage rise. Several of these strategies are described in the Electric Power Research Institute's report on smart inverter functions [3], however additional control features are also tested, specifically with the aim of evaluating the appropriateness of the schemes for upcoming revisions to Australian Standards AS/NZ4755 and AS/NZ4777.

Although different inverter manufacturers have adopted different approaches for when network power quality problems are detected, one standard function is for inverters to shut-off on detection of over-voltage conditions, resulting in the 100% loss of power generation (and thus earnings) for the PV owner for the duration of the event (which is often at peak tariff times). Another common voltage rise mitigation strategy is to curtail active power (the APC – active power curtailment – strategy), which is explored in Refs. [4,5] which produces beneficial results. An example of this behaviour is shown in Fig. 1 (which also shows curtailment behaviour when PV power is below a minimum level). However, by using knowledge of the electricity network and loads – that loads and network lines are typically inductive – a more intelligent control scheme for inverters can be implemented that utilises reactive power control to reduce the amount of real power curtailed, while providing a greater reduction in overvoltage. This type of control strategy is explored in Refs. [6,7], with profit-generating motives in Ref. [8], and with a more sophisticated controller in Ref. [9]. While these and many other papers propose and evaluate alternative schemes, this paper is instead focused on comparing the relative performance, specifically considering curtailment losses, of different types of inverter control models.

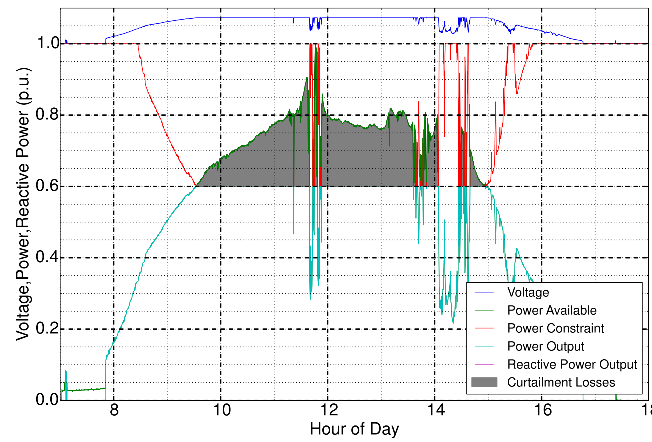

Fig. 1. Example of over-voltage curtailment.

The feeder used for these simulation studies is from the Australian NFTS, though it has been anonymised and simplified for use in this paper. The simulation results are therefore useful for comparing the different inverter control schemes, but would need to be tested across the range of prototypical feeders before an assessment could be made of the PV hosting capacity of the existing Australian electricity system or existing PV curtailment losses therein. This will be a subject of our future work. Of final note is that in this paper, *penetration* refers to the proportion of the peak load power that is provided by the PV at the peak generation time.

2. Experimental platform

PV generation data, together with customer load and voltage measurements were collected from a number of trial sites in Newcastle, Australia. This experimental platform was setup to support the CSIRO Virtual Power Station (VPS), which aggregates a large number of geographically dispersed and technically diverse small scale renewable energy generators together to form a 'virtual power station', which presents to the electricity system as a single reliable dispatchable entity. This dispatch capability can be used to manage exposure to high NEM spot prices or to address specific network constraints by exporting additional (stored) energy when required.

For the VPS trial, each of the 20 individual site nodes were retrofitted with a small embedded controller (see Fig. 2) that interfaces to the inverter to monitor energy which is communicated to the VPS central control and monitoring system hosted by CSIRO. Site PV sizes ranged from 1 kW to 10 kW, with the total trial VPS system peak output just over 50 kW. Sites that have both generation and battery storage also receive a battery charge setpoint from the VPS central control system, which is used to balance the total output of the VPS as is required due to the inevitable (minor) mismatch between forecast and actual generation output. The planned VPS output is determined on a 5 min cycle (consistent with the Australian National Energy Market dispatch cycle) and regulated with a 10 s control loop. Communications between sites is achieved using 3G wireless modems, which operate to transfer data over the existing mobile phone network.

The VPS central control system also implements a database storing 10 s sampled data from each of the sites and provides a web interface. This allowed easy visualisation and reporting of the system performance, and has also served as an engagement tool for