Solar Photovoltaic Inverter Behaviour

1. Introduction

In the modern electricity network, inverter equipment forms an important interface between renewable energy resources and the electricity grid. Such renewable energy resources include rooftop solar photovoltaic (PV) panels.

An important aspect of operating an electricity network is to maintain voltage levels at customer premises within a specified range so that connected equipment can operate properly and without damage. This voltage range is specified in national voltage standards. These standards specify that low voltage customers should be supplied at a nominal voltage of 230V line to neutral, and specify steady state voltage limits of +10% to -6% of the nominal voltage (253V to 216V) at the connection point. These limits apply to 10-minute root mean square (rms) voltages and are 99th and 1st percentile limits, measured over a period of at least 7 days and disregarding periods of supply interruption.

2. What problems are associated with inverter operation?

One of the challenges to integrating solar PV is that the normal operation of solar PV systems can lead to increased voltage levels at customer premises which, if excessive, can cause the PV inverter to disconnect from the grid resulting in loss of revenue from the PV system. In addition to loss of generation revenue, excessively high voltages can also reduce the lifespan of other appliances connected nearby.

3. What causes voltage rise?

To a first approximation, a PV inverter can be modelled as a current source. When the current from the inverter is injected into the combined impedance of the network and installation, a voltage rise will occur at the point of injection if all other variables are kept constant.

The components of the customer's installation can have the greatest influence on the voltage rise at the PV inverter. The main components of influence include the installation cabling and the PV inverter itself. The higher the total impedance of these cables, the greater will be the voltage rise; and the greater the rating of the PV inverter, the higher the voltage rise.

4. What is being done to reduce voltage rise?

The problem of voltage rise due to PV inverter operation has been addressed by changes to grid-connected inverter standards as well as the Service and Installation Rules of NSW, as outlined below. In particular, the introduction of power quality response modes in the grid-connected inverter standards allows customer solar photovoltaic systems to generate more energy than would otherwise be the case as it allows for voltage levels to be managed by reductions in inverter outputs as opposed to complete disconnection that was previously the case.

In addition to the above, many network service providers have also been taking proactive steps to reduce voltage levels on LV networks. These actions work together with the changes to the standards and Service rules to provide an electrical environment suitable for integration of solar PV generation.

The Service and Installation Rules of NSW now specify a 2% maximum voltage rise between the point of supply and the inverter output terminals (with a maximum of 1% rise across both the consumers mains and the final subcircuit to the inverter) when the PV inverter is delivering maximum power i.e. a 4.6 V rise based on a nominal voltage of 230 V. Conductor sizes to achieve this requirement are given in the Rules.

The Service and Installation Rules also allow varying of the output power factor (PF) of the inverter in order to help limit voltage rise. The grid-connected inverter standards now specify inverter power quality response modes, some of which allow for the control of output power and/or PF in order to help control voltage rise.

The volt-watt response mode varies the output power according to the voltage at the inverter terminals. The inverter progressively lowers the real power output as the voltage exceeds the threshold voltage resulting in the inverter operating at reduced power while the voltage is high.

The volt-var response mode varies the reactive power output of the inverter according to the voltage at the inverter terminals. Voltage is managed by controlling reactive power import or export based on measured voltage.

The integration of both volt-watt and volt-var response modes requires careful consideration to choose suitable reference values and power/var levels to achieve optimum outcomes. Recently, Energy Networks Australia (ENA) has recommended new default power quality response reference values and power levels for inverter manufacturers to use in order to increase network PV hosting capacity and net energy exports.

5. What you can do to help

Customers can help minimise the voltage rise issues associated with solar PV operation by maximising self-consumption of the solar PV electricity. This minimises the current injected back into the distribution network. This can be achieved in several ways including:

- Moving as much energy consumption as possible to the middle of the day when network loads are generally smaller. This could involve running air conditioning to pre-cool or pre-heat premises, using microwaves, ovens or cooktops for meal preparation, operating appliances such as washing machines, dishwashers or swimming pool pumps. This approach is becoming more viable with the increasing availability of internet-connected appliances. For multi-phase installations, care must be taken to ensure that loads and PV generation are on the same phase or phases for this strategy to be effective.
- Install battery storage. This allows excess solar PV output to be directed to the batteries and not to the distribution network. Battery systems remain quite expensive so a cost/benefit analysis should be undertaken before purchase.