This article serves to address a technical nuance of solar panels: that of their high source impedance. The technical description of source impedance is introduced and then expanded to describe this impedance component in electricity distribution.

Overload and short circuit protection of photovoltaic panels

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The prevalence of photovoltaic panels in residential low voltage installations is increasing. This increase is primarily driven by the residential consumer demand for a secure supply. Even though Camden power station, the first of three mothballed power stations to be returned to service, adds 1,58 GW to the installed generation capacity of the South African network, the reserve margin is under severe pressure. The age of low cost electricity in South Africa is over with NERSA-approved increases between 20 and 35% for the next three years - this makes distributed generation projects like small, low-voltage, photovoltaic systems attractive.

Source impedance

Power circuits may be distilled into generation or source elements and dissipation or load elements. Source elements inherently contain a load component due to the generation mechanism. For example in batteries the source impedance is a function of the electrode resistance, electrolyte conductivity and ion mobility. Source impedance in steam turbine generators, used in Eskom’s coal fired power plants, arises from the resistance of the conductors in the electromagnetic coils as well as the transmission components (HV lines, transformers, etc.). In photovoltaic cells there are two impedances: a series resistance which arises from the traditional ohmic loss components and a parallel shut resistance which models the losses from the inherently present diode components.

This circuit gives rise to a unique current-voltage and power-voltage profile shown in the following figure. The first thing to note about such a profile is that there is a small voltage region, around 17 V, where the PV panel is efficient. This region is referred to as the Maximum Power Point (MPP). The power profile quickly collapses for higher voltages (higher impedance loads) and slowly collapses for lower voltages (lower impedance loads). Maximum power point trackers (MPPPs) are specifically designed to vary their input impedance to match the maximum power point of a photovoltaic panel.

Common wiring schemes

An islanded configuration is where the photovoltaic installation is the only source and thus the installation may be regarded as an island of power, operating independently from the grid and national power utility. These installations are limited by the load profile, particularly after the sun has set and the photovoltaic cells are not producing any energy. Often these installations include battery banks to provide standby power when the cells are not illuminated.

Grid-tied installations are not yet a reality in South Africa, but are common throughout Europe and North America. In these types of installations the photovoltaic system is connected in parallel with the grid and power may...
flow from the residential installation back into the grid. In times when the photovoltaic cells are not illuminated the load is driven from grid generated power.

Photovoltaic cells generate DC power from incident solar radiation and through the application of power electronics, often in the form of a transformerless inverter, DC is converted into the commonly used AC waveform. In grid-tied installations, the inverter is synchronised to the grid phase.

**Fault characteristics**

Faults in electrical systems arise from a variety of causes: small magnitude faults (overloads) and large magnitude faults (short circuits). Essentially the protection components within a circuit are specifically included to limit the amount of fault energy and prevent destructive failures.

When a fault occurs the resulting current is described by the source voltage across the serial combination of impedances between the generator and fault. In grid connected electrical networks where the fault is close to the transformer or generator, the magnitude of fault current in a short circuit type fault is several orders of magnitude larger than the rating of the circuit. For example short circuit currents in the region of 6 kA are possible in circuits rated for 5 A or 10 A. The closer the fault is to the transformer or generator, the larger the resulting fault current since the distribution impedance is reduced.

This is not the case for short circuit faults in the DC network of a photovoltaic installation because the source impedance of the photovoltaic cell limits the fault current. The difference between short circuit current and maximum power point current may only be as large as 10%. Thus faults on the DC network of photovoltaic cells that may be caused by short circuits will only result in overload type faults. Thus it is not possible to achieve overload and short circuit discrimination as circuit breaker time delay curves are not fast enough to provide sufficient selectivity between these types of faults.

With reference to the common wiring scheme presented in the IEC standard for photovoltaic installations, faults may occur on the DC side of the network (as discussed above), and also on the AC side of the network. In the case of a fault on the AC side of the inverter, the current limiting impedance consists of the inverter source impedance, a limited distribution impedance because of the proximity of the fault to the inverter, and the fault impedance. Thus short circuit currents in a circuit close to the inverter may be larger than faults found in grid powered low voltage systems.

Lastly, in grid-tied installations the fault impedance is reduced further since the
inverter source impedance is effectively in parallel with the grid source impedance - this results in an even smaller source impedance.

**Design rules**

The complexity of these systems may be managed effectively through the consistent application of the following design rules:

- On the DC circuit, consisting of the photovoltaic panels (in strings and/or arrays), select the cable rating in excess of the short circuit current for the photovoltaic panels.
- Rate the DC circuit breakers for this circuit at or in slight excess of the photovoltaic maximum power point current; understanding that circuit breakers are required to hold (not respond to) 105% of their rating.
- Ensure the circuit breaker protecting the low voltage AC connection between the inverter and load has a sufficient short circuit rating, and that this connection has residual current detection.
- For grid tied installations ensure that each feed into the installation is rated at the fault level for the common bus bar. The common bus bar may have a fault level greater than any of the sources.

Since the short circuit current for a photovoltaic cell is only slightly larger than the maximum power point current, the associated cost of increasing the rating of the interconnection cables is small in comparison to the increased safety of the circuit.

Rating the DC circuit breakers at the maximum power point current gives the installation some overload type protection, although these circuit breakers may only function in the case of extreme faults where energy from the inverter somehow flows into the photovoltaic circuit. These protection components should be of the type where the rating of the device is temperature invariant as photovoltaic cells may experience a wide range of operating temperatures with moderate changes to efficiency.

Circuits connected to inverters, or any other source, require both overload and earth-leakage protection, where the combination of inverter and grid sources may increase the fault level above the individual fault level of any one of the sources.

**Conclusion**

The selection of protection components in photovoltaic installations is not trivial. There are both DC and AC circuits with very different characteristics. The DC circuit is categorised by a high source impedance, small operating range and large temperature range. If traditional AC network design rules are employed for this DC network the resulting protection will be ineffective. DC breakers with a rating between the maximum power point and short circuit point should be used, with the cables rated for the short circuit current. The AC circuit has a lower source impedance and hence designing for the short circuit characteristics is critical. In grid tied configurations the combined fault level may exceed the fault level of any one of the sources.

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