Grid connection code for renewable power plants South Africa

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Regulations have and still play a major role in the successful penetration of renewable energies in the power grid. In South Africa, the White Paper on Renewable Energy of 2003 has set a target of 10 000 GWh of energy to be produced from renewable energy sources (mainly from biomass, wind, solar and small-scale hydro) by 2013 [1]. The incorporation of these renewable technologies, especially wind and solar, can only happen through unlimited access to the power grid.

However, a high penetration of renewable energies harbours the risk of the grid instability in case the generating plants are not able to support the grid. On this background, the National Energy Regulator of South Africa (NERSA) approved in November 2012 the new grid code for connecting renewable power plants (RPPs) to the transmission system (TS) or the distribution system (DS) in South Africa. This paper provides an overview of the grid code for the connection of RPPs to electric power systems.

In many countries, renewable energy technologies, which include photovoltaic (PV) and concentrated solar power (CSP), wind, small scale hydropower, landfill gas and biomass, expands and covers a steadily increasing part of these countries’ power demand. This is as a result of the policies and incentives given by governments around the world which has caused the inclusion of renewable energy as a significant part of the power system network. Although South Africa predominantly makes use of coal-fired power stations to supply over 90% of the electricity needs of the country, the government has committed itself to increase the generation mix to include more sustainable and environmentally friendly forms of generation.

In South Africa, renewable energy technologies will be integrated into the utility grid and due to its nature, this type of generation will not only geographically dispersed but also distributed across several voltage levels, at either the transmission level or distribution level, depending on the scale of generation. Both types of interconnections present different type of challenges that must be carefully analysed before systems are designed. The connection of RPPs to electrical power systems influences the system operation point, the load flow of real and reactive power, nodal voltages and power losses [2]. At the same time, RPPs must maintain uninterrupted generation throughout power system disturbances, supporting the network voltage and frequency, and therefore, extending features such as low voltage ride through or reactive and active power capability.

Low voltage ride through is particularly important to maintain the voltage stability, especially in areas with high concentration of RPPs i.e. wind and PV power generation [3]. The aim of the grid connection code is to keep the safety and reliability of the network operation with a growing share of decentralised generation plants and keep the voltage quality in accordance to the limits formulated in applicable standards.

Challenges faced by electricity distributors with increasing growth of RPPs

As more and more RPPs added to the distribution system, the nature of the medium voltage (MV) and low voltage (LV) system is changing from a traditional passive radial network to an active network with power flows in both directions from and to the transmission system. This presents particular challenges in terms of network protection, system operation and safety as more faults on the network may now be energised by multiple sources. The majority of new RPP being added to the South African distribution system is in the form of inverter-interfaced generators, with very specific technical characteristics which are quite different to those of traditional large-scale thermal generation.

There are many potential challenges faced when large amounts of RPPs are connected to a distribution network [4]:

- Protection co-ordination: Risk of under-reach of existing impedance protection. Also, selectivity between series overcurrent or impedance protection can be lost unless RPP is considered when calculating settings.
- Voltage regulation: Control of system voltages can become difficult on weak systems where generation may be intermittent in nature (e.g. wind turbines). Can lead to overvoltages and undervoltages following connection or loss of RPP.
- Islanding: Issues of safety and power quality on isolated power systems fed by RPP that may be created following system disturbances or operation of protection.

Power factor: Under conditions of light local load demand and high levels of renewable generation, power can be exported from the distribution system to the transmission system. However, reactive power may still be required from the transmission system. Under these conditions, this can cause a low power factor to be measured at the feeding transmission substation and can cause spurious protection trips if it is not considered in the protection relay settings of the substation.

It is therefore with these challenges that the industry has provided the RPP code which sets out technical framework for integrating renewable energy into the electricity grid, especially distribution system. The following sections outline some of the technical aspects proponent generators must identify and ensure that are incorporated early during project development phase.

Objectives and scope

The primary objective of the grid connection code is to specify minimum technical and design grid connection requirements for RPPs connected to or seeking connection to the South African electricity grid. This grid connection code, at minimum, applies to the following RPP technologies:

- Photovoltaic
- Concentrated solar power
- Small hydro
- Landfill gas
- Biomass
- Biogas
- Wind

The requirements of the RPP grid connection code are organised according to defined categories as illustrated in Table 1.

<table>
<thead>
<tr>
<th>Sub-categories</th>
<th>Rated power range</th>
</tr>
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<tbody>
<tr>
<td>A1</td>
<td>0 &lt; A1 ≤ 13,8 kVA</td>
</tr>
<tr>
<td>A2</td>
<td>13,8 kVA &lt; A2 &lt; 100 kVA</td>
</tr>
<tr>
<td>A3</td>
<td>100 kVA ≤ A3 &lt; 1 MVA</td>
</tr>
<tr>
<td>B</td>
<td>1 MVA ≤ B &lt; 20 MVA</td>
</tr>
<tr>
<td>C</td>
<td>≥ 20 MVA</td>
</tr>
</tbody>
</table>

Table 1: RPP categories.
Overview of South African RPP code

South African renewable power plant code for generating plants connected to TS and DS networks came into effect on November 2012 [3]. The new code is one of the efforts of network service providers (NSP) whose role is to provide network services through the ownership and maintenance of an electricity network towards the integration of renewable technologies into the network. The requirements deemed relevant are voltage and frequency operating ranges and the corresponding trip times. For mitigating voltage suppression and power surges in the wake of transient faults, the active power and reactive power control requirements are also taken into account. The voltage and frequency operating ranges determine the limits within which the RPPs must not disconnect from the grid and have to sustain operation. The active and reactive power control requirements determine control capabilities under various fault and system situations.

Tolerance of frequency and voltage deviations

The RPP shall be able to withstand frequency and voltage deviations at the point of connection (POC) under normal and abnormal operating conditions described in this grid connection code while reducing the active power as little as possible [4].

Normal operating conditions

RPPs shall remain continuously connected to the TS or DS at maximum available active power output in normal system conditions. This range will be defined by the NSP for different elements in the grid. Also, the RPP shall have the capability to operate continuously at normal rated output at frequencies in range from 49 Hz to 51 Hz and to remain connected to the power system at frequencies within a bigger range (for example from 47 Hz to 52,0 Hz) for a certain duration as shown in Fig. 1 [5].

Abnormal operating conditions

RPPs shall remain connected to the grid for system voltage dips on any or all phases, where the system voltage, measured at the HV terminals of the grid connected transformer, remains above the heavy black line in Fig. 2. Fig. 2 shows that RPPs of category A3, B and C, shall remain transiently stable and connected to the system without tripping for a close-up solid three-phase short circuit fault or any unbalanced short circuit fault on the TS or DS with a total fault clearance time of up to 150 ms. Throughout the operating range of the RPP, these type of faults must not result in instability or isolation from the network.

Furthermore, Fig. 2 shows that the RPP shall be capable of continuous operation down to 90% of rated voltage at the POC. The code is to be fulfilled by all RPPs that are to be connected through high-voltage transmission level and the medium-voltage distribution level either directly or through a dedicated transformer. This scope also includes some RPP units, which are typically connected to the low-voltage level such as PV inverters if they are clustered to achieve larger power levels. In addition, all thermal and hydro units shall also comply with the design requirements specified in the SA Grid Code (specifically section 3.1. of the Network Code) [5].
In case of frequency deviations in the power system, category B and C specifically shall be designed to be capable to provide power-frequency response in order to stabilise the grid frequency as illustrated in Fig. 4 [5].

Except for the mandatory high frequency response (above 50.5 Hz), the provision of frequency response will be entered into a specific agreement with the system operator (SO). At a given frequency range provided by the SO the RPP must be able to change its controllable power output depending on the frequency at which the grid is operating at a given moment.

Reactive power capability

Reactive power requirements for interconnection are specified at the POC. This is an important consideration for wind and solar plants. First of all, it means that several technical options can be considered in the plant design to meet the grid interconnection requirements. Technically, a plant with inverter-based wind or solar generators could rely on the inverters to provide part or all the necessary reactive power range at the POC [3].

The code requires that the RPP of category A be designed to operate according to a power factor characteristic curve (between 0.95 lagging and 0.95 leading), which will be determined by the NSP or the SO. Category B and C shall be designed to supply rated power (MW) for power factors ranging between 0.975 lagging and 0.975 leading for category B; while category C shall operate between 0.95 lagging and 0.95 leading, available from 20% of rated power, measured at the POC. This is illustrated in Fig. 5. Also, when operating above 20% of rated power P (MW) the RPP of category B & C must have the capability of varying reactive power at the POC within the reactive capability ranges as defined by Fig. 6.

Below 20%, the reactive power capability of the RPP may decrease due to low wind or solar resource, which may result in some generators in the plant to be disconnected from the grid. For active power levels below 5% of rated MW output (point C in Fig. 5), there is no reactive power capability requirement. In this range, it is required that the RPP operates within the tolerance range specified by point A and point B in Fig. 5.

In addition, RPP of category B & C must be designed with the capability to operate in a voltage, power factor or reactive power control modes. The actual operating mode (V, power factor or Q control) as well as the operating point shall be agreed with the NSP [5].

of rated voltage at the POC. Furthermore, RPPs have to provide a mandatory voltage support during voltage dips. The required reactive current in terms of dynamic voltage support is defined as shown in Fig. 3.

Frequency response

All the generating equipment in an electric system is designed to operate within very strict frequency margins. Grid codes specify that all generating plants should be able to operate continuously between a frequency range around the nominal frequency of the grid and to operate for different periods of time when lower/higher frequencies down/up to a minimum/maximum limit. Operation outside these limits would damage the generating plants. The loss of generation leads to further frequency deviation and a black-out may occur [6].

Fig. 4: Frequency response requirement for RPPs of category B and C.

Fig. 5: Reactive power requirements for RPPs of category B & C.

Fig. 6: Requirements for voltage control range for RPPs of category B & C.
Power quality

Power quality and voltage regulation impact shall be monitored at the POC. Impact assessment shall include amongst the disturbances at the POC:

- Voltage fluctuations
- High-frequency currents and voltages
- Unbalanced currents and voltages

Voltage and current quality distortion levels emitted by the RPP at the POC shall not exceed the apportioned limits as determined by the relevant NSP. Maximum allowable voltage change at the POC after a switching operation by the RPP (e.g. of a compensation device) shall not be greater than 2% [5].

Active power constraint functions

In order to cope with different scenarios in the grid and for system security reasons, additional power control strategies may be necessary. Depending on the local state of the grid, the RPP shall be equipped with constraint functions, i.e. supplementary active power control functions. The constraint functions are used to avoid imbalances in the power system or overloading of the TS and DS in connection with the reconfiguration of the TS and DS in critical or unstable situations, as illustrated in Fig. 6 [5].

The required constraint functions are as follows:

- Absolute production constraint
- Delta production constraint
- Power gradient constraint

Conclusions

Intermittence nature of renewables brings about a different challenge to the power system, hence NERSA has introduced new grid code requirements to minimise these risks. In this paper, a couple of the minimum technical requirements were presented for the connection of RPP to the power systems, at the transmission and distribution level. The objective of these requirements is to provide RPPs with the control and regulation capabilities encountered in conventional power plants that are necessary for the safe, reliable and economic operation of the power system.

The major concerns in connection of RPPs at the distribution level are related to protection, voltage control and power quality. The reserve requirements, reactive power and the grid support during the fault ride through are among the major issues to be considered in grid integration of RPPs at HV level.

References


[5] Grid connection code for renewable powerplants (rpps) connected to the electricity transmission system (TS) or the distribution system (ds) in South Africa, Version 2.6, November 2012.


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