Impact of embedded generation on distribution networks

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The growing need for competition in utility and energy markets, and policy supporting the inclusion of embedded generation in the future generation mix in South Africa implies that the number of generators connected to the sub-transmission and distribution networks will increase significantly.

Embedded generators introduce a new paradigm in the electric power industry and change some of the assumptions on which networks have been designed and operated, particularly with respect to voltage control and protection. What are the impacts of embedded generation on the distribution networks? How can they be counteracted?

Recent embedded generators initiatives in South Africa

Drivers to increase the renewable energy component of electricity utilised in South Africa include sustainability, climate change, future fossil price volatility, and risk-aversion. South African utilities (Eskom and the municipal distributors) are receiving an increasing number of requests to allow the connection of various types of embedded generators, including renewable generation, to the grid. As detailed in the South African Distribution Network Code (application for connection), the utility is obliged to provide an offer to connect the embedded generator to the network [1].

In March 2009, NERSA released the renewable feed-in tariff (REFIT), the culmination of a study initiated in 2007 by NERSA to facilitate the introduction of renewable energy generation into the electricity network. This was aimed at meeting the target of 10 000 GWh from renewable energy sources by 2013, as set in the 2004 government white paper on renewable energy. The REFIT will be reviewed every year for the first five-year period of implementation, and then every three years thereafter. The REFIT will only apply to new projects and presently caters for landfill gas, small hydro schemes, wind, concentrating solar thermal, biomass and large scale photovoltaic generation technologies [2].

There has also been a focus on cogeneration via the pilot national cogeneration Project (PNCP) [3]. A cogenerator is a source of electrical power that is a co-product, by-product, waste product or residual product of an underlying industrial process. In addition, NERSA and Eskom introduced the medium term power purchase programme (MTPPP), a competitive bidding process to award power purchase agreements to establish embedded generation plants totaling a target of 3000 MW. Individual project sizes ranged from 5 to 1000 MW.

Technical considerations

Sub-transmission and distribution networks have historically not been designed to incorporate the integration of embedded generation. Planning, protection and operation have been based on unidirectional power flow from the high voltage grid to load centers at lower voltages.

The magnitude of generation that can be connected to the network is determined by many factors, including for example, the voltage level at the point of connection, distance from the source, size of the conductor, load demand on the network, interaction of other generation connected to the network and type and operating regime of the generation.

Impacts of generators on distribution networks

The connection of embedded generators to sub-transmission and distribution networks can pose technical challenges [4]. During all loading and generation patterns, voltage rise and voltage drop need to be kept within specific limits so that voltage variation at customer points of supply are within limits specified in the South African electricity quality of supply standards [5]. The reverse flow of power from embedded generators may cause voltage rise in networks which have been designed to mitigate the effects of voltage drop. Embedded generators may cause the loading levels of individual elements (transformers and lines) to increase, specifically in cases of maximum generation and minimum load. Thermal ratings could be exceeded.

Step voltage changes may be caused by inrush currents, which occur when transformers and/or induction generators are energized from the network. A sudden voltage reduction can be experienced when a generator is disconnected.

Connecting a generator to a network has the effect of increasing the fault levels in the network close to the point of embedded generator connection. This may result in the violation of equipment fault levels ratings.

Generator transient instability is not normally an issue with generators connected to the distribution system. However, generators connected to long lines subject to long protection clearance times could experience transient instability. Multiple generator installations could be particularly prone to instability.

The ability of local embedded generators to improve network performance may be dependent on the ability to island and supply customer loads in the event of network faults that would otherwise result in outages. Embedded generators are however not allowed to island with portions of the utility network and other customers.

Technical losses may increase or decrease due to changes in equipment loading. Connecting an embedded generator to a weak network and thereby forcing power flow through the weak network can increase losses. In many cases embedded generators will contribute positively to a reduction in network technical losses.

Embedded generation grid integration process

The generic process followed by utilities for the technical assessment of embedded generation connection to the distribution network is summarised in Fig. 1. The process starts with an application by the potential embedded generation developer for a grid connection. At this stage, the developer provides basic information about the proposed embedded generation plant such as the number of generating units, type and size (rating) of generator, fuel resource, physical location of the plant and single line diagram of the connecting equipment.

Preliminary system studies are performed to identify connection options, evaluate any technical constraints, and establish the most cost effective solution to integrate the generation whilst complying with utility and industry standards.
During the preliminary study, the steady-state thermal and voltage performance of various scenarios (such as maximum load and maximum generation, maximum load and minimum generation, minimum load and maximum generation, and minimum load and minimum generation) are assessed for the existing and future networks. Fault level studies are performed to identify if fault level ratings will be exceeded. Studies are performed for all of the network integration options identified by the planning engineer. Technically suitable alternatives are identified, scoped and costed. The results of the preliminary system study provide information on:

- The feasibility of connection.
- Proposed point of connection to the grid and the associated scope of work and cost.
- Identification of any technical issues that may require further consideration in the advanced system studies phase.

If the embedded generation developer proceeds with the connection then the design phase of the process commences. During this stage, advanced system studies are performed; which may typically include transient stability studies, harmonic and quality of supply studies and protection coordination studies. Advanced system studies require additional data that may not be available at the initial stages of a project. These advanced studies are unlikely to result in a change in preferred connection option, but are rather to assist with operating and protection settings.

Options to mitigate technical constraints

The solutions to address embedded generation connection constraints may be interdependent. For example, a voltage rise and fault level rating violation problem may be solved by a single solution such as network reconfiguration. The constraints should be assessed holistically to ensure that an optimum solution to all constraints can be identified. In instances where the siting of the embedded generation is flexible, the embedded generators could be physically located to minimise network impacts e.g. locating the generation close to existing substations of suitable capacity and fault level rating. Embedded generators could also be located to alleviate existing network constraints and reduce technical losses.

The selection of the appropriate technical solution to integrate an embedded generator follows the same fundamental principles associated with normal network expansion and strengthening. This selection process needs to take into consideration the existing and future needs of both the customers (e.g. load growth) and networks (e.g. equipment refurbishment) considering the lifetime cost implications of technical losses and the network performance implications associated with different levels of network redundancy. Examples of typical solutions to constraints follow.

If thermal ratings are exceeded, the following possible remedies will typically be considered:

- Re-templatting overhead line. The conductor is tensioned to attain the required templating temperature; which is the conductor temperature that results in the conductor being at the statutory clearance above ground.
- Installation of larger conductors i.e. reduce the line impedance.
- Construct another line/cable in addition to the existing line/cable(s).
- Upgrade or augment existing transformers.
- Connect the embedded generators at a higher voltage level.
- Reconfigure the network in order to change the power flow and thereby reduce loading on constrained elements.

The mitigation options to address excessive voltage rise typically include:

- Reactive power compensation achieved by altering the generator control mode (in the case of synchronous generators). This may result in the generator absorbing reactive power under specific operating conditions and thereby reduce the voltage rise in the network.
- Coordinated voltage control via optimised on-load tap changing voltage control settings on substation power transformers.
Constraining the generator(s) so that the real power output is kept below the level at which problems arise.

Traditional network upgrade options such as upgrading conductor sizes, constructing additional lines, upgrading to a higher voltage (e.g. 88 – 132 kV, 11 – 22 kV) and the installation of voltage regulators (only applicable to medium voltage).

The following options can be used to mitigate high network fault levels:

- Upgrade existing equipment. Replace inadequately rated equipment with equipment with a higher fault level rating.
- Create normally open points (network splitting). Change the network configuration such that the impedance (between the generation and equipment with inadequate fault level rating) is increased and the fault level reduced.
- Series reactors. Increase the impedance between the generation and equipment with inadequate fault level rating. Series reactors are usually used in conjunction with standard impedance transformers.
- High impedance transformers. High impedance transformers are used as an alternative to the combination of standard impedance transformers and series reactors.
- Fault limiters. Extremely fast acting fuses or super conductive switches can be used to interrupt fault current extremely quickly and thereby prevent equipment damage.
- Earthing of transformer and generator neutrals. Changing the earthing configuration and ground impedances of generators and transformers will affect the zero sequence impedance, and hence the single phase fault current.
- With y-wound transformer, extra impedance can be added into the zero sequence network by connecting the transformer neutral via a resistor to ground thereby reducing the single phase fault level.

Conclusion

Drivers in the electrical supply industry are expected to result in an increase in applications for embedded generation grid access. Embedded generation presents new challenges for distribution engineers. Additional technical studies are required and may pose a challenge to planners and designers that have traditionally not modelled generation. A future article will focus on Eskom Distribution challenges and the plans and progress to address these challenges.

References

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