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Grid Compliance for the Land based Power Generators

Abstract

With the increase of power penetration from distributed renewable resources, mainly wind and solar power, the total stored system energy as a form of rotating mass has been decreased in many power systems. In addition, the intermittent characteristics of the renewable energy resources also leads to high variation in power generation from the renewable power plant. These changes pose a threat on maintaining system stability and reliability. On the other hand, utility electric power systems were not designed to accommodate power generation at the distribution level. Consequently, the stability in the distribution grid might be affected if the penetration of the distributed resources is significant. Power generators driven by reciprocating internal combustion engine (RICE) are increasingly involved in power generation at grid level, especially in the distribution level (<35 kV). Gas engine generators (GEGs) are favourable in power grid in parallel operation to support peak demand, because of the low investment cost, fast response, shorter lead time and low emission of pollutions. Likewise, diesel engine which are normally operated as backup power or stand-alone systems, could be connected to the power system under the operating reserve contract with power grids.

Reciprocating-engine generators are used by utilities and distributed power generation sectors. Customizing these power generation systems to meet grid codes and connection standards in various countries is a challenge. A comprehensive knowledge on these codes and standards used in different countries is essential to customize the power systems solutions accordingly and ensure the proper operation in an equilibrium state following a disturbance. More importantly, generators should be able to ride through faults on the far side of the transformer in the grid which is normally cleared after some time. Different countries/regions have different grid code requirements on fault ride through (FRT) or low voltage ride-through (LVRT) by specifying parameters such as duration of fault and severity of fault. The assessment of fault ride through capability of land based power generation systems against these requirements helps identify possible non-compliances and develops suitable solutions. Therefore this work is to the fault ride through behaviour of engine generators at full power condition, partial power conditions and different power factor conditions including maximum lagging/leading power factor conditions, and to develop solutions for LVRT non-compliant cases.

The conducted main research works are briefly described as following.

1) Literature survey

   Study on the LVRT requirement has been carried out on 15 grid codes and distribution codes, international standards and connection rules. LVRT capability is required for generators connected in distribution level in countries such as Australia, Germany and Saudi Arabia, in which the power grids are generally small in size, low generation margins and/or higher level of penetration of renewable energy resources to the grid. But LVRT capability is not mandatory in some countries such China, India and Canada where the power grid is relatively large and/or integration of the renewable resources is low.

   In addition, Literature survey on has been conducted on published papers and patents. Many solutions are proposed for LVRT capability enhancement such as control strategies for rotor or stator side converters, energy storage systems, crowbar circuits, shunt and series braking resistors. Different control strategies for rotor side and stator side converter are presented by L. Yang, et al. However, these methods are not directly applicable to synchronous generating systems in which there is no converter connected in between the system and the grid. Energy storage systems are described by S. M. Muyeen, et al., but these solutions are not capable for LVRT capability enhancement when 100% voltage drop occurs at the point of common coupling (PCC). Braking resistors are used in power systems to consume the excess energy and limit the fault current in transient period for enhancing the system stability. Various configurations and control of braking resistors

have been proposed in literatures. Series dynamic braking resistors and crowbar resistor are described in the power electronic switches are in cascade during normal operation in these solutions, thus the lifetime and reliability of the switches might be reduced. Shunt connected braking resistors are presented in by A. H. M. A. Rahim, et al., but it will not work effectively in the case of large voltage drop at the connection point. Patent EP3032684 A1 describes a method for LVRT capability enhancement with switched-in braking resistors and a control of the engine ignition. This approach may not work properly for various fault conditions in the system. EP 2869426 A1 presented an approached with a dynamic braking resistor. A high rating of the power electronic switches is required to accommodate the high sub-transient fault current and higher cost and lower reliability may be resulted with this solution.

2) Proposed solution for LVRT capability enhancement for engine generators.

A topology utilising the switched-in dynamic braking resistors (SDBR) along with the implementation of an effective control strategy is proposed for the LVRT capability of engine generating unit in parallel operation with power grids.
In normal operation, the dynamic braking resistor is by-passed by a circuit breaker. Thus no loss and reliability issue are incurred for the LVRT system. When in fault is detected in the power grid and the voltage is below the predetermined voltage level, the dynamic braking resistors will be switched-in to absorb the excessive energy from the generator. The power consumption by the dynamic braking resistors is control such that the speed of the generator is maintained close to 1 pu for maintaining the synchronism with the power grid.

This topology can be configured two ways. One way is to connect the SDBR at the primary side of the unit transformer in series with the delta windings. The advantage of this configuration the voltage and current rating for the power electronic switches is reduced. Another way is to connect the SDBR with the neutral end of the star-connected windings at the secondary side of the unit transformer. The current rating of the power electronic switches is largely reduced compared with the delta winding connected SDBR due to high voltage at the secondary windings.

Simulations model has been developed for a 2.5MVA engine generating unit with the generic system parameters for the simulation studies. Simulation studies have been conducted to assess the LVRT capability of the engine generating unit with and with the proposed LVRT solution. The simulation results show that the proposed solution can enhance the LVRT capability of the generating unit to meet the LVRT capability requirement even in the most stringent grid code. A down-scaled LVRT test-bed of 10 kVA has been developed to verify the proposed solution. The test-bed has demonstrated successfully demonstrated the functionality and the performance of the proposed the solution.

3) Proposed solutions for rotor angle estimation and measurement for synchronous generators.

Based on the current version of the connecting requirements, no out-of-synchronism protection is required and normally it is not installed for distributed synchronous generators. In the event of grid fault, the disconnection of the generator is based on the timing setting on the relevant relay. However, out-of-synchronism be caused if the LVRT solution fails to operate or by reasons other than grid faults, e.g., small signal and frequency stability, etc. Thus a cost effective solution for out-of-synchronism detection is necessary for the distributed synchronous generators in the future power grid applications. An accurate rotor angle information can be used for the system stability analysis and system control and protection.

A holistic approach is proposed for rotor angle estimation in transient and steady-state of the operation for synchronous generators. In this approach, the steady-state angle is first estimated based on the generator parameters and the load current. And it is added to the integration of change of the rotor angle estimated based on the measured engine speed. In steady-state, the change of the rotor angle is almost zero. Thus, the rotor angle is same as the estimated steady-state angle.

When the speed deviation of the engine is out of the predetermined threshold, the estimated rotor angle will be temporarily held constant as the pre-value. The sum of the constant angle and the accumulated angle deviation will be rotor angle in transient state. The simulation model has been developed and the simulation result shows that the proposed the solution can estimate the rotor angle correctly. A verification system with a digital signal processor will be developed to verify the proposed solution.

The method using a signalling generator is also proposed for rotor angle measurement. The signalling generator is rigidly coupled with the shaft of the power generator. The signalling generator shall be aligned with the power generator so that the phase difference is zero between the voltage from the signalling generator and no-load voltage from the terminal of the power generator for the same phase. For steady state rotor angle determination, the signalling generator is be connected to a high resistive load. The current flow in the generator is negligible so that the terminal voltage angle of the signalling generator is same as the internal angle of the signalling generator. To compute the rotor angle in transient period, the voltages from the signalling generator and the point of common coupling are fed into a digital signal processor. The angle of the voltages are computed using the space vector method. The rotor angle is the difference between the voltage angle from the signalling generator and the voltage angle from the point of the common coupling.

List of Publications:

1. S.C. Yang, G.V. Shagar, A. Ukil, S.D. Gamini Jayasinghe, A.K. Gupta, "**Evaluation of Low Voltage Ride-Through capability of synchronous generator connected to a grid**", Power & Energy Society General Meeting, 2015 IEEE, Denver, USA, Jul. 2015.
2. S.C. Yang, A. Ukil, A.K. Gupta, "**Development of Low Voltage Ride-Through Capability Curve for Grid Connected Diesel Engine Generators**", 42nd Annual Conference of IEEE Industrial Electronics Society, Florence Italy. Oct 2016
3. S. Keerti, V. M. Balijepalli, S.C. Yang, A. Ukil, N. Karthikeyan, A.K. Gupta, "**Modeling Diesel Generators for Weak and Strong Grid Conditions: Emphasis on LVRT Compliance**", TENCON, 2016
4. V. M. Balijepalli, A. Ukil, N. Karthikeyan, A.K. Gupta, S.C. Yang, "**Virtual Synchronous Generators As Potential Solution for Electric Grid Compliance Studies**", TENCON, 2016
5. S. C. Yang, A. Ukil, S. Dasgupta, A. K. Gupta and VSK M. Balijepalli, "**LVRT Capability Enhancement for Grid Connected Distributed Synchronous Generators Using Switch-in Braking Resistors**", ACEPT 2017

List of Invention Submissions:

1. Shicong Yang, Souvik Dasgupta, Amit Kumar Gupta, Abhisek Ukil, Michael Kreissl, Johannes Demharter, "**LVRT Capability Enhancement for Synchronous Gensets using Dynamic Braking Resistors",** ISF17474 (Rolls-Royce Case number)
2. Shicong Yang, Souvik Dasgupta, Amit Kumar Gupta, Michael Kreissl, Johannes Demharter, **"Signalling generator of rotor angle measurement",** ISF17475 (Rolls-Royce Case number)
3. Shicong Yang, Souvik Dasgupta, Amit Kumar Gupta, Michael Kreissl, Johannes Demharter, **"Holistic rotor angle and load angle estimation for synchronous generators",** ISF17476 (Rolls-Royce Case number)