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A new technique for improving stability of distributed synchronous generators during temporary faults in a distribution network

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ABSTRACT

A system is developed for performing coordinated control of operation of distributed synchronous generators during transients caused by disturbances due to faults in the interconnecting network. For this purpose a braking resistor is used where excess electrical energy is dissipated, thus preventing over-speeding and loss of synchronism of the machine during transient processes caused by temporary faults and actions of the protection system together with the system for automatic reclose of the line. In addition to controlling the operation of the braking resistor, the proposed system performs a coordinated control of the excitation of the generator. The coordinated control of the braking resistor and excitation voltage of the generator provides a good fault ride through capacity of the machine even during faults when the generator stays in the island operating mode for some time. The functionality and practical applicability of the developed system have been tested by dynamic simulations carried out on a real model of a hydro-aggregate incorporating a synchronous machine and with real parameters of a distribution network. The simulations were performed by using program package DIgSILENT PowerFactory.

1. Introduction

Distributed sources, such as small hydro power plants and combustion engine power plants are mainly realised by using traditional synchronous generators directly connected to distribution network. By connecting such distributed sources to a medium voltage network, the issue of maintaining the stability of synchronous generators during faults in the network becomes very important. Reclosers are widely used in medium voltage distribution networks for the purpose of automatic reclose (AR), which enables the elimination of temporary faults. The application of the braking resistor for an intelligent Special Protection System in extra-high-voltage is presented in article [1]. Article [2] demonstrates damping of power swings by control of braking resistors. When the AR system operates, due to a temporary disconnection of the part of the network with a fault, island mode operation of a distributed generator may occur. This usually causes the generator to stop since the delivery of the produced energy is not possible, but also due to disturbances which may cause machine overspeed and the corresponding overvoltage at the generator output. Temporary faults which cause the operation of the AR system are relatively frequent, and therefore the number of generators out of service can be large, i.e. the energy delivered to the network can be significantly reduced. In order to eliminate these technical and economic consequences, a stabilisation of generator operation during disturbances should be provided. Coordination of fuzzy logic controlled braking resistor and optimal reclosing during unsuccessful reclosing is presented in article [3], while stability improvement of a large induction generator in the wind farm is presented in [4,5]. This article presents a simple and practical solution to the problem.

The integration of small power plants into a distribution network is a current problem from several points of view. The influence of distributed generators on voltage stability and voltage situation is analysed in the literature [6,7], together with the analysis of this influence on power losses in a network [8]. Voltage stability during the island mode operation of microgrids incorporating wind turbines is analysed in [9], the improvement of the transient performances during an island operation is analysed in [10] and the secondary regulation of frequency in AC microgrids is analysed in [11]. Article [12] presents stability analysis and control of microgrids with renewable energy sources by sliding mode control, while a coordinated primary frequency regulation support by distributed generators is analysed in [13]. A practical estimation of stability of distributed generators - synchronous machines is presented in [14]. As there are mutual interactions between distributed generators, the phenomenon of small signal stability which is of interest

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is analysed in [15]. Paper [16] presents the small signal model, while the transient stability is analysed in [17]. The prospective benefits of the installation of distributed generators can be used as criteria for selecting the positions of their building-in and the amount of installed power. In [18,19] the optimum position and size of distributed generators is analysed in order to minimise the active and reactive power losses in the network, while the optimum positions of the specified distributed generators for the purpose of minimising losses in the system are analysed in [20]. Determination of the optimum sizes and locations of the batteries for storing the electrical energy for the purpose of best exploitation of distribution networks is analysed in [21].

The problem of stability of small generators during a short island mode operation due to a fault has not been sufficiently analysed in the literature. The problem of loss of network is mainly related to a fast detection of island operation, thus several methods have been developed for this purpose. Some of them are generally known [22], while new techniques are being intensively investigated [23–30].

The most common causes of the loss of network are short circuits which cause the operation of relay protection with or without AR, usually performed in the HV/MV substation, or by use of reclosers in the MV network. When AR is not successful, the generator is left without network for a long time. In such cases the generator is stopped, until the conditions in the network are acceptable for resynchronisation. If the generator is part of an industrial facility, there is a possibility of introducing it into a mode of isolated work. In this case the stability of the generator is highly significant for the continuous supply of consumers. As most failures in the distribution network are temporary, it is necessary to provide fault ride through (FLR) capabilities of the generator during the transient process caused by temporary faults. The problem of maintaining stability in large power plants connected to the transmission system is usually a lighter problem because the transmission grids are embedded, so isolation of the fault location does not require separation of the power plant from the network. In this case, FLR capabilities of the generator are realised through an appropriate control of a converter, through which the generator is usually connected to the network. Small synchronous generators are usually directly connected to the radial distribution network and, in the event of faults, they must be separated from the network in order to provide a non-voltage break required for the correct operation of the AR. For this purpose, it is required that the generator can maintain the parameters, angular speed and voltage during the non-voltage break on connected distribution feeder, which will ensure a fast resynchronisation to the network in case of a successful AR.

This paper proposes an innovative technique for the coordinated control of generator excitation and braking resistor. The technique allows a short isolated operation of the generator until the relay protection clears a temporary fault in the connected network and provides conditions for the resynchronisation of the generator.

The main purpose of the braking resistor is to solve the problem in the transmission network [1–4], while the proposed solution meets the economic and technical criteria for maintaining the stability of the synchronous generator in the distribution network. In the distribution network, short circuit can be relatively frequent, especially in case of long distance overhead lines. In case of any fault and operation of the AR, the generator needs to be introduced into the stop and demagnetisation mode. This can lead to a significant loss of production and deterioration of the economic parameters of a small power plant. In addition, synchronous generator manufacturers define the maximum number of times the generator can be turned on during a certain period of time. In case of too frequent turn-ons/turn-offs, there may be a problem of meeting this requirement. Also, the loss of the network leads to transients that can cause dangerous operating conditions or increase the risk of damage. The proposed solution with the coordinated control of the excitation system and the braking resistor ensures a practically continuous operation of the generator in case of transient faults in the connected network and acceptable transients of speed and voltage. The braking resistor provides additional safety with regard to the prevention of hazardous operating conditions, and can be used for the emergency stop of the generator. In the case of longer network loss, the proposed concept allows a soft stop of the machine without activating special emergency hydraulic systems for stopping the flow through the turbine circuits. Finally, when moving to island operations, the proposed system provides better transient conditions with regard to the balance of generator production and consumption, and the introduction of the generator into the new regime. The proposed concept does not require expensive elements and can be upgraded from standard equipment in new or existing distributed power plants with synchronous generators.

Unlike the existing algorithms, suitable for large generators in the transmission network where the only body of control is the braking resistor, this paper proposes a new algorithm of coordinated control of the resistor and the driving voltage generator. The proposed algorithm provides a simple solution that can be applied in practice to maintain the stability of small power and its better resynchronisation to the distribution network after a transient disturbance in the terminal network.

2. Theoretical basis

The concept of coordinated control proposed in this paper, is illustrated in Fig. 1.

When a fault occurs in the distribution network, the corresponding recloser recognises the fault and starts the AR cycle, due to which a distributed generator together with a part of consumption stays in island operation. On the other hand, distributed generators connected to a medium voltage grid are required to possess protection against island operation which should disconnect the production unit from the network [22]. The distribution system operator requires the distributed generator to be separated from the distribution network in a very short period after the loss of network voltage at the PCC. These requirements are defined by national recommendations, as well as by the recommendations of international working groups [22]. Among popular reference standards for islanding are IEEE 1547 and VDE 0126-1-1 [31,32]. In Serbia, Grid Code for distribution system is required that a small power plant will be disconnected from the network in case of isolated operation [33]. Therefore, the distribution system operator requires that the generator must be equipped with a relay protection which will identify the loss of network voltage at the PCC and in the required time open the circuit breaker by which the generator is connected to the distribution network. Standard VDE 0126-1-1 requires that the protection must disconnect the generator from the distribution network for a maximum of 0.2 s [32]. The fast turn-off of the generator from the distribution network in the event of a fault in it is necessary in order to create the conditions for the successful operation of the AR in case of transient faults, because the generator supplies a failure point. Also, the isolated operation of the DGs may compromise security, restoration of service and the reliability of the equipment in the islanding part of the distribution network. In the literature, a lot of algorithms have been developed for a reliable and fast detection of network loss and separation of the generator from the network [24–30]. In such conditions, maintaining the stability of a synchronous generator is of particular importance in order to allow its fast reconnection to the distribution network in case of a successful AR. It should be noted that these regulations do not prohibit the transition to the isolated work of generators in the internal network, which is not within the competence of the distribution system operator. This means that the distribution system operator requires the opening of the CB2 switch in Fig. 1 in case of fault in the connected network, while the CB4 can remain closed, so that the generator can continue to supply local consumption.

The protection against island operation opens a circuit breaker (CB2 in Fig. 1) whereby the generator stays in island operation with the consumption which is connected to its terminal. These transients are