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Power Engineering Letters

Transient Stability Analysis of a Distribution Network With Distributed Generators

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***Abstract*—This letter describes the transient stability analysis of a 10-kV distribution network with wind generators, microturbines, and CHP plants. The network being modeled in Matlab/Simulink takes into account detailed dynamic models of the generators. Fault simulations at various locations are investigated. For the studied cases, the critical clearing times are calculated. Results obtained from several case studies are presented and discussed.**

***Index Terms*—Critical clearing time, distributed generation, distribution network, power system protection.**

I. INTRODUCTION

NOWADAYS, intensive efforts are made to utilize renewable energy sources (such as wind) as well as nonrenewable sources [such as high-efficiency small-scale Combined Heat and Power (CHP) schemes] to generate electric power. The generators are mostly integrated into utility networks at distribution voltage level and they are commonly referred to as "distributed generators" (DGs). Various investigations conducted by industry and academia have shown that DGs could affect negatively the host distribution network in a number of ways. This letter deals with transient stability analysis of distribution network with DGs. The novelty of this letter is in the analysis of the transient stability at the distribution network level, where transient stability problems were typically not an issue due to the passive character of distribution networks (DNs) of the past. However, nowadays, the situation is changing due to the introduction of DGs. In this letter, critical clearing times (CCTs) of DGs were determined for an existing Dutch 10-kV distribution network, where three-phase faults at different network locations have been analyzed. Such CCT is determined by the onset of a DG becoming unstable. Results obtained from several case studies are presented and evaluated. The general conclusion of this letter is that problems with transient stability of DG might occur at the distribution network level, and therefore, this issue has to be taken into account when new DG units are to be connected to the network. It is also concluded that DG undervoltage protection settings can be determined based on transient stability analysis, and this is an important issue as some types of DG units can remain connected and support the grid during and after a disturbance.

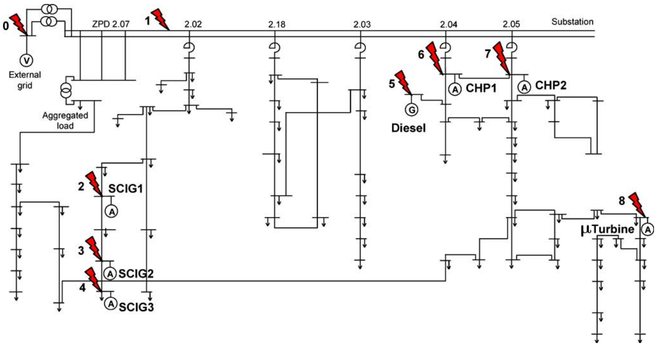

Fig. 1. Schematic diagram of the investigated network with distributed generators.

II. CONCEPT OF CRITICAL CLEARING TIME

In IEEE report [1], the critical clearing time is defined as "the maximum time between the fault initiation and its clearing such that the power system is transiently stable". For synchronous generators (SGs), there exists a maximum rotor angle (critical clearing angle) below which SG can retain a stable operation. The corresponding maximum clearing time is known as critical clearing time. However, the CCT for an induction generator is the maximum time of the fault to be cleared, within the time span that the induction generator is able to retain its stability. In this letter, we define the CCT as the smallest from all CCT values for different generators.

III. MODELING OF THE MV GRID USING MATLAB/SIMULINK

The one-line schematic diagram of the system analyzed in this investigation is shown in Fig. 1. Modeling and simulations have been performed by using Matlab/Simulink and SimPowerSystems toolbox. Fault current levels are also checked by the commercially available Vision network analysis software. Table I describes the type and the number of DGs.

Detailed information concerning the dynamic models of all DG units included in the grid model can be found in [2]. A detailed description of the wind turbine dynamic models is given in [3]. A squirrel cage induction generator (SCIG) wind turbine

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Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

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TABLE I
DG POWER RATINGS

DG Type	Snom [MVA]
SCIG 1	0.66
SCIG 2	0.66
SCIG 3	0.66
Diesel	3.125
CHP1	2.5
CHP2	2.5
μturbine	0.25

TABLE II
CRITICAL GENERATORS AND THEIR CCT

Fault Location	0	1	5	6	7	8
t_{cct} [ms]	363	373	1032	657	359	438
Critical generator	M	M	CHP_1	CHP_1	M	M

model has been utilized, which is available in Matlab/SimPowerSystems. The diesel generator model [4] is characterized by the electrical and mechanical equations of a synchronous machine. Excitation and governor circuits of the generator are modeled as well. The model parameters of the split shaft microturbine, and its detailed description can be found in [5]. Since the electromechanical behavior is of main interest for this study, the recuperator and the heat exchanger are not included in the model. The CHP model is an aggregated model consisting of ten microturbines. All generators are connected to the distribution network through transformers. The loads are represented by constant impedances. The external system, to which the DN is connected, is assumed to behave as an ideal voltage source.

IV. INVESTIGATED CASE

A. *CCT Calculation*

The system is subjected to various faults at different locations. Only the worst-case scenario, thus only three-phase faults, have been taken into account in the investigation, since they are the most severe disturbances leading to the smallest possible CCT, although their occurrence is less probable than unbalanced single phase or phase to phase faults. In order to determine the critical clearing times, simulations are performed for different fault durations. First the simulation is started with a long time duration of approximately 2 s. Then the time duration is halved and new simulations are performed until CCT is determined. In Table II, CCT and critical generators are presented for various fault locations as shown in Fig. 1. M stands for microturbine, and CHP_1 stands for CHP_1 plant. For fault locations 2, 3, and 4, it turns out that all generators are stable, even for a maximum fault duration of 2 s. As it can been seen from Table II, the critical system element is the microturbine, due to its low inertia (it has the smallest CCT), and the critical fault location is at the node where CHP2 is connected.

B. *Behavior of DGs During the Post-Fault Period*

Once the CCTs are determined, the behavior of the generators following the clearance of a fault is investigated. In this particular case, the microturbine, being the most critical generator in the network, is chosen. The dynamic behavior of the microturbine following a three-phase fault with duration of 373 ms and 374 ms at location 1 is examined.

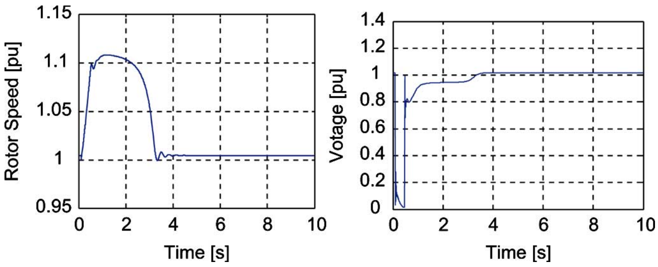

Fig. 2. Rotor speed and terminal voltage of m-turbine following a three-phase 373 ms (CCT) fault on the substation MV busbar.

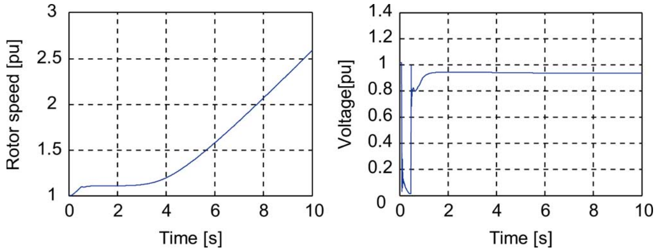

Fig. 3. Rotor speed and terminal voltage of m-turbine following a three-phase 374 ms duration fault on the substation MV busbar.

Figs. 2 and 3 illustrate the variation of the terminal voltage and the rotor speed of the microturbine for both cases. It can be concluded that microturbine cannot retain normal operation when the clearing time is greater than 373 ms. This also shows that when the fault is cleared for time spans larger than the CCT, the rotating speed of the induction generator continues to increase and a sustained voltage sag at the terminals of the generator is the result.

C. *Transient Stability Impact on DG Protection*

According to IEEE Std. 1547 [6], the DG clearing time should be based on the during-fault voltage range. The standard states that for voltage levels less than 0.5 p.u., recommended clearing time is 160 ms, while for voltage levels between 0.5 and 0.88 p.u., it is 2 s. However, the standard does not state directly any limits of the recommended clearing time with respect to transient stability of DG units. Therefore, while the standard makes no distinction between different types of DG units, in this letter, it is shown that each specific type of DG unit is influencing transient stability and, consequently, DG undervoltage protection settings at the interconnection point. Thus, keeping some types of DG units (for example, wind turbines) connected during a disturbance for a longer time (fault ride-through capability) might result in increased support to the grid, prevent unnecessary tripping of large amount of DG units, and prevent possible power deficit in the system after fault elimination. This is an important issue for highly densed networks with high penetration level of DGs, like the typical power systems of The Netherlands, where the penetration level of DG is reaching 25%–30%.

V. CONCLUSION: DISCUSSION OF RESULTS

Several studies have been carried out to determine the effect of the clearing time of a fault on the transient stability of DGs. The intention of this letter is to show that in principle, transient stability problems might occur in distribution networks with DGs. Therefore, transient stability analysis of such networks has to be performed, and, if necessary, the protection settings have to be adjusted accordingly to avoid these problems. It is also shown that for some types of DG units, these problems are more pronounced (split-shaft microturbines); for some other types, the effect is a bit less (diesel units based on synchronous generators) and for some are not an issue at all (wind turbines). The authors, additionally, propose that DG undervoltage protection settings should be different for different types of DG units, and that undervoltage settings can be determined based on transient stability analysis (also certain safety margin has to be introduced and coordination with network protection has to be performed). This conclusion points out much more optimal utilization of DG units fault ride-through capabilities, while at the same time, it guarantees their transient stability.

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