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Transient Stability Analysis of a Distribution Network With Distributed Generators
Ioanna Xyngi, Anton Ishchenko, Marjan Popov, Senior Member, IEEE, and Lou van der Sluis, Senior Member, IEEE

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.

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 SimPow-erSystems 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
model has been utilized, which is available in Matlab/SimPow-
erSystems. The diesel generator model [4] is characterized by
the electrical and mechanical equations of a synchronous ma-
nine. Excitation and governor circuits of the generator are mod-
eled as well. The model parameters of the split shaft microtur-
bine, 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 distribu-
tion 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 loca-
tions. 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 \( \mu \) stands for plant.

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>0</th>
<th>1</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_{\text{w}} ) [ms]</td>
<td>363</td>
<td>373</td>
<td>1032</td>
<td>657</td>
<td>359</td>
<td>438</td>
</tr>
</tbody>
</table>

Critical generator: M M CHP1 CHP2 M M

As it can be seen from Table II, the crit-
ical 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 partic-
ular case, the microturbine, being the most critical generator in
the network, is chosen. The dynamic behavior of the microtur-
bine following a three-phase fault with duration of 373 ms and
374 ms at location 1 is examined.

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 in-
crease and a sustained voltage sag at the terminals of the gener-
or 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 tran-
sient 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 tran-
sient 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 dis-
turbance for a longer time (fault ride-through capability) might
result in increased support to the grid, prevent unnecessary trip-
ing 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.

REFERENCES