Journal of Electrical and Electronics Engineering Research Vol. 2(5), pp. 107-113, November 2010
Available online at http://www.academicjournals.org/jeeer
ISSN – 2141 – 2367 ©2010 Academic Journals

Full Length Research Paper

Rotor angle stability analysis of a distributed generator connected to distribution network

T. Ananthapadmanabha[1]*, A. D. Kulkarni[1], ManojKumar Pujar[2], H. Pradeep[1] and S. Chetan[1]

[1]Department of Electrical and Electronics Engineering, National Institute of Engineering, Mysore, India.
[2]Gulbarga Electricity Supply Company (GESCOM), Bellary Division, India.

Accepted 19 August, 2010

This paper describes the rotor angle stability analysis of a distributed generators connected to a 10 kv distribution network consisting of wind generators, microturbines, and CHP plants. The distribution network being modeled in Matlab/Simulink/Sim Power-system 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 and the influence of the inertia on the CCT of DG's is analyzed. Results obtained from several case studies are presented and discussed.

Key words: Distributed resources, distribution system, dynamic modeling, critical clearing time, rotor angle stability, power system protection.

INTRODUCTION

Distributed power generation is any small-scale power generation technology that provides electric power at a site closer to customers sites to meet specific customer needs, to support economic operation of the existing power distribution grid, to meet an ever growing demand for electrical energy. Currently, intensive efforts are made to utilize renewable energy sources (such as wind) as well as nonrenewable sources (such as gas turbine, 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 have shown that DGs could affect negatively the host distribution network in a number of ways. This paper deals with rotor angle stability analysis of distributed generators. The novelty of this paper is in the analysis of rotor angle stability of DG's at distribution level, where stability problems were typically not an issue due to the passive nature of distribution networks (DNs) of the past.
However, nowadays, the situation is changing due to the introduction of DGs. In this paper, critical clearing times (CCTs) of DGs were determined for a 10-kV test distribution network with DG's, where three-phase faults at different network locations have been analyzed. Such CCT is determined by the onset of a DG becoming unstable, parameter influencing the CCT's is analyzed and relation between that parameter and CCT is determined. Results obtained from several case studies are presented and evaluated. The general conclusion of this paper 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 under voltage protection settings can be determined based on stability analysis, and this is an important issue as some types of DG units can remain connected (fault ride through) and support the grid during and after a disturbance.

Concept of critical clearing time and rotor angle stability

As in (IEEE report, 1982) the critical clearing time is defined as, "If a particular disturbance includes the initiation and isolation of a fault on a power system, the critical clearing time is the maximum time between the

*Corresponding author. E-mail: drapn2008@yahoo.co.in

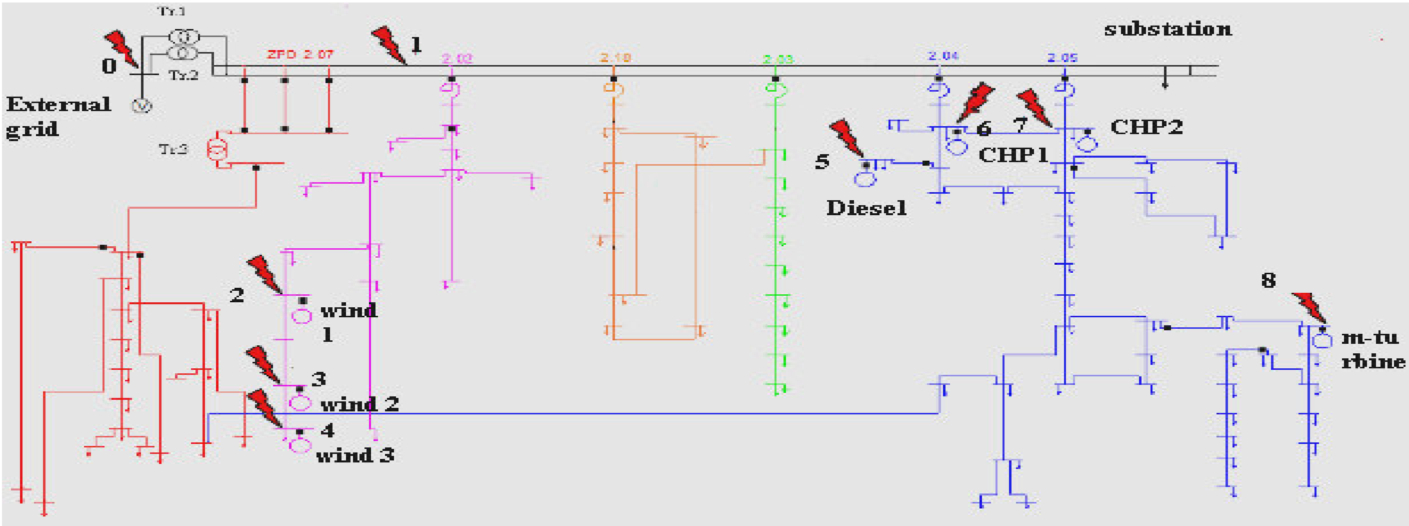

Figure 1.Schematic diagram of the investigated network with distributed generators.

Table 1. DG power ratings.

DG type	SCIG1	SCIG2	SCIG3	Diesel	CHP1	CHP2	µturbine
Rating [MVA]	0.66	0.66	0.66	3.125	2.5	2.5	0.25

initiation and the isolation such that the power system is transiently stable". In (IEEE report, 1982), Transient Stability of a Power System is defined as, "A power system is transiently stable for a particular steady-state operating condition and for a particular disturbance if, following that disturbance, it reaches an acceptable steady-state operating condition". The objective of the transient stability study is to ascertain whether the load angle returns to a steady value following the clearance of the disturbance. 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.

Dynamic modeling of the distributed generators and MV grid using matlab/simulink/sim power-system

The one-line schematic diagram of the 10 kv test system analyzed in this investigation is shown in Figure 1. Modeling and simulations have been performed by using Matlab/Simulink and Sim Power-systems toolbox. Table 1 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 (http://alexandria.tue.nl/).

A detailed description of the wind turbine dynamic models is given in (Wind Turbine Induction Generator, Matlab/ Simulink Help, Sim Power- Systems Blocks). A squirrel cage induction generator (SCIG) wind turbine model has been utilized, which is available in Matlab/Sim Power-systems. The diesel generator model (Yeager and Willis, 1993) is characterized by the electrical and mechanical equations of a synchronous machine. Excitation and governor circuits of the generator are modeled as well. Here the electromechanical behavior is of main interest for this study so time scale of interest is in the range from tens of milliseconds to several seconds. The gas turbine is a good representative of a microturbine. The gas-turbine generator is modeled as a synchronous generator (Tomonori et al., 2009)

The gas-turbine generator has automatic voltage regulator (AVR) and governor (GOV). The excitation and governor system can be generally described as the first-order lag system shown in Figures 2 and 3. In this paper, these excitation and governor systems are defined as the conventional control system.

The CHP[co-generation] 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

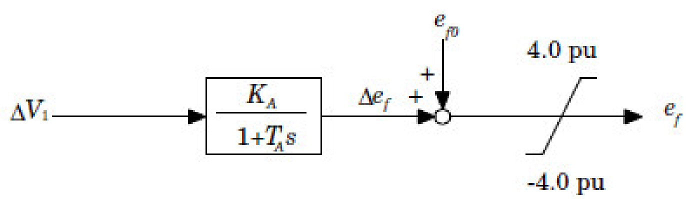

Figure 2. Automatic voltage regulator.

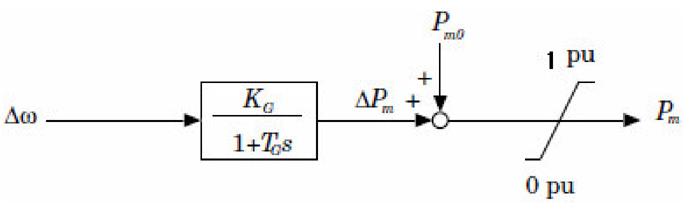

Figure 3. Governor.

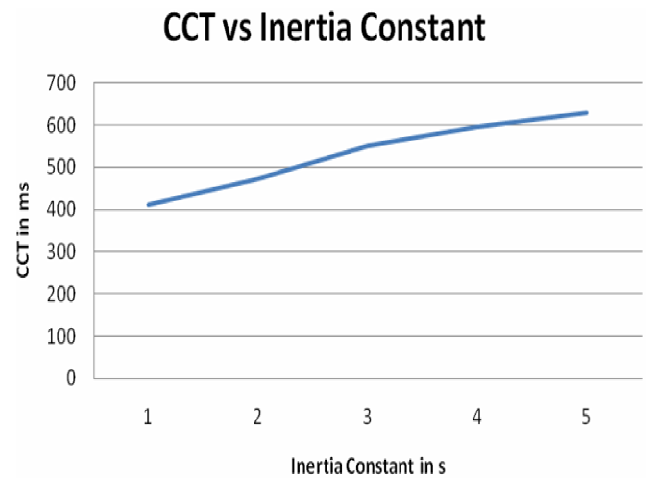

Figure 4. Relation between the inertia constant of a microturbines and CCT.

Table 2. Critical generators and their CCT.

Fault location	0	1	5	6	7	8
t_{cct} in ms	341	361	803	725	403	411
Critical generator	M	M	CHP1	CHP1	M	M

Table 3. CCT's vs. Inertia constant.

Inertia constant	1	2	3	4	5
t_{cct}(ms)	411	472	551	596	628

external system, to which the DN is connected, is assumed to behave as an ideal voltage source.

Investigated case

CCT computation

The study is conducted on a simulated system that consists of a distribution network (DN) with DGs using Sim Power-systems toolbox. Initially, iterative simulations are performed for various faults at different locations. For each fault location, fault duration is iteratively modified until the determination of CCTs. 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 long time duration of approximately 2 s. Then the time duration is halved and new simulations are made until CCT does not converge to a solution with the precision of 1 ms.

In Table 2, CCT and critical generators are presented for various fault locations as shown in Figure 1. M stands for microturbine, 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 be seen from Table 3, the critical system element is the microturbine, due to its low inertia [H(s)] (it has the smallest CCT), and the critical fault location is at the node where CHP2 is connected.

PARAMETER INFLUENCING CCT AND THEIR RELATION

The parameter influencing electromechanical frequency of oscillation is inertia constant of the generators. The microturbines used in this study have an inertia constant of 1 s, in case of microturbines with smaller inertia constants, the transient instability will most probably occur faster. To study the influence of the inertia on the CCT, the inertia constants of the microturbines in the test distribution network are varied, and the CCT values are determined (results are plotted in Figure 4). It is obvious that the relationship between the inertia constant and the CCT is found to be almost linear.

Behavior of DGs during fault conditions and during the post-fault period

Once the critical clearing times are determined, the behavior of the generators during a disturbance and following the clearance of a fault is investigated. In this particular case, the microturbine, being the most critical generator in the network, is selected. The dynamic behavior of the microturbine following a three-phase fault with duration of 411 and 412 ms at location #8 is examined Figures 5 and 6 illustrate the variation of the rotor speed of the microturbine for both cases.

Figures 7 and 8 illustrate the variation of the terminal voltage of the microturbine and Figures 9 and 10

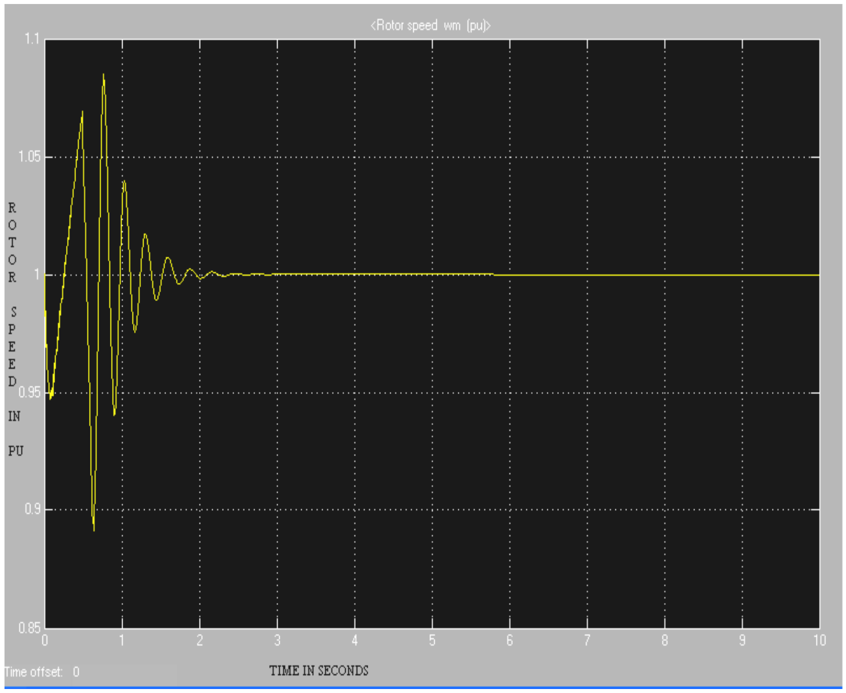

Figure 5. Rotor speed of m-turbine following a three-phase 411 ms (CCT) fault at location 8.

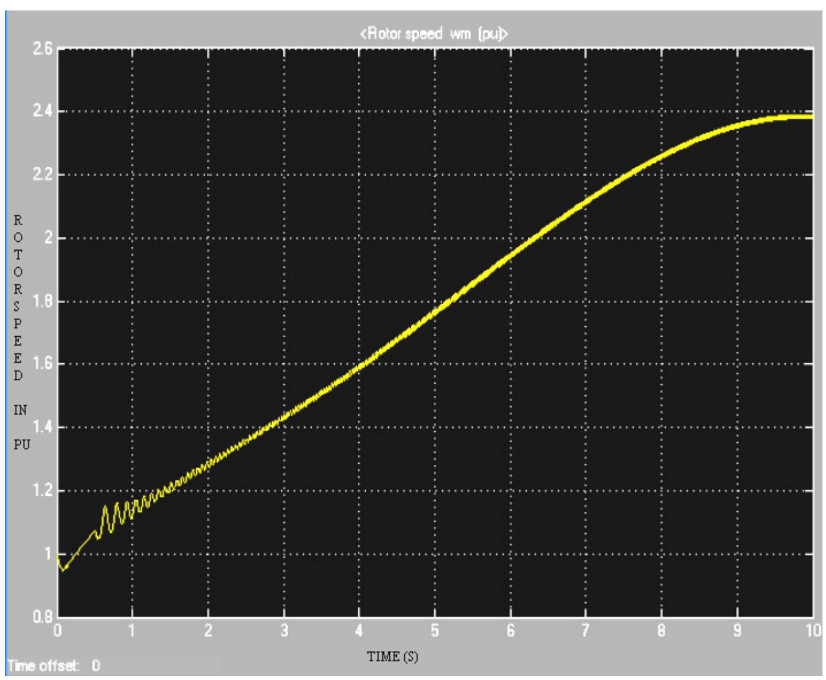

Figure 6. Rotor speed of m-turbine following a three-phase 412 ms (CCT) fault at location 8.

illustrate the variation of the real power of the microturbine It can be concluded that microturbine cannot retain normal operation when the clearing time is greater than 411 ms. This also shows that when the fault is cleared for time spans larger than the CCT, the rotating speed of the generator continues to increase and a sustained voltage sag at the terminals of the generator is the result.

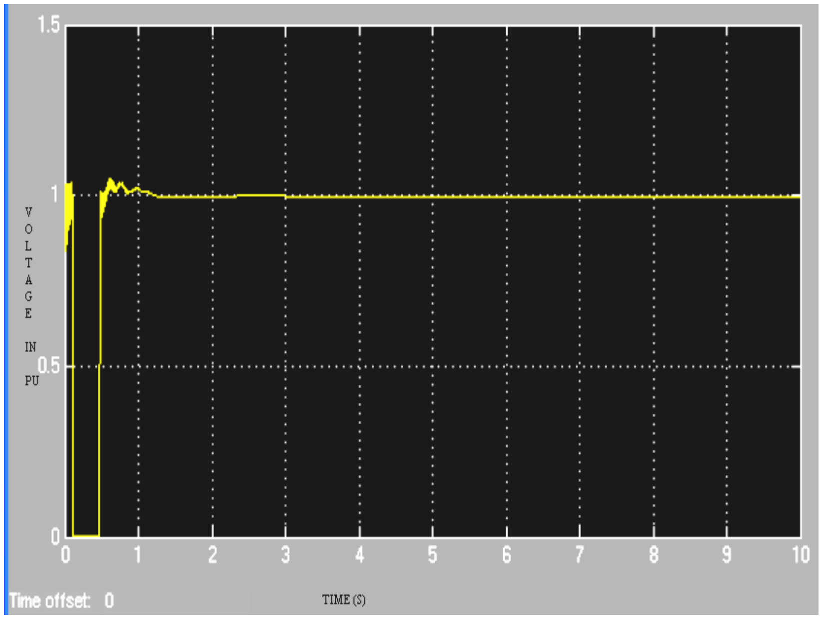

Figure 7. Terminal voltage of m-turbine following a three-phase 411 ms (CCT) fault at location 8.

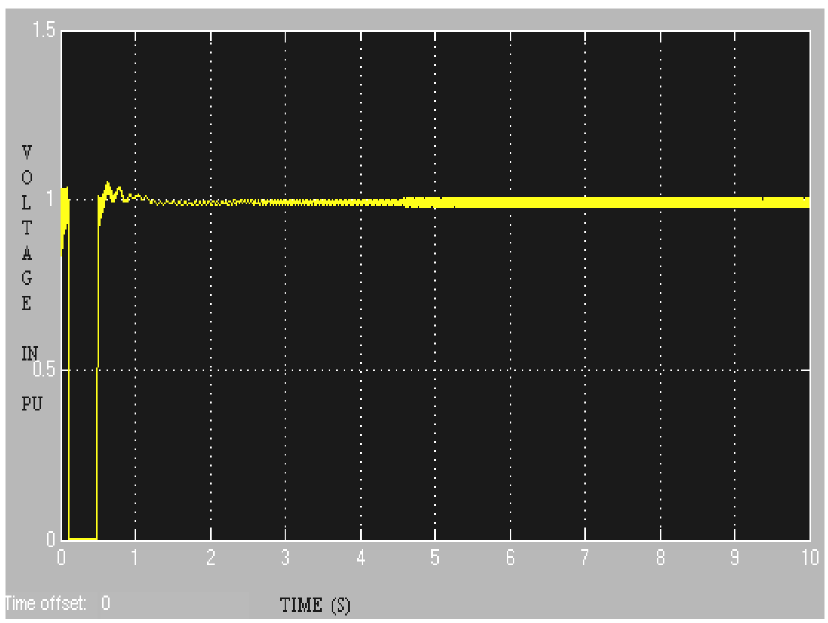

Figure 8. Terminal voltage of m-turbine following a three-phase 412 ms (CCT) fault at location 8.

Transient stability impact on DG protection

According to IEEE press (2003), 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 paper, it is shown that each specific type of DG unit is influencing rotor angle stability and, consequently, DG under voltage protection settings at the interconnection point. Thus, keeping some types of DG units (for example, wind turbines) connected during a disturbance

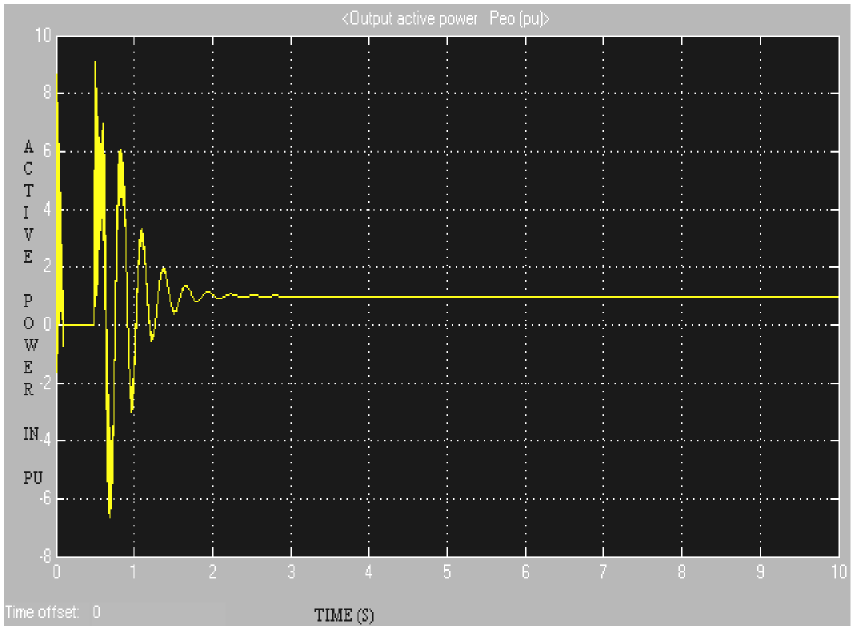

Figure 9. Active power output of m-turbine following a three-phase 411 ms (CCT) fault at location 8.

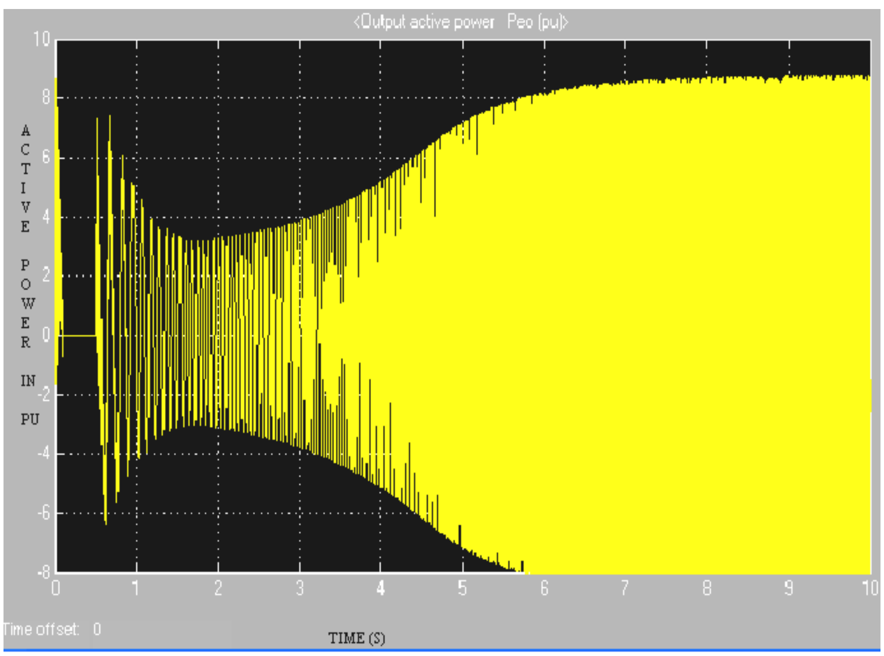

Figure 10. Active power output of m-turbine following a three-phase 412 ms (CCT) fault at location 8.

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 dense networks with high penetration level of DGs.

DISCUSSION AND CONCLUSION

The aim of this work is to analyze the influence of increasing penetration levels of DG on the stability of distribution network operation under normal and faulty (transient stability) situations. The following general conclusions can be drawn.

Several studies have been carried out to determine the effect of the clearing time of a fault on the stability of DGs. The intention of this paper is to show that in principle, stability problems might occur in distribution networks with DGs. Therefore, 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 [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], additionally, propose that DG under voltage protection settings should be different for different types of DG units, and that under voltage 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].Rotor angle stability of generators connected to the distribution network level might be a problem in case of a direct connection to the grid of electrical machines with low inertia, such as microturbines. The important point, that always has to be checked, is whether the protection of DG will prevent transient instability of the connected generator.

REFERENCES

IEEE Committee Report (1982). Proposed terms and definitions for power system stability," IEEE Trans. Power App. Syst., vol. PAS-101, pp. 1894–1898, A. Ischenko, "Dynamics and stability of distribution networks with dispersed generation," Ph.D. dissertation, Tech. Univ. Eindhoven, Eindhoven, The Netherlands [Online]. Available: http://alexandria.tue.nl/ extra2/200712108.pdf

IEEE Press (2003). IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems. New York:. Authorized.

Tomonori G, Eitaro O, Tomonobu S, Atsushi Y, Naomitsu U, Toshihisa F (2009) Suppression of Decentralized Generators Based on H_∞ Control Theory. International Conference on Power systems Transients (IPST2009) in Kyoto, Japan.

Wind Turbine Induction Generator, Matlab/ Simulink Help, Sim Power-Systems Blocks

Yeager E, Willis JR (1993). Modeling of emergency diesel generators in an 800 megawatt nuclear power plant, IEEE Trans. Energy Convers. 8(3): 433–441.