Impact of Transient Stability of Dispersed Generation on Relay Time Settings of Distribution Feeders

Metodija B. Atanasovski[1]

Abstract – **Increased presence of dispersed generation (DG) has significant technical impact on radial or weakly meshed distribution network on which it is connected. Distribution management system functions like power flow calculations, fault analysis, relay settings, state estimation, network reconfiguration, etc. are significantly affected by the DG. This paper reports an investigation to determine the impact of transient stability of small hydro DG unit on the relay time settings of distribution network feeders emanated from the substation to which DG is connected. Results from a case study are presented and discussed.**

Keywords – **DG, transient stability, critical clearing time, relay time setting, NEPLAN, distribution network.**

I. Introduction

Increased presence of DG has significant technical impact on radial or weakly meshed distribution network on which it is connected. Since the distribution network with DG is not passive, all issues about planning, construction, maintaining and operation of the distribution network become very interesting and need re-investigation. Actually, overall model of the distribution network should be renewed. Distribution management system functions like power flow calculations, fault analysis, relay setting, state estimation, network reconfiguration, etc. are significantly affected by the DG. It means that the distribution management system functions should be re-considered in order to respect the presence of DG in the distribution network [1,2].

From the perspective of the electrical interface that will be interconnected to the power system, there are generally two types of DG resources that can be connected [3]:

1. Electronically interfaced generators
2. Rotating machine interfaced generators

Electronic interfaces are inverter-based units and rotating machine interfaced DG are synchronous or induction generator based machines.

The main idea of this paper is to determine the impact of transient stability of DG on the relay time settings of distribution network feeders emanated from the substation to which DG is connected. Detailed investigation of this problem has already been done in [5], for two types of DG resources: CHP schemes with gas turbine synchronous generator and wind farms with induction generator. DG transient stability studies are similar to large scale power system transient stability studies, except that DG capacity is normally very small relative to the bulk system and has no significant influence on its frequency or stability. This paper is also focused (as [5]) on the investigation of the ability of rotating synchronous generator (SG) of small DG hydro unit to remain synchronized and determining its critical clearing time (CCT), when feeder disturbance occurred on the distribution network. For that purpose a case study with small hydro DG unit connected to distribution network is simulated using NEPLAN [4] power system software package, Results from a case study are presented and discussed.

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II. Critical Clearing Time of Synchronous Generator vs. Distribution Feeder Relay Time Setting

The concept of stability is well defined for the case of synchronous machines. During normal operating conditions a synchronous generator connected on a distribution network run at synchronous speed with a rotor angle δ_0 corresponding to an electrical output power P_e and mechanical input power P_m. When a fault occurs on the network, P_e suddenly reduces due to a sudden change in network voltage. This leads to the acceleration of SG to account for the difference between input/output powers, according to the well known swing equation [5,6]:

$$\frac{d^2\delta}{dt^2} = \frac{\omega_s}{2H}\left(P_m - P_e\right) \tag{1}$$

where

- ω_s angular frequency
- t time
- H inertia constant of the rotating mass.

When the fault is cleared at time t_c which corresponds to a rotor angle δ_c, the power demand by the network re-establishes and generator find itself generating power greater than P_e due to a new rotor angle. Assuming that the input mechanical power remains unchanged the extra power is supplied from the kinetic energy of the rotating mass. However due to the moment of inertia the rotor angle continues to increase , but because the input power is less than the output power the generator begins to decelerate passing its synchronous speed. The oscillation of the speed (and rotor angle) continues for a while, but eventually they settle to a new steady-state condition and the system is considered stable. Otherwise, δ continues to increase further and generator losses synchronism with the network and is considered unstable. There is a maximum rotor angle below which synchronous generator can retain a stable operation. This position is known as critical clearing angle. The corresponding maximum critical time is known as critical clearing time [6].

In distribution networks, for short circuit protection, overcurrent relays are usually used. Overcurrent protection has two setting dimensions: current and time. This settings are performed on the basis of two types of calculations [7]: 1)steady-state (power flow or state estimation is used) and 2) short circuit. In order to achieve one of the basic principles of protection design, removal of a fault with minimum tripping of equipment or disruption supply, proper coordination (time setting) of protective devices should be done. This however may lead the operation time of protective devices near the substation HV/MV of a distribution network, to be as high as 1-1,5 seconds.

When DG is connected into a distribution network on the substation HV/MV, the operating time of protective devices installed on load feeders may exceed the critical clearing time required to maintain the stability of DG.

III. Modelling the Case Study Network with NEPLAN

The case study network considered in this paper is shown in Fig. 1. It consists of a distribution network with DG hydro u with 3,2 MVA synchronous generator. Synchronous generator with NEPLAN is simulated with fully detailed subtransient model using typical data for time and reactance constants for hydrogenerators [6]. The machine reactances and inertia are normally per unitized on the machines voltage and MVA base. With NEPLAN control circuits function blocks, prime mover (governor and turbine) is simulated, using nonlinear turbine model [6] assuming inelastic water column and also speed governor is modeled for account of gate position and rate limits. The hydraulic turbine governors have a very slow response from the viewpoint of transient stability, but their effects can be more significant in studies of small isolated systems. For simulation of excitation system simplified IEEE AC4A excitation system model is used [6]. Generator is integrated into the distribution network at 20 kV voltage level through 2x1,6 MVA 0,4/20 kV/kV step-up transformers and 20 kV distribution line 1. 110 kV grid is represented by infinite model with voltage source behind its Thevenin's equivalent impedance. The fault level of the 110 grid is assumed 5000 MVA. HV/MV substation is represented by three windings transformer 110/20/10 kV/kV/kV and 31,5/31,5/10,5 MVA/MVA/MVA. The load is connected to the substation through distribution line 2 and 20/0,4 kV/kV transformers. Load characteristic is represented with constant impedance model. Both lines 1 and 2 are simulated with π-equivalent circuit with impedance of $(0{,}413 + j0{,}36)\Omega/\boldsymbol{km}$. All transformers are modeled in a same way as in short circuit calculations.

IV. Simulation and Results

Simulation is performed for a three-phase fault on line 2 at location F (see Fig. 1.), which is on 20% of the length of line 2 from the substation HV/MV. Results for fault duration of 200 ms are shown on Fig. 2. The corresponding generator rotor angle position is shown on Fig. 2(a). This figure shows that rotor angle assumes a stable position following few oscillations after the removal of the fault. It can be seen from Fig 2(b) that generator terminal voltage magnitude has dropped to a value 30% of its nominal voltage, but after isolation of the fault the voltage retained its normal operation level. The corresponding variation of generator stator current is shown on Fig 2(c).

After several simulations for different durations of three-phase fault at location F, it was found that the critical clearing time of the SG is 340 ms. Fig. 3(a) and 3(b) show the variation of generator rotor angle and its terminal voltage, following a three-phase fault at location F with a duration of 350 ms. It can be seen from Fig. (3a) that the rotor angle continues to grow and the generator continues to accelerate until it loses its synchronism with the network.

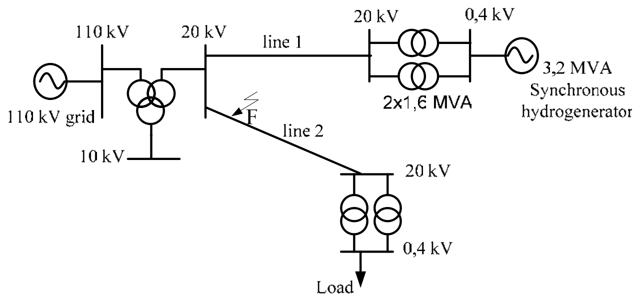
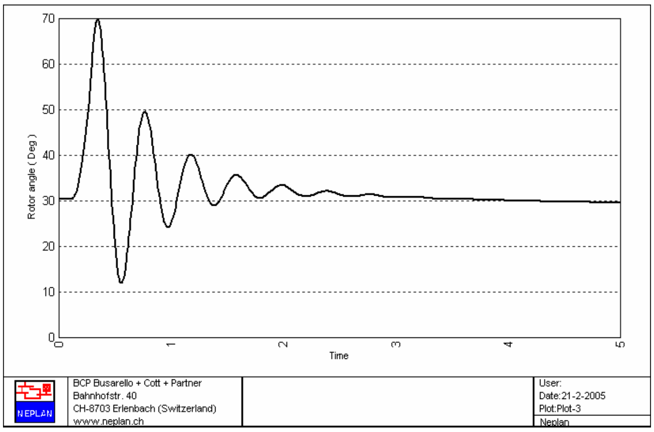
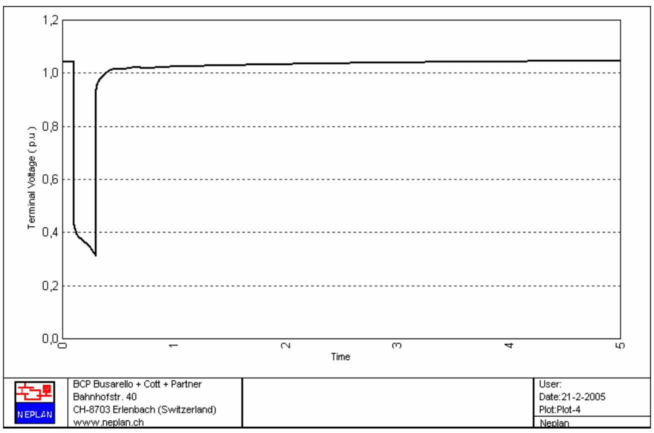


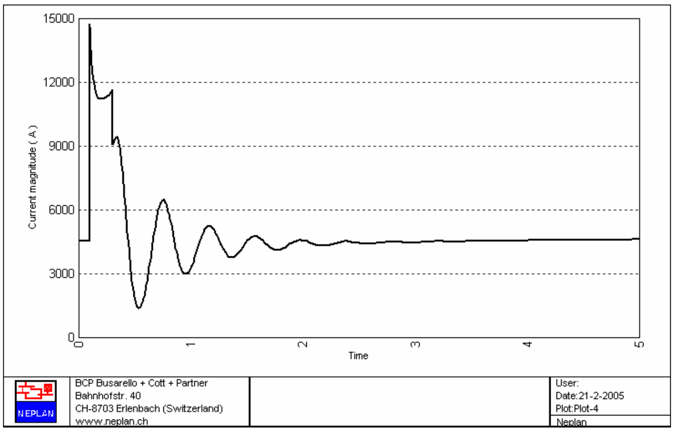
Fig.1. Schematic diagram of the case study network



(a)



(b)



(c)

Fig.2. (a) Variation of rotor angle of SG following a three-phase 200 ms duration fault on the network. (b) Variation terminal voltage of SG following a three-phase 200 ms duration fault on the network. (c) Variation of generator stator current following a three-phase 200 ms duration fault on the network.

V. Conclusion

NEPLAN software package, has been successfully used in this paper to simulate distribution system with small DG hydro unit with synchronous generator. The simulation is then used to investigate the impact of transient stability of DG hydro unit with synchronous generator on the relay time settings on the distribution network feeders. For the case study under consideration, it has been found that the maximum clearing time of a three-phase fault at the beginning of a load feeder is 340 ms. The results confirm the conclusions in [5] that immaterial of the type of the dispersed generator used and network under consideration, the maximum clearing time can be much lower than the expected operating time of protective relay usually applied for distribution feeders. It is, therefore, important that protection coordination should be carefully done when integration of DG into a distribution network is considered.

References

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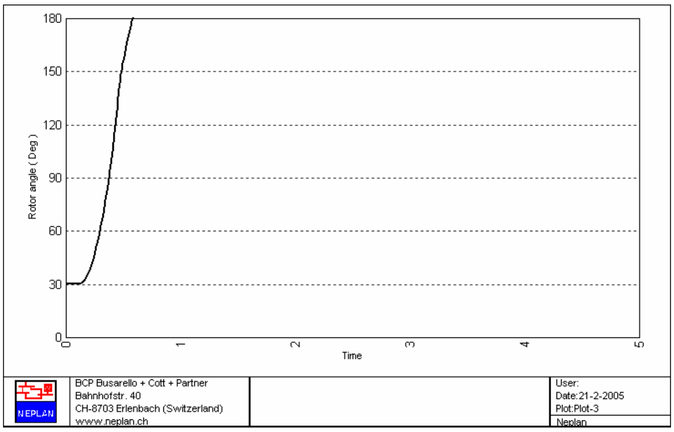
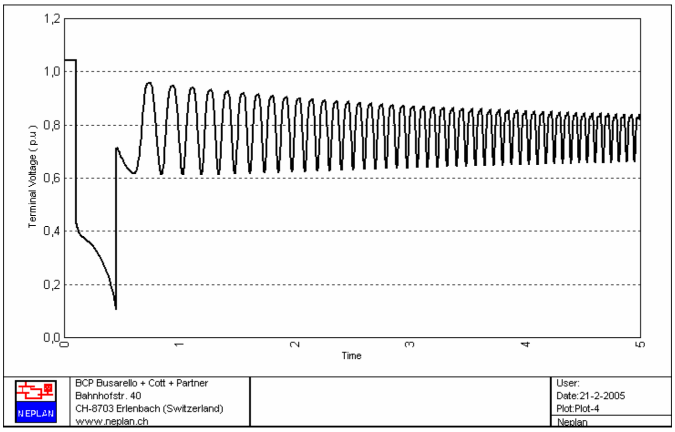


(a)



(b)

Fig. 3. (a) Variation of rotor angle of SG following a three-phase 350 ms duration fault on the network. (b) Variation terminal voltage of SG following a three-phase 350 ms duration fault on the network.

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