# Transient Stability of Asynchronous Generator on Distribution Network

Metodija Atanasovski[1], Mitko Kostov, Nikola Acevski, Blagoj Arapinoski, Elena Kotevska

*Abstract* – **Dispersed generation (DG) brings together wide range of technologies for electricity production. Most frequently used electric machines for electricity production at each technology that belongs to DG group are: synchronous generators, asynchronous generators (AG) and power converters. This paper deals with transient stability of AG. Typical model of distribution network (DN) is developed with AG connected to it. The modelling and simulation are performd with NEPLAN and MATLAB/SIMULINK/Simpowersystems toolbox software packages. AG with squirrel cage is used. Several short circuits are simulated in order to investigate dynamic behaviour of AG. Following parameters are analyzed: rotor speed, active and reactive power, and currents of AG. Critical clearing time is calculated for keeping stable operation of AG. Several useful and practical conclusions are obtained.**

*Keywords* – **Asynchronous generator, Transient stability, Distribution network.**

## I. INTRODUCTION

Last decade of past century bring remarkably revival of interest for connection generation units to DN. This phenomena in power systems is called dispersed generation. The term dispersed is introduced to make a difference with conventional centralized generation usually connected on transmission network. The story of DG is not a new one. Construction of small generating units is well known long ago from the beginning of power systems industry [1].

The installed capacity of DG is a key factor for obtaining voltage level for its connection to DN. Voltage levels for DG connection are the typical distribution voltage levels which vary from 400 V up to 110 kV [2].

DG category definition is not based on primary source used for electricity generation, but it is based on its technical performances from power system point of view. DG brings together wide range of technologies for electricity production. Most frequently used electric machines for electricity production at each technology that belongs to DG group are: synchronous generators, asynchronous generators (AG) and power converters (dc/ac or vice versa). AGs are mostly used at wind farms, small and medium size hydro power plants [2].

The problem of transient stability on DN becomes very interesting with increased presence of DG. Reasons about this can be summarized as: investigation of generators behaviour on DN and their impact on it, calculation of critical clearing time for remaining generator stable operation and impact of generators transient stability on networks protection.

This paper deals with transient stability of AG. Typical model of distribution network is developed with AG connected to it. The paper is consisted of four sections. Concept and model of AG for transient stability analysis is explained in section II. Also critical clearing time for stable operation is defined. The modelling and simulation are performed with NEPLAN and MATLAB /SIMULINK/ Simpowersystems toolbox software packages. AG with squirrel cage is used. Obtained results from performed simulations are depicted in section III. Three phase and two phase short circuits are simulated in order to investigate dynamic behaviour of this type of generators. Following parameters are analyzed: rotor speed, active and reactive power, and currents of AG. Critical clearing time is calculated for keeping stable operation of AG. Several useful and practical conclusions are obtained and elaborated in section IV.

## II. DISTRIBUTION NETWORK MODEL WITH ASYNCHRONOUS 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. The research is performed for DG that uses AG as electric machine. Practically the purpose is to investigate the ability of AG unit to remain synchronized and determining its critical clearing time, when feeder disturbance occurred on the DN.

The concept of critical clearing time in the case of synchronous generator is well known. Unlike synchronous generators, AGs do not have field windings to develop the required electro-magnetic field in the machine's air-gap. Therefore, AGs can not work with out external power supply. The electro-magnetic torque ($T_e$) developed inside an induction machine at any given speed is proportional to the square of the terminal voltage as follows [3]:

$$T_e = K \cdot s \cdot U^2 \tag{1}$$

Where $K$ is constant value depends on the parameters of the machine, $s$ is the machine slip.

Electro-magnetic torque is, therefore, bound to reduce following a fault condition, proportionally to square of voltage. On the other hand, the dynamic behavior of the rotor is governed by the swing equation given below:

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$$J\frac{dw}{dt}=T_m-T_e \tag{2}$$

Where: J is moment of inertia of the rotating mass, $T_m$ is the mechanical torque applied on rotor of the associated wind or hydro turbine, $w$ is rotor speed.

It can be concluded from (2) that assuming the mechanical torque is kept constant, then any reduction in the electro-magnetic torque, for instance due to fault condition, causes the rotor to accelerate. This in turn leads to an increase in the kinetic energy of the rotating mass. When the fault is cleared and consequently system voltage recovers, the magnetic field inside the air-gap of the machine starts to build up. This causes high inrush current to be drowned by the machine from the network which in turn causes a voltage drop across the interfacing link between the AG and the substation leading to a reduction in the voltage at the generator terminals. The resulting electro-magnetic torque acts on the rotor in a direction opposite to that of mechanical torque applied by turbine. If the energy stored in the newly established rotating magnetic field becomes higher than that stored in the rotating mass, rotor speed is forced to slow down and the generator eventually retains its normal operating condition following few oscillations, otherwise, its speed continues to increase until it is tripped by appropriate protection devices. When this is happening generator terminals usually experience sustained voltage dip. This investigation has shown that there is a maximum time for the fault to be cleared, otherwise AG losses its stability. Such time will thereafter be referred to as the critical clearing time for AG [4].

## III. SIMULATION AND RESULTS

Study case analyzed in this paper is shown on Fig. 1. It consists of DN with AG of 1 MVA rated power. The modelling and simulation are performed with NEPLAN [5] and MATLAB /SIMULINK/ Simpowersystems toolbox [6] software packages. AG with squirrel cage is used which is represented with fourth and sixth order model for transient stability. Mechanical moment (power) of prime mover (turbine) is considered constant to achieve greater generics of results. Part of the reactive power consumed by AG is supplied locally with model of capacitor.

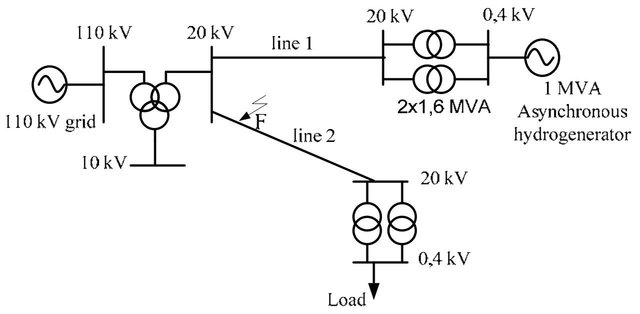
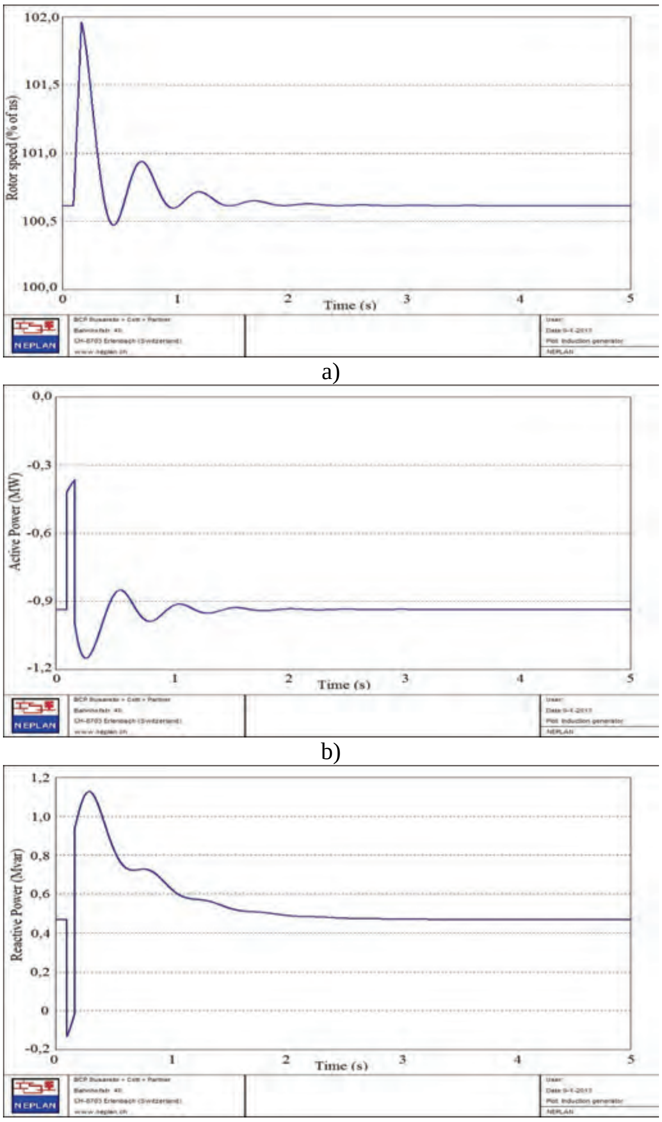


Fig.1. Schematic diagram of the case study DN with AG

Generator is integrated into the DN 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 network 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 $\pi$-equivalent circuit with impedance of $(0.413+j0.36)\Omega/km$. All transformers are modeled in a same way as in short circuit calculations.

Simulations are performed for three and two phase short circuits at location F (see Fig. 1), located on 20 % of line 2 length measured from substation HV/MV/MV. Results for three phase fault duration of 70 ms are shown on Fig. 2. The corresponding AG rotor speed is shown on Fig. 2(a), active power of AG on 2(b) and reactive power on 2(c).



a)

b)

c)

Fig. 2. Simulation of three phase fault at location F with duration of 70 ms; a) Rotor speed of AG in %, b) Active power of AG, c) Reactive power of AG.

Fig. 2a) shows that rotor speed retains stable position through few oscillations after fault clearance. Analyzing Fig. 2b) it is obvious that AG active power has dropped to 40 % of its nominal value during fault duration, but after short circuit is cleared active power retained its normal operational value. Fig. 2c) depicts reactive power variation of AG.

The different behavior of each generator can be explained by analyzing the response of the reactive power exchanged between the generator and the network for each situation. In the case of the induction generator, the reactive power exchanged takes into account the reactive power supplied by the capacitors. When fault occurs (Fig. 2c)) AG for a fault duration injects reactive power into the network due to self-excitation phenomenon, but, soon after fault clearance, AG consumes a large amount of reactive power, which can lead the system to a voltage collapse if it is not disconnected quickly with fast response of protection.

Due to this response of reactive power of AG, its small critical clearance time can be explained. Namely, after several repeated simulations by increasing fault duration time, critical clearance time of AG is calculated to be 100 ms. Fig. 3 shows rotor speed behaviour due to fault duration of 130 ms. It is obvious that AG is unstable and its rotor speed continuously increase until protective devices disconnect AG from the network.

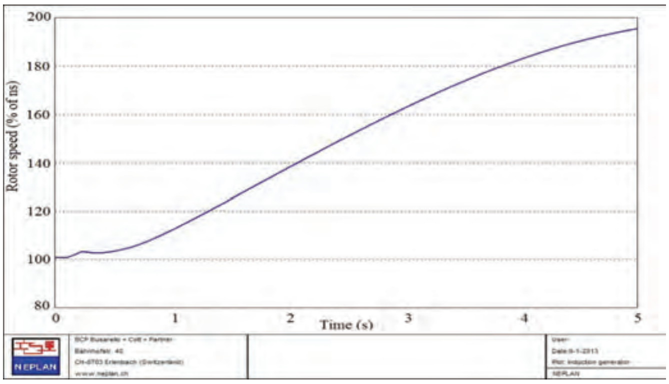


Fig. 3. AG rotor speed variation in % for simulation of three phase fault at location F with duration of 130 ms

The same DN from Fig. 1 is also modeled using program for analysis electromagnetic transients. MATLAB SIMULINK/Simpowersystems toolbox is used for investigating the response of AG phase currents to symmetrical and asymmetrical short circuits in DN. Three phase model of network elements is developed and simulations are performed in continuous time domain. Previous simulations in NEPLAN are done in phasor domain which is usually used for transient stability analysis.

For purposes of these simulations at location F three and two phase short circuits are applied. Fig. 4 and Fig. 5 show AG stator phase currents behavior for three and two phase short circuit appropriately. Analyzing stator phase currents of AG for three phase short circuit (Fig. 4) at location F occurred at t=50 ms, it can be seen that initially current magnitude is high but, it decrease quickly because this machine has no capacity to provide sustained short-circuit currents during three-phase faults. Voltages (phase or line to line) on AG terminals drop on 30 % of their nominal value. If short circuit occurs on AG terminals voltages drop to zero and the capacitor bank becomes unloaded. Consequently, there is no external excitation source for the generator, and it becomes unable to produce voltage. Theoretically, this fact could become the detection of faults by protection systems based on over-current relays more difficult. However, in this case, voltage-based relays could be used.

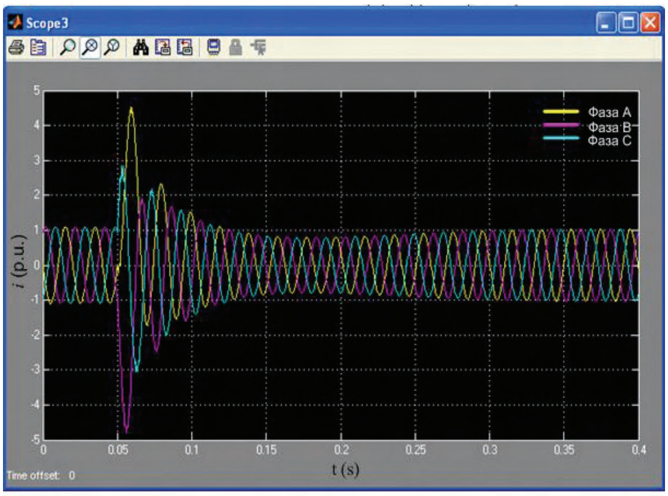


Fig. 4. Stator phase currents of AG for three phase short circuit at location F

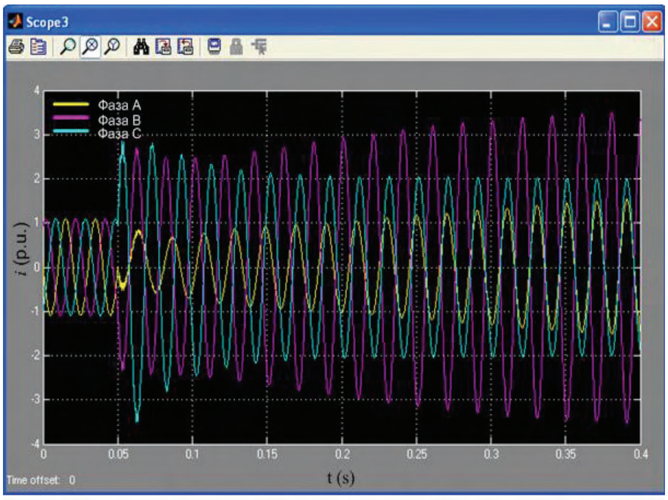


Fig. 5. Stator phase currents of AG for two phase short circuit at location F

Analyzing AG stator phase currents for two phase short circuit (Fig. 5) at location F occurred at t=50 ms, it can be concluded that AG current response demonstrates capacity for sustainable supply of short circuit current. All three phases remain excited by the network. Currents at faulted phases B and C present sustained response, although current at healthy phase A also shows sustainable increase of its amplitude.

## IV. CONCLUSION

Dynamic behaviour of AG connected on DN is investigated in the paper. It can be concluded that AG has very low critical clearing time to remain its stability during fault in the network. Reasons for this phenomenon are in reactive power response during fault occurrence and after its clearance.

Performed simulations have clearly shown that current response of AG is with high amplitudes of currents at all phases in the moment of three phase short circuit (symmetrical short circuit) occurrence. However, currents rapidly decrease because AG has no capacity to provide sustained supply of short-circuit currents during three-phase faults. This fact imposes conclusion that in networks which have reached circuit breakers breaking current limit, AG can be used in DG installations. For asymmetrical short circuits, current response of AG has capacity to provide sustained supply of short-circuit currents.

Comparison of AG dynamic behavior with synchronous generator is very important for determination of there advantages and disadvantages from DN stand point of view. This conclusion suggests further investigation about this matter. Synchronous generator can be applied on the same network model for obtaining its dynamic performance and critical clearing time for same fault conditions in DN.

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