59th International Scientific Conference on Information, Communication and Energy Systems and Technologies, Sozopol, Bulgaria, July 1 – 3, 2024

Comparison of Dynamic Behavior of Dispersed Generation Based on (A)Synchronous Generator and Inverter

Hristina Petreska[1], Pande Popovski[1], Goran Veljanovski[1], Metodija Atanasovski[1] and Blagoja Arapinoski[1]

Abstract – **Dispersed generation (DG) represents wide spectre of technologies for electricity production. Mostly used electrical machines for generation of electricity at each technology integrated in DG group are synchronous generator (SG), asynchronous generator (AG) and inverter based resource (IBR). This paper investigates the comparison of dynamic performance of these three types of electric machines of DG when fault conditions are present in the distribution network. For that purpose model of radial distribution 20 kV network is developed. Several simulations are performed in order to compare the response of active and reactive power and voltage of each mentioned machine due to fault riding through in the network. Results are presented, discussed and useful conclusions are derived.**

Keywords – **Dispersed generation, dynamic behaviour, inverter based resources, synchronous generator, asynchronous generator.**

I. Introduction

The dispersed generation category is not defined as a type of production that uses a certain type of primary source, but it is defined on the basis of its technical characteristics from the point of view of the power system. The most commonly used machines for the production of electricity in each of the technologies included in the dispersed generation group are: SGs, AGs and IBRs. The notion of transient stability of distribution network has become very relevant with the frequent occurrence of dispersed generation. Being a highly relevant topic, there has been extensive research on the impact of DG on the power grid. An analysis of the distributed generation (DG) impact on studies of voltage sags caused by system faults is presented in [1]. For each case study, different fault positions were simulated by considering different DG levels connected to the consumer bus bar. In [2], the effect of increasing penetration level of different types of DGs on power loss and voltage profile are analysed on IEEE 14-bus test system. The simulation is carried out using MATLAB software. A review of wind energy technology and its challenges is presented in [3], including the effects of wind farms on nearby communities, generation uncertainty, power quality issues, angular and voltage stability, reactive power support, and fault ride-through capability. [4] studies the impact of IBRs on a variety of protective relay schemes including line distance protection, memory-polarized zero sequence directional protective relay element, negative sequence quantities-based protection, line current differential protection, phase comparison protection, rate-of-change-of-frequency, and power swing detection. The objective in [4] is to provide an improved understanding of the way IBRs may negatively impact the performance of traditional protection schemes. In, [5], analysis on the interaction between grid-forming (GFM) IBRs with SG is performed.

This paper is conceived in five chapters. In the second chapter, the concept of critical disconnection time of SG, AG and IBR is explained. The third chapter shows the performed simulations and the obtained results. The objective is to determine the ability of generators and the IBR to remain synchronized on the network. The fourth chapter is a discussion about the obtained results, the fifth chapter presents the obtained useful and practical conclusions and in the sixth chapter is presented the used literature.

[1]H. Petreska, P. Popovski, G. Veljanovski, M. Atanasovski and B. Arapinoski are with University of St. Kliment Ohridski - Bitola, Faculty of Technical Sciences - Bitola, Makedonska falanga 37, 7000 Bitola, North Macedonia, E-mail: hristina.petreska@uklo.edu.mk.

II. Dispersed generation modelling for dynamic behaviour analysis

A. DG with synchronous generator

The concept of stability is well defined in the case of synchronous machines. During normal operating conditions, the SG which is connected to the distribution network works with synchronous speed with a rotor angle δ_0. When a fault in the network occurs, electrical power P_e suddenly decreases as a result of the unexpected change of the network voltage. This causes the SG to speed up as a result of the difference between input and output power, according to the well known equation for working of the SG [7, 8]:

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

where:

ω_s - angular frequency

t - time

H - inertion constant of rotary mass.

After eliminating the fault for time t_c, the load of the network is re-established and now the generator produces more electrical power than P_e. Assuming that the mechanical power of the generator remains unchanged, more power is provided by the kinetic energy of rotating masses. Oscillation of the speed of the generator and the angle of its rotor continues for short time, but finally their oscillations subside, they get new stacionary state and the system gets recognised as stable. If δ continues to rise, the generator starts to lose its synchronism with the network and it is recognised as unstable. This position of the rotor angle of the generator is called critical disconnection angle. The maximum critical time, which corresponds to the critical angle, is called critical clearance time [7].

B. DG with asynchronous generator

Dispersed generation transient stability studies are similar to studies for transient stability of large electric power systems, with the difference that the capacity of DG is very small in relation to the whole power systems and has no influence on the stability and the frequency of power systems. When an AG is connected to the network, the ability of AG to stay synchronized with the network should be determined and to determine its critical time when a fault occurs on a certain outlet of the distribution network. The electromagnetic moment (T_e) developed inside the machine is proportional to the square of the voltage U at the plugins of AG, where follows [8]:

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

where K is a constant, and s is the slip of the machine.
The electromagnetic moment, according to equation (2), in the case of a short circuit decreases significantly in proportion to the square of the voltage. The dynamic behavior of the rotor of AG is determined by the equation of motion:

$$J\,\frac{dw}{dt} = T_m - T_e \tag{3}$$

where: J is the moment of inertia of the rotating masses; T_m is the mechanical torque which is applied to the rotor by the turbine (wind or hydro turbine) and w is the speed of the rotor. The equation (3) shows that if we guess that the mechanical moment is constant, than every decrease of electromagnetic moment, for example because of the condition of short circuit, it will cause the rotor to increase its speed. When the short circuit is eliminated, the voltage is renewed and then the magnetic field in the air beam of the machine starts to form again. This causes the machine to draw a large current from the network, which then makes big drop of the voltage on the line which connects AG and the substation where it is connected and brings to lowering the voltage on the connectors of the AG. If the energy which is stored in the newly formed rotary magnetic field is larger than the energy stored in the rotary masses, the rotor is forced to decrease its speed and at the end the generator holds its normal work state after couple of oscillations. This research shows that exists maximal time in which the short circuit should be eliminated, in other hand the generator will lose its stability. That time is called critical clearence time for the AG [8].

C. DG with inverter

Because of the rise of sources that are renewable which are integrated into the power systems, the analysis for the short circuit should get in consideration the answer of the defect for those generators which are connected via electronically IBR device for power supply. The contribution for the short circuit of IBR mainly is determined by convertor control and limits related with the convertor. As a result the integration of IBR into the power system represented technical challenge for protection of the system and planning studies. The failure response of the IBR is determined by the control strategy of the invertor. Current from the output phase of the inverter is limited on a value that is designed to protect the powerful equipment of the inverter according to the thermal limits and varies depending on the manufacturer. Fault currents from the IBR usually consist of 2 components, the initial current before the detection of the fault and the component for stable operational work after the detection of the fault. Before the detection of the fault, the output current from IBR will increase to maintain the active and reactive power constant for lower voltage than the nominal. As a result, the injected current can get a value that vary in range from zero to maximum apparent current of the inverter. After the detection of the fault, current injection depends from the work mode of the fault, remaining voltage and power available from the supply. The inverter controls enable IBR to ride through faults and to secure reactive power to support the voltage at faults [11].

III. Study Case

The case studied in details in this paper is shown in Figure 1. It consists of a distribution network modeled in NEPLAN, with a small HPP with a 3 MVA SG, a WPP with a 3 MVA asynchronous generator and a 3 MW PV plant. Each of these plants are connected to the network successively. The SG is modeled with the fully detailed subtransient model using typical data for time constants and reactances for hydro generators. The reactances of the machine and its inertia are reduced to unit values according to the base voltage and power (MVA) of the machine. An AG with a cage rotor was used for which a model of the fourth and sixth order was used for the simulation of the transient stability. The mechanical moment (power) of the turbine is considered constant in order to achieve the best possible genericity of the results. The photovoltaic panels that are connected in parallel and series make a 3MW power and are connected through inveter to the 0.4kV side of the transformers.

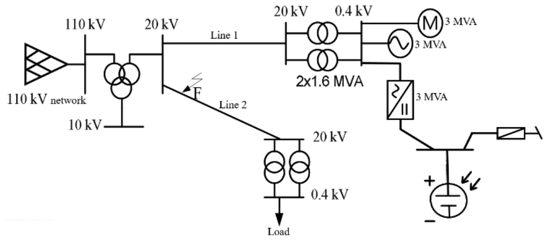


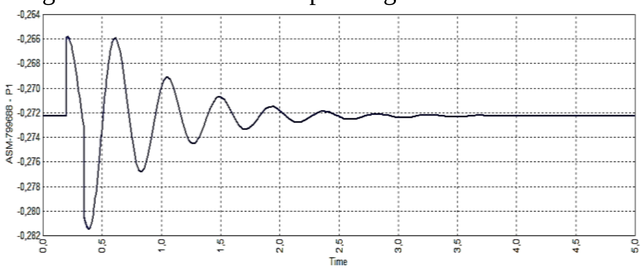
Fig. 1. Single line diagram of distribution network with AG, SG and inverter

The SG, the AG and the inverter are connected to the distribution network at 20kV voltage level through 2x1.6 MVA 0.4/20kV/kV transformers and 20kV distribution line 1. The 110 kV network is represented by a network equivalent which consists electromotive force and Thevenin equivalent impedance. High voltage substation is represented by a three-phase power transformer 110/20/10 kV/kV/kV and 31.5/31.5/31.5 MVA/MVA/MVA. The load is connected to high voltage substation through distribution line 2 and 20/0.4 kV/kV transformers. The load is represented by the constant impedance model. All transformers are modeled in the same way as in the calculation of short circuits.

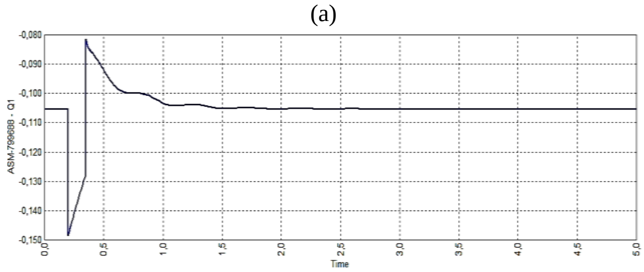
The simulation is performed for a three-phase short circuit on line 2 at location F (see Figure 1), which is located at 20% of the length of line 2, measured from high voltage substation. The results which are shown in Figure 2, 3 and 4 are results for the short circuit lasted 150 ms at location F.

Figure 2 shows the changes in the active and reactive power and voltage of the AG, for the duration of time of the three-phase short circuit of 150 ms.

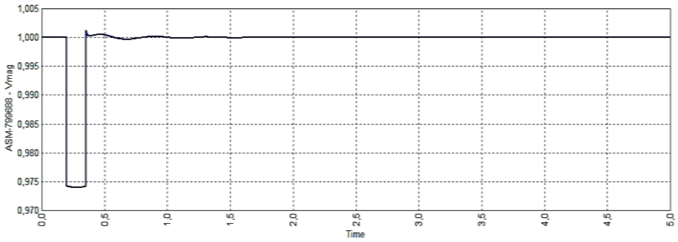
From Figure 2(a) can be seen that the active power of the AG drops to a certain value in relation to the rated power, but after the fault is eliminated it returns to its normal operating value. Figure 2(b) shows the change in reactive power of the AG. The stability of the AG can be explained by the response of its reactive power during the time of the fault and after its elimination. At the moment of the occurrence of the fault from Figure 2(b) it can be seen that the AG enters the so-called phenomenon of self-excitation and it starts injecting reactive power into the network. It lasts for a very short time and immediately after the fault is eliminated it draws a large reactive power from the network which is several times greater than the one it consumed in the normal mode before the fault occurred in the network. This phenomenon is the same as the start-up of AG and can cause a voltage collapse in the distribution network. The AG with fast protection should be disconnected from the network very quickly to avoid this negative phenomenon. From Figure 2(c) it can be observed that the voltage of the AG drops to a certain value in relation to its nominal voltage, but after the fault is eliminated the voltage returns to its normal operating value.



(a)



(b)

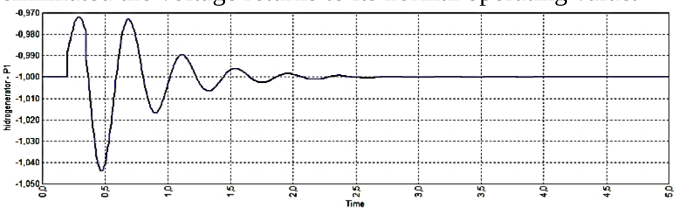


(c)

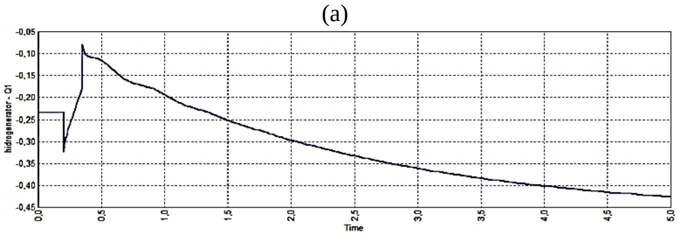
Fig. 2. Simulation for a three-phase short circuit at location F with a duration of 150ms; a) Change in the active power of AG; b) Change in reactive power of AG; c) Change in AG voltage

Figure 3 shows the changes in the active and reactive power and voltage of the AG during the time of the three-phase short circuit of 150 ms.

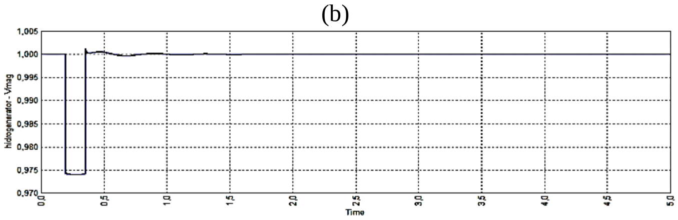
From Figure 3(a), it can be observed that the active power of the SG drops to a certain value in relation to the nominal power but after the fault is eliminated it returns to its normal operating value. From Figure 3(b) it can be observed that when a short circuit occurs there is a sudden reactive power rush while the generator works to secure the greater demand for reactive power to support the current from the fault. After the first peak there is fast drop because the system for excitation for the generator reacts to the fault, trying to retrieve the stability with lowering the output reactive power. The voltage change of the SG is shown in Figure 3(c). This figure shows that the generator voltage drops to a certain value related to its nominal voltage but after the fault is eliminated the voltage returns to its normal operating value.



(a)



(b)

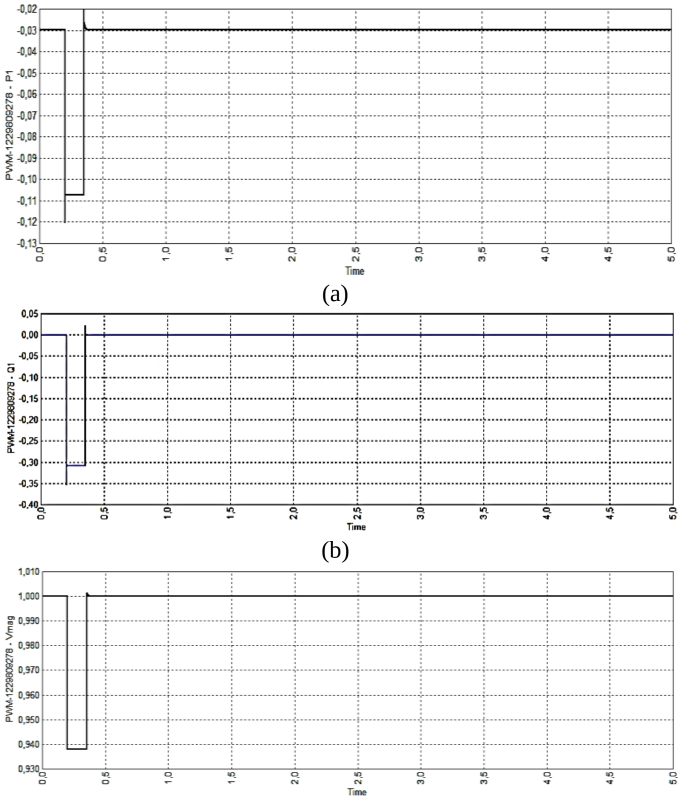


(c)

Fig. 3. Simulation for a three-phase short circuit at location F with a duration of 150ms; a) Change in the active power of SG; b) Change in reactive power of SG; c) Change in SG voltage

Figure 4 shows the changes in active and reactive power and IBR voltage during the time of the three-phase short circuit of 150 ms.

From Figure 4(a) can be seen that there is an unbalance of the PV active power and it drops to a certain value in relation to the nominal power but after the fault is eliminated it returns to its normal operating value. The same can be observed for the reactive power of PV Figure 4(b). The change in voltage of the synchronous generator is shown in Figure (c). This figure shows that the generator voltage drops to a certain value related to its nominal voltage but after the fault is eliminated the voltage returns to its normal operating value.



(a) (b) (c)

Fig. 4. Simulation for a three-phase short circuit at location F with a duration of 150 ms; a) Change in the active power of PV; b) Change in reactive power of PV; c) Change in PV voltage

IV. Discussion

In this paper the dynamic behavior of AG, SG and inverter connected to distribution network is investigated. First the AG was examined and from the analysis it can be seen that the AG have a very small critical time of disconnection of the fault in the network in order to remain stable. Then analyses were made for the shown example when a SG is connected and finally when an inverter is connected to compare and examine their dynamic behavior. The obtained results show that the maximum critical disconnection time is lower than the expected operating times of the protective relays normally applied to distribution outlets. That is why it is very important to carefully coordinate the protection when there is a DG integration in the distribution network.

V. Conclusion

NEPLAN software package has been successfully used in this paper in order to simulate a distribution network to which a SG, AG and IBR are connected and to investigate the comparison of dynamic performance of these three types of electric machines of DG when fault conditions are present in the distribution network.

References

[1] Ramos et al., " A First Approach on the Impact of Distributed Generation on Voltage Sags", 2014, International Conference on Renewable Energies and Power Quality (ICREPQ'14)

[2] D. Duppalla et al. "The Technical Impact of Increase in Penetration Level of DG Technologies on Power System", 2019 IEEE Region 10 Symposium (TENSYMP)

[3] Muhammad S. D. et al., "Large-scale wind power grid integration challenges and their solution: a detailed review", Environ Sci Pollut Res Int. 2023. doi: 10.1007/s11356-023-29653-9

[4] Aboutaleb H. et al., "Impact of Inverter Based Resources on System Protection", Energies 2021, https://doi.org/10.3390/en14041050

[5] R. W. Kenyon et al., "Interactive Power to Frequency Dynamics Between Grid-Forming Inverters and Synchronous Generators in Power Electronics-Dominated Power Systems", IEEE Systems Journal, 2023, https://doi.org/10.1109/JSYST.2023.3257284

[6] NEPLAN User's Guide V5, BCP Bussarelo+Cott +Partner, www.neplan.ch.

[7] P. Kundur. Power System Stability and Control, EPRI Power System Engineering Series, McGraw-Hill, Inc., 1993

[8] Salman K. Salman, Ibrahim M. Rida. "Investigating the Impact of Embedded Generation on Relay Settings of Utilities Electrical Feeders." IEEE Transactions on Power Delivery. Vol. 16, No. 2, April 2001.

[9] Rade M. Ciric, Antonio Padilha, Iara Fernanda Ehrenberg Dossi Denis, Luis F. Ochoa. "Integration of the Dispersed Generators in Distribution Management System." 2003 IEEE Bologna Power Tech Conference, June 23th-26th.

[10] Walmir Freitas, J. C. M. Vieira, A. Morelato, L. C. P. da Silva, V. F. da Costa, F. A. B. Lemos. "Comparative Analysis Between Synchronous and Induction Machines for Distributed Generation Applications". IEEE Transactions on Power Systems, Vol. 21, No.1, pp. 301−311. February 2006.

[11] "Simulation methods, models, and analysis techniques to represent the behavior of bulk power system connected inverter-based resources", IEEE Power & Energy Society, Technical Report PES-TR113, September 2023