A review of transient effects of different types of distributed generation units on overcurrent protection system

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ABSTRACT

Adding distributed generation (DG) units to the passive electricity networks causes several significant changes in their characteristics like power flow direction, voltage profile and short circuit level. Therefore the currently used control and protection strategies can no longer work properly and they have to be revised and modified. One of the most important issues is protection problem. For a reliable and efficient protection system, both transient and steady state effects of DGs on fault current should be considered. In this paper the exact model of three different types of DGs with different grid interfaces (PSMG with full size converter, DFIG with partial size, commonly met on Belgian grids, and directly connected IG) including power electronics and control systems, are presented. After that, the fault currents generated by different size and location of DGs are compared with those one which are produced by ideal model of DGs in the same condition. The PSCAD software is used for simulation of transient contribution of DG in fault current, in an assumed medium voltage grid.

INTRODUCTION

Increasing the integration of DG, especially renewable energy based, in the distribution network and close to the consumption, provides several advantages like lower CO_2 emission, but also some severe difficulties such as voltage and frequency instability, voltage distortion and protection problems.

Indeed, the added DGs to the grid could contribute to the fault current and increase the short circuit current in case of downstream fault. In addition to the fault current increase, DG reduces the grid fault current contribution and increases the risk of blinding of the related protection. Moreover, the presence of DG may change the direction of power flows and fault currents. Therefore, in the case of neighboring feeder faults, it can force the relay to make an inappropriate tripping command.

The intensity of these problems depends on the penetration level of DG and its location. Therefore finding a comprehensive solution for protection issues needs accurate studies, analysis and simulation.

Firstly, the effects of DGs should be identified. Lots of studies and researches have been done in this field and results are published in different papers [1-3]. In most of the publications, DG is modeled as a simple voltage source and its dynamics have not been considered ([4] and [5]). Using ideal model makes the simulation fast and simple but with a low accuracy in the results. Computations based on ideal source representations can, indeed, produce high short circuit current depending on the fault impedance while the short circuit power of DGs, especially renewable energy based, is limited and do not effectively contribute to fault current like an ideal source in the same conditions. Practically, the duration of fault current and its transient behavior depends on the type of generator, its interface to the grid and also depends on the control strategy which is used. The mentioned problems could be more tangible when power electronic is used as interface between DG and grid. The produced fault current is not greater than 2 or 2.5 times of converter rated current [2]. This issue will be investigated in more detail in the following sections.

EFFECT OF IDEAL MODEL OF DG ON OVER CURRENT PROTECTION

According to fig.1, for illustrating the effects of added DG on overcurrent protection, a test medium voltage network is considered and simulated in PSCAD. A 63kV sub transmission network is connected to the bus 1via a 100MVA 63kV/20kV transformer and through the breaker 1. Feeder 1 and feeder 2 are 3 and 6 km long respectively. In first

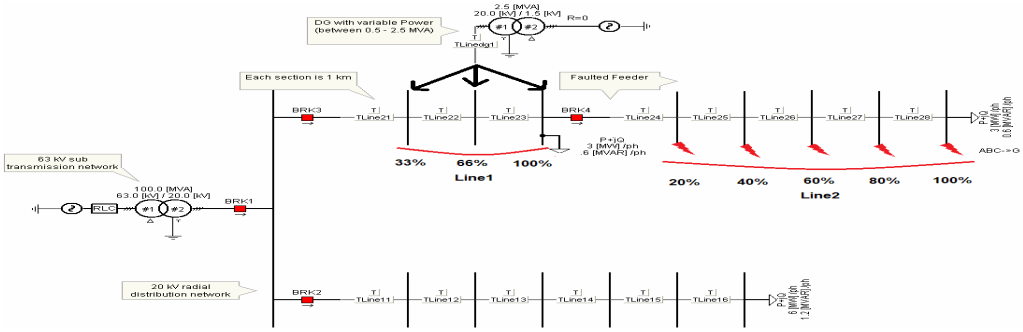

Fig.1) Test MV grid including DG

experiment a variable power AC source is added, as a DG, to feeder 1 as upstream feeder and faults are applied to the feeder 2 as downstream feeder. The power of DG is varied between 0.5 and 2.5 MVA and DG is connected to the 33, 66 and 100% of feeder 1 while the fault is applied to 20, 40, 60, 80 and 100% of the feeder 2 during different simulations. Time dependant overcurrent relay is used as protection system. The integrated DG at the end of the feeder 1 with different output power increases the fault current seen by relay 4 (fig.2 (b)) and decreases the grid contribution current seen by relay 3 (fig.2 (a)). Fault current Injected by DG with the power higher than 1 MVA causes that the total fault current seen by relay 3 does not reach to the pickup current margin. This problem could be seen obviously in fig.3 (b) where the upstream relay 3 does not send the tripping signal to the related breaker for a connected DG higher than 1 MVA. Fig.3 (a) shows that the injected fault current causes relay sense higher current. Therefore according to the time dependant curves, the overcurrent relay operates earlier in comparing with no-DG situation.

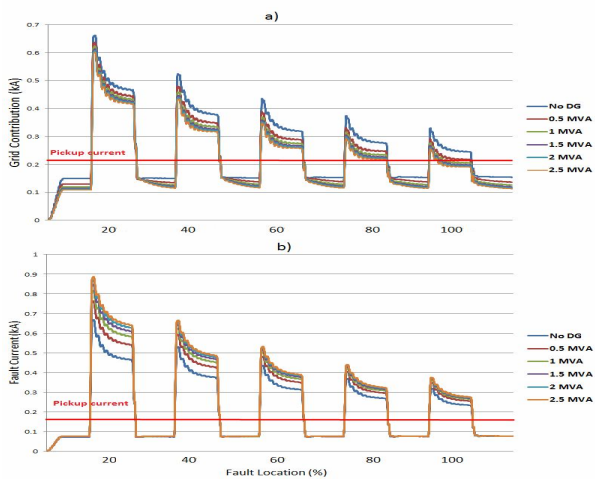

Fig.2) Fault current: a) seen by relay 4, b) seen by relay 3 (grid contribution) when DG is the end of upstream feeder 1.

Fig.4 shows current grid and fault contribution when a 2.5 MVA DG is located at different points (33, 66 and 100%) of the upstream feeder 1 and fault happens in downstream feeder 2. According to the fig.4 (a), grid contribution in fault current reaches its maximum value when DG is connected at the 33 or 100% upstream feeder and because of the equivalent impedance of DG and grid, it is reduced when DG is connected at the middle points of the feeder. Furthermore, as indicated in fig.4 (b), the total fault current seen by relay 4 is getting close to its normal value (before connection of DG) when DG is connected at the beginning points of upstream feeder (for example 33% of line 1). Therefore, according to the results, the beginning parts of upstream line could be the best place for DG installation taking into account the higher grid contribution and lower total fault current increment that could both lead to protection miscoordination. In the next experiment, the DG and fault are located in the same line, feeder 2. In this step, a three phase fault happens at the end of the feeder 2 and effect of DG on grid fault contribution is investigated.

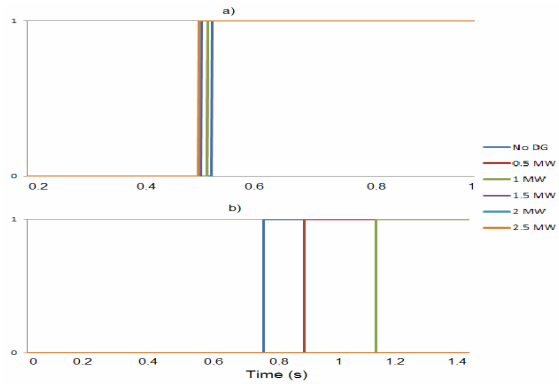

Fig.3) trip signals: a) relay 4, b) relay 3, when DG is at the end of upstream feeder 1 and fault is at the end of feeder 2

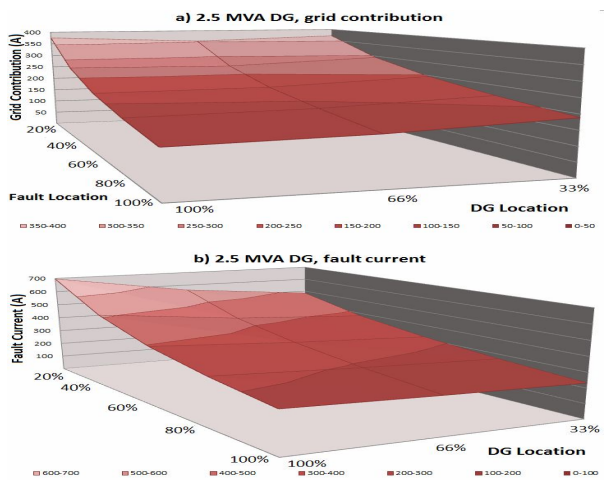

Fig.4) a) Grid contribution and b) fault current when DG is 2.5 MVA and located in different points of feeder 3

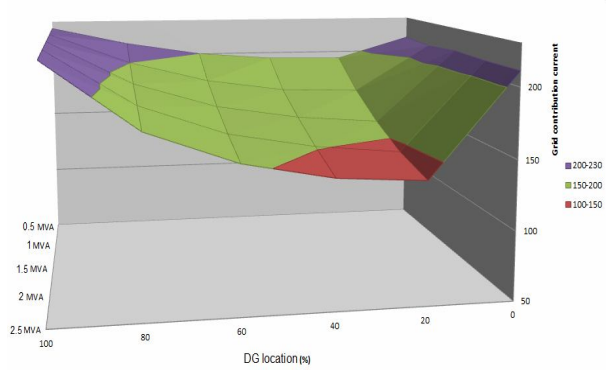

Fig.5) Grid contribution to fault current when DG is located in different point of feeder 2 and fault is at the end of feeder 2

The location of DG varies between 20% and 100% of the feeder 2 and its size is varied from 0.5 MVA to 2.5 MVA. As shown in fig.5, the fault current seen by relay 4 depends on both location and size of DG. In general, the higher size of DG causes lower fault contribution from main grid especially when they are connected at the middle parts of the feeder. The

red region which is indicated in fig.5 shows that DGs with higher output power reduce grid contribution below the relay pickup current which leads to blinding of the protection. Also note that the high power DG connected to the beginning or end of the feeder does not change the grid contribution significantly.

TRANSIENT MODEL OF DG AND ITS EFFECTS ON OVERCURRENT PROTECTION

As mentioned in the introduction, the ideal power source can feed the fault current significantly without special transient characteristic. However, DGs have practically some limitations in output power and current. Furthermore, the transient state of DG depends on the generator characteristics and their interface to the grid, and for these reasons, the behavior of DG could not be identical to an ideal voltage source. So, considering a generator as an ideal power source model is not appropriate for verifying the performance of the protection system when DG is integrated. In this section, different types of DGs are modeled and simulated during the fault condition with the same test MV grid.

DFIG with partial size converter

One of the most interesting topologies of wind generators is the Doubly Fed Induction Generator (DFIG) which is shown in fig.6.

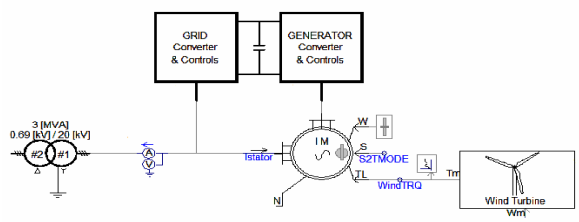

Fig.6) DFIG exact model in PSCAD

For evaluating the effects of different size of DFIG on fault current and overcurrent protection system, a transient model of wind generator with power electronic interface including control loops, is simulated in PSCAD (fig.6). As indicated in fig.7, a three phase short circuit fault is applied to the connection point between generator and grid. As can be seen during the fault, stator voltage drops to zero since the fault happens near the stator terminal. But the main point is stator current. As can be seen the current is no longer sinusoidal and during the fault DFIG injects unsymmetrical decreasing current that can make some problems for the overcurrent protection relays. For more details, fig. 8 illustrates the case during which a three phase fault happens in different points of feeder 2 while a DFIG with different output power is connected to the end of feeder 1. Since the DG is located at end of the line, grid contribution seen by relay 3 have not changed considerably but total fault current seen by relay 4, due to injected transient current, increases particularly at the beginning of the line. However this point should be mentioned that the effective DFIG contribution in fault current is limited to 2 or 3 cycles and reduces afterward rapidly to zero. Therefore the fault current supplied by DFIG may not be detected by relay when the penetration level of DG is low.

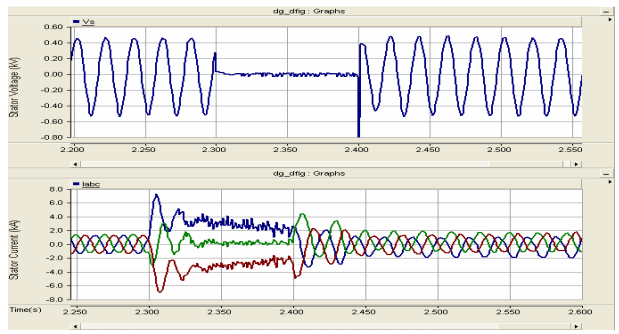

Fig. 7) Stator voltage and stator current of DFIG during fault at the stator terminal

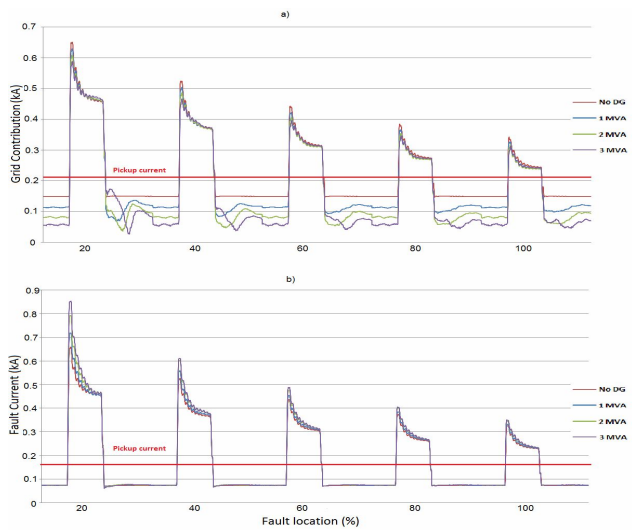

Fig. 8) Rms fault current: a) seen by relay 3, b) seen by relay 4 when fault happens in feeder 2 and DG is located at the end of feeder 1

PMSG with full size converter

Permanent magnet synchronous generator (PMSG) is another interesting topology of wind generators where a back to back converter is used as interface to the grid. The same simulations are done in order to evaluate the PSMG fault contribution characteristics. A wind generator with different output power is connected at the end of the feeder 1 and a three phase 200ms fault happens at different points of the feeder 2. Injected fault current and stator voltage are shown in fig. 9. As it could already be seen for the DFIG in fig.7, stator voltage also reduces to zero. On the opposite, the injected fault current shows a completely different behavior compared to the DFIG. The current is continuous and it does not reduce during fault and also remains symmetrical. However, due to the use of back to back converter as interface and semiconductors current limitations, the current magnitude is low and only reaches approximately 2 times of nominal current of converters. This problem can be seen in fig.10

where both grid contribution seen by relay 3 and total fault current seen by relay 4 do not change significantly even at a higher level of DG penetration.

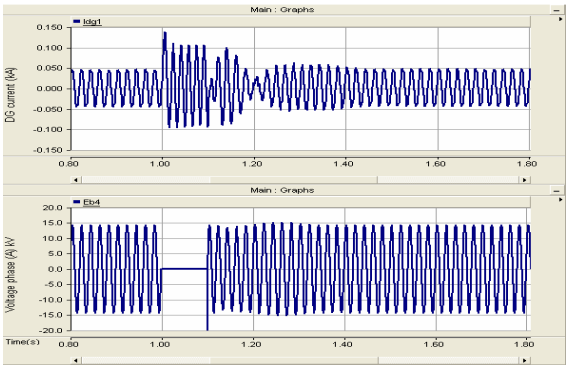

Fig. 9) Injected current and bus voltage of 1 MVA PMSG during fault at the connection point

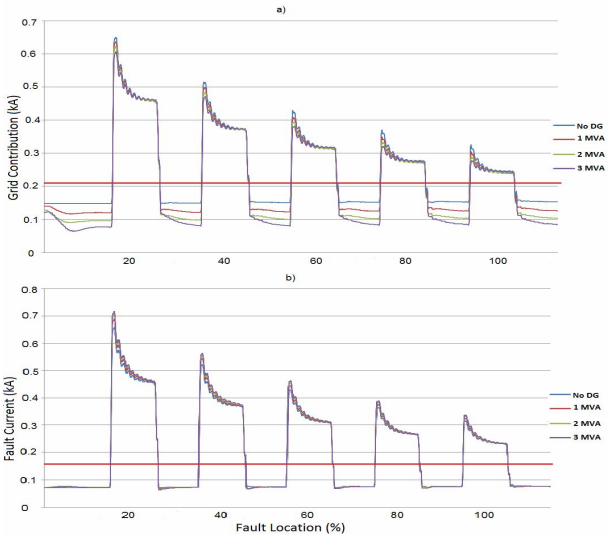

Fig.10) Rms fault current: a) seen by relay 3, b) seen by relay 4 when fault happens in feeder 2 and DG is located at the end of feeder 1

Directly connected IG

In the last part, the induction generator based wind turbine is introduced. This topology is the simplest and cheapest configuration of wind generators which is used widely around the world. Therefore the study of fault contribution of IG could be interesting. Fig. 11 shows the transient fault current of a 3MVA Induction generator when a fault happens at the connection point between DG and grid. As indicated the fault current generated by DG is very high within the first cycle but, after that period, it reduces severely by the next cycles. This very short term fault contribution makes the relay to be reset quickly and with high probability, the fault current is not detected by the relay. Fig. 12 explains the effects of induction generator on total fault current and grid contribution in more detail. As illustrated, the total fault current is increased significantly during the first cycle after the fault, but it reduces to the normal value after second period. Thus, the induction generator could not have a remarkable effect on overcurrent protection.

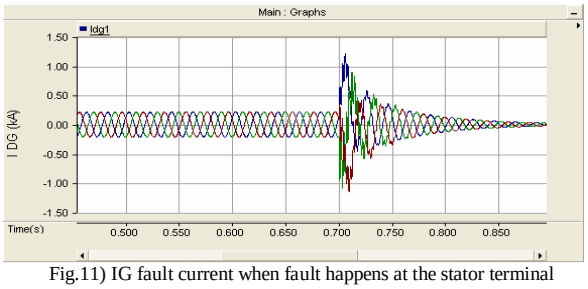

Fig.11) IG fault current when fault happens at the stator terminal

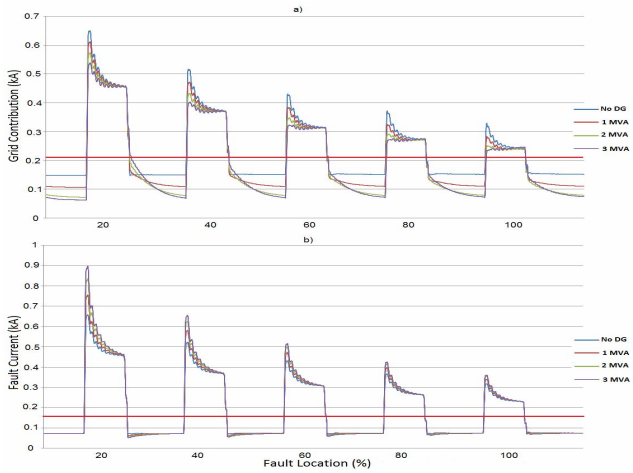

Fig.12) Rms fault current: a) seen by relay 3, b) seen by relay 4 when fault happens in feeder 2 and DG is located at the end of feeder 1

CONCLUSION

In most papers and technical documents, DGs are modeled by an ideal AC voltage source and transformer. However as it was described along the paper, the steady state and transient of the waveforms, when DG is modeled as an exact model including all dynamics, are completely different from the waveforms generated by ideal model. For designing a repayable, secure and optimized protection system in presence of DGs, it is important not to use ideal power sources for the DG modeling.

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