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Impact of PV/Wind/Diesel Hybrid System on the Distribution Networks – Fault Currents

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Abstract. The short circuit analysis secures the electrical power systems protection scheme. Thus, in turn ensures the power system reliability, safe mode of operation, and uninterruptable power supply. The impact of distributed generation on the power systems stability, power quality, and short circuit level is still unclear and uncertain. The different characteristics of each distributed generation type, such as synchronous generators, induction generators, power electronics inverters make it more complicated to assess. Studying the effect of the penetration of distributed generation on fault current level of existing distribution networks is crucial. This paper will examine the impact of implementing distributed generation mix, including wind turbine generators, photovoltaic, and diesel generators on the fault current level of the distributed network under study. The short circuit analysis is carried out on the IEEE 13-bus distribution test system using ETAP software. The simulation results are presented in a comparison between four cases, comparing the impact of the distributed generation mix on the fault current level at different levels of penetration. Moreover, a comparison showing the contribution of each distributed generation type separately as a percentage is presented. The selection of distributed generation technology and location has a significant impact on the fault current.

Key words

Distributed Generation, renewable energy, short circuit current, fault analysis

1. Introduction

In February 2015, The European Union (EU) has adopted a new set of climate change and energy targets to be met by 2030. The main developments include the launch of the Energy Union by the European Commission and the increased target for the reduction of its greenhouse gas emissions to 40% by 2030 compared to 1990 levels. Also, a legally binding target of at least 27% share of renewable energy consumption, and an indicative target of at least 27% energy savings compared with the business-as-usual scenario [1], [2]. This will increase the uptake of renewable energy systems and encourage the deployment of variable renewable energy mix such as wind, photovoltaics, and wave. It is expected that the renewable energy generation mix will be almost double the current generation capacity by 2020 and will reach around 30% in 2030 [2]. This raises a significant question, apart from the economical and energy markets capabilities; are the technologies technically (such as mechanical, electrical, and civil) mature and available to accommodate this boost. Research is still undertaken to study the impact of renewable energy on the electrical power systems. Electrical power systems have three major consequential pillars generation, transmission, and distribution. This paper is specifically concerned with the electrical distribution networks, and the impact of distributed generation (DG) on the fault current level.

The presence of DG alters the conventional theory of the flow of power in one-direction. Some existing networks are not designed to accommodate more DG [3]. The connection of DG to the distribution networks remains a contraint in the power distribution planning. The DG capacity limits; total DG capacity penetration level; DG capacity reserve; and short circuit current limit are considered from the major factors affecting the power distribution planning, when it comes to DG integration [4]. Moreover, there are technical aspects inhibiting the implmentation of DG on a large scale; Voltage control, fault level, grid protection, power quality, and power losses [5], [6]. The increasing exploitation of DG units has a significant impact on the short circuit currents and the fault level of the distributed network. Therefore, the introduction of DG will to lead to a change in the fault current. Consequently, this will affect the existing overcurrent protection scheme, which in return may have a significant influence on the power system reliability. Hence, a redesign to the fault protection system will be needed [3], [5], [7]. The influence of DG on the system total harmonics distortion, voltage profile and sag during faults, with máximum penetration level of 30% is investigated in [8]. The impact of DG depends on several factors such as DG size, penetration level, DG location, the technology of DG used, its operation mode, interface of the DG, system voltage prior fault, location of fault, and type of fault. Therefore, it is essential and recommended to examine the contribution of each DG unit installed [7]. The safest way to assess the impact of DG on fault current level and the relay protection scheme of the distribution network is to model the grid with DG

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and to simulate different scenarios with different operating conditions [5].

This paper will examine the effect of DG allocation, capacity and level of penetration on the fault current of the system under study. This includes balanced and unbalanced faults. There are two case studies investigated in this paper. Case study I will examine the impact of DG capacity on the system under study. Case study II will examine the impact of DG type at two different locations. Simulated results from the short circuit study will be taken and the percentage of DG contribution of total fault current at its allocated bus will be calculated.

A. Definition of DG

The most common general definition used in the literature for Distribution Generation (DG) is proposed in [3]. "DG is an electric power source connected directly to the distribution network or the consumer side of the meter" [3]. This may include both, renewable and non-renewable energy sources such as (Wind, solar, biomass, diesel generators, and combined heat and power). DG penetration level has no maximum permissible rating; it may vary from few watts up to hundreds of megawatts, depending on distribution network capacity, which is correlated to the voltage level within the distribution system [3]. The main advantages of DG are: reduces the active power losses, improves the voltage profile; that in return enhances the system performace, reliablity and efficiency [7], [9].

The DG units are connected directly to the grid through synchronous; asynchronous; or power electronics converters depending on the characteristics of the DG connected, such as PV and fuel cells are connected through power electronics converters.

B. Type 3 Wind Turbine Generators

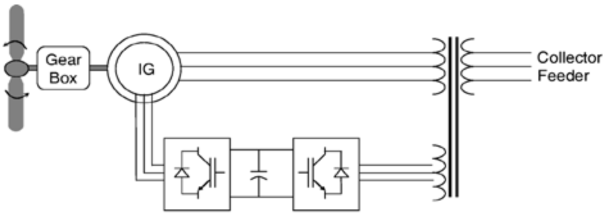

Fig. 1. Type 3 wind turbine generators [11].

The DFIG is a wound rotor induction generator. This machine has a unique characteristic in which both the stator circuit and the rotor circuit are connected to the grid (Fig. 1), providing more operational and controllable features and more efficiency than other types of wind turbines. The stator circuit is connected directly to the grid through a step-up transformer, whereas the rotor circuit is connected to the grid through power electronics circuit via slip rings by a current regulated, voltage-source converter, and step up transformer. This power electronics circuit controls the rotor current magnitude and phase. It allows more variable operation speed range, both above and below synchronous speed ± 50%. The converters offer a wide range of output control that is only 30% of the rating of the machine. Active power is delivered to the grid through the stator circuit via the grid-connected invertor when the generator is running more than the synchronous speed. However, when the generator runs below the synchronous speed, active power flows form the grid, through both converters, and from rotor to stator. This in turn, offers the benefit of more speed range. Also, this adds to its flexible operation feature of active and reactive power control, while being able to run asynchronously [11], [12], [13].

2. System Under Study

The IEEE PES distribution system analysis subcommittee has several radial test feeders and common set of data available [10]. The main purpose of these test feeders is for the evaluation of power system analysis software. The distribution test system used in this study is the IEEE 13-bus, shown in Figure 2. This system is described as small test feeder operating at 4.16 kV; however, it displays wide variety of components and characteristics that include:

"1. Short and relatively highly loaded for a 4.16 kV feeder
2. One substation voltage regulator consisting of three single-phase units connected in wye
3. Overhead and underground lines with variety of phasing
4. Shunt capacitor banks
5. In-line transformer
6. Unbalanced spot and distributed loads" [14]

The model is implemented in ETAP 12 software and the short circuit analysis is performed. The IEEE 13-bus distribution test system original model is modified through connecting DG with various sizes and at different locations throughout the system under study. The DG units used are; Type 3 (DFIG) wind turbine generators (WTG), photovoltaics, and diesel generators.

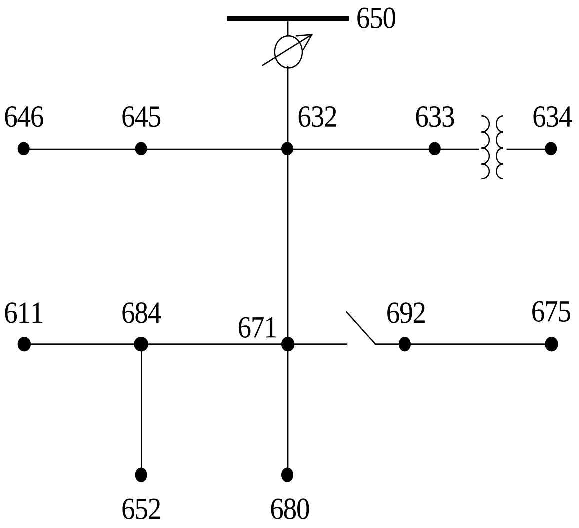

Fig. 2. The IEEE 13-bus distribution test system [14].

3. Case Studies

A. Impact of DG Penetration Level

Case study I examined the impact of DG penetration level on the system under study. Simulation is performed on four different cases separately; each case examined the DG capacity at different measures, with respect to the same location on the DN. Four types of faults were simulated; three-phase (3-ph), line to ground (LG), line to line (LL) and double-line to ground (LLG) at three different buses 632, 671, and 675 respectively. The DG capacity is taken as a percentage of grid rating. These percentages are selected randomly as it could possibly happen in existing distribution networks. The different operating scenarios of DG connections are considered as follows:

- Case A ~ 85% of the main grid rating, 3 MW total of DG units connected at bus 675 consisting of 1 MW Type 3 WTG, 1 MW PV unit , and 1MW diesel generator
- Case B ~ 42% of the main grid rating, 1.5 MW total of DG units connected at bus 675 consisting of 0.5 MW Type 3 WTG, 0.5 MW PV unit, and 0.5 MW diesel generator
- Case C ~ 30% of the main grid rating, 1.05 MW total of DG units connected at bus 675 consisting of 0.35 MW Type 3 WTG, 0.35 MW PV unit, and 0.35 MW diesel generator
- Case D ~ 10% of the main grid rating, 0.35 MW total of DG units connected at bus 675 consisting of 0.1 MW Type 3 WTG, 0.1 MW PV unit, and 0.1 MW diesel generator

Simulated results from the short circuit study of total fault currents at each case are presented in Table I.

Table I. Simulated Results For Short Circuit Currents (kA)

Location of Fault	**3-Phase Fault**			
	Case A	**Case B**	**Case C**	**Case D**
Bus 632	12.283	11.714	11.589	11.400
Bus 671	7.923	7.049	6.872	6.615
Bus 675	7.286	6.384	6.201	5.936
	Line-Ground Fault			
	Case A	**Case B**	**Case C**	**Case D**
Bus 632	9.491	9.034	8.886	8.650
Bus 671	6.657	5.616	5.309	4.867
Bus 675	6.405	5.286	4.966	4.512
	Line-Line Fault			
	Case A	**Case B**	**Case C**	**Case D**
Bus 632	10.730	10.225	10.095	9.891
Bus 671	7.017	6.221	6.034	5.753
Bus 675	6.478	5.650	5.456	5.166
	Line-Line-Ground Fault			
	Case A	**Case B**	**Case C**	**Case D**
Bus 632	11.713	11.132	10.989	10.771
Bus 671	7.652	6.645	6.419	6.098
Bus 675	7.034	6.083	5.838	5.479

Figures 3- 6 noticebly distinguishes between the four different penetration levels for each type fault separately. Case A showed the highest fault current values at the selected faulted buses for the balanced and unbalanced faults, then the fault current values have decreased marginally through cases B, C, and D respectively.

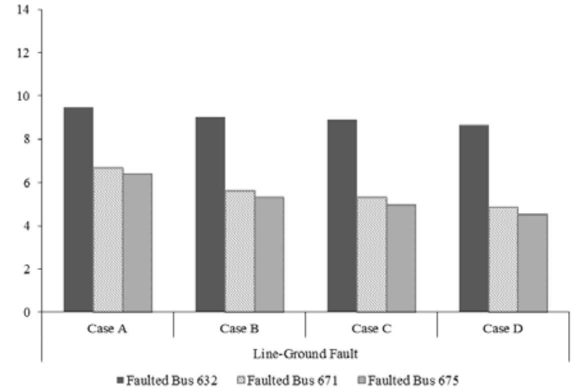

Fig. 3. Fault Currents for Line-Ground Fault.

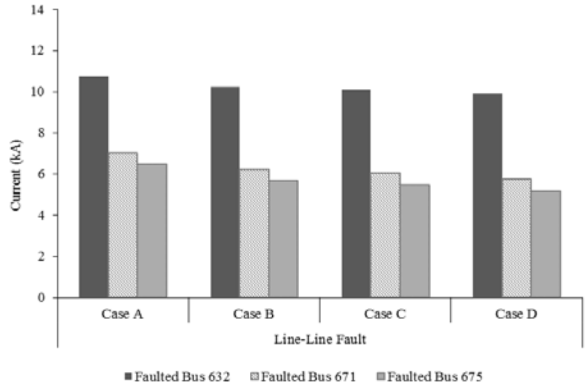

Fig. 4. Fault Currents for Line-Line Fault.

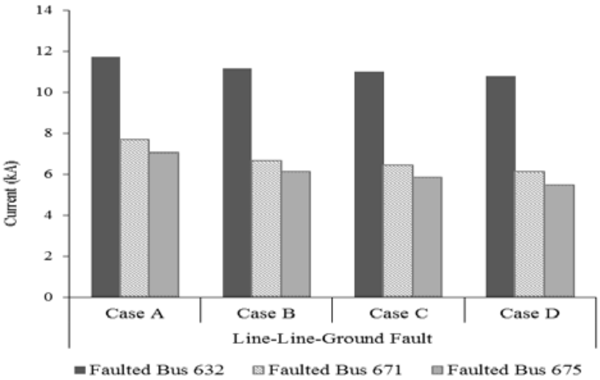

Fig. 5. Fault Currents for Line-Line-Ground Fault.

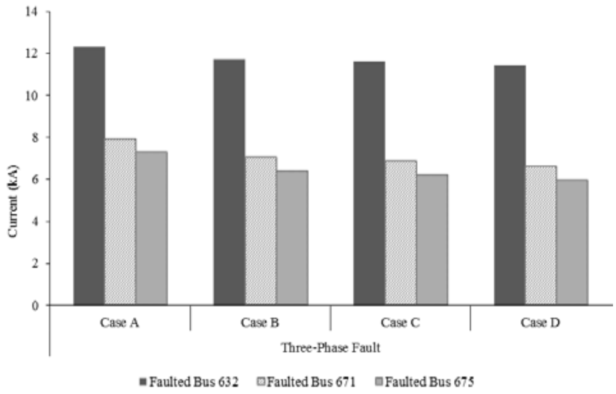

Fig. 6. Fault Currents for Three-Phase Fault.

B. Impact of DG Type

Case study II studied the contribution of each DG type separately on the fault current of the IEEE 13-bus distributed test system. Thus, by connecting 1 MW Type 3 DFIG wind turbine, 1MW PV farm, and 1 MW diesel generator; at buses 632 and 675 respectively. These 2 scenarios are represented as scenarios A and B respectively. The total capacity of DG connected represented 85% of the main grid rating. The attempted DG locations are selected on the criteria of nearest and farthest buses from the grid. The simulation considered the occurrence of 3-ph and line to ground fault level currents at three different buses 632, 671, and 675 respectively.

Simulated results from the short circuit study were taken and the percentage of DG contribution of total fault current at its allocated bus has been calculated, presented in Tables II and III.

Table II. Comparison of DG units contribution on the fault current level at scenario A

Fault at Bus 632	**U1 %**	**WTG%**	**PV %**	**Diesel Generator%**
3-ph	77.1	5.5	0.2	6.7
Line to Ground Fault	69.9	4.5	0.1	14.3
Fault at Bus 671	**U1 %**	**WTG%**	**PV %**	**Diesel Generator%**
3-ph	67.7	4.9	0.1	5.9
Line to Ground Fault	59.4	4.0	0.1	11.5
Fault at Bus 675	**U1 %**	**WTG%**	**PV %**	**Diesel Generator%**
3-ph	67.0	4.8	0.1	5.8
Line to Ground Fault	58.5	3.9	0.1	11.3

Table III. Comparison of DG units contribution on the fault current level at scenario B

Fault at Bus 632	**U1 %**	**WTG%**	**PV %**	**Diesel Generator%**
3-ph	80.3	4.3	0.1	5.2
Line to Ground Fault	76.6	3.5	0.1	9.1
Fault at Bus 671	**U1 %**	**WTG%**	**PV %**	**Diesel Generator%**
3-ph	62.6	8.6	0.3	10.4
Line to Ground Fault	52.9	6.9	0.2	21.2
Fault at Bus 675	**U1 %**	**WTG%**	**PV %**	**Diesel Generator%**
3-ph	60.2	9.7	0.3	11.8
Line to Ground Fault	50.1	7.8	0.2	23.3

The utility grid contribution has the highest percentage of the total fault current level, exceeding more than 50% in both scenarios A and B respectively, in comparison to the percentage contribution of the DG types connected. The highest percentage reached up to 80.3% in Scenario B at the occurrence of 3-ph fault at bus 632. It is noticed that the diesel generator percentage contribution represented the highest percentage (23.3%) of the total fault current at scenario B, when the DG mix was located at the farthest bus (675), at the occurrence of LG fault at the same bus. Remarkably, it is almost double the percentage for the same conditions at scenario A. The DFIG wind turbine contribution never exceeded the 10% in both scenarios. The PV contribution ranged from 0.1 – 0.3% in both scenarios A and B. It is noticed that when the DG mix was located at the nearest bus to the grid (632) the grid contribution was higher in Scenario A than scenario B, for faults occurring at buses 671, and 675.

Conclusion

This paper examined the effect of DG allocation and level of penetration on the fault current of IEEE 13-bus distribution test system. Comparing the impact of DG types used, diesel generator had the most significant percentage of the total fault current, followed by the Type 3 WTG; then the PV was the least percentage. From this, PV may be considered as negligible to the other two types of the DG connected. In case study I, the optimal location of the DG mix was near the grid, this is due to that the DG mix influence was limited. To an extent, the DG penetration level is directly proportional to the fault current. The increase in DG penetration level, leads to an increase in the fault current at the selected buses. In evaluating the difference between the cases studied, that reflects the size of the DG penetration level, the level of DG penetration have a limited impact on the fault currents of the distributed network. Despite this outcome, the effect of DG penetration capacity still should be considered in power systems design and planning, in particular in weak networks, where the impact may not be predicted or based on evolution of other strong networks.

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