Influence of Location and Capacity of Distributed Generations on Voltage Sags Mitigation Using Alternative Transient Program

Surya Hardi¹, S M Hutasoit² and Fanidia Purnamasari³

¹,²Department of Electrical Engineering, Universitas Sumatera Utara, Medan, Indonesia.
³Department of Information Technology, Universitas Sumatera Utara, Medan, Indonesia

E-mail : surya.hardi@usu.ac.id , hutasoit27@gmail.com , fanindia@usu.ac.id

Abstract. This paper presents the influence of distributed generation (DG) location and capacity for mitigating voltage sag caused by faults. The voltages sags are caused by the faults were simulated on the IEEE 13 bus system for single line to ground close to 650 and three-line phase faults at bus 646 using Alternative Transient Program (ATP) software. The voltages are monitored at every buss system. The DG is installed for one DG, two DG and three DG as the alternative. The DG locations are installed based on trial and error. DG total capacity is 2/3 load total installed in the system. As the alternative DGs installed viz. for one DG at Bus 611 with the capacity of 2.5 MVA; Two DGs at Bus 611 and Bus 680 with their respective capacities of 1.25 MVA; Three DGs are located at Bus 611, Bus 680 and Bus 633 with their respective capacities of 1 MVA. The results show that DG location placement in many locations gives the better results for mitigating voltage sags.

1. Introduction

The power quality disturbance most frequent is reported by customer is voltage sag [1][2]. The sag can causes disruption even shutdown the operation of many industrial sectors, especially which uses modern power electronic equipment such as the computer, power electronic device and microcontroller, variable speed drive (VSD), program logic control (PLC), contactors, electrical machine, etc. This equipment is identified as sensitive against voltage sags. When the sag come on at the industry terminal, it can lead to the degradation of equipment even can cause industry shutdown or interruption. An interruption can lead to loss production and failure in the end product. For process industries such as textile, glass, hot rolling mill industries, sag can cause disruption and finally leads to product damage. Commonly the industries use VSDs are to control the motor speed [3][4].

Voltage sags effects on the equipment have been reported in the previous studies in some papers including that computers reboot for sags less than sag of 50% in duration more than 50 milliseconds. The contactor will drop out for sag less of 70% with duration of more than 20 milliseconds [5]. Even microcontroller drops out for higher voltage sag of 78% [6]. Three-line phase sag can cause VSD disruption for sag magnitude of 70% and single sag with sag magnitude of 57% [7].

Distributed generation (DG) is defined as something power generation unit connected directly to distribution network system or industries facility grid at the consumer. DG can mitigate power quality...
disturbance including voltage sag [8]. Previous works related DG as an electric power source which can mitigate voltage sags were reported in [9][10]. Voltage sag resulted by faults were simulated by ANAFAS on simple radial distribution system that focused sag resulted in different fault locations [10]. The IEEE system 13 buses have been used in alternative transient program (ATP) simulation of DG effect on distribution network during the fault. Effect of DG in distribution was investigated in terms of increased fault current in percentage, etc [11].

The short faults in the power system can be categorized namely three-line phase fault, phase to phase fault, two-phase fault to the ground and single line to ground. The faults are the primary source of voltage sag. The three-line phase fault (3LG) affects the largest on voltage sag but it very rare. The single-line to ground (SLG) fault has probability are the largest occurred of them. Hence in this the study source of voltage sags in simulation is SLG and 3LG fault. The purpose of the study is to investigate the influence of location and capacity of DG to mitigate voltage sag. ATP program was used for simulating the IEEE 13 bus in industrial distribution.

2. Methodology

2.1. Distribution Generation

Distribution generation technology is new relative technology in electric power system. Generally, DGs are small scale including photovoltaic, micro turbine, wind turbine, fuel cell. Effect of DG installation in network distribution is not similar and it depends on their application, location, capacity, consumers’ characteristic, and technology [9]. Commonly DGs are developed from renewable energy which one capacity is limited to 10 MVA [12]. Determination of DG capacity was determined in this paper is using trial and error which is the method based on the rule of thumb calculation. It is obtained with a formula [13].

\[
\text{DGCap} = \frac{2}{3} \times TL \quad \text{MVA}
\] (1)

where DGCap is DG capacity connected and TL is load totally existing in the system

2.2. Voltage sag

Main sources of voltage sag are short circuit faults in power system and others are starting of large motor, transformer energizing. But the both do not lead to becoming problems serious at electrical equipment, because the voltage sag resulted is small relative. Even though sag produced by starting motor taking a longer time. The sag is transient disturbance in power system. Voltage sag is defined as a voltage drop suddenly start to happen from 10% until 90% of rms nominal voltage at a point measured in the power system in duration from 0.5 cycles to one minute [7]. Sag magnitude and sag duration are primary characteristics of voltage sag. These both parameters generally take effect on the electrical equipment performance. The voltage sag in there-phase system described magnitude and duration such as in Figure 1.

The Figure 1 shows peak value of voltage sag, \( V_{\text{peak}} \) with magnitude of 50% and 100 m/s induration. hence sag magnitude measured in rms is,

\[
V_{\text{sag}} = \frac{V_{\text{peak}}}{\sqrt{2}}
\] (2)

Simple model of distribution equivalent circuit use voltage divider for voltage sag due to short circuit fault is shown in Figure 2 [9].
The voltage at bus point common coupling (PCC) can be calculated by

\[ V_{pcc} = E_s \frac{Z_f}{Z_s + Z_f} \]  

Equation (2) is before DG is connected, whereas for after DG connected is given such as equation (3)

\[ V_{eq} = V_{pcc} \frac{Z_{DG}}{Z_t + Z_{DG}} + E_{DG} \frac{Z_t}{Z_t + Z_{DG}} \]  

where \( E_s \) and \( E_{DG} \) are source voltages of generator and DG, respectively. \( Z_t \) and \( Z_{DG} \) are the impedance between PCC and Bus monitored.

2.3. Proposed procedure
To obtain the result from this research, voltage sags caused by short circuit fault occurred close to bus 650 in the system and some steps carried:

**Figure 1.** Voltage sag of 50% and 100 milliseconds in duration

**Figure 2.** The simple model of the voltage divider
• Modelling one-line diagram of the IEEE 13 busses system including them parameters.
• Set the SLG fault location close to the source i.e., at Bus 650 to find level of voltage sag for each bus before and after the DG connected.
• Determine the location and capacity of DG connection based on the rule of thumb and trial and error.
• Connect one DG, two DGs or three DGs to selected bus and observe the voltage level.
• For 3LG, repeat procedure step 2 until finish.

The one-line diagram of the IEEE 13 busses system [14] modeled using ATP draw is shown in Figure 2.

![Figure 2](image)

**Figure 2.** The one-line diagram of the IEEE 13 busses system

Figure 3 is distribution system has distinct voltage level viz., 11kV source, 4.16kV/0.48kV. Loads connected to busses which are the total loads of 3.466 MW. A Substation at bus 650 has a three-line phase voltage regulator which is its function to adjust the voltage.

3. Result

**3.1. Voltage sag produced by single line to ground without DG**
Voltage sags result from the single line to ground fault (SLG) simulation in phase A close to bus 650 during one second. Amount of voltage sags are observed before and after DG installation. The voltage at every bus is monitored. For examples the voltages waveform at Bus 650 and Bus 646 are presented in Figure 4. The Figures are three-line phase waveform which they are red, green and blue colours represent phases A, B and C, respectively. In the figure shows, the vertical (Y) is the voltage (Volt) whereas a horizontal (X) is time (seconds).
Figure 4. Voltage waveform caused by SLG close to Bus 650

From Figure 4 can be seen that the voltage drop occurred one phase only viz. in phase A, therefore phase A occurred voltage, whereas two other phases are remains in magnitude. During the fault, the voltage drops or sag, after the fault is cleared by opening circuit breaker the voltage returns to normal in several cycles. In this case, the highest the voltage drops occur on the bus subjected to close to the fault meanwhile the bus voltage that far relative from the fault, the busses voltage to drop small relative. This is because the impedance is inversely proportional to the source and this according to equation (4). The bus location farther from the fault point, the impedance is larger. The voltage at Bus 650 and Bus
646 are 46.6% and 83.0% of nominal voltage, respectively. The complete result of voltage profile at each bus before and after the fault is presented in Table 1.

**Table 1. Voltage profile of busses without DG**

| Bus name | Voltage before fault (Volt) | Voltage during fault (Volt) | Voltage sag (%) |
|----------|-----------------------------|----------------------------|-----------------|
| 650      | 2478.9                      | 1154.1                     | 46.6            |
| 646      | 2428.0                      | 2017.1                     | 83.0            |
| 645      | 2446.7                      | 1932.7                     | 79.0            |
| 632      | 2600.0                      | 2050.0                     | 78.6            |
| 633      | 2714.7                      | 1929.7                     | 71.1            |
| 634      | 290.6                       | 223.2                      | 76.8            |
| 611      | 2877.0                      | 2284.8                     | 79.4            |
| 684      | 2926.0                      | 2280.6                     | 77.4            |
| 671      | 2924.1                      | 2134.5                     | 73.0            |
| 692      | 2924.1                      | 2134.5                     | 73.0            |
| 675      | 3027.7                      | 2305.6                     | 76.2            |
| 652      | 3043.8                      | 2341.9                     | 76.9            |
| 680      | 3051.4                      | 2024.0                     | 66.8            |

From Table 1 can be shown that the voltages at buses during fault drop. Largest drop is at Bus 650, which the fault occurred. Some the bus voltage is less than 78% of it nominal. The equipment such as microcontroller may drop out at the voltage [6].

**3.2. Voltage profile caused by single-line phase to ground fault after DG connected**

Amount of capacity DG installation is determined based on 2/3 of the loading total (3.47MVA). For one DG capacity is required approximately is 2.5 MVA. Based on trial and error the one DG location is selected at Bus 611. For two DG, the capacity divided by two DGs with their respective capacity is 1.25 MVA and it is connected at Bus 611 and Bus 680 and then for three DGs, the capacity are 1 MVA with the location at buses 611, 680 and 633. Percentage increasing of voltage sag due to DGs locations compared with without DG is shown in Table 2. Increasing of voltage sag, it means voltage drops become decrease so that the nominal voltages increase.

**Table 2. Voltage sags (%) of busses systems for SLG at Bus 650 after DG installation**

| Bus Name | Without DG (%) | Voltage Increasing (%) | Two DGs Voltage Increasing (%) | Three DGs Voltage Increasing (%) |
|----------|----------------|------------------------|--------------------------------|---------------------------------|
| 650      | 47.6           | 2.1                    | 47.8                           | 2.6                             | 48.1                           | 3.2                             |
| 646      | 86             | 3.6                    | 86.3                           | 4                               | 88.1                           | 6.1                             |
| 645      | 82.1           | 3.9                    | 82.9                           | 4.9                             | 85.3                           | 8                               |
| 632      | 81.2           | 3.3                    | 82.6                           | 5.1                             | 85.8                           | 21.7                            |
| 633      | 77.3           | 8.7                    | 79.7                           | 12.1                            | 86.5                           | 21.7                            |
| 634      | 77.8           | 1.3                    | 80.1                           | 4.3                             | 86.2                           | 12.2                            |
| 611      | 81.7           | 2.9                    | 84.4                           | 6.3                             | 82.4                           | 3.8                             |
| 684      | 83.5           | 7.9                    | 84.6                           | 9.3                             | 83.5                           | 7.9                             |
| 671      | 81.6           | 11.8                   | 81.2                           | 11.2                            | 80.5                           | 10.3                            |
| 692      | 81.6           | 11.8                   | 81.2                           | 7.9                             | 80.5                           | 10.3                            |
| 675      | 80             | 5                      | 82.2                           | 1.2                             | 82.2                           | 7.9                             |
| 652      | 78.4           | 2                      | 77.8                           | 1.6                             | 78.9                           | 1.6                             |
| 680      | 81             | 22.6                   | 77.6                           | 7.9                             | 74.5                           | 11.5                            |
From Table 2 can be observed that the voltages on busses increased due to installed DG. By placement one DG on the bus 632, the voltage increase is highest at bus 671 and 692 which the busses are near to bus connected DG for two DGs and also three DGs. Generally, the voltage increasing at all the busses on average is 6.7%, 7.4% and 8.6% for one DG, two DGs and three DGs respectively. High transient occurs at recovery voltage instant on the bus faulted compared with the other bus. This is a concern to electronic equipment that sensitive against to high current.

3.3. Voltage profile caused by three-lines to ground fault after DG connected

The three-line phase fault was simulated at Bus 646. Examples of voltage waveform is captured at bus 646 and 650 are shown in Figure 5 without DG installation. The three-line phase fault leads to the voltages drop as large in all the phases. The phase A (red colour), phase B (green colour) and phase C (blue colour) drop in similar magnitude. The voltage sag resulted in bus 646 is 66.8%, whereas at Bus 650 is 95.3%.

The voltage sag resulted in the bus faulted is the highest drop compared with other busses because the voltage bus is close to the fault point. Figure 4b shows voltage waveform at Bus 650 which it is far from the fault point. From both the figures show voltage sag resulted is difference.

Figure 5. Voltage waveform caused by 3LG at Bus 646
Table 3. Voltage sags (%) of busses systems for 3LG at Bus 646 before and after DG installation

| Bus Name | Without DG (%) | One DG | Voltage Increasing (%) | Two DGs | Voltage Increasing (%) | Three DGs | Voltage Increasing (%) |
|----------|----------------|--------|------------------------|---------|------------------------|-----------|------------------------|
| 650      | 95.3           | 95.7   | 0.4                    | 96.3    | 1                      | 96.8      | 1.5                    |
| 646      | 66.8           | 67.1   | 0.5                    | 68.9    | 3.1                    | 69.3      | 3.7                    |
| 645      | 67.6           | 68.2   | 0.9                    | 70.9    | 4.9                    | 71.2      | 5.3                    |
| 632      | 69.2           | 71     | 2.6                    | 74.3    | 7.4                    | 73.7      | 6.5                    |
| 633      | 69.7           | 70.2   | 0.7                    | 76.1    | 9.2                    | 75.8      | 8.8                    |
| 634      | 69.4           | 69.7   | 0.4                    | 75.9    | 9.4                    | 76.1      | 9.7                    |
| 611      | 63.2           | 75.7   | 9.8                    | 78.4    | 24.1                   | 81.4      | 28.8                   |
| 684      | 68.6           | 78.4   | 14.3                   | 77.8    | 13.4                   | 80.1      | 16.8                   |
| 671      | 66.2           | 77.1   | 16.5                   | 76.1    | 15                     | 77.6      | 17.2                   |
| 692      | 66.2           | 77.1   | 16.5                   | 76.1    | 15                     | 77.6      | 17.2                   |
| 675      | 69.1           | 76.6   | 10.9                   | 78.5    | 13.6                   | 80        | 15.8                   |
| 652      | 68.1           | 73.2   | 7.5                    | 70      | 2.9                    | 73.1      | 7.3                    |
| 680      | 66.6           | 83.3   | 25.1                   | 79.9    | 17.1                   | 81.2      | 21.9                   |

The transient voltage after clearing is higher than SLG then toward normal in several cycles. The complete result of voltage sags due to three-line-phase fault at Bus 646 at busses systems such as in Table 3. The Table 3 is amount voltage sags of each bus without DG and with DGs installation. The percentage of voltage increasing is significantly at busses 684, 671, 675 and 680 and they have the increasing more than 10%. The busses are close to the busses DGs that DGs installed.

4. Conclusion
Study has been carried out used ATP simulation for single line to ground close to Bus 650 and three-phase fault on Bus 646 at different locations as the voltage sags source. When faults occur the bus voltages are far from the source voltage have voltage drop higher. The bus voltages close to DG provide voltage increasing significantly. To mitigate voltage sag, placement small DG in several locations is better than one DG location for similar capacity. DG capacity has influence on profile voltage improvement, but the placement of DG location is more influential than DG capacity to mitigate the voltage profile. The DG can improve the voltage profile, even though the busses voltage drop larger, this is indicated while there-line phase fault it is more effective.

5. References
[1] McGranaghan MF, Mueller DR, Samotyj MJ 1993 Voltage sags in industrial systems IEEE Transactions on industry applications, 29 (2) pp 397-403
[2] Wang Z Q, Zhu S 2002 October Comparative study on power quality disturbance magnitude characterization In Proceedings International Conference on Power System Technology 1 pp 106-111
[3] Weldemariam L E, et al 2015 Experimental investigation on the sensitivity of an industrial process to voltage dips 2015 IEEE Eindhoven PowerTech pp 1-6
[4] Carlsson F, Widell B, and Sadaranagani C 2000 Ride-through investigations for a hot rolling mill process In PowerCon 2000 2000 International Conference on Power System Technology Proceedings (Cat No 00EX409) 3 pp 1605-1608
[5] Hardi S, and Daut I 2010 Sensitivity of low voltage consumer equipment to voltage sags In 2010 4th International Power Engineering and Optimization Conference (PEOCO) pp 396-40
[6] McGranaghan M F, Mueller D R and Samotyj MJ 2009 Effects of Voltage Sags on Industrial Equipment Electric Power Research Institute (EPRI)
[7] Hardi S, Harahap R, Ahmad S, Isa M 2019 Ride through testing of variable speed drive due to voltage sag types (Types I, II and III) Int J Pow Elec & Dri Syst ISSN 2088(8694), p 8694
[8] Santosh E, Nilakantan R and Anguraja R 2016 Power Quality and Reliability Improvement in distributed Generation System using SVC International journal of engineering Research and Management (IJERM) 3

[9] Ipinnimo O, Chowdhury S, Chowdhury SP, and Mitra J 2013 A review of voltage dip mitigation techniques with distributed generation in electricity networks Electric Power Systems Research 103 pp 28-36

[10] Ramos A C, Batista A J, Leborgne R C, Emiliano P H, 2009 Distributed generation impact on voltage sags 2009 Brazilian Power Electronics Conference pp 446-450

[11] Kaddah S, El-Saadawi S, Magdi M, El-Hassanin M D 2015 Influence of Distributed Generation on Distribution Networks During Faults Taylor & Francis Electric Power Components and Systems 43 (16) pp1781-1792

[12] Boutsika TN and Papathanassiou SA 2008 Short-circuit calculations in networks with distributed generation Electric Power Systems Research, 78(7) pp 1181-1191

[13] Fitrizawati, Suharyanto, and Isnanei M B S 2012 Influence of Distributed Generation placement against to voltage profile in distribution line using ETAP Techno, ISSN 1410 – 8607 13 pp 12–19

[14] Renders B, De Gussemé K, Ryckaert WR, Stockman K, Vandevelde L, Bollen MH 2008 Distributed generation for mitigating voltage dips in low-voltage distribution grids IEEE Transactions on Power Delivery 23(3) pp1581-1588