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Impact of Distributed Generation on the Fault Current in Power Distribution System

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Abstract

Monitoring fault current is very important in power system protection. Therefore, the impact of installing Distributed Generation (DG) on the fault current is investigated in this paper. Three types of fault currents which are single line-to-ground, double line-to-ground and three phase fault are analyzed at various fault locations. The optimal location of DG was identified heuristically using power system simulation program for planning, design and analysis of distribution system (PSS/Adept). The simulation was conducted by observing the power losses of the test system by installing DG at each load buses. Bus with minimum power loss was chosen as the optimal location of DG. In order to study the impact of DG to the fault current, various locations and sizes of DG were also selected. The simulations were conducted on IEEE 33-bus distribution test system and IEEE 69-bus distribution test system. The results showed that the impact of DG to the fault current is significant especially when fault occurs at busses near to DG location.

***Keywords**: Distributed Generation; Fault Current; Power Losses; Power System Protection*

1. Introduction

In recent years, the concept of installing small scale energy sources namely Distributed Generation (DG) over the distribution network has gained a great interest. DG is defined as limited power resources approximately less than 10 MW that connected either to the substation, distribution feeder or load levels. Some of DG technologies such as photovoltaic, fuel cells, and biomass and wind turbines has received widespread attention due to highly promotion on renewable energy [1-3]. DG installation is beneficial for both owner and the utility such as efficiency improvement and environmental benefits especially in the application of combined heat and power [4]. Moreover, DG installation may reduce power losses more significant as compared to other methods of loss reduction. However, DG may also lead to higher system losses if it is connected at inappropriate locations and sizes. Therefore, proper planning is required before connecting DG into distribution power system. From previous studies, various methods have been implemented to determine the placement of DG [5-10]. Most of the studies only look into the benefit of DG to the power losses and voltage stability. Unfortunately, the impact of DG installation to the fault current was not considered.

Fault studies are an important part of power system analysis. The analysis involved the determination of bus voltages and line currents during various types of fault. Fault analysis in distribution system becomes more complicated with the presence of DG since the fault current contributed from DG current as well as main source current [11]. The fault current may increase beyond the maximum capacity of circuit breakers and fuses. Thus, disturbs the existing distribution protection system such as protection coordination, false tripping of feeders and relay mal-operation [12].

Few references investigated the impact of DG installation in the distribution system to the fault current. Reference [13] discussed the effect of type and interconnection of DG on the fault current contribution in the distribution systems. The results indicated that the increment of fault currents in the synchronous machine is often greater than inverter-based design. A method of applying superconducting fault current limiters (SFCLs) to minimize the problems of miss-coordination, false tripping, blinding and reduction of reach of protective devices caused by DG is presented in [14]. It was found that the fault current contribution of a DG resource can be controlled by placing the fault current limiter in series with the DG unit. Various methods of

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determining the suitable location of SFCL were proposed [15-17], for safeguarding the protection devices from fault current increment.

This paper will investigate the impact of DG installation at the optimal location to the fault current increment in power distribution systems. Three types of fault including single line to ground, double line to ground and three phase fault are analyzed at various fault location with DG. The results from the analysis might be useful for power system engineer to consider protection devices before installing DG in the system. The information from line to ground fault analysis is use to select and set ground relays while the three phase fault information is use for phase relays setting.

2. Research Method

The methodology in this paper are divided into three steps. Firstly, determining the suitable location of DG. Then, calculating the sizing of DG. Finally, determining the fault current after installing DG at the identified location. The overall flowchart is presented in Figure 1.

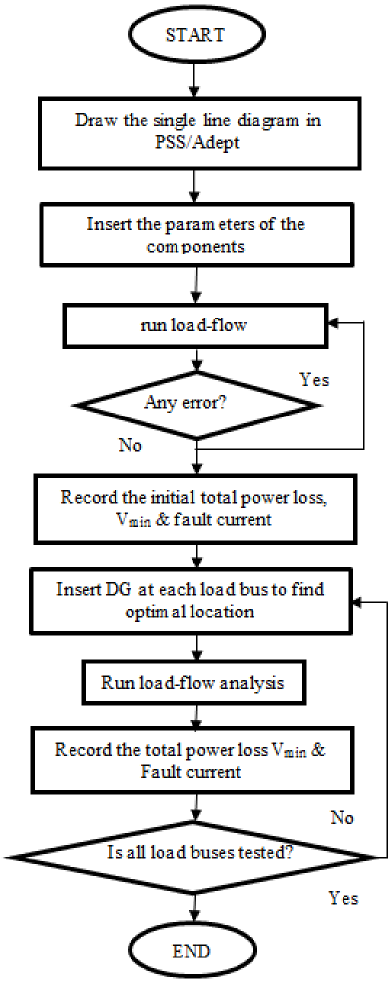

Figure 1. Overall flowchart

2.1. Optimal Location of DG

The optimal location of DG is determined based on heuristically method. The simulation was conducted by observing the power losses of the test system by installing DG at each load buses. Bus with minimum power losses was chosen as the optimal location of DG. The simulation was executed using Power System Simulator and Advanced Distribution Engineering Productivity Tool (PSS/Adept). In this paper, the operation of the DG is considered to be at steady state and is modelled as injected active and reactive power.

2.2. Optimal Sizing of DG

The optimal sizing of the DG is determined by using the formula shown in (1) and (2):

$$\sum P_G + \sum P_{DG} = \sum P_{load} + \sum P_{loss} \quad (1)$$

$$\sum Q_G + \sum Q_{DG} = \sum Q_{load} + \sum Q_{loss} \quad (2)$$

2.3. Fault Current

The symmetrical component method is employed for determining the fault current at each bus. Three types of fault that are considered in this paper are single line to ground, double line to ground and three phase fault. Figure 2 shows the general representation of single line to ground fault. Fault current for single line to ground can be calculated using (3).

$$I_a = 3I_a^0 = \frac{3E_a}{Z^1 + Z^2 + Z^0 + 3Z_f} \quad (3)$$

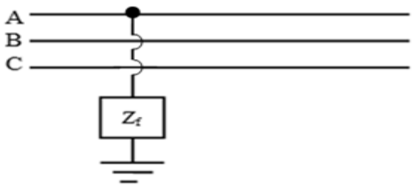

Figure 2. Single line to ground fault

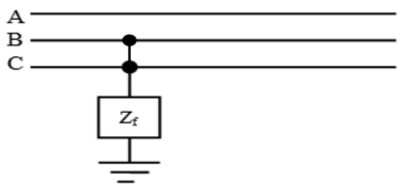

Figure 3. Double line to ground fault

Figure 3 shows the general representation of double line to ground fault. Fault occurs on phases B and C through impedance Zf to ground. The fault current can be calculated using (4).

$$I_f = I_b + I_c = 3I_a^0 \quad (4)$$

Where

$$I_a^0 = -\frac{E_a - Z^1 I_a^1}{Z^0 + 3Z_f}$$

Figure 4 illustrate the general representation of three phase fault. It occurs infrequently. However, it is the most severe type of fault encountered. Three phase fault has only positive-sequence network. Therefore, the fault current can be expressed as (5).

$$I_a = \frac{E_a}{Z_{eq}^1 + Z_f} \quad (5)$$

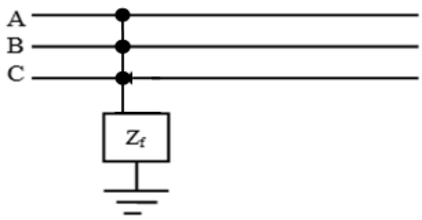

Figure 4. Three phase fault

3. Results and Analysis

The proposed method was tested on IEEE 33-bus distribution test system and IEEE 69-bus distribution test system. The one-line diagram for both test systems are shown in Figure 5 and Figure 6 respectively. The result for the power losses and the voltage magnitude were obtained from the load flow analysis.

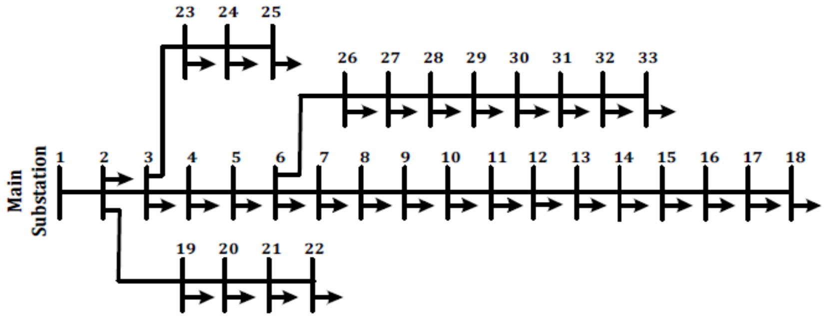

Figure 5. IEEE 33-bus distribution test system

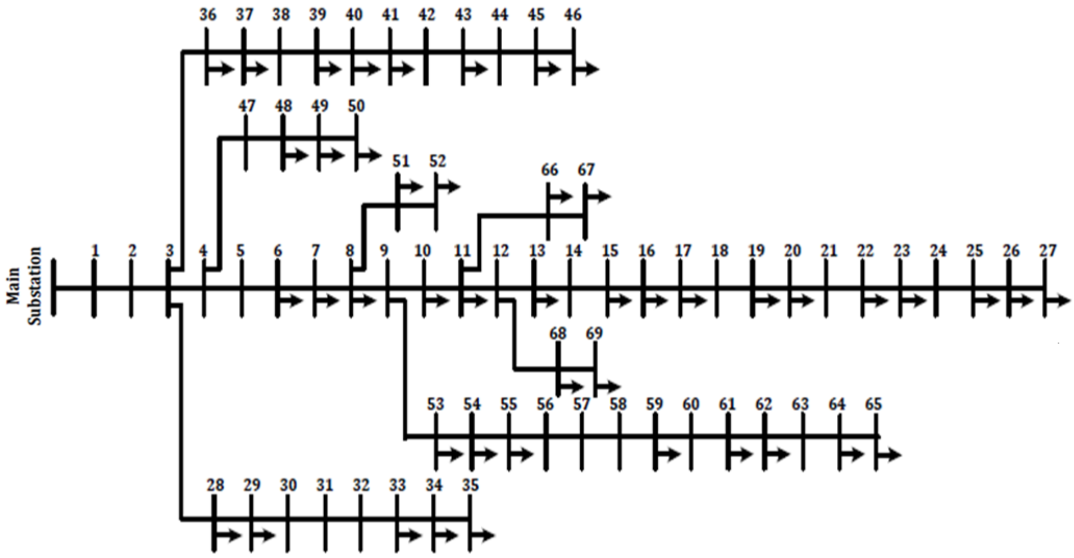

Figure 6. IEEE 69-bus distribution test system

3.1. Results of IEEE 33 Bus Distribution Test Systems

The optimal location of DG was determined using heuristically method from load flow analysis. The optimal location of DG was selected based on the lowest power losses. For comparison, the other two DG locations were also selected. The results of the optimal location of DG for IEEE 33-bus test system is shown in Table 1. Meanwhile, Table 2 tabulate the sizing of each DG.

Table 1. Minimum Voltage and Total Power Loss Before and After DG Allocation for IEEE 33-Bus Distribution Test System

	Min. voltage (pu)	$\sum P_{loss}$(kW)
Initial	0.914	201
DG at Bus 6	0.966	61
DG at Bus 26	0.963	62
DG at Bus 27	0.961	63

Table 2. Optimal Location and Sizing of DG

	P_{DG} (MW)	Q_{DG} (MVar)
DG at Bus 6	0.2449	0.1716
DG at Bus 26	0.2332	0.1643
DG at Bus 27	0.2190	0.1558

After determining the optimal location and sizing of DG, maximum fault current for three types of fault are recorded. Three type of fault are considered, which are single line to ground fault (SLG), double line to ground fault (DLG) and three phase fault (3ph). Three buses are selected randomly as fault locations:

1. bus 3
2. bus 30
3. bus 15

Table 3 shows the results obtained when fault occur at bus 3. From the results presented in Table 3, it can be seen that the percentage increase of fault current after installing DG at certain locations are between 27% ~ 54%. The highest fault current is 14.47kA when three phase fault occurs in the system with DG connected at bus 6. The results obtained when fault occur at bus 30 and bus 15 are presented in Table 4 and Table 5 respectively.

Table 3. Fault at bus 3

Type of Fault	DG location	Fault Current (kA)	Fault Current %
SLG	Initial	4.449	-
	Bus 6	6.821	53.32
	Bus 26	6.275	41.04
	Bus 27	5.92	33.06
DLG	Initial	10.245	-
	Bus 6	14.07	37.34
	Bus 26	13.59	32.65
	Bus 27	13.13	28.16
3ph	Initial	10.725	-
	Bus 6	14.47	34.92
	Bus 26	14.08	31.28
	Bus 27	13.65	27.27

Table 4. Fault at bus 30

Type of Fault	DG location	Fault Current (kA)	Fault Current %
SLG	Initial	0.743	-
	Bus 6	1.37	84.39
	Bus 26	1.583	113.06
	Bus 27	1.91	157.07
DLG	Initial	1.163	-
	Bus 6	2.03	74.55
	Bus 26	2.164	86.07
	Bus 27	2.385	105.07
3ph	Initial	1.167	-
	Bus 6	2.07	77.38
	Bus 26	2.251	92.89
	Bus 27	2.542	117.82

From the results presented in Table 4, the highest fault current is 2.542kA when three phase fault occurs in the system with DG connected at bus 27. The percentage increase of fault current after installing DG at certain locations are between 74% ~ 157%. Similar observation could be seen in Table 5 where three phase fault contributed to the highest fault current of 0.95kA when DG is connected at bus 6. The percentage increase of fault current occurs at bus 15 is between 32% ~ 49%. From the results tabulated in Table 3, Table 4 and Table 5, it can be concluded that the fault current can increased up to 157% with the installation of DG. In order to study the effect of DG location to the fault current, Figure 7, Figure 8 and Figure 9 are presented.

Table 5. Fault at Bus 15

Type of Fault	DG location	Fault Current (kA)	%
SLG	Initial	0.466	-
	Bus 6	0.68	45.92
	Bus 26	0.641	37.55
	Bus 27	0.613	31.55
DLG	Initial	0.674	-
	Bus 6	0.920	36.50
	Bus 26	0.895	32.79
	Bus 27	0.895	28.93
3ph	Initial	0.685	-
	Bus 6	0.950	38.69
	Bus 26	0.932	36.06
	Bus 27	0.892	30.22

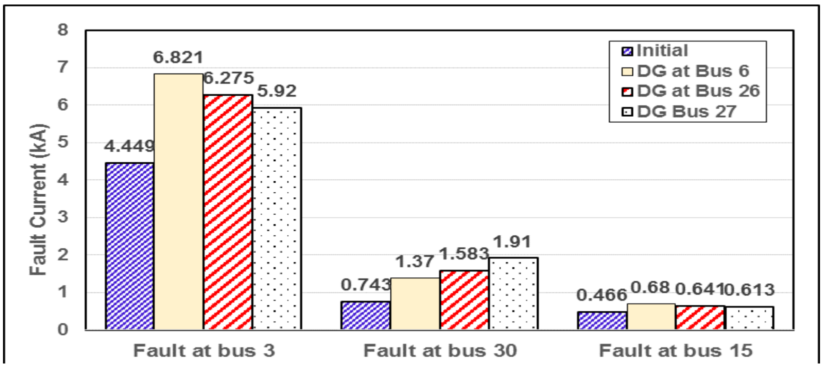

Figure 7. Single Line to Ground Fault

Based on the results presented in Figure 7, it can be observed that DG at bus 6 gave highest fault current when SLG fault occurs at bus 6. On the other hand, DG at bus 27 produce highest fault current when SLG fault occurs at bus 30. However, when SLG fault happened at bus 15, DG at bus 27 produced the highest fault current.

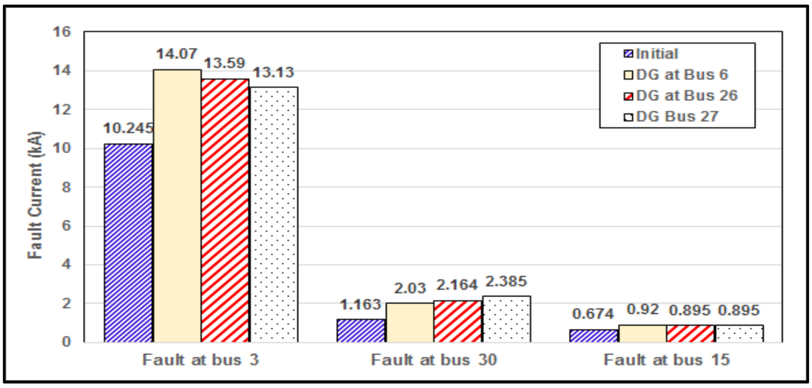

Figure 8. Double Line to Ground Fault

Similar observation can be seen in Figure 8 and Figure 9 for DLG and three phase fault where the highest fault current obtained when fault occurs near to DG location. From all the simulation results obtained using IEEE 33-bus distribution test system, it can be observed that the maximum fault current is 14.47kA when three phase fault occurs at bus 3 which is near to DG location.

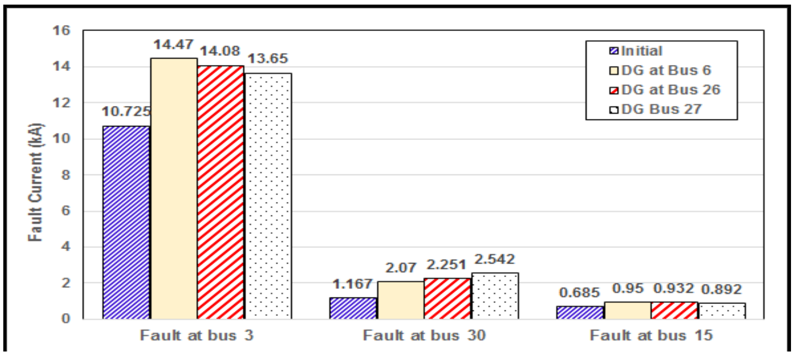

Figure 9. Three Phase Fault

3.2. Results of IEEE 69 Bus Test Systems

Similar analysis is carried out using bigger test system. The results of the optimal location of DG for IEEE 69-bus distribution test system is shown in Table 6.

Table 6. Minimum Voltage and Total Power Loss Before and After DG Allocation for IEEE 69-Bus Distribution Test System

	Min. voltage (pu)	∑Ploss (kW)
Initial	0.909	223
DG at Bus 61	0.973	22
DG at Bus 62	0.973	24
DG at Bus 64	0.971	40

From the results obtained in Table 6, the optimal location of DG for IEEE 69-bus test system is bus 61. However, for comparison purposes, bus 62 and bus 64 also selected. The sizes of the corresponding DG are tabulated in Table 7.

Table 7. Optimal Location and Sizing of DG for IEEE 69-Bus Distribution Test System

	PDG (MW)	QDG (MVar)
DG at Bus 61	1.843	1.269
DG at Bus 62	1.816	1.253
DG at Bus 64	1.606	1.129

Three buses are chosen for fault locations;

1. bus 6
2. bus 59
3. bus 65

Table 8 shows the results obtained when fault occur at bus 6 which is near to source. From the results presented, it can be observed that the percentage of fault current after installing DG at certain location is increase between 7%~24%. The maximum fault current is 16.69 kA which is three-phase fault with DG connected at bus 61. Similar analysis is carried out when fault occur at bus 59. The percentage increment of fault current is presented in Table 9.

As depicted in Table 9, it can be observed that the percentage of fault current after installing DG is increase between 239.28% ~ 555.90% depending on DG location. The highest fault current is 8.838kA when three phase fault occurs at bus 59 with DG located at bus 61. Meanwhile, the highest percentage of fault current increment is 555.9% when SLG fault occurs in the system with DG at bus 61. Table 10 shows the results obtained when fault occur at bus 65.

Table 8. Fault at bus 6

Type of Fault	DG location	Fault Current (kA)	%
SLG	existing	2.317	-
	Bus 61	2.88	24.30
	Bus 62	2.829	22.10
	Bus 64	2.741	18.30
DLG	existing	13.662	-
	Bus 61	14.94	9.35
	Bus 62	14.91	9.13
	Bus 64	14.72	7.74
3ph	existing	15.305	-
	Bus 61	16.62	8.59
	Bus 62	16.59	8.40
	Bus 64	16.39	7.09

Table 9. Fault at bus 59

Type of Fault	DG location	Fault Current (kA)	%
SLG	existing	0.703	-
	Bus 61	4.611	555.90
	Bus 62	3.492	396.73
	Bus 64	2.305	227.88
DLG	existing	1.423	-
	Bus 61	8.791	517.78
	Bus 62	7.84	450.95
	Bus 64	4.873	242.45
3ph	existing	1.474	-
	Bus 61	8.838	499.59
	Bus 62	8.102	449.66
	Bus 64	5.001	239.28

Table 10. Fault at bus 65

Type of Fault	DG location	Fault Current (kA)	%
SLG	Initial	0.462	-
	Bus 61	1.903	311.90
	Bus 62	2.323	402.81
	Bus 64	5.427	1074.68
DLG	Initial	0.855	-
	Bus 61	3.227	269.64
	Bus 62	3.392	288.55
	Bus 64	6.126	601.72
3ph	Initial	0.873	-
	Bus 61	3.266	281.99
	Bus 62	3.545	314.62
	Bus 64	6.931	710.64

From the results presented in Table 10, it can be observed that the highest value of fault current were obtained when DG is connected at bus 64 which is nearest to fault. The percentage increase of fault current after installing DG at bus 64 also highest compared to other DG locations. The highest percentage increase of fault current in IEEE 69-bus distribution system obtained when DG is connected at bus 64 and fault happened at bus 65. The comparison of fault current at various location of DG are illustrated in Figure 10, Figure 11 and Figure 12 for single line to ground (SLG), double line to ground (DLG) and three phase fault respectively.

The results presented in Figure 10 shows that DG at bus 61 gave highest fault current when SLG fault occurs at bus 6 and 59. On the other hand, DG at bus 64 produce highest fault current when SLG fault occurs at bus 65. Similar results could be seen for double line to ground fault and three phase fault as depicted in Figure 11 and Figure 12 where the fault current is increased tremendously when fault occurs near to DG location. It can be concluded that the installation of DG would give higher impact to the fault current especially when fault occurs at busses near to the DG.

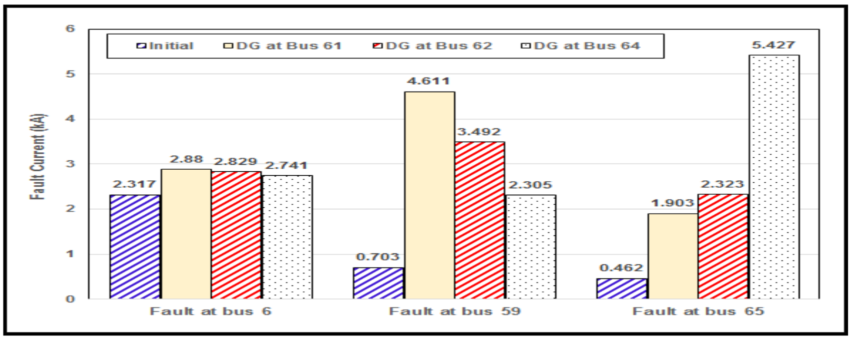

Figure 10. Single Line to Ground (SLG)

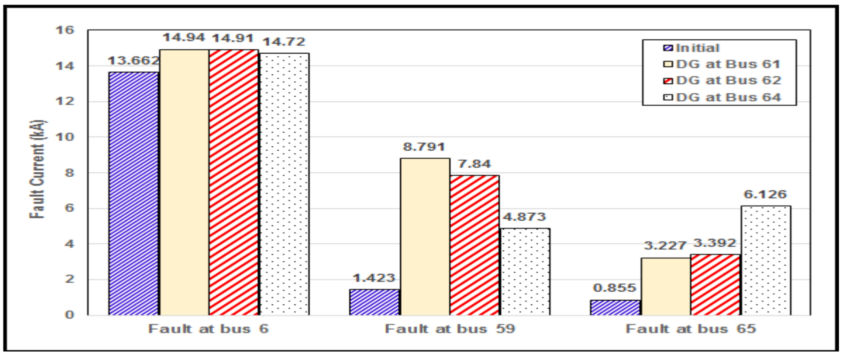

Figure 11. Double Line to Ground (DLG)

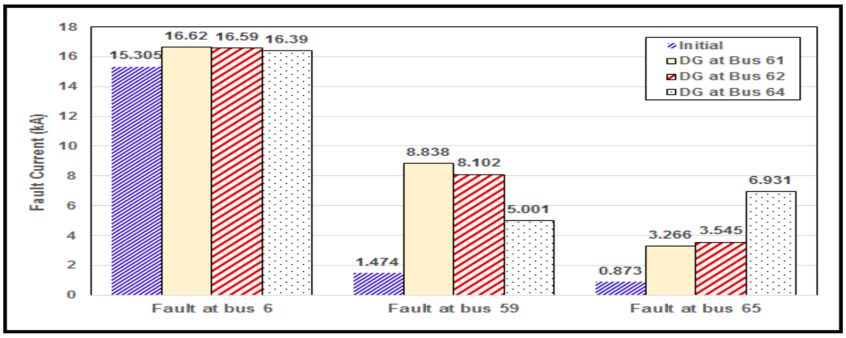

Figure 12. Three phase fault

4. Conclusion

This paper had presented the impact of distributed generation (DG) on fault current in distribution system. The optimal location of the DG is determined heuristically and the best three locations of DG with minimum power losses were chosen. The optimal sizing of the DG is obtained by the formula given in section II. Then, three types of fault current analysis which are single line to ground fault, double line to ground fault and three phase fault were obtained using PSS/Adept at various locations of fault. The results were compared with the initial condition without DG and the percentage different were calculated. The excessive fault current should be taken into consideration before implementation of DG. From the numerical simulation, the impact of DG to the fault current is significant especially when fault occurs at busses near to DG. The results obtained from this paper might be useful for power system engineer in planning suitable and proper protective fault current limiter at the distribution or substation site to prevent any miscellaneous occurrence tripping or disruption to users due to DG installation.

Acknowledgment

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Nomenclature

$\sum P_G$	total real generator power
$\sum Q_G$	total reactive generator power
$\sum P_{DG}$	total real DG power
$\sum Q_{DG}$	total reactive DG power
$\sum P_{load}$	total real load power
$\sum Q_{load}$	total reactive load power
$\sum P_{loss}$	total real power loss
$\sum Q_{loss}$	total reactive power loss
I_a, I_b, I_c	phase current
E_a	Internal voltage
Z_1	positive sequence impedance
Z_2	negative sequence impedance
Z_0	zero sequence impedance
Z_f	fault impedance
I_f	fault current
Z_{eq}	equivalent impedance

References

[1] Barker PP, Mello RWD. Determining the Impact of Distributed Generation on Power Systems. I. Radial Distribution Systems. *IEEE Power Engineering Society Summer Meeting.* 2000; 3: 1645-1656.
[2] Sailaja CVSS, Prasad PVN. Reliabilty and Cost Benefit Analysis of DG Integrated Distribution System. *Bulletin of Electrical Engineering and Informatics*. 2016; 5(4): 383–389.
[3] Nigam MK, Sethi VK. Optimal Location of Distributed Generation and its Impacts on Voltage Stability. *International Journal of Electrical and Computer Engineering (IJECE).* 2016; 6(2): 504–11.
[4] Pilehvarani AD, Hakimzadeh M, Far MJ, Sedaghati R. Application of GAMS and GA in the Location and Penetration of Distributed Generation. *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering.* 2014; 8(11): 1786–1789.
[5] Rani PS, Devi AL. Optimal Sizing of DG Units using Exact Loss Formula at Optimal Power Factor. *International Journal of Engineering Science and Technology (IJEST*). 2012; 4(9): 4043–4050.
[6] Eid AM, Akher MA, Ali AA, Kishky HE. Optimal Size and Location of Distributed Generation Unit for Voltage Stability Enhancement. *IEEE Energy Conversion Congress and Exposition.* 2011: 104–108.
[7] Rani PS, Devi AL. Sizing and Placement of Multi Distributed Generation Using Exact Loss Formula. *International Journal of Advanced Research in Electrical, Electronic and Instrumentation Engineering.* 2013; 2(11): 5741–5746.
[8] Tan WS, Hassan MY, Majid MS. *Multi Population Genetic Algorithm for Allocation and Sizing of Distributed Generation.* IEEE International Power Engineering and Optimization Conference (PEOCO). Melaka, Malaysia. 2012: 108-113.
[9] Aman MM, Jasmon GB, Bakar AHA, Mokhlis H. *A New Approach for Optimum DG Placement and Sizing Based on Voltage Stability Maximization and Minimization of Power Losses.* Energy Conversion and Management. 2013; 70: 202–210.
[10] Rao RS, Ravindra K, Satish K, Narasimham SVL. Power Loss Minimization in Distribution System Using Network Reconfiguration in the Presence of Distributed Generation. *IEEE/Transactions on Power Systems.* 2013; 28(1): 317–325.
[11] C Ozansoy. A Methodology for Determining *Fault Current Impact Coefficients of Distributed Energy Resources in an Adaptive Protection Scheme.* 9th International Conference on Electrical and Electronics Engineering (ELECO). 2015: 479-483.
[12] Shahriari SAA, Abapour M, Yazdian A, Haghifam MR. *Minimizing the Impact of Distributed Generation on Distribution Protection System by Solid State Fault Current Limiter*. Transmission and Distribution Conference and Exposition. New Orleans, LA, USA. 2010: 1–7.
[13] Baghaee HR, Mirsalim M, Sanjari MJ and Gharehpetian GB. *Effect of Type and Interconnection of DG Units in the Fault Current Level of Distribution Networks.* 13th IEEE Power Electronics and Motion Control Conference. 2008: 313-319.

[14] Hemmati S and Sadeh J. *Applying Superconductive Fault Current Limiter to Minimize the Impacts of Distributed Generation on the Distribution Protection Systems.* 11th IEEE conference on Environment and Electrical Engineering. 2012.
[15] Kalage AA, Ghawghawe ND. *Optimum Location of Superconducting Fault Current Limiter to Mitigate DG Impact*. 2nd International. Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB). 2016: 1-4.
[16] Rayudu SS, Ganesh C, Naik BV. Analysis of Superconducting Fault Current Limiterin DC System with Renewable Energy Sources. *Bulletin of Electrical Engineering and Informatics.* 2016; 5(3): 263-270.
[17] Kim Y, Jo H, Joo S. Analysis of Impacts of Superconducting Fault Current Limiter (SFCL) Placement on Distributed Generation (DG) Expansion. *IEEE Transactions. on Applied Superconductivity.* 2016; 26(4): 1-5.