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Analysis Impact of Distributed Generation Injection to Profile of Voltage and Short-Circuit Fault in 20 kV Distribution Network System

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Abstract. This study was a case study in PT. PLN (Ltd.) APJ Bandung area with the subject taken was the installation of distributed generation (DG) on 20-kV distribution channels. The purpose of this study is to find out the effect of DG to the changes in voltage profile and three-phase short circuit fault in the 20-kV distribution system with load conditions considered to be balanced. The reason for this research is to know how far DG can improve the voltage profile of the channel and to what degree DG can increase the three-phase short circuit fault on each bus. The method used in this study was comparing the simulation results of power flow and short-circuit fault using ETAP Power System software with manual calculations. The result obtained from the power current simulation before the installation of DG voltage was the drop at the end of the channel at 2.515%. Meanwhile, the three-phase short-circuit current fault before the DG installation at the beginning of the channel was 13.43 kA. After the installation of DG with injection of 50%, DG power obtained voltage drop at the end of the channel was 1.715% and the current fault at the beginning network was 14.05 kA. In addition, with injection of 90%, DG power obtained voltage drop at the end of the channel was 1.06% and the current fault at the beginning network was 14.13%.

1. Introduction

Large-capacity power plants are generally located far from the load center; therefore, a long transmission and distribution line are required to supply the load. This leads to voltage drop and power losses. On the other hand, the limited resources of fossil fuels which become the problems against the environment and the high cost of operating the transmission system and distribution systems in a system of conventional power plants has contributed to the development of small-scale power plants system near to the load centers and integrated with the grid through a distribution network known as a distributed generation (DG). In general, DG utilizes the technology of renewable energy resources such as solar energy, wind energy, small hydropower, as well as ICE (Internal Combustion Engine) [1].

In recent years, the use of DG has given the influences on the power system. International Council on Large Electric Systems defines the characteristic of DG is between 50 kW to 100 MW scale, distributed and close to load centers, and usually connected to the distribution network [2]. This power plant is environmentally friendly, restricting the construction of new transmission networks, reliably responding to load changes, and reducing fossil fuel use. Several studies on the impact of DG installation

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to the electric power systems show that DG has an impact on the improvement of the voltage profile and decrease of power losses at the load center [3]. The method applied to DG is likely similar to the use of capacitors to reduce power losses. What make it different is that DG can affect the active power and reactive power, meanwhile the installation of capacitor banks only affects the active power.

Several studies have shown that interconnection between power plants in the transmission system leads to the increase in short-circuit current disruption in the channel. Installation of DG to the distribution system can increase the current disturbance in the distribution system and provide new challenges in the distribution network protection system. The faults commonly occur are balanced load fault (Balanced Fault) and unbalanced load fault (Unbalanced Fault). The number of current faults depends on DG injection power and the installation type of DG in the distribution system [4]. The evaluation in distribution network protection system after DG installation must be conducted to maintain the quality and reliability of the system.

In this modern era, we are more facilitated by the number of software or programs that can help all our works to be quickly resolved. One of the programs that is commonly used in electric power system analysis is a program called Electrical Transient Analyzer Program (ETAP) v12.6.0. This program is able to work offline for simulation of electric power systems and online for real-time data management or system control. This program can be used to solve some problems in the power system more quickly and precisely.

2. Theoretical background

2.1. Distributed generation

The definition of Distributed Generation (DG) is generally based on the objective, the source of energy, capacity, location, and technology [5]. DG is commonly called on-site generation, dispersed generation, embedded generation, or decentralized generation. Basically, DG generates electrical energy from some small-capacity energy source and connected directly to the distribution network with a capacity between 50 kW to 500 MW, spread out, close to load centers, and environmentally friendly technologies. DG can be simply described as follows [6].

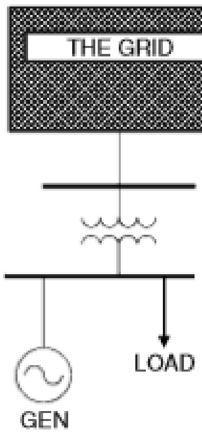

Figure 1. *Distributed Generation* Installed in Distribution Network

Electric power system problems, especially in the power quality is affected by DG are discussed in the following studies:

a) The Increase of Voltage Profile

Conventionally, electricity in the distribution system always flows from the relay station to the end of the repeater both in operation and planning. The farther from the source the smaller the voltage will be. This is in accordance with Ohm's law which states that the magnitude of the voltage is directly proportional to the current and the channel impedance. Before DG is installed, current will flow from the power grid to the end of the repeater. After DG is installed, current will flow from two sources, namely: the power grid and the DG injection point to the load. The selection of precise DG injection location will cause the current flowing in a channel will be reduced significantly and finally will minimize the voltage shrinkage[7].

b) The Decrease of Power Losses
The power losses in a channel are influenced by the magnitude of the current and the channel impedance referring to the formula $P = I^2R$. Due to the channel impedance in the distribution system has a constant value, power losses are more influenced by the amount of current flowing in the channel. The vary of DG injection locations will affect the large changes in current direction and current in the channel; therefore, it will affect a large power loss [2][7].

c) The Increase of Short-Circuit Current Fault
At the moment when the DG is not installed in the system, short-circuit current is merely the contribution of the power grid. The amount of short-circuit current fault is determined by the total impedance between the power grid to the point of interruption. This impedance includes the impedance of the power grid, relay station transformer, and channels. Installation of DG in the distribution system will lead to impedance changes of the system and will affect the short-circuit current fault. The amount of short-circuit current is determined by the impedance between the power grid to the fault location and the impedance between the DG to the fault location. The closer the fault location to the installation of DG, the greater the short-circuit current will be. This is due to getting closer to the DG, the channel impedance will be smaller thus the DG contribution to the short-circuit current fault will be greater[8].

2.2. Voltage profile
The voltage profile is the gap between the receiving end voltage and the voltage drop value, in which the voltage drop is caused by the resistance and current flowing on the channel. The electric power channel generally serves loads that have left power factor. The factors that underlie the variations in voltage value in the distribution system are[9]:
a) Customers generally use equipment that requires a certain voltage.
b) Location of the customers is widespread; therefore, the distance of each customer with the point of service is not the same.
c) Service centers cannot be placed evenly or spread.
d) A voltage drop occurs.

Customers who are far from the point of service will tend to receive relatively lower voltage than the customers who close to the service center; therefore, the voltage profile in the end of repeaters will usually be smaller. Some common methods used to improve voltage profile in distribution channels are [10]:
a) Application of automatic voltage regulators in distribution relay station.
b) Installation of capacitors in relay station.
c) Installation of parallel capacitors and series capacitors in primary distribution channels.
d) Use of transformer with tap variable.

Distorted waveforms can be decomposition submitted to a number of fundamental frequency and harmonic distortion coming from the characteristics of non-linear load and the load on the power system [6]. This nonlinearity is that the current is not proportional to the applied voltage. It can be seen in the picture below.

2.3. Voltage drop
The voltage drop is the amount of voltage lost in a conductor. The voltage drop in the power line is generally inversely proportional to the length of the channel and the load and inversely proportional to the cross-sectional area. The amount of voltage drops is symbolized in percent or in volt quantities. The amount of upper and lower limit is determined by the electricity company’s policy. The voltage drop is the cause of the loss on the channel because it can reduce the voltage of the load. Phasor voltage drop

(V_d) in the conductor that has an impedance (Z) and carrying a current (I) can be described in the formula [11].

$$V_d = I \times Z \qquad (2.1)$$

To calculate the voltage drops, the reactors as well as the unequal power factor of each other are calculated. To simplify the calculation, it is assumed that the loads are balanced three-phase loads and the power factor is between 0.6 and 0.85. The voltage can be calculated based on the interaction approach as follows [11].

$$\Delta V = I \times (R \times \cos\varphi + X \times \sin\varphi) \times L \qquad (2.2)$$

Where ΔV is the voltage drop value obtained by multiplying the current and total impedance with the length of channel.

2.4. Short-circuit fault

short-circuit is a disruption that occurs because of an error between the parts with voltage in the power system. short-circuit fault may be caused by the penetrating or damaged insulation because they are not resistant to overcurrent, either from inside or outside the system or due to lightning strikes.

this short-circuit fault can cause currents larger than the nominal current. if the short-circuit is left for long periods in an electric power system, it will decrease the reliability of the system as follows [4]:

a) the power supply system stability limits are decreased.
b) the components located close to the fault will be damaged since there is unbalanced currents
c) the components containing insulating oil will explode and may cause a fire.

analysis of short-circuit faults is required to learn the electrical power systems both during planning and after the operation. the short-circuit analysis is used to determine the protective relay settings used to protect the electrical system from possible faults. the benefits of short-circuit analysis in the electric power system are as follows [12]:

a) to determine the maximum and minimum current of short-circuit flowing in the power system.
b) to determine the current of the faults that will occur.
c) to set and coordinate the protection equipment.
d) to determine the capacity of the circuit breaker equipment to be used.
e) to determine the distribution of current faults and the busbar voltage level during the faults.

2.5. three-phase short-circuit fault

Three-phase short-circuit fault is included in the classification of symmetric faults, where the current or voltage flowing in each phase remains balanced after the fault occurs. Therefore, the fault in such systems can only be analyzed using only positive sequence components. The three-phase short-circuit can be seen in the following figure.

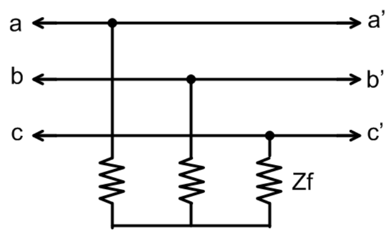

Figure 2. Three-phase Short-Circuit Fault

Three-phase short-circuit fault can be calculated by the following formula [11]:

$$I_a = I_1 = \frac{V_a}{Z_1 + Z_f} \qquad (2.3)$$

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where the short-circuit current is obtained from the calculation of the voltage flowing in phase to neutral divided by the total impedance of the positive sequence.

3. Methods

3.1. Research procedures

The procedures carried out in this study consist of several steps described as follows:

a) Make a model of network distribution system prior to the addition of DG with ETAP Power Station.
b) The data obtained on the field observation are included in the distribution system model.
c) Once the model is complete, the power flow simulation is performed to determine if the model is made correctly. If it is not complete yet, do the model improvement and simulate it again.
d) The simulation of short-circuit current fault is run by first determining the fault locations.
e) The results of power flow and short-circuit current fault simulations before DG injection are recorded.
f) Add DG into the attributed system model that has been created by first determining the location and capacity of DG injection.
g) Reperform the simulation of power flow and short-circuit current fault.
h) Perform some simulations by varying the location and the degree of DG injection power
i) Analyze the short-circuit current fault data that have been recorded.

3.2. Field data

The data obtained from the results of observation and research field are as follows:

a) Specification of Bengkok Hydropower Generator

The generator specification used as DG model in this research can be seen in table 1 below.

Table 1. Specification of Bengkok Hydropower Generator k

ID	**Rating**	
	kVA	**kV**
ESCHERWYSS 1	1.500	6
ESCHERWYSS 2	1.500	6
ESCHERWYSS 3	1.500	6

b) Specification of NDJ-NDO Repeater Transformer

Table 2. Specifications of NDJ-NDO Repeater Transformer

ID	**Rating**			**Load (A)**
	kVA	**Primer kV**	**Secondary kV**	
TRF 3 BDG.UTR	60.000	150	20	*1.562
UNP	630	20	0,38	909,35
BCAS	630	20	0,38	721,7
TSB	630	20	0,38	632
HHS	250	20	0,38	128,1
CTB	400	20	0,38	103
HVD	1.000	20	0,38	841,7
BCAJ	1.000	20	0,38	841,7
BM	630	20	0,38	509
BBR	630	20	0,38	525,7
CL	630	20	0,38	909,35
KTKS	400	20	0,38	331,2
BCAD	400	20	0,38	153,5
BB	630	20	0,38	712,6
BKS	250	20	0,38	208,1
EEP	250	20	0,38	56,37
DKL	250	20	0,38	89,38
DPZ	2 x 1.000	20	0,38	1665
ABT	630	20	0,38	632
GLL	250	20	0,38	43,45
BIPA	400	20	0,38	71,86

c) Data of Channel Impedance

Table 3. Impedance of Aluminum Cable

Sectional Area (mm)	**Impedance**	
	Sequence +/- (Ω/km)	**Sequence 0 (Ω/km)**
150	0,206 + j0,104	0,356 + j0,312
240	0,124 + j0,097	0,275 + j0,290
300	0,100 + j0,094	0,250 + j0,282

d) Distance between Channels

Table 4. Distance between Channels

Segment		Conductor Type	Channel Length (m)
GI. BDG UTR	UNP	NA2XSEBY 3 x 150 mm2	521
UNP	BCAS	NA2XSEBY 3 x 150 mm2	521
BCAS	TSB	NA2XSEBY 3 x 240 mm2	1.203
TSB	HHS	PILC 3 x 150 mm2	2.388
HHS	CTB	PILC 3 x 150 mm2	438
CTB	HVD	PILC 3 x 150 mm2	166
HVD	BCAJ	NA2XSEBY 3 x 240 mm2	555
BCAJ	BM	PILC 3 x 150 mm2	413
BM	BBR	NA2XSEBY 3 x 240 mm2	135
BM	CL	PILC 3 x 150 mm2	180
CL	KTKS	PILC 3 x 150 mm2	190
KTKS	BCAD	PILC 3 x 150 mm2	230
BCAD	BB	PILC 3 x 150 mm2	416
BB	BKS	NA2XSEBY 3 x 240 mm2	64
BB	EEP	PILC 3 x 150 mm2	318
EEP	DKL	NA2XSEBY 3 x 300 mm2	140
DKL	DPZ	NA2XSEBY 3 x 240 mm2	310
DPZ	ABT	PILC 3 x 150 mm2	220
ABT	GLL	PILC 3 x 150 mm2	335
GLL	BIPA	PILC 3 x 150 mm2	387
BIPA	GH. DAGO	NA2XSEBY 3 x 240 mm2	588
GH. DAGO	GI. BDG UTR	NA2XSEBY 3 x 300 mm2	7.235

Determination of Short-Circuit Fault Points

The fault point of the channel is the entire Medium Voltage Bus at the repeater with nominal voltage of 20 kV in which each of them will be simulated in three-phase short-circuit fault simulation.

Determination of Point and Injection Level of Distributed Generation

The point and injection level of DG in the channel is determined as follows:

a) The first injection point is at the bus TM HHS within 4.633 km from the power grid with the injection rate scenarios by respectively 50% and 90% of the capacity of DG.
b) The second injection point is at the bus TM DPZ within 8.733 km from the power grid with injection rate scenarios by respectively 50% and 90% of the capacity of DG

4. Results and discussion

4.1. Voltage profile of NDJ-NDO repeater before dg injection

The total load installed in the network is 6069 kVA. The simulation result of power flow obtained the comparison of voltage in each bus before DG injection. Table 4.1 shows the voltage in each medium voltage bus based on the power flow simulation results.

Table 5. Voltage Profile of NDJ-NDO Repeater before DG Injection

Bus	Voltage Profile (kV)	Voltage Drop (%)
Bus TM NDJ	19,84	0,80
Bus TM UNP	19,804	0,98
Bus TM BCAS	19,771	1,15
Bus TM TSB	19,722	1,39
Bus TM HHS	19,595	2,03
Bus TM CTB	19,572	2,14
Bus TM HVD	19,564	2,18
Bus TM BCAJ	19,553	2,24
Bus TM BM	19,537	2,32
Bus TM BBR	19,537	2,32
Bus TM CL	19,531	2,35
Bus TM KTKS	19,526	2,37
Bus TM BCAD	19,52	2,40
Bus TM BB	19,51	2,45
Bus TM BKS	19,51	2,45
Bus TM EEP	19,504	2,48
Bus TM DKL	19,502	2,49
Bus TM DPZ	19,499	2,51
Bus TM ABT	19,497	2,52
Bus TM GLL	19,497	2,52
Bus TM BIPA	19,497	2,52

Figure 3 shows the amount of the voltage along with a large percentage of the voltage shrinkage in each intermediate voltage bus with a constant load state.

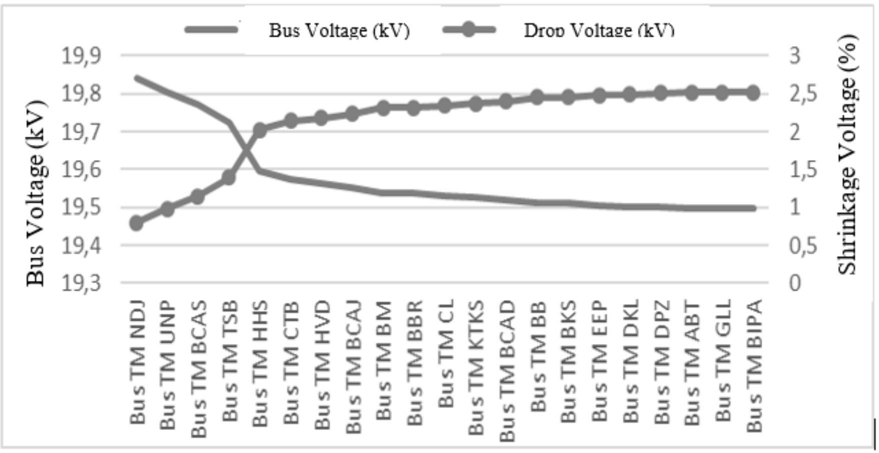

Figure 3. Comparison of Voltage Profile and Voltage Losses Before DG Injection

Figure 4.1 shows the voltage value at the beginning of the channel is 19.840 kV or experiencing voltage shrinkage at 0.8%, while the voltage value at the end of the channel is 19.497 kV or experiencing voltage shrinkage at 2.515%.

4.2. Three-phase short-circuit fault of NDJ-NDO repeater before dg injection

Table 6 shows the simulation results of three-phase short-circuit fault performed in NDJ-NDO repeater.

Table 6. Three-Phase Short-Circuit Fault of NDJ-NDO Repeater Before DG Injection

Point of Fault	Distance from Power Grid (km)	Short-Circuit Current Fault (kA)
Bus TM NDJ	0,521	13,43
Bus TM UNP	1,042	12,45
Bus TM BCAS	2,245	11,52
Bus TM TSB	4,633	10,03
Bus TM HHS	5,071	7,35
Bus TM CTB	5,237	6,99
Bus TM HVD	5,792	6,86
Bus TM BCAJ	6,337	6,46
Bus TM BM	6,75	6,18
Bus TM BBR	6,885	6,12
Bus TM CL	7,065	6,07
Bus TM KTKS	7,255	5,95
Bus TM BCAD	7,485	5,82
Bus TM BB	7,901	5,59
Bus TM BKS	7,965	5,57
Bus TM EEP	8,283	5,43
Bus TM DKL	8,423	5,38
Bus TM DPZ	8,733	5,27
Bus TM ABT	8,953	5,17
Bus TM GLL	9,288	5,02
Bus TM BIPA	9,675	4,86

The variation amount of three-phase short-circuits current fault (kA) at the fault point when the system is not connected with DG can be seen in Figure 4.

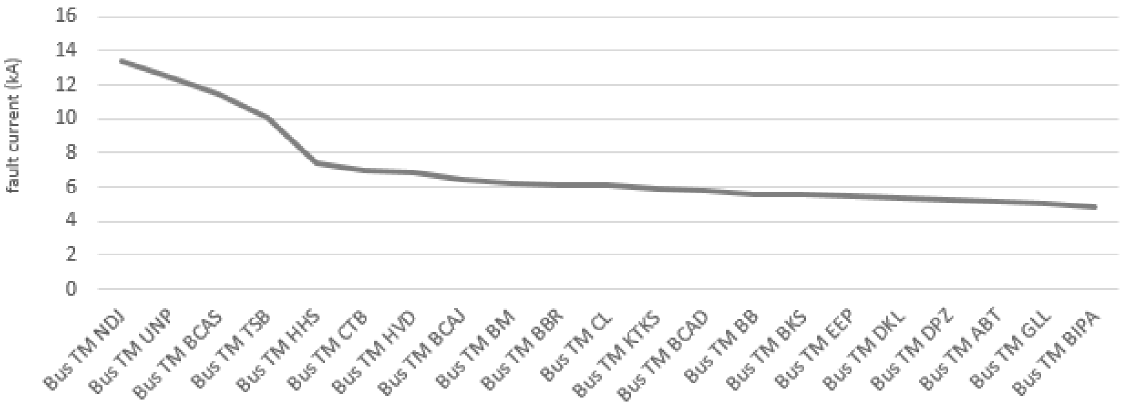

Figure 4. Three-Phase Short-Circuit Fault of NDJ-NDO Repeater Before DG Injection

The amount of three-phase short-circuits current generated by the system when it is not connected to DG as shown in Figure 4.2 depends on the fault location. The biggest current fault occurs in the TM NDJ bus i.e. 13.43 kA. Meanwhile, the smallest current fault is found in the bus TM BIPA i.e. 4.86 kA.

4.3. Voltage profile of NDJ-NDO repeater after DG injection in the TM HHS bus

The power flow simulation is performed after DG is injected in the network with respectively 50% of DG capacity or 1800 kW and 90% of DG capacity or 3240 kW. Table 7 shows the results of the power flow simulation on the NDJ-NDO repeater after DG injection in the TM HHS bus.

Table 7. Voltage Profile of NDJ-NDO Repeater after DG Injection in the TM HHS Bus

Bus	Voltage Profile (kV)			Voltage Drop (%)		
	Without DG	DG Injection 50%	DG Injection 90%	With DG	DG Injection 50%	DG Injection 90%
Bus TM NDJ	19,84	19,916	19,958	0,8	0,42	0,21
Bus TM UNP	19,804	19,892	19,945	0,98	0,54	0,275
Bus TM BCAS	19,771	19,871	19,935	1,145	0,645	0,325
Bus TM TSB	19,722	19,843	19,925	1,39	0,785	0,375
Bus TM HHS	19,595	19,771	19,903	2,025	1,145	0,485
Bus TM CTB	19,572	19,748	19,88	2,14	1,26	0,6
Bus TM HVD	19,564	19,739	19,871	2,18	1,305	0,645
Bus TM BCAJ	19,553	19,714	19,845	2,235	1,43	0,775
Bus TM BM	19,537	19,697	19,829	2,315	1,515	0,855
Bus TM BBR	19,537	19,697	19,828	2,315	1,515	0,86
Bus TM CL	19,531	19,691	19,823	2,345	1,545	0,885
Bus TM KTKS	19,526	19,696	19,817	2,37	1,52	0,915
Bus TM BCAD	19,52	19,68	19,811	2,4	1,6	0,945
Bus TM BB	19,51	19,669	19,801	2,45	1,655	0,995
Bus TM BKS	19,51	19,669	19,801	2,45	1,655	0,995
Bus TM EEP	19,504	19,664	19,795	2,48	1,68	1,025
Bus TM DKL	19,502	19,662	19,793	2,49	1,69	1,035
Bus TM DPZ	19,499	19,658	19,79	2,505	1,71	1,05
Bus TM ABT	19,497	19,657	19,788	2,515	1,715	1,06
Bus TM GLL	19,497	19,657	19,788	2,515	1,715	1,06
Bus TM BIPA	19,497	19,657	19,788	2,515	1,715	1,06

Figure 5 shows the change in voltage profile of the system after the power in DG is injected in the TM HHS bus with respectively 50% and 90% of DG power.

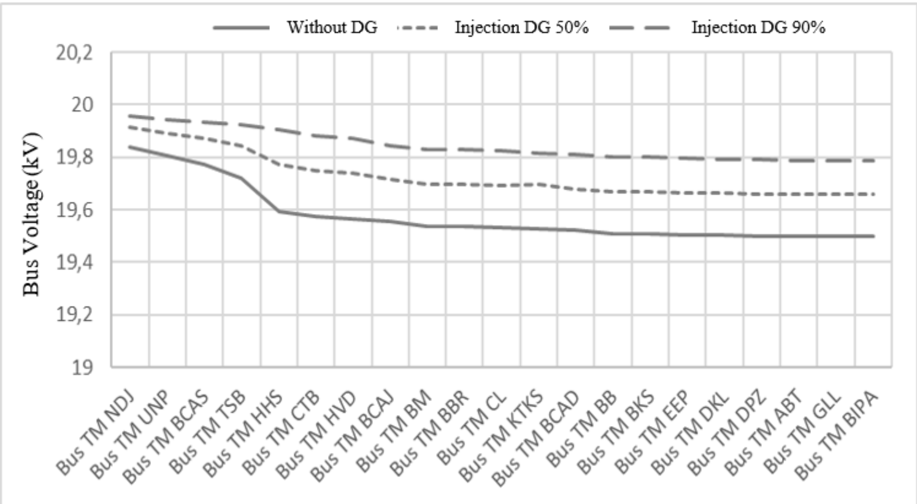

Figure 5. The Change of Voltage Profile of NDJ-NDO Repeater after DG Injection in the TM HHS Bus

Each injection provides a change in the voltage profile across the entire system. The greater the injection DG the more increase the voltage profile will be as shown in Figure 4.3 where the injection 50% of the DG capacity provide improvements to the voltage in the TM NDJ bus in the beginning channel at 19.916 kV until the voltage at the end of the channel at 19.657 kV. Meanwhile, 90% injection of DG capacity provides a voltage correction at 19,958 kV in the beginning channel until the voltage at the end of the channel at 19.788 kV.

4.4. Three-phase short-circuit fault of NDJ-NDO repeater after DG injection in TM HHS bus

The simulation result of three-phase short-circuit fault after DG installed in TM HHS bus can be seen in table

Table 8. Three-Phase Short-Circuit Fault of NDJ-NDO Repeater After DG Injection in TM HHS Bus

Point of Fault	Short-Circuit Current Fault (kA)		
	With DG	DG Injection	
		50%	90%
Bus TM NDJ	13,43	14,08	14,14
Bus TM UNP	12,45	13,09	13,16
Bus TM BCAS	11,52	12,15	12,21
Bus TM TSB	10,03	10,65	10,71
Bus TM HHS	7,35	7,92	7,79
Bus TM CTB	6,99	7,51	7,57
Bus TM HVD	6,86	7,37	7,42
Bus TM BCAJ	6,46	6,91	6,96
Bus TM BM	6,18	6,60	6,64
Bus TM BBR	6,12	6,53	6,51
Bus TM CL	6,07	6,47	6,37
Bus TM KTKS	5,95	6,34	6,38
Bus TM BCAD	5,82	6,19	6,23
Bus TM BB	5,59	5,94	5,97
Bus TM BKS	5,57	5,91	5,94
Bus TM EEP	5,43	5,75	5,79
Bus TM DKL	5,38	5,71	5,74
Bus TM DPZ	5,27	5,58	5,62
Bus TM ABT	5,17	5,47	5,5
Bus TM GLL	5,02	5,30	5,33
Bus TM BIPA	4,86	5,13	5,15

The change amount of the three-phase short-circuits current in all buses after DG injection in the TM HHS bus with 50% and 90% respectively of DG power can be seen in Figure 6.

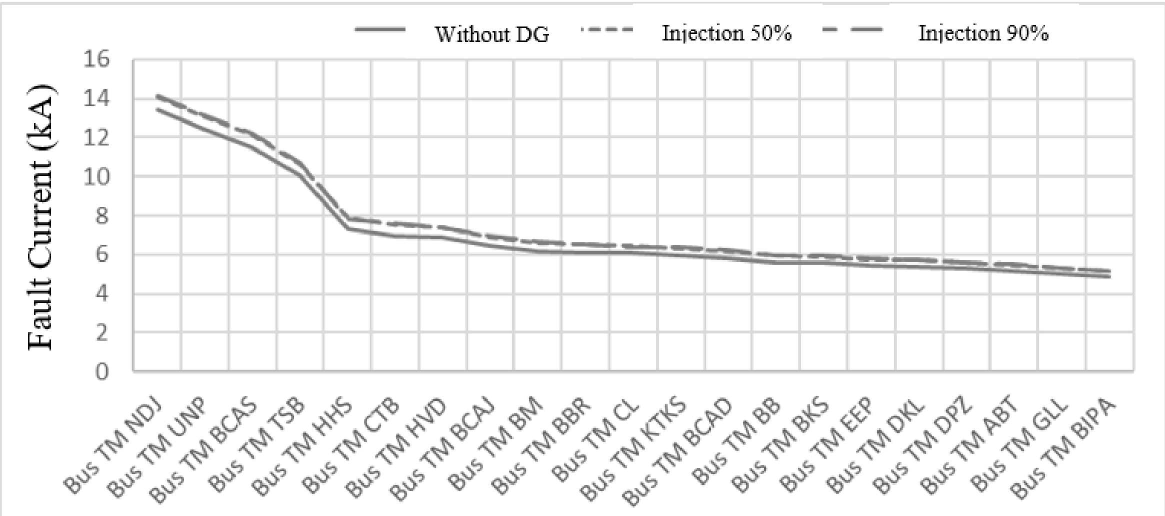

Figure 6. Three-Phase Short-Circuit Fault of NDJ-NDO Repeater After DG Injection in TM HHS Bus

With 50% injection of DG capacity, the current fault in the TM NDJ bus located at the beginning of the channel increased from 13.43 kA to 14.05 kA. Whereas with 90% injection of DG capacity, the current fault in the TM NDJ bus increased from 13.43 kA to 14.13 kA.

4.5. Voltage profile of NDJ-NDO repeater after DG injection in the TM DPZ bus

Table 9 shows the simulation results of power flow in NDJ-NDO repeater after DG installation in TM DPZ bus.

Table 9. Voltage Profile of NDJ-NDO Repeater after DG Injection in the TM DPZ Bus

Bus	Voltage Profile (kV)			Voltage Drop (%)		
	With DG	DG Injection		Without DG	DG Injection	
		50%	90%		50%	90%
Bus TM NDJ	19,84	19,915	19,948	0,8	0,42	0,26
Bus TM UNP	19,804	19,891	19,935	0,98	0,54	0,32
Bus TM BCAS	19,771	19,87	19,925	1,145	0,65	0,37
Bus TM TSB	19,722	19,841	19,915	1,39	0,79	0,42
Bus TM HHS	19,595	19,768	19,894	2,025	1,16	0,53
Bus TM CTB	19,572	19,755	19,89	2,14	1,22	0,55
Bus TM HVD	19,564	19,75	19,889	2,18	1,25	0,55
Bus TM BCAJ	19,539	19,737	19,889	2,305	1,31	0,55
Bus TM BM	19,523	19,73	19,891	2,385	1,35	0,54
Bus TM BBR	19,522	19,73	19,891	2,39	1,35	0,54
Bus TM CL	19,517	19,729	19,893	2,415	1,35	0,53
Bus TM KTKS	19,511	19,728	19,896	2,445	1,36	0,52
Bus TM BCAD	19,505	19,727	19,901	2,475	1,36	0,49
Bus TM BB	19,495	19,726	19,909	2,525	1,37	0,45
Bus TM BKS	19,495	19,726	19,909	2,525	1,37	0,45
Bus TM EEP	19,489	19,727	19,918	2,555	1,36	0,41
Bus TM DKL	19,488	19,728	19,92	2,56	1,36	0,4
Bus TM DPZ	19,484	19,729	19,926	2,58	1,35	0,37
Bus TM ABT	19,483	19,728	19,925	2,585	1,36	0,37
Bus TM GLL	19,483	19,728	19,925	2,585	1,36	0,37
Bus TM BIPA	19,482	19,728	19,924	2,59	1,36	0,38

Figure 7 shows the change in voltage profile of the system after power in DG is injected in the TM DPZ bus with 50% and 90% of the DG power respectively.

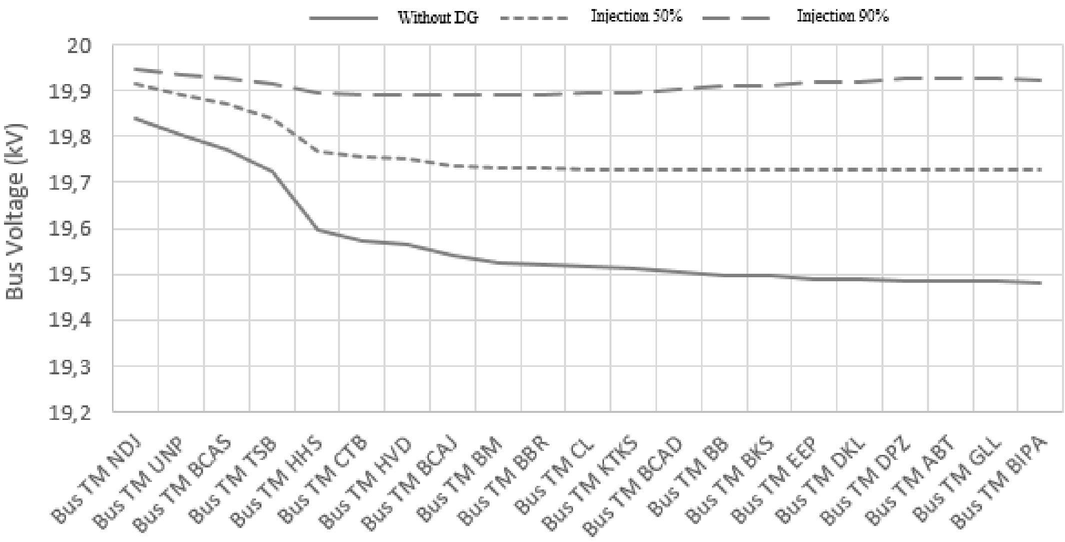

Figure 7. Voltage Profile of NDJ-NDO Repeater after DG Injection in the TM DPZ Bus

Figure 7 shows that 50% injection of DG capacity provides the voltage correction at 19.84 kV in the beginning of channel into 19.917 kV at the end of the channel that previously from 19.497 kV into 19.728 kV. 90% injection of DG capacity provides the voltage correction at 19.948 kV in the beginning channel into 19.924 kV at the end of channel.

4.6. Three-phase short-circuit Fault of NDJ-NDO repeater after DG injection in TM DPZ bus

The simulation result of three-phase short-circuit fault of NDJ-NDO repeater after DG installed in TM DPZ bus can be seen in table 10.

Table 10. Three-Phase Short-Circuit Fault of NDJ-NDO Repeater After DG Injection in TM DPZ Bus

Point of Fault	Short-Circuit Current Fault (kA)		
	Without DG	DG Injection	
		50%	90%
Bus TM NDJ	13,43	14,05	14,13
Bus TM UNP	12,45	13,07	13,15
Bus TM BCAS	11,52	12,13	12,21
Bus TM TSB	10,03	10,63	10,71
Bus TM HHS	7,35	7,91	7,98
Bus TM CTB	6,99	7,54	7,61
Bus TM HVD	6,86	7,41	7,48
Bus TM BCAJ	6,46	6,99	7,07
Bus TM BM	6,18	6,71	6,78
Bus TM BBR	6,12	6,64	6,71
Bus TM CL	6,07	6,6	6,67
Bus TM KTKS	5,95	6,48	6,55
Bus TM BCAD	5,82	6,34	6,41
Bus TM BB	5,59	6,11	6,18
Bus TM BKS	5,57	6,08	6,15
Bus TM EEP	5,43	5,94	6,01
Bus TM DKL	5,38	5,89	5,96
Bus TM DPZ	5,27	5,79	5,86
Bus TM ABT	5,17	5,67	5,73
Bus TM GLL	5,02	5,49	5,56
Bus TM BIPA	4,86	5,3	5,36

The change amount of three-phase short-circuit fault of NDJ-NDO repeater after DG injection in TM DPZ Bus can be seen in Figure 8.

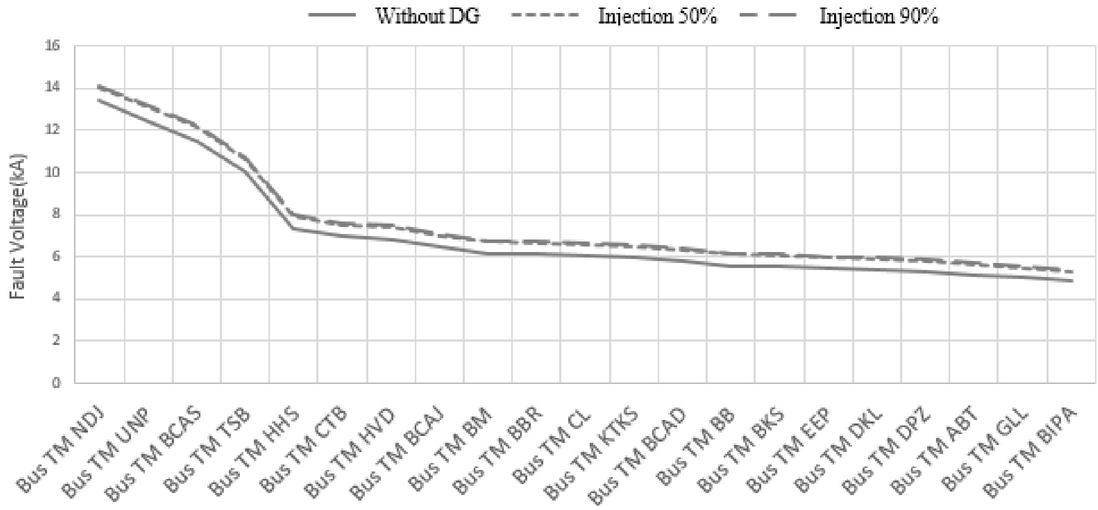

Figure 8. Three-Phase Short-Circuit Fault of NDJ-NDO Repeater After DG Injection in TM DPZ Bus

From the above simulation results, there is a change of current fault in the bus after DG injection. With the injection 50% of the DG capacity, three-phase short-circuit current fault in the TM NDJ bus at the beginning of the channel experienced increase from 14.05 kA into kA 13.43. Whereas with 90% injection of DG capacity, the current fault in TM NDJ bus experienced increase of 13.43 kA in the beginning of the channel to 14.13 kA at the end of the channel.

4.7. Effect of DG injection to voltage profile

In general, DG injection in 20 kV distribution network decreases value of the voltage drop and increases the voltage profile in the channel. It happens because each DG injection scenario in the channel will change loading current in the channel. Therefore, a fixed value of resistance and reactance and a smaller loading current will make voltage drop become smaller. The greater the DG power in the injection, the smaller the voltage drop in the channel will be, and the voltage profile will increase.

DG injection point also affects the value of the voltage drop. It can be seen from the result of TM DPZ bus within 8.733 km from the power grid with injection power at 90%, the value of the voltage drop at the end of the channel is at 0.38%. While the results of injection in TM HHS bus within 4.633 km from the power grid with the injection at 90%, the value of the voltage drop at the end of the channel is at 1.06%. Therefore, the closer the point of DG injection with the end of the channel, the smaller the value of the voltage drop in the channel will be.

4.8. Three-phase short-circuit fault of NDJ-NDO repeater after DG injection in TM HHS bus

DG injection in the 20 kV distribution network system increases the amount of three-phase short-circuit current. It happens when because when DG has not been installed in the system, the amount of three-phase short-circuit current fault only comes from the transformer impedances of the power grid and the source equivalent impedance to the fault point. Whereas after DG is installed, the amount of DG impedance and the DG equivalent impedance to the fault point is considered. With the existence of DG, the load which is initially supplied from the power grid will be supplied from the DG.

5. Conclusion

From the research results, it can be concluded as follows:

a) The result of power flow simulation and voltage drop calculation after DG injection in TM HHS bus and TM DPZ bus with 50% and 90% DG injection respectively give significant decrease of voltage drop value in the channel and increase the voltage profile in the channel. The increase of voltage profile depends on the DG injection point and the of DG injection power.
b) Three-phase short-circuit fault occurs after DG injection in the TM HHS bus and the TM DPZ bus with 50% and 90% DG power injection respectively. The increase in three-phase current fault depends on the amount of the power injection in the DG.
c) The average voltage in the NDJ-NDO repeater before DG injection was 19.576 kV. The average voltage of the repeater after DG injection at 50% and 9 0% in the TM HHS bus were 19.726 kV and 19.844 kV respectively. Meanwhile, the average voltage of the repeater after DG injection at 50% and 90% in the TM DPZ bus were 19.761 kV and 19.910 kV respectively. The increase in the value of the average voltage in the repeater was directly proportional to the amount of DG power injection in the repeater.
d) The percentage increase of three-phase short-circuits current fault in the NDJ-NDO repeater in Bandung area after DG injection at 50% and 90% in TM HHS bus were 7.76% and 8.30% respectively. While the percentage increase of the amount of three-phase short-circuits current fault after DG injection at 50% and 90% in the TM DPZ bus respectively were 9.87% and 11.20% respectively.

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