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OPTIMIZATION SCHEME OF DISTRIBUTED GENERATION INSTALLATION GROWTH CONSIDERING NETWORK POWER QUALITY

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ABSTRACT

The distributed generation (DG) installation growth must be anticipated, primarily by electrical power network operator. An unmanaged DG installation will cause problems of network power quality. This research discussed optimization scheme of DG installation growth considering network power quality. This research was conducted by using multi-type DG eg. capability to inject active power only, capability to inject active and reactive power and capability to inject active power and to absorb reactive power. The three types of DG were connected simultaneously to the network. The objective of this research was obtaining the maximum allowable DG penetration on the network and based on the result, arranging the DG installation growth scenarios at 75, 50, and 25 % level. The Particle Swarm Optimization (PSO) based optimization method was conducted to obtain maximum allowable DG penetration on the network. The DG optimization in this research was expected to obtain minimum network active power losses with network voltage value within 0.95 – 1.1 pu standard value. The proposed optimization scheme was implemented on the IEEE 30 bus network. Based on optimization result, DG was distributed on 8 distribution load bus with maximum 205 MW+ j1 Mvar total capacity. The optimization result indicated that DG penetration improving network power quality. After DG optimization, the network active power losses was reduced by 74.176 %. The voltage of entire bus were still maintained within 0.95-1.1 pu standard value even though network average voltage was increased by 2.066 %. For 75, 50 and 25 % DG growth installation scenario, the active power losses was reduced by 69.2, 55.7, 33.96 %, respectively and the network average voltage was increased by 1.9472, 1.6869, 1.2257 %, respectively.

Keywords: *Optimization Scheme, Multi-Type Distributed Generation (DG), Particle Swarm Optimization (PSO), Power Quality*

1. INTRODUCTION

The distributed generation (DG) is an electrical power generation system based on dispersing small-scale electrical power generation unit on power system. The DG is generally connected to distribution network even though it possible to connect with transmission network [1],[2].

Nowdays, the DG has been developed rapidly. The development is supported by investment and electricity market opening for DG [3]. From regulation aspect, DG is also possible to be built and owned by final user/community in addition to project developer and utility [4]. The DG plant technology is also designed to be more efficient and environmental friendly. Thus, it is not surprising that the DG system will play an important role in the future [5].

In the future, the DG development by final user/ community will take massively. It will be one of network operator main challenge. The DG with varies of type, capacity and location can make an affect on network power quality. The negative impact on network power quality can occured if DG development is not well regulated. The impact includes voltage profile deterioration and harmonic incidences on network.

The planning development scheme to ancipate the DG growth is a necessity for electrical network operator. The planning should ensures network capability to accept DG presence. Thus, the planning will regulate the capacity, location and type of DG. The DG installation must be correlated with network power quality improvement. The improving network power quality includes power losses reduction and voltage profile enhancement. The planning scheme should be optimal scale from the technical aspects. Therefore, the optimization techniques must be conducted to determine the DG penetration level into network. The optimization techniques allow the DG penetration achievement while satisfying a number of constraints that has been determined.

This research discussed optimization scheme of DG installation growth considering network power quality using Particle Swarm Optimization (PSO) method. The objective of this research was obtaining maximum allowable DG penetration on network and based on the result, arranging the DG growth scenario at 75, 50, and 25 % level. Minimization of network active power losses was formulated as optimization objective function. Ensuring network voltage within determined standard value (0.95 – 1.1 pu) was formulated as the one of optimization main constraint. Thus, the DG optimization in this research expected to obtain minimum active power losses with network voltage within 0.95 – 1.1 pu standard value.

The optimization schemes was implemented on IEEE 30 bus network. The optimization results presented optimal distribution of active power capacity, reactive power capacity and location of DG on the network. Based on the optimization result, the DG penetration scenario at 75, 50, and 25 % was also created in this research

This research had several research questions to be answered. They were:
1. For maximum allowable DG penetration condition, how obtained the optimal distribution of DG capacity (active and reactive power capacity) on candidate location of DG (network distribution load buses)?
2. How the comparison of network active power losses before and after DG optimization?
3. How the comparison of network voltage before and after DG optimization?
4. How the network active power losses and average voltage for 75, 50 and 25 % DG penetration level ?

The optimization schemes was proposed in this research can be implemented on other network. Thus, this optimization scheme can be used as one of reference in DG-grid connected planning. This optimization scheme can be utilized as DG development regulation and restriction method by electrical network operator.

2. LIMITATION OF STUDY

This study had several limitations. They were:
1. The load of network was assumed not change before and after DG optimization.
2. The DG optimization scheme considered network power quality only. They were active power losses and voltage of network.
3. The result of optimization process was based on multi-type DG initial capacity had been selected.

3. LITERATURE REVIEW

The research to determine the DG penetration level on the network had been conducted by several previous researchers. Reference [6] discussed DG penetration capacity determination using analytic method. The objective research was obtaining DG allowable penetration level on a distribution network before harmonic voltage limit (as specified in IEEE 519-1992) was exceeded. Reference [7] discussed maximum possible DG penetration on a distribution network. The research had form of technical constraints, namely thermal rating, transformer capacity, voltage profile and short circuit. The DG was modeled generating active power only. The analytical method was used in this research.

Reference [8] proposed the evaluation of DG maximum allowable capacity connecting to distribution grid considering network short circuit capacity. In the research, DG location and capacity were predetermined. The research recommended network operating conditions in accordance with the DG installation. The Dual Genetic Algorithm method was used in the research. In reference [9], a research of DG penetration optimization on distributed electric power systems was conducted. The DG effect on distribution network stability and control was analyzed using voltage and losses review limit. The objective research was maximising the DG penetration while technical safety levels maintaining.

Reference [10] discussed DG location and sizing optimization on a distribution system. The research used losses minimization, voltage profile improvement and voltage stability improvement as objective functions. In the research, DG was modeled injecting active power only. A combination of Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) was used in the research. In reference [11], an IPSO and Monte Carlo method was implemented for DG location and sizing optimization. The research used cost active and reactive losses minimization, voltage profile improvement and system reliability improvement as objective functions. The DG was modeled as an active power plant.

This research was different with the previous researches. In this research, the network power quality became a major consideration of DG penetration. The multi-type DG was also used in this research. The previous researches used only single-type DG [6]-[11]. In the previous research, DG was modeled to generate active power only [6]-[11]. In this research, three types of DG were connected simultaneously to network. In fact, reference [12] and [13] had been used multi-type DG. The multi-type DGs in those researches were used for optimization of DG capacity and location. In those researches, number of DG units connecting with network had been predetermined. Each of DG unit had active and reactive power capacity within specified range values

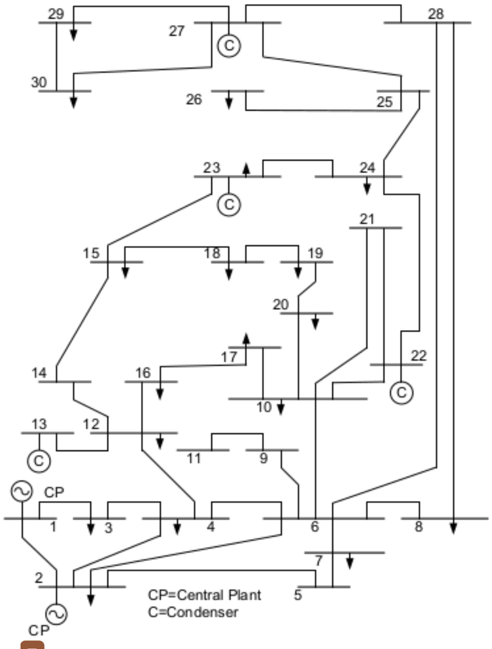

Figure 1: The Single Line Diagram Of IEEE 30 Bus Network

4. PROPOSED OPTIMIZATION SCHEME

The proposed optimization scheme in this research was divided into several steps. The steps of scheme was explained as follows.

4.1 Determination of Research Plant

The research plant was needed for optimization scheme implementation. This research used the IEEE 30 bus network The original data was found at reference [14]. The research plant was also found at reference [12],[13]. The total load of network was 283.4 MW + j126.2 Mvar. The network voltages were 132 kV, 33 kV, 11 kV and 1 kV. The network had 24 load bus where 18 load bus had 33 kV voltage. The number of buses were 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, and 30. In this research, the DG was assumed to connect with those distribution load buses. In this optimization scheme, the network load was assumed not to change. The single line diagram of the IEEE 30 bus network was showed in figure 1 [12].

4.2 Formulation of Optimization Objective Function and Constraints

This research used active power losses minimization objective function. The objective function was formulated by equation (1).

$$Min\ F = \sum_{i=1}^{N_L} P_{loss-w-DG} - P_{loss-wo-DG} \qquad (1)$$

$$i = 1,2,3,...N_s$$

where F was a function of total active power losses, N_L was total number of network line, $P_{loss\text{-}w\text{-}DG}$ was active losses with DG and $P_{loss\text{-}wo\text{-}DG}$ was active losses without DG.

The optimization process was limited by a number of constraints. The two power quality parameter constraints were voltage profile and active losses value. The other was power equality constraint.

The voltage constraint was lower and upper voltage limit value that can not be violated during optimization process. The lower voltage limit was set at 0.95 pu, while the upper voltage limit was set at 1.1 pu. The voltage constraint was formulated by equation (2).

$$\left|V_i\right|_{\min} \le \left|V_i\right| \le \left|V_i\right|_{\max} \quad i = 1,2,...N_B \qquad (2)$$

$$V_{i\min} = 0.95\ pu,\ V_{i\max} = 1.1\ pu$$

where V_{imin} was the lower voltage limit value, V_{imax} was the upper voltage limit value, V_i was voltage value bus i and N_B was the number of network buses.

The active losses constraint was a rule that the total network active losses value after connecting with DG less than or equal with the total network active losses value before connecting with DG. This constraint was formulated by the equation (3).

$$P_{loss-w-DG} \leq P_{loss-wo-DG} \tag{3}$$

where $P_{loss\text{-}w\text{-}DG}$ was total network active losses after connecting with DG and $P_{loss\text{-}wo\text{-}DG}$ was total network active losses before connecting with DG.

The power equality constraint explained the equilibrium rules of generating power, load power and power losses value on network. The constraint was expressed in equation (4) and (5) [15]:

$$P_{Gi} - P_{Li} - \sum_{k=1}^{N_B} |V_j||V_k|(G_{jk} \cos\theta_{jk} + B_{jk} \sin\theta_{jk}) = 0$$
$$i = 1,2,3,\ldots, N_B - 1 \tag{4}$$

$$Q_{Gi} - Q_{Li} - \sum_{k=1}^{N_B} |V_j||V_k|(G_{jk} \cos\theta_{jk} + B_{jk} \sin\theta_{jk}) = 0$$
$$i = 1,2,3,\ldots, N_B - 1 \tag{5}$$

where P_{Gi} was active power generation at the bus i, Q_{Gi} was reactive power generation at bus i, P_{Li} and Q_{Li} were active and reactive power load at bus i, V_j was bus voltage at bus j, V_k was bus voltage at bus k, G_{jk} was the conductance between bus j and k, B_{jk} was the suceptance between bus j and bus k, θ_{jk} was the voltage angle between bus j and bus k, N_B was the total number of network buses.

4.3 Determination of DG Type and Initial Capacity

This research used multi-type DG. The multi-type DG was consisted of three types of DG. The DG type was classified based on power generating and or absorbing by DG [12],[13]. The three types of DG were:

1. DG type 1 had capability to inject active power only.
2. DG type 2 had capability to inject active power and reactive power.
3. DG type 3 had capability to inject active power and to absorb reactive power.

The optimization scheme of DG installation growth program required initial capacity of the DG. The DG initial capacity that using in this research was presented in table 1.

Table 1: DG Initial Capacity

No	DG Type	Initial Capacity (MW ± Mvar)
1	DG Type 1	5 + j0
2	DG Type 2	5 + j1
3	DG Type 3	5 - j0.5

4.4 Conduction of Maximum Allowable DG Penetration Optimization Program

The maximum allowable DG penetration was determined by using the PSO based optimization program. The Newton-Raphson load flow program developing by Hadi Saadat became an integral part of this optimization program [16]. The load flow program was conducted to check active losses and voltage profile value. The optimization program was created in MATLAB programming language.

The PSO based optimization program used a number of parameters. The parameters were presented in table 2.

Table 2: The PSO Parameters

No	Parameter	Value
1	Swarm	10
2	Acceleration coefficient, c_1	0.7
3	Acceleration coefficient, c_2	0.9
4	Weight factor, w	0.4
5	Maximum iteration, *iter max*	400

The optimization procedures using PSO were described as follows [13].

a. Particle position and velocity initialization.

Initialization was conducted to position and velocity of particle. The particle position was expressed in equation (6).

$$X_i^0 = (P_{i1-1}\ P_{i1-2}\ P_{i1-3}\ Q_{i1-1}\ Q_{i1-2}\ Q_{i1-3})\ \ldots$$
$$(P_{im-1}\ P_{im-2}\ P_{im-3}\ Q_{im-1}\ Q_{im-2}\ Q_{im-3}) \tag{6}$$

where:

X_i^0 = particle position at *1st* iteration
P_{im-1} = DG type 1 active power capacity at bus m
P_{im-2} = DG type 2 active power capacity at bus m
P_{im-3} = DG type 3 active power capacity at bus m
Q_{im-1} = DG type 1 active power capacity at bus m

Q_{im-2} = DG type 2 active power capacity at bus *m*
Q_{im-3} = DG type 3 active power capacity at bus *m*

For *1st* iteration, the particle *i* had a velocity as expressed in equation (7).

$$V_i^0 = (v_{i1},...,v_{im}) \quad (7)$$

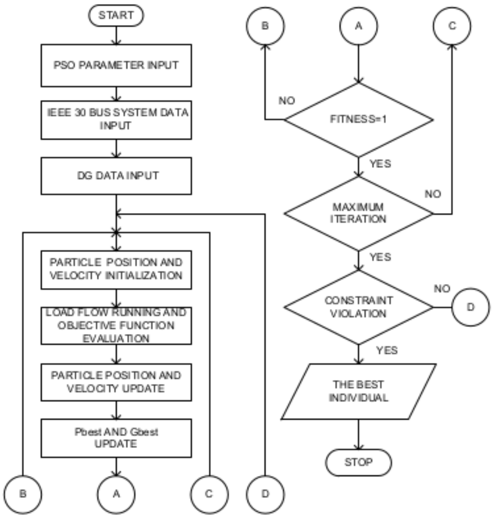

Figure 2: Optimization Process Using PSO

b. Evaluation of fitness value for each particle.

The optimization objective function was used to evaluate each particle. The evaluations took into account possible violation of constraint.

c. Comparison of fitness value for each particle with its *Pbest*.

If the fitness value of particles better than *Pbest* then *Pbest* set as based on that value.

d. *Pbest* for each individual at *k+1* iteration was modified using the equation (8) and (9).

$$Pbest_i^{k+1} = X_i^{k+1} \text{ if } TC_i^{k+1} < TC_i^k \quad (8)$$

$$Pbest_i^{k+1} = Pbest_i^k \text{ if } TC_i^{k+1} < TC_i^k . \quad (9)$$

objective function evaluation at individual position *i* was expressed by TC_i. After evaluation, *Gbest* at *k+1* iteration was also set as the best position. It was applied same to $Pbest_i^{k+1}$.

e. Particles with best result was further identified.

f. Particle position and velocity updating

g. Returned to step 1 untill the desired criteria had been achieved. Optimization process stopped when met two conditions. The condition were the maximum number of iterations had been reached or had been a constraint violation. The optimization process flow chart using PSO was expressed in figure 2.

4.5 Checking of Network Active Losses and Voltage Profile

The next step was active losses and voltage profile checking. The active losses for each line and total network active losses were checked. The voltage checking included voltage value for each bus. The buses voltage were investigated to ensure that all of bus voltage remained within standar value. The total average voltage increasing was also checked and compared with initial voltage.

4.6 Conduction of Several DG Installation Growth Scenario

The DG installation growth scenario was required if DG was installed through certain stages. It had an implication to recalculate active losses and voltage profile value for every DG installation level.

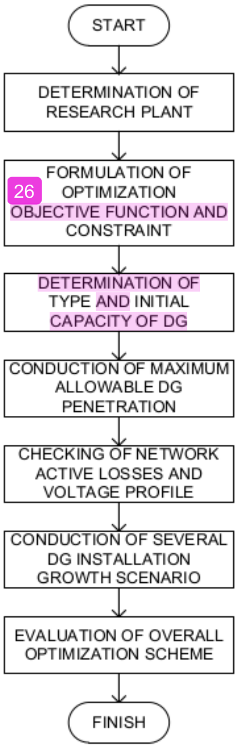

Figure 3: The DG Optimization Schema

4.7 Evaluation of Overall Optimization Scheme

The evaluation of the entire optimization scheme was required to ensure the scheme was runned well as expected. The DG optimization scheme steps was expressed through a flow chart as figure 3.

5. RESULTS

The simulation results for maximum allowable DG penetration was presented in table 3. The table presented simulation result for optimal distribution of active and reactive power capacity on network buses.

Table 3: Maximum Allowable DG Penetration On IEEE 30 Bus Network

No	Bus No	Installed Capacity (MW ± Mvar)			
		Per Type of DG			Total
		1	2	3	
1	10	50	20+j4	0	70 + j4
2	12	0	5+j1	50-j5	55-j4
3	14	0	0	0	0
4	15	0	20+j4	0	20+j4
5	16	0	0	0	0
6	17	0	0	0	0
7	18	0	0	0	0
8	19	0	5+j1	0	5+j1
9	20	0	0	0	0
10	21	0	0	0	0
11	22	0	0	10-j1	10-j1
12	23	0	0	0	0
13	24	0	0	0	0
14	25	0	0	0	0
15	26	0	5+j1	0	5+j1
16	27	0	0	30-j3	30-j3
17	29	0	0	0	0
18	30	0	0	10-j1	10-j1
Total		50	55+j11	100 - j10	205+j1

The simulation results showed that the DG was allocated on 8 bus of possible 18 load bus. The bus were 10, 12, 15, 19, 22, 26, 27, and bus 30. DG type 1 was located on bus 10 with 50 MW total capacity. DG type 2 was placed on bus 10, 12, 15, 8, 19 and 26 with 55 MW + j11 Mvar total capacity. DG type 3 was connected on bus 12, 22, 27, 30 with 100 MW - j10 Mvar total capacity.

The largest DG penetration with 70 MW + j4 Mvar capacity was located on bus 10. While the smallest capacity with 5 MW + j1 Mvar on buses 19 and 26. Some buses were placed by different DG type. DG type 1 and type 2 were located at bus 10. DG type 2 and type 3 were located at bus 12.

Table 4: The Line Active Losses Value For No DG and Maximum DG Penetration Condition

Line			P_{loss} No-DG (MW)	Losses With DG	
No	Bus From-To			P_{loss} (MW)	ΔP_{loss} (MW)
1	1	2	5.409	0.295	5.114
2		3	2.862	0.092	2.77
3	2	4	1.137	0.066	1.071
4		5	3.060	1.382	1.678
5		6	2.083	0.074	2.009
6	3	4	0.787	0.029	0.758
7	4	6	0.586	0.074	0.512
8		12	0	3.092	-3.092
9	5	7	0.163	0.845	-0.682
10	6	7	0.376	1.058	-0.682
11		8	0.111	0.115	-0.004
12		9	0.00	1.432	-1.432
13		10	0.00	1.318	-1.318
14		28	0.062	0.041	0.021
15	8	28	0.001	0.057	-0.056
16	9	10	0.000	0.000	0
17		11	0.000	0.000	0
18	10	17	0.008	0.015	-0.007
19		20	0.069	0.014	0.055
20		21	0.113	0.057	0.056
21		22	0.053	0.022	0.031
22	12	13	0.00	0.000	0
23		14	0.088	0.027	0.061
24		15	0.277	0.030	0.247
25		16	0.098	0.059	0.039
26	14	15	0.013	0.016	-0.003
27	15	18	0.013	0.048	-0.035
28		23	0.058	0.059	-0.001
29	16	17	0.036	0.017	0.019
30	18	19	0.011	0.008	0.003
31	19	20	0.014	0.001	0.013
32	21	22	0.001	0.010	-0.009
33	22	24	0.038	0.021	0.017
34	23	24	0.026	0.029	-0.003
35	24	25	0.005	0.032	-0.027
36	25	26	0.047	0.010	0.037
37		27	0.036	0.007	0.029
38	27	28	0.0	0.000	0
39		29	0.090	0.016	0.074
40		30	0.168	0.015	0.153
41	29	30	0.035	0.002	0.033
Total			17.9773	4.6425	

Table 4 presented network line active power losses value for no DG condition and maximum DG penetration condition. The active power losses value for no DG conditions was 17.9773 MW. For maximum DG penetration condition, total active power losses was reduced to 4.6425 MW. The decreasing losses occured at most of line. The largest losses decline was 5.114 MW occurred at line 1.

However, active power losses of 14 line were increased. Those line were 8, 9, 10, 11, 12, 13, 15, 18, 26, 27, 28, 32, 34, and 35. The largest losses increasing 3.092 MW was occured at line 8.

Table 5 presented the relationship between DG capacity and active power losses value for maximum DG penetration condition. Total capacity of DG type 1 was 50 MW. Total capacity of DG type 2 and type 3 were 55 MW + j11 Mvar and 100 MW - j10 Mvar, respectively. The total capacity for the three DG types was 205 MW + j1 Mvar. It made 13.3348 MW power losses reduction or equivalen with 74.176 %.

Table 5: Total Active Power Losses Before And After DG Optimization

DG Capacity (MW ± Mvar)			ΔP_{loss-} (MW)	ΔP_{loss} (%)
DG Type 1	50+j0	205+j1	13.335	74.176
DG Type 2	55+j11			
DG Type 3	100-j10			

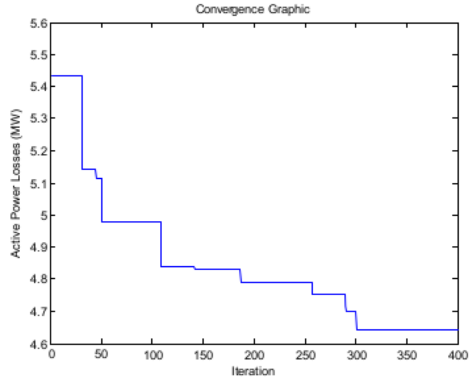

Figure 4: The Convergence Graphic For PSO Optimization Program

The convergence graphis for PSO optimization program was presented in figure 4. The graphic showed the number of iterations was needed to reach the convergent value of active power losses.

The optimization program was converged at 300th generation. At 300th generation, the minimum value of losses was obtained while voltage was maintained within 0.95-1.1 pu value. After 300th generation, voltage constraint violation had occurred. The voltage already had been passed 1.1 pu upper limit value.

Table 6: The IEEE 30 Bus Network Voltage

Bus No	V_{wo-DG} (pu)	Voltage With DG	
		V_{w-DG} (pu)	ΔV_{w-DG} (pu)
1	1.060	1.060	0
2	1.033	1.043	0.01
3	1.013	1.033	0.02
4	1.003	1.027	0.024
5	1.000	1.010	0.01
6	1.000	1.022	0.022
7	0.992	1.009	0.017
8	1.000	1.010	0.01
9	1.030	1.049	0.019
10	1.013	1.035	0.022
11	1.072	1.082	0.01
12	1.045	1.058	0.013
13	1.071	1.071	0
14	1.028	1.046	0.018
15	1.020	1.048	0.028
16	1.025	1.041	0.016
17	1.011	1.032	0.021
18	1.005	1.035	0.03
19	1.000	1.030	0.03
20	1.002	1.030	0.028
21	1.001	1.025	0.024
22	1.001	1.026	0.025
23	1.004	1.031	0.027
24	0.991	1.017	0.026
25	0.994	1.021	0.027
26	0.976	1.020	0.044
27	1.005	1.024	0.019
28	0.998	1.022	0.024
29	0.985	1.012	0.027
30	0.973	1.009	0.036
Avg	1.0117	1.0326	0.0209

The voltage value for no DG and maximum DG penetration condition was presented in table 6. For no DG condition, all of buses voltage were in 0.95-1.1 pu range. The highest voltage 1.060 pu was occured at bus 1. The lowest voltage 0.973 pu was occured at bus 30.

For maximum DG penetration condition, the highest voltage 1.060 pu was remain occured at bus 1. While the lowest voltage 1.009 pu was occured at bus 7 and 30. The average voltage was increased from 1.017 to 1.0326 pu. This means that there had been 0.0209 pu or 2.066 % average voltage increasing.

Figure 5 showed the voltage profile comparison for no DG and maximum DG penetration condition. For maximum DG penetration condition, the graphic showed that all of bus voltage higher than 1.0 pu. The voltage of

28 bus was increased. Only the voltage at bus 1 and bus 13 did not change. The all bus voltage for maximum DG penetration condition were maintained in the range of 0.95-1.1 pu.

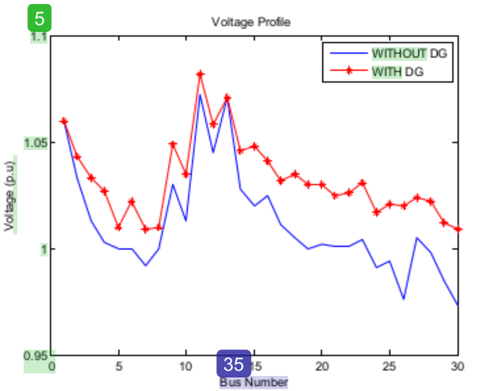

Figure 5: Voltage Profile Comparison Of No DG And Maximum DG Penetration Condition

Table 7: DG Installation Growth Scheme - 25 % Level

No	Bus No	DG Capacity (MW ± Mvar)		
		Type 1	**Type 2**	**Type 3**
1	10	12.5	5+j1	0
2	12	0	1.25+j0.25	12.5-j1.25
3	15	0	5+j1	0
4	19	0	1.25+j0.25	0
5	22	0	0	2.5-j0.25
6	26	0	1.25+j0.25	0
7	27	0	0	7.5-j0.75
8	30	0	0	2.5-j0.25
Total		12.5	13.75+j2.75	25-j2.5
		51.25 + j0.25		

Table 8: DG Installation Growth Scheme - 50 % Level

No	Bus No	DG Capacity (MW ± Mvar)		
		Type 1	**Type 2**	**Type 3**
1	10	25	10+j2	0
2	12	0	2.5+j0.5	25-j2.5
3	15	0	10+j2	0
4	19	0	2.5+j0.5	0
5	22	0	0	5-j0.5
6	26	0	2.5+j0.5	0
7	27	0	0	15-j1.5
8	30	0	0	5-j0.5
Total		25	27.5+5.5	50-j5
		102.5 + j0.5		

Table 9: DG Installation Growth Scheme - 75 % Level

No	Bus No	DG Capacity (MW ± Mvar)		
		Type 1	**Type 2**	**Type 3**
1	10	37.5	15+j3	0
2	12	0	3.75+j0.75	37.5-j3.75
3	15	0	15+j3	0
4	19	0	3.75+j0.75	0
5	22	0	0	7.5-j0.75
6	26	0	3.75+j0.75	0
7	27	0	0	22.5-j2.25
8	30	0	0	7.5-j0.75
Total		37.5	41.25+j8.25	75-j7.5
		153.75 + j0.75		

In this research, several DG growth scenarios were simulated. The scenario was based on maximum DG penetration results that had been obtained. The scenario assumed the DG growth at 25, 50 and 75% level. The DG growth was assumed to be linear. The distribution of DG type, active power capacity, reactive power capacity and location was presented in tables 7, 8 and 9.

The active power losses and average voltage value simulation results for each DG growth level scenario was presented in table 10.

Table 10: Active Losses And Average Voltage Value For Each DG Growth Scenario

No	Item	DG Growth Level		
		25 %	**50 %**	**75 %**
1	P_{losses} (MW)	12.017	7.964	5.537
2	ΔP_{losses} (pu)	5.9603	10.0133	12.440
3	ΔP_{losses} (%)	33.960	55.700	69.200
4	V_{avg} (pu)	1.0241	1.0288	1.0314
5	ΔV_{avg} (pu)	0.0124	0.01707	0.0197
6	ΔV_{avg} (%)	1.2257	1.6869	1.9472

Table 10 indicated that the increasing of DG penetration level caused lower active losses and higher average voltage. DG growth levels from 0 to 25 % yielded the largest losses and average voltage deviation The active losses deviation value was 5.96 MW. The average voltage value deviation was 0.0124 pu. The DG growth scenario levels from 25 to 50 %, 50 to 75% and 75 to 100% yielded smaller value.

The active losses value for each DG growth level was presented in figure 6. The average voltage for each DG growth level was presented in figure 7. The IEEE 30 bus network voltage profile for each DG growth level was showed in figure 8.

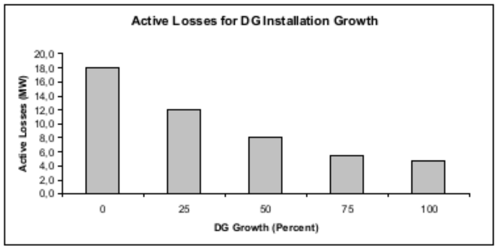

Figure 6: Comparison Of Active Losses For Each DG Growth Level

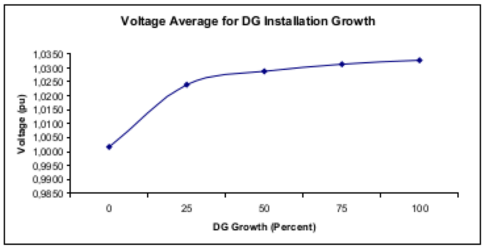

Figure 7: Comparison Of Average Voltage For Each DG Growth Level

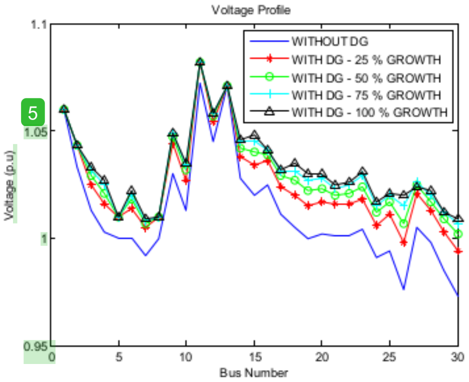

Figure 8: IEEE 30 Bus Network Voltage Profile For Each DG Growth Level

6. CONCLUSION

The proposing optimization scheme of DG installation growth considering network power quality had been succesfully implemented on IEEE 30 bus network in this research. Based on optimization result, total 205 MW + j1 Mvar maximum capacity of DG could be installed at network. The DG was distributed on 8 distribution load bus. The DG maximum capacity was consisted of 50 MW DG type 1 capacity, 55 MW + j11 Mvar DG type 2 capacity and 100 MW – j10 Mvar DG type 3 capacity. After DG optimization, the active power losses reduced by 74.176 % and average voltage increased by 2.066 %. Even though the average voltage increased, the entire bus voltage were maintained within 0.95-1.1 pu.

For 75, 50 and 25 % level DG growth scenario, the active losses DG was reduced by 69.2, 55.7 and 33.96 %, respectively. The average voltage was increased by 1.9472, 1.6869 and 1.2257 %, respectively.

This study has several limitations. In the future, the limitation will be the main subject to investigated. The future work will develop the DG installation growth optimization scheme with considering of dynamics load change and network stability aspect. The future work will also focus on implementation of more advanced artificial intelligence method.

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