Optimal Substation Placement for Microgrid Power System Based on Nearly Positioning of Bus on the Free Space Area

Y. Kongjeen[1,*], K. Buayai[1], and K. Kerdchuen[1]

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ABSTRACT

This paper presents the optimal substation placement (OSP) by using a genetic algorithm optimization technique in a microgrid power system. The objective function for finding the position of the substation is defined by using the load voltage deviation (LVD). The backward-forward sweep method based on a matrix platform is applied to compute balanced power flow. The IEEE 33 bus testing system is selected to analyze the problem for the purpose. The simulation results are defined in 3 cases by varying the power transmission line distance from the positioning of the substation installed on the free space area. The results show that the LVD and total power loss reduced from the Base case with an optimal position the substation at Bus No.6. The comparison results of the LVD with the Base case in a percentage reduction from Case 1, Case 2, and Case 3 are -83.6855 %, -82.8402 %, and -79.7971 %, respectively. Meanwhile, the arrangement of the percentage of the total power loss reduction based on the Base case from the highest is presented by Case 1, Case 2, and Case 3 with of -55.2160 %, -53.8986 %, and -49.2046 %, respectively. Therefore, the optimal substation placement for the microgrid system can be improved power system stability in a condition of voltage profiles and total power loss reduction.

1. INTRODUCTION

Recently, the trending of energy demand from the grid is widely increasing due to an increase dramatically connection of a new load. Because of the advancement from power electronics and material science, the technology is highly developed and increased the level of competition from the commercial that made a new apparatus for modern daily life [1]. Meanwhile, several types of energy sources are connected to the grid and transferred energy from each source by using the power transmission line [2]. So, energy sources for providing to end users are becoming a vital issue and need to manage in the optimal condition. Nowadays, the power transmission line has connected in a wide area and can be auto transferred to manage for the essential area of the loads. Many researchers have proposed optimum this condition by adding a tie switch for operating the transmission line system as described in [3]. However, the tie switch had some limited from a rewiring or a rerouting of the power transmission line and amount operating times. Alternatively, optimum distributed generators (DGs) were interested in studying for installing based on each type of DGs and the need for the optimal location placement. However, the consideration of DGs installation is cloud be not permitted to install and placement the DGs in a condition of the realistic installing location [4]. Many reasons from the environment and an economic impact from DGs placement are needed to solve for achieving the target in long term condition.

Therefore, the proposal of this paper is a study of optimal substation placement (OSP) under the relocation substation from the root bus to a free space area. The OSP is defined by using a single objective that analyzed in a minimizing load voltage deviation (LVD). Backward-forward sweep based on a matrix platform is adapted to solve the balanced power flow condition. A genetic algorithm is used to apply for finding each objective function from purpose. However, this study is not considered the cost and economic role function of the land. The IEEE 33 bus primary radial distribution system is used to analyze the optimal condition of the sub-station placement from the proposal, as presented in Fig. 1.

The rest of this paper is organized as follows: Section 2 purposes the methodology consists of the backward-forward sweep, load voltage deviation, and total power loss, respectively. Simulation results are presented in Section 3. Finally, Section 4 is showed the conclusion and discussion.

[1]*Department of Electrical Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhonratchasima, Thailand.*
**Corresponding author:* Yuttana Kongjeen; Phone: 66-44-233-000; E-mail: yuttana.ko@rmuti.ac.th.

2. OPTIMAL SUB-STATION PLACEMENT (OSP)

The private area using for operating control, the energy to the distribution system, is called distributed sub-station. The role of the sub-station is to spread the energy from a high voltage system to a medium voltage system by using a step-down power transformer, control and manage the transmission line system to the users in each area. Generally, the substation is needed to install or construct at the center of the load in optimal located condition. However, the substation may not be installed in the best location. Therefore, the substation position should be defined in the optimal condition by applying the optimization technique.

Genetic algorithm (GA) is the best optimization tool and popularly used to solve any engineering problem [5], which adapts to find the OSP from the proposal. The theories to investigate the OSP are related backward-forward sweep method (BFS), load voltage deviation (LVD), and total power loss described as follows.

2.1 Backward-forward sweep method (BFS)

The BFS is used to solve the power flow of the radial distribution system (RDS) by defining a matrix platform. Basically, the load of the power system each bus (N) is defined on the complex power load (S_k) and injection current each iteration $\left(I_k^t\right)$ on the bus based on real (r) and imaginary (i) part of the current can show in Equation (1) and (2), as follows [6].

$$S_k = P_k + jQ_k \qquad ; k = 1 \ldots N \tag{1}$$

$$I_k^t = I_k^r\left(V_k^t\right) + jI_k^i\left(V_k^t\right) = \left(\frac{P_k + jQ_k}{V_k^t}\right)^* \tag{2}$$

where S_k, P_k and Q_k are represented the apparent power (kVA), active power (kW), and reactive power (kVar), respectively. N is represented the total number of buses, t is designated as the iteration to compute. V is represented voltage at k bus. I is represented as injection current on the bus.

The BFS methodology is composed based on the three matrices from Kirchhoff's law. [7]. There are consist of the bus injection to branch injection matrix **[BIBC]** , the branch current to bus voltage matrix **[BCBV]**, and the current injection matrix **[I]**. Current flow each branch **[B]** delivered from Equation (3). Meanwhile, voltage tolerance $[\Delta\mathbf{V}]^{t+1}$ from the iteration t, can be found as equation (4) and (5), respectively.

$$[\mathbf{B}] = [\mathbf{BIBC}][\mathbf{I}] \tag{3}$$

$$[\Delta\mathbf{V}]^{t+1} = [\mathbf{BCBV}][\mathbf{BIBC}][\mathbf{I}]^{t+1} \tag{4}$$

$$= [\mathbf{DLF}][\mathbf{I}]^{t+1} \tag{5}$$

The distribution system has consisted of a radial structure and a high R/X ratio of the transmission line. So, the ill-conditioned to compute from the Newton-Raphson method is not convergence and reaches tolerance defined by a radial distribution system. A significant problem with the traditional way was applied to solve by BFS. Hence, the proposed approach presents a load flow study using a BFS, which is one of the most effective methods for the load-flow analysis of the radial distribution system. This method has been applied to the IEEE 33-bus radial

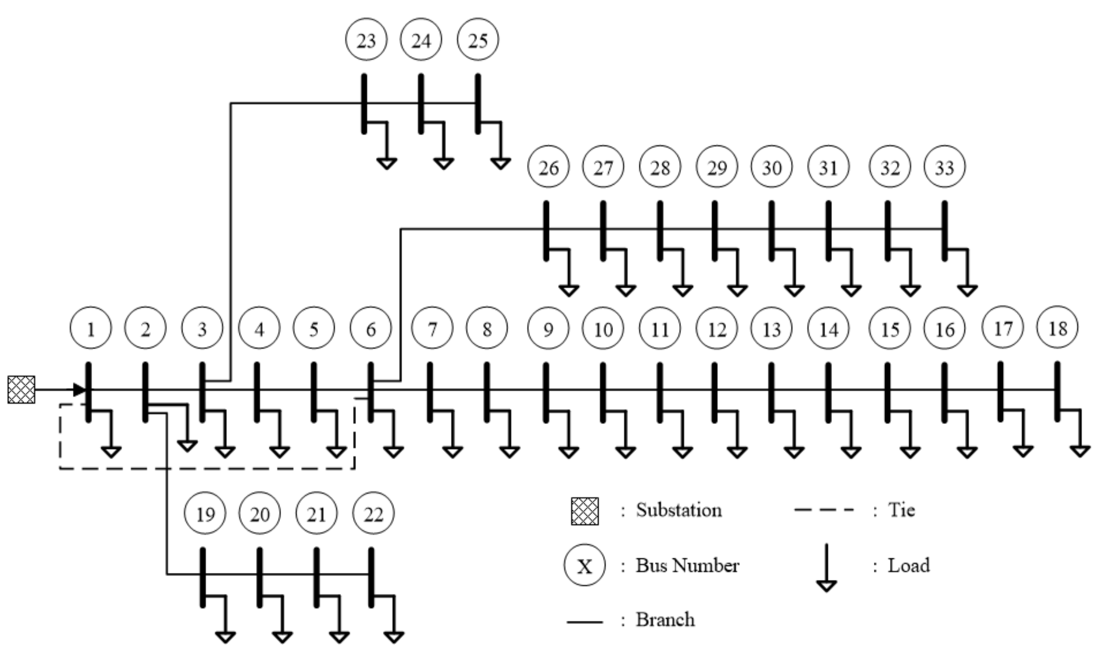

Fig. 1: Optimal sub-station position for IEEE 33 bus.

distribution system, and effective results are obtained using MATLAB for the proposal.

2.2 Load voltage deviation (LVD)

The voltage characteristic of the electrical power system will vary when consumed energy from the load installed. The voltage level of the electrical power system used to determine the static voltage stability level. The LVD is adapted to indicate in a condition of voltage stability level. The LVD is composed of the summation of difference from voltage each bus (N) between the voltage standard $\left(V_k^{ref}\right)$ of 1 pu. and actual bus voltage (V_k). The criterion to evaluate the LVD is a minimal value that indicates the power system's low impact from the load installed in Equation (6) as follows [2].

$$LVD = \sum_{n}^{N}\left(\frac{V_k^{ref} - V_k}{V_k^{ref}}\right)^2 \quad (6)$$

2.3 Total power loss

The active power loss of the transmission line is used to investigate the total power loss of the electrical power system. The total power loss $\left(P_{T,Loss}\right)$ is totally value from the summation of transmission lines loss can be described in Equation (7) as follows [7].

$$P_{T,Loss} = \sum_{k=1}^{n}\left(R_k \times \frac{\left(P_k^2 + Q_k^2\right)}{\left|V_k\right|^2}\right) \quad (7)$$

where R_k is represented resistance of the transmission line (k). P_k and Q_k are represented active and reactive power of the transmission line (k). V_k is bus voltage. n is a number of transmission line.

2.4 Genetic algorithm (GA)

GA is adapted to solve the OSP by defining LVD for the objective function. The main structure of GA is consisting of section process, crossover, and mutation based on the meta-heuristic. Therefore, the position of the substation will be provided in the best condition from the objective function. The coordinate of the free space area is developed by using randomize the position x and y from the GA process. Therefore, the possible position of the substation is represented by using the x and y coordination in a free space area described in Fig.2. Hence, the transmission line length of the substation is defined from randomize value and used to compute by using the BFS.

2.5 Free space area conceptual for the OSP

The landscape of the search space area has become a significant issue of the investment cost for the OSP. This paper needs to present the concept for the OSP by applying the free space area when integrated the IEEE 33 bus testing

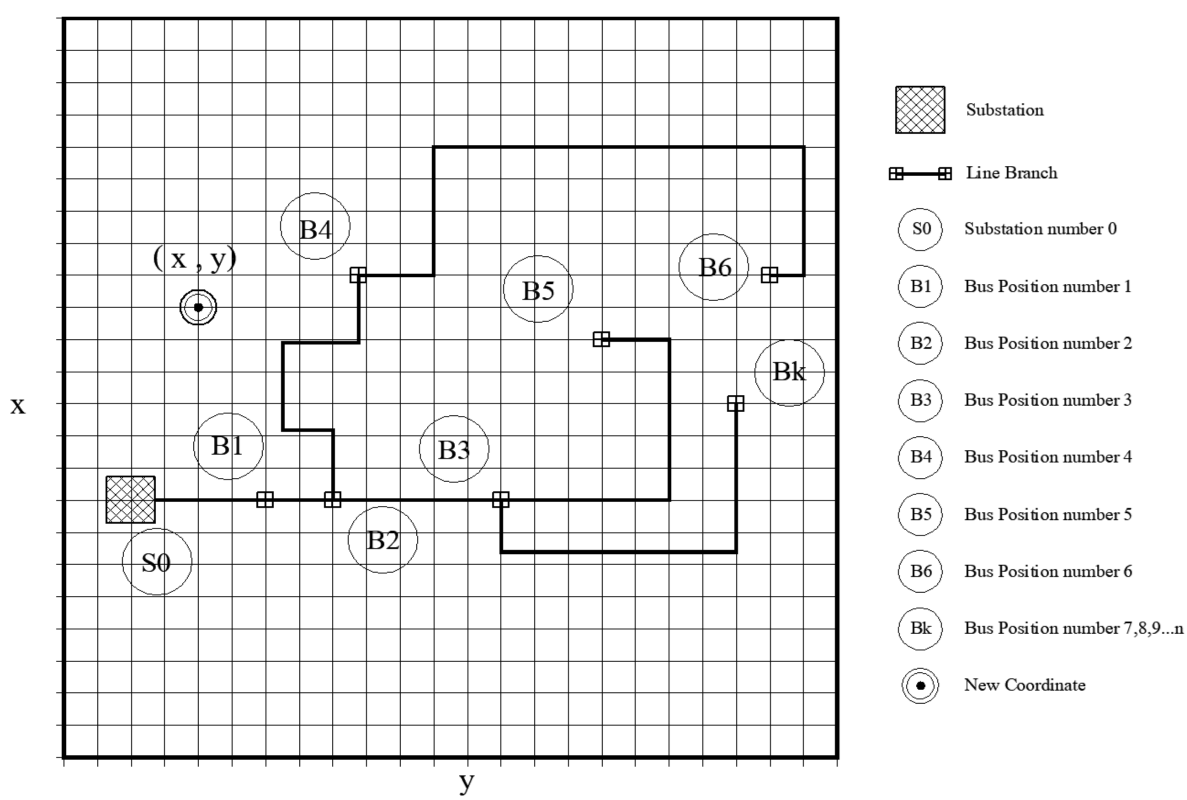

Fig. 2: A conceptual of the x-y coordinate in a free space area.

system in the landscape and ignored the economy from land in the free space area. The free space for the searching area is represented by the x-y dimension of a free space area in kilometers. The topology of the electrical power system is combined in a free space area. The positioning of x-y coordination in a free space area is indicated a new substation installed in the electrical as Fig.2. The new substation will have proceeded to the OSP process.

Fig.2 shows the conceptual of x-y coordination in a free space area with a network connection. The original substation (S0) is defined on x-y coordination in a free space area. A new substation is located in the x-y coordinate from B1 to Bk for finding the OSP from the GA process. The x-y coordination is using a random of the real number of the GA and is defining within the searching boundary of the free space area. The OSP in a free space area needed to find in the optimal condition and improved the electrical power system. Nearly positioning of the bus on the free space area is a vital indicator of the OSP because the substation can be moved in the free space in a radial around the optimal bus to place the substation.

3. SIMULATION AND RESULTS

The IEEE 33 bus radial distribution system is selected to solve the OSP show as Fig.1 [8]. The IEEE 33 bus has a total load connected active and reactive power of 3.7150 MW and 2.3000 Mvar, which total power loss 0.2027 MW and 0.1351 MVar, respectively. The mapping of the free space area is included IEEE 33 bus in the x-y coordinate with using to find the OSP from the purpose. A free space area dimension for searching the OSP is supposed in a square area. However, in a realistic area is related to the geographical information area and more complexity of the free space area than defined from the purpose. The simulation is set in balanced power flow and considered a steady-state on the power flow of the power system.

A single objective function is used to find the OSP. The minimizing of LVD is selected for solving the problem of the objective function. The objective function can be defined by Equation (8). The process of identifying the OSP using GA based on MATLAB programming. The m files from the MATLAB are used to find the optimal condition by applied GA and BFS. The methodology is demonstrated step in Fig.3 as follows [7].

$$\min\left(f\right)=\text{minimize}\left(LVD\right) \tag{8}$$

349

- Step 1: Initialize the parameter of the IEEE 33 bus are consist of the transmission line, bus type, load capacity, network topologies.
- Step 2: The GA process initialization is defined relevant to the population size, maximum number of generations, number of variables, crossover, mutation, the x-y dimension of a free space area in kilometers of 100, 200, 1, 0.8, 0.2, 5, respectively.
- Step 3: Randomly generate an initial population of the chromosomes by decode to real number for the x-y position for OSP and calculate fitness function by using the BFS method.
- Step 4: Generate the new population set from the GA operator (section, crossover, and mutation) is representing the x-y position for OSP in next generation.
- Step 5: Evaluate the fitness function of the new population.
- Step 6: Consideration and termination criteria which in the best solution or reaching maximum iteration and tolerance. If neither criterion is satisfied go to Step 3 nor proceed to step 7.
- Step 7: Terminate the GA and show the simulation results.

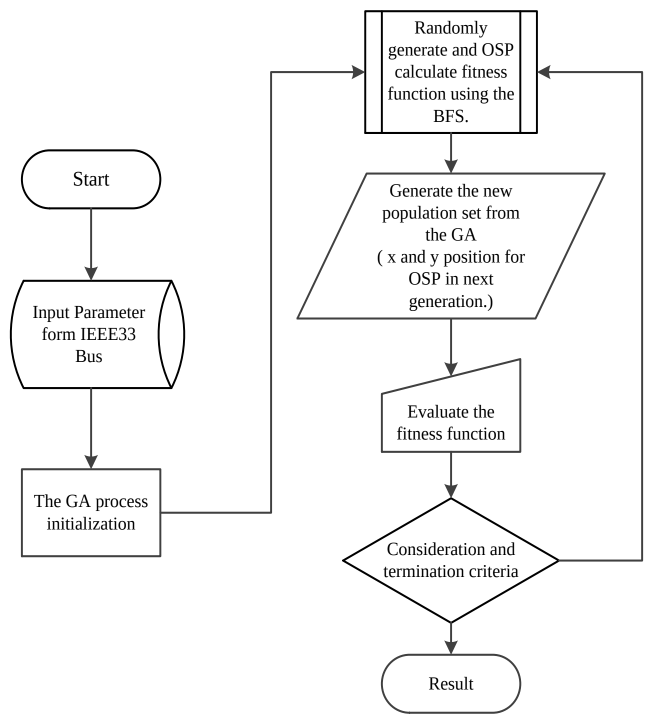

Fig. 3: Flow chart of the OSP process using GA.

Aims of this study need to find the conceptual of the OSP in the free space area by using a nearly positioning of bus. A case study approach was used to allow ignored the land economy in a free space area. Therefore, the simulation for finding the OSP is divided into 3 cases by defining based on the x-y dimension of the free space area as follows.

Case 1: the OSP uses GA and varies the power transmission line distance from the free space area (R and X value of transmission line changed from a new position on a free space area).

Case 2: the OSP uses GA and varies the power transmission line distance from the free space area with an additional constant distance from real data at 50.38 m (Constant distance is defined by the length of high voltage feeder incoming to the substation as 115 kV feeders. An actual data measurement on the temporary substation is located on the Suranarai road Nakhonratchasima province).

Case 3: the OSP uses GA and constant R and X value of power transmission line on the free space area (Original R and X value from Bus No.1 to Bus No.2).

The simulation result from the study cases can be presented in Table 1 as follows.

Table 1 compares the position of the substation, voltage, total power loss (T.Loss), and percentage of load voltage deviation (LVD) from the OSP process. The total power loss is reduced by comparing the base case with Case 1, Case 2, and Case 3 of -55.22%, -53.90% and -49.20%, respectively. Meanwhile, the LVD obtaining by comparing the Base case with each scenario from Case 1, Case 2 and Case 3 of -83.69%, -82.84% and -79.80%, respectively.

Table 1: Simulation results from test cases

Data/Case	Base case	Case 1	Case 2	Case 3
Position	2	6	6	6
Voltage (pu.)	0.9970	1.0000	0.9994	0.9971
T. Loss (kW)	202.4549	90.6673	93.3345	102.8377
(%) T. Loss	0	-55.2160	-53.8986	-49.2046
LVD	0.1183	0.0193	0.0203	0.0239
(%) LVD	0	-83.6855	-82.8402	-79.7971

The OSP results from the study are installed on the near bus No.6. Then the lowest in a total power loss and a percentage of the LVD become the condition of Case 1. Therefore, the OSP from the proposed can be reduced total power loss and rate of LVD. Hence, the electrical power system can be improved in terms of voltage profiles and the total power loss reduction as illustrated in Table 2 and Fig.6, respectively.

Table 2 compares the voltage profile results from the scenarios. The voltage profile results are presented from bus No.1 to bus No.33 of the IEEE33 bus testing system.

The voltage magnitude profiles standard of the IEEE33 bus testing system is presented in a study base case. Meanwhile, the new voltage profiles from the OSP are showed in the study case 1 to case 3. The substation location obtains from the OSP has revealed the voltage profiles changed from the electrical source. The optimal bus position for connecting the new substation is presented in bus No.6 from the studied. The highest voltage magnitude from the Base case is bus No.1 of 1.000 pu.,

Interestingly, the highest voltage magnitude from the study cases after using the OSP is provided in bus No.6 from the Case 1, Case 2, and Case 3 with values of 1.0000 p.u., 0.9994 p.u. and 0.9971 pu., respectively (Bold values). There was a significant difference between the Base case and the study cases in the minimum voltage magnitude, which changed from bus No.18 (Base case) to bus No.25 (study cases). As shown in Table2, the minimum voltage magnitudes are the underline values from the Base case, Case 1 Case 2, and Case 3, which are 0.9126 p.u., 0.9645 p.u., 0.9638 p.u., and 0.9615 p.u., respectively.

Table 2: Comparison of the voltage profile results

Bus No.	Base case	Case1	Case2	Case3
1	**1.0000**	1.0000	1.0000	1.0000
2	0.9970	0.9764	0.9757	0.9734
3	0.9829	0.9782	0.9775	0.9752
4	0.9753	0.9826	0.9819	0.9796
5	0.9679	0.9875	0.9868	0.9845
6	0.9494	**1.0000**	**0.9994**	**0.9971**
7	0.9459	0.9967	0.9961	0.9938
8	0.9410	0.9921	0.9914	0.9891
9	0.9347	0.9861	0.9854	0.9831
10	0.9288	0.9805	0.9799	0.9776
11	0.9280	0.9797	0.9791	0.9767
12	0.9264	0.9783	0.9776	0.9753
13	0.9203	0.9725	0.9718	0.9695
14	0.9181	0.9704	0.9697	0.9674
15	0.9166	0.9690	0.9684	0.9660
16	0.9153	0.9677	0.9671	0.9647
17	0.9132	0.9658	0.9652	0.9628
18	0.9126	0.9653	0.9646	0.9622
19	0.9965	0.9758	0.9752	0.9728
20	0.9929	0.9722	0.9715	0.9692
21	0.9922	0.9714	0.9708	0.9684
22	0.9915	0.9708	0.9701	0.9678
23	0.9792	0.9746	0.9739	0.9716
24	0.9725	0.9678	0.9672	0.9648
25	0.9692	0.9645	0.9638	0.9615
26	0.9475	0.9982	0.9975	0.9953
27	0.9449	0.9957	0.9951	0.9928
28	0.9334	0.9849	0.9842	0.9819
29	0.9252	0.9770	0.9764	0.9741
30	0.9216	0.9737	0.9730	0.9707
31	0.9174	0.9697	0.9690	0.9667
32	0.9165	0.9688	0.9682	0.9658
33	0.9162	0.9686	0.9679	0.9656

Fig.4 compares the results obtained from the study cases of total power loss (Ploss). The location of the substation is connected to the grid that affected the total power loss of the electrical power system. Hence, the OSP from the purpose needed to find in the optimum condition from the objective function. The outgrowth from the total power loss is a secondary objective of this study. However, when the voltage of the bus changed any case in the electrical power system, which difficulty avoided impact on the transmission line loss and total power loss. Therefore, simulation results show that the total power loss reduced from the Base case. The comparison results between the Base case and each Case found that the total power loss reduced from Case 1, Case 2, and Case 3, with of 90.6673 kW, 93.3345 kW, and 102.8377 kW, respectively.

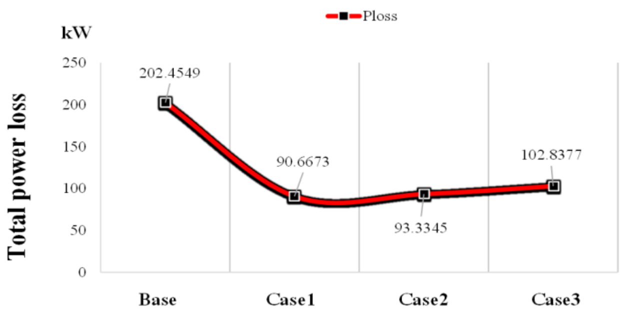

Fig. 4: Comparison of the total power loss from the study cases.

Meanwhile, a comparing of the total power loss by using the Base case in a percentage reduction is revealed the total power loss reduced from Case 1, Case 2 and Case 3 with of -55.2160 %, -53.8986 % and -49.2046 %, respectively. The yield from the comparison is the total power loss reduced from the new position of the substation. The lowest of the total power loss is shown in Case 1 from the study case.

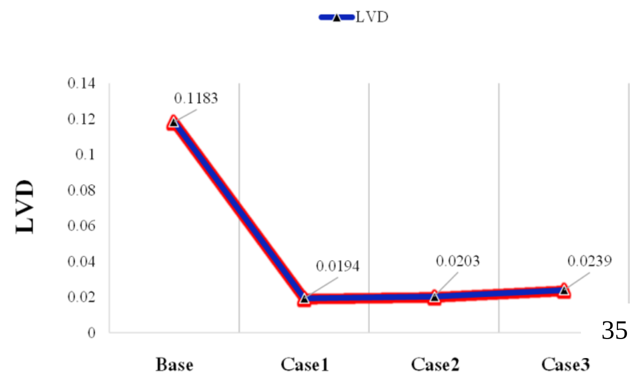

Fig. 5: Comparison of the LVD from the study cases.

Fig.5 compares the simulation results data of the LVD. The role of the LVD in the electrical power system is affected by the number or level of the load connected in the electrical power system. The voltage magnitude levels on each bus of the network directly impact the energy transfer and total power loss. Therefore, the voltage magnitude level index is concerned the static voltage stability and more affected by the electrical power system. The comparison results between the Base case and each Case found that the LVD reduced from Case 1, Case 2, and Case

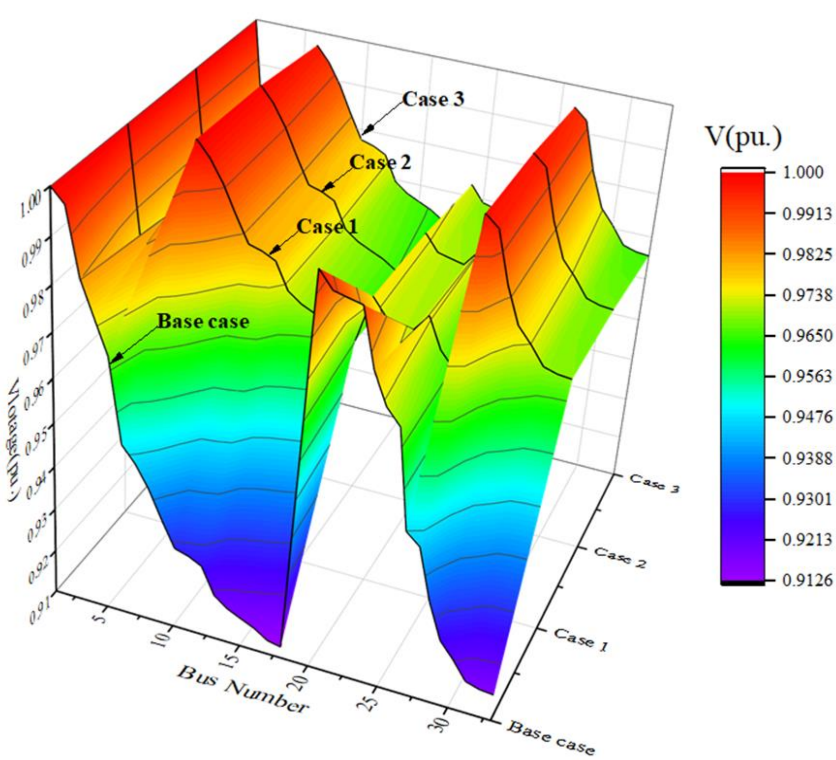

Fig. 6: Comparison of the voltage profiles from the study cases.

3 with of 0.0194, 0.0203 and 0.0239, respectively. A comparing of the LVD by using the Base case in a percentage reduction is showed the LVD reduced from Case 1, Case 2, and Case 3 with of -83.6855 %, -82.8402 %, and -79.7971%, respectively.

Interestingly, the LVD was observed in the Base case and study cases differed. The LVD from the study cases is presented lower than the Base case. So, the OSP from the purpose technique can be improved the electrical power system. The weakest of the LVD has shown in a study Case 1, with bus No.6 represented the optimal substation position.

Fig.6 shows that the contour of voltage profiles each bus from the test cases when the substation moves to the optimal condition at bus No.6. The voltage profiles obtain from the study cases differs from the base case. The new voltage profiles from the OSP can improve the voltage profiles level of the electrical power system. The contour of voltage profiles from the Base case indicated the lowest in the bus No.33 and bus No.18. Meanwhile, the OSP from each study cases is installed the new substation to bus No.6. Therefore, the voltage profiles of the electrical power system will be changed from the traditional of the Base case. The OSP improves the levelling of the voltage profiles from the new substation placement from the purpose. However, the OSP process can be found the optimal condition from the objective function, but differs from the study cases. The near value was obtained when analyzed the contour of voltage profiles of each Case. The advantage of voltage profiles has presented the overall of the voltage profiles compared and easy to inspect the electrical power system. Interestingly, the comparison from the Base case and each study case by using the contour of voltage profiles are distinguished from the new substation placement with better voltage profiles than the traditional condition.

Finally, the effect from the location of the substation in the grid is the voltage profile level of each bus. The OSP from the purpose can be improved the static voltage stability of the electrical power system. Notably, the indirect impact of the voltage profiles, improving has reduced the total power loss of the grid. Meanwhile, the free space area of searching space is applied to find for mapping topology the grid structure. The realist of the network has been complicated, and many factors for providing in-depth details. The conceptual from the propose has revealed the method to improve the electrical power system from the previous method [9-12] . It can be enhanced the voltage profiles and reduced the total power loss in the adequately significant.

4. CONCLUSION

In this research paper, the GA is proposed for optimal substation placement (OSP) for improving the voltage profile level and the total power loss reduced. The IEEE 33 bus test network is used for validating the effectiveness of the GA to deal with a free space area to find the OSP. The system was modified integrated into the searching of the free space area for finding the optimal condition. The LVD is used to find the objective function of the GA process. The simulation results revealed the direct impact to reduce LVD reduction of the electrical power system. However, the OSP did not only reduce the LVD for study cases reducing in Case 1, Case 2, and Case 3 with about -83.6855 %, -82.8402 %, and -79.7971%, but also reduced the total power loss in Case 1, Case 2 and Case 3 of -55.2160 %, -53.8986 % and -49.2046 %, respectively. The OSP from each case is indicated to connect the substation on bus No.6. So, the OSP for the purpose can improve the voltage profiles and reduce the total power loss of the electrical power system. Strategies to enhance the OSP might involve the real economy of the land for installing the substation. A further study to investigate the land economy would be a highly fascinating topic.

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