Multiple Distributed Generators integration on IEEE 33-bus power distribution network using voltage stability Index and XGBoost regressor model

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ABSTRACT

In this work, multiple Distributed Generators (DG) integration on IEEE 33-bus power distribution network using voltage stability Index and XGBoost regressor model is presented. The multiple DG are optimally located and sized to minimize the overall power loss while maintaining the voltage profile within the acceptable range. The IEEE 33-bus was modeled in Matlab, the line data and bus data of the power network were read into the Mtalab and the load flow analysis was conducted for the baseline case without DG integration using the Gauss-Siedel power flow approach. The Voltage Stability Index (VSI) was computed based on the voltage profile results obtained from the load flow analysis. First, the XGBoost regressor model was used for sizing of the DG capacity installed on the top 10 candidate buses identified using the VSI ranking. In this case, the candidate buses are ranked in descending order of the VSI value of each of the bus. In the second case, the XGBoost regressor model was used to determine the candidate buses and also to determine the DG capacity installed in each of the top 10 candidate buses identified by the XGBoost regressor model. Results of the baseline case without DG integration showed that the mean voltage of the buses was 0.98648 p.u. and the minimum was 0.9812 p.u. while the maximum was 0.9989 p.u. The mean VSI of the buses was 0.9928 .and the minimum was 0.982 while the maximum was 0.9997. The top 10 buses based on the VSI included bus 3,4,2,6,10,13,25,7,11, and 16. In all, the results show that the use of the VSI and XGBoost Regressor resulted in power loss of 7.92 % while the use of XGBoost Regressor Model alone resulted in power loss of 8.1245 %. Essentially, about 0.2028 % reduction in power loss was achieved by using the VSI in the optimal placement of the multiple DG installation.

KEYWORD: Multiple Distributed Generators, XGBoost Regressor Model, IEEE 33-Bus, Voltage Stability Index, Power Distribution Network

1. INTRODUCTION

Today, the advancements in the smart grid technologies have increase the adoption of distributed generator (DG) integration to Power Distribution Networks (PDN) [1,2 , 3]. The DG integration on PDNs enhances power security [4,5]. It also help to support diversification or energy source. Individuals and organizations can contribute to the energy generation solution by integrating their locally generated energy into the grid [6,7,8].

Also, the growing demand for green energy solutions has also prompted the growing adoption of DG integration on PDN [9]. The small and medium scale green energy generators are integrated at various sections of the PDN. However, researchers and experts have noted that DG integration requires careful planning to avoid negative impact on the power system stability and reliability [10,11]. The location and size of each DG to be integrated need to be determined using some approaches like analytical methods and in recent times using machine learning models [12,13,14]. If the DGs are not properly located or sized, they can cause voltage instability, excessive power losses and possible system breakdown [15,16,17]. Accordingly, in this work, the optimal placement and sizing of multiple DGs on PDN is presented [18,19]. The approach in this work used voltage stability Index and XGBoost Regressor model to ensure appreciate location and sizing of multiple DG integrated on IEEE 33-bus network [10,21]. The solution options are presented and the best options is identified based on its ability to minimize the power loss in the PDN.

2. METHODOLOGY

The approach used to determine the optimal location and size of multiple Distributed Generators (DG) installed on IEEE 33-bus network is presented. The multiple DG are optimally located and sized to minimize the overall power loss while maintaining the voltage profile within the acceptable range. The flow diagram showing the steps used in the research process is presented in Figure 1. The single line diagram model of the IEEE 33-bus network is presented in Figure 2.

According to the process steps in Figure 1, the IEEE 33-bus was modeled in Matlab. The line data and bus data of the power network is read into the Mtalab and the load flow analysis is conducted for the baseline case without DG integration using the Gauss-Siedel power flow approach. The Voltage

Stability Index (VSI) was computed based on the voltage profile results obtained from the load flow analysis. Notably, the expression for the Voltage Stability Index (VSI) is derived based on the two bus system in Figure 3, and it is given as **[22];**

$$VSI = |V_1|^4 - 4[P_2X - Q_2R]^2 - 4[P_2R + Q_2X]|V_1|^2 \quad (1)$$

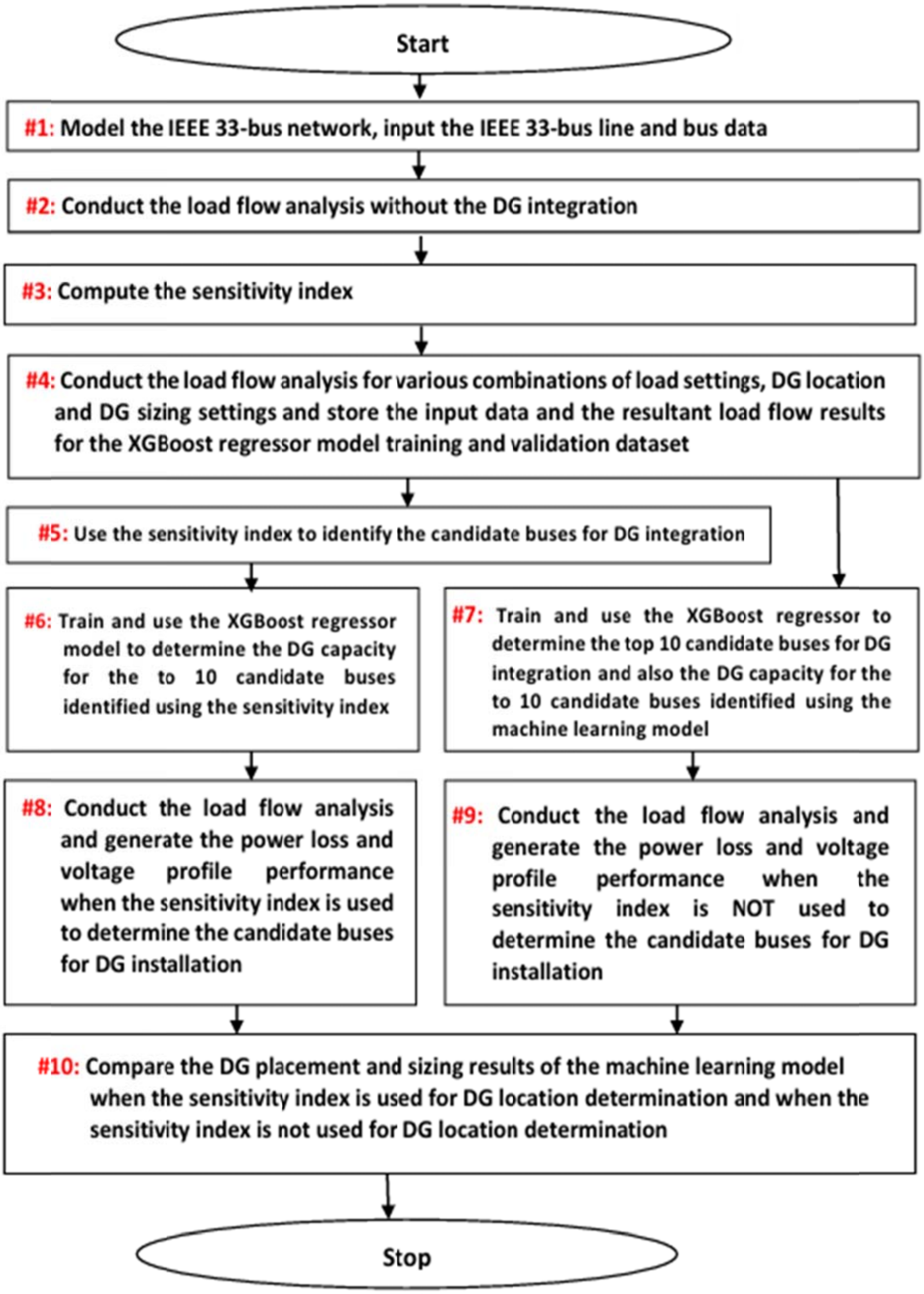

Figure 1 The flow diagram showing the steps used in the research process

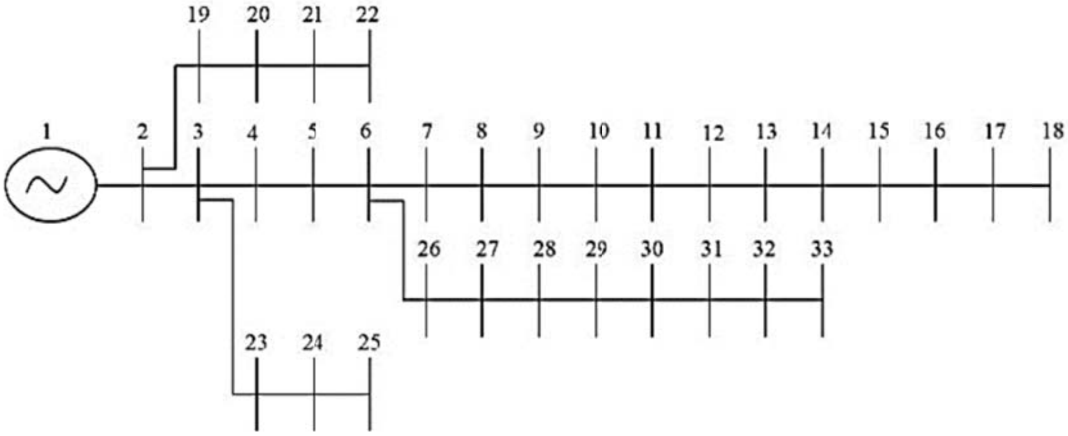

Figure 2 The single line diagram model of the IEEE 33-bus network

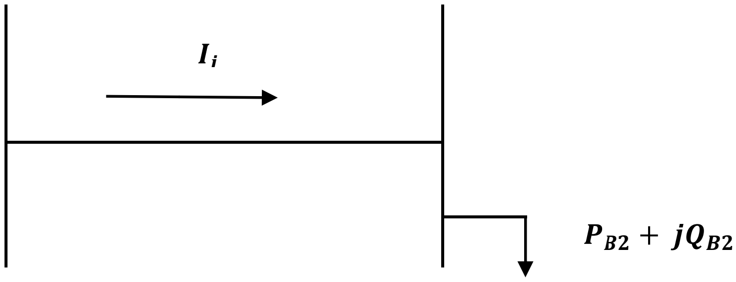

Figure 3 The two bus system used for the Voltage Stability Index [22]

The flow diagram of the Gauss-Siedel power flow approach is presented in Figure 4. The Acording to the research process in Figure 1, the load flow analysis is conducted for various combinations of load settings, DG location and DG sizing settings and the input dataset for each of the load flow analysis is stored along with the resultant load flow results. The dataset (input and output data of the numerous load flow analysis so conducted) is used for the XGBoost regressor model training and validation. Specifically, the XGBoost regressor model (shown in Figure 5) is used in two cases, as shown in Figure 1, the firsts is that the XGBoost regressor model is used for sizing of the DG capacity installed on the top 10 candidate buses identified using the VSI ranking. In this case, the candidate buses are ranked in descending order of the VSI value of each of the bus. The top 10 candidate buses are considered for DG installation using the XGBoost model. The second application of the XGBoost regressor model is to determine the candidate buses and also determine the DG capacity to be installed in each of the top 10 candidate buses identified by the XGBoost regressor model.

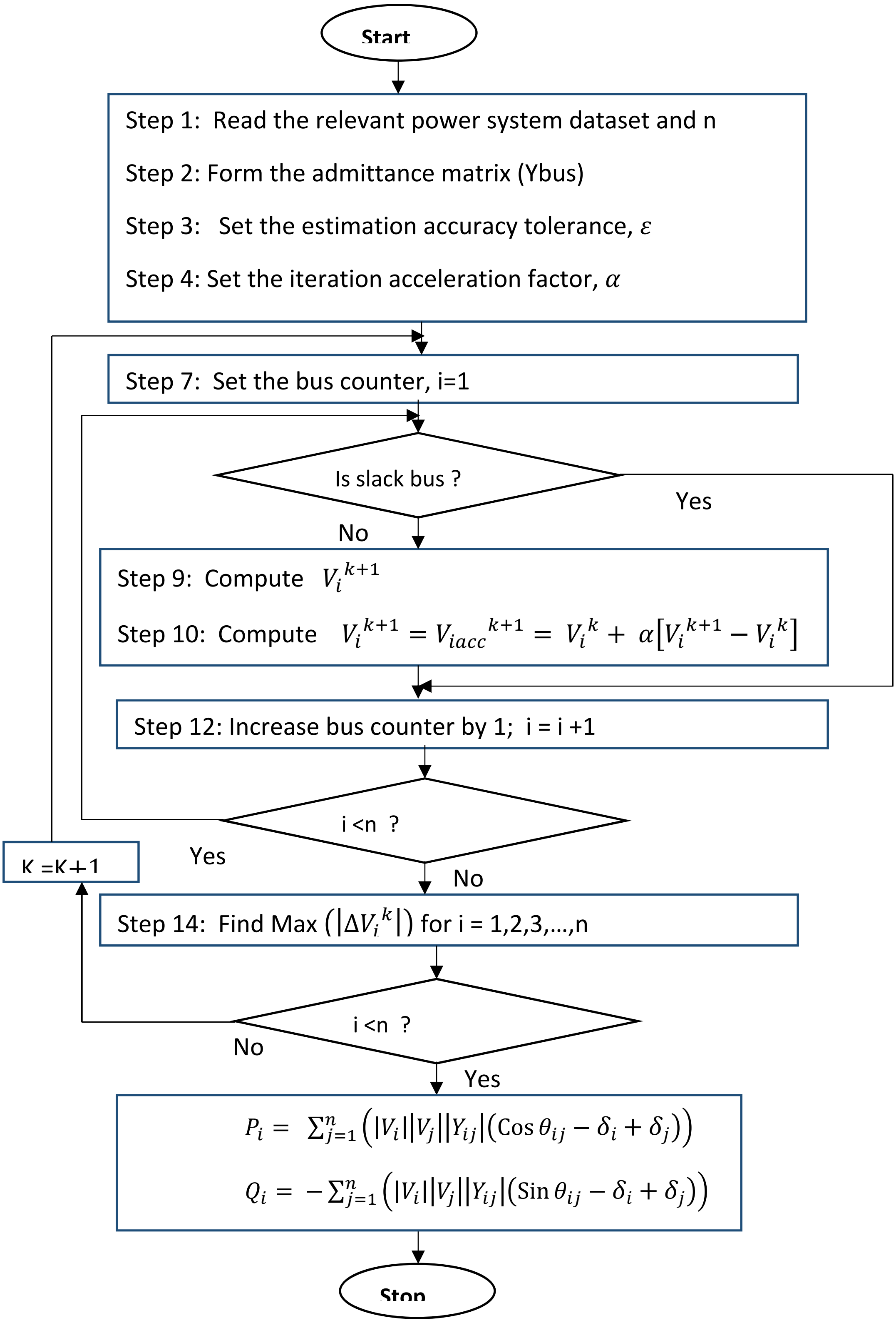

Figure 4 The Gauss-Siedel power flow approach [23]

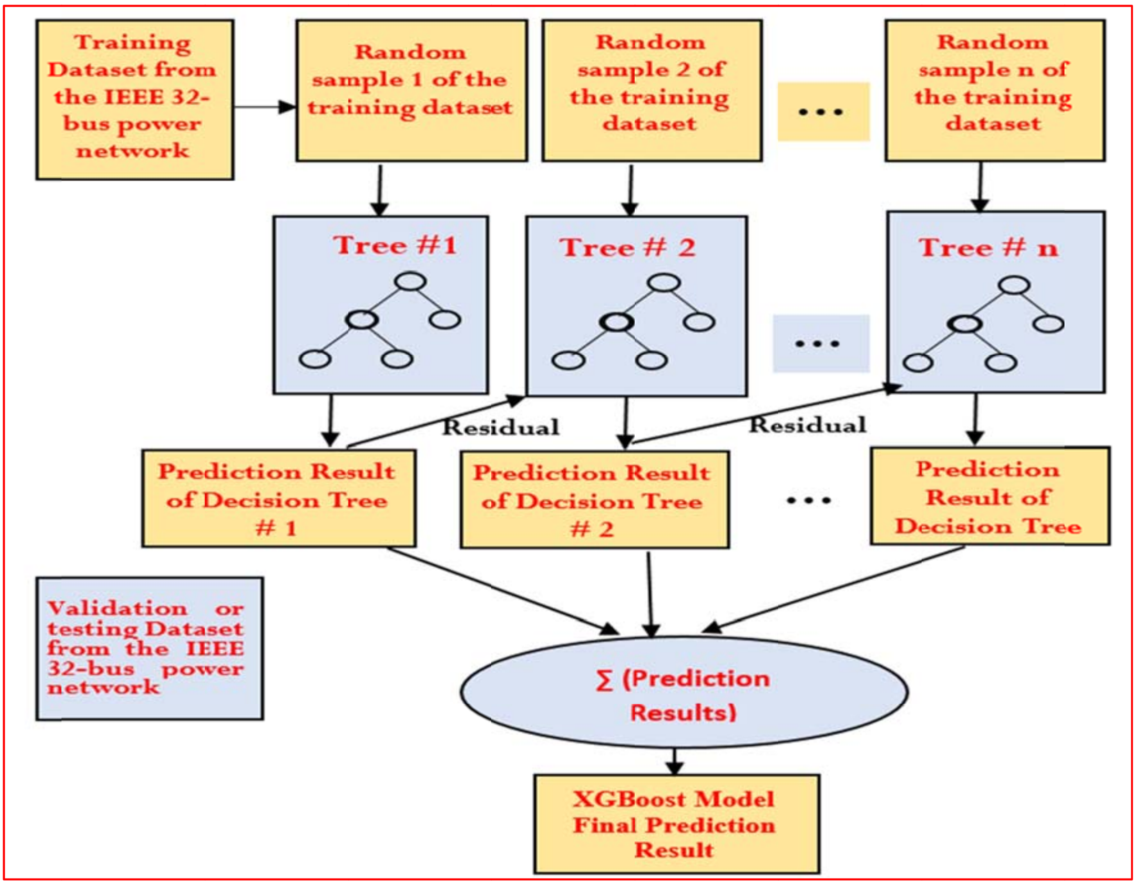

Figure 5 The architecture of the XGBoost Regressor Model

Essentially, the research examined the optimal DG location determination and the DG capacity determination using two approaches, one using the XGBoost Regressor model alone and two, using the VSI for the DG location determination and the XGBoost Regressor model for the DG capacity determination. The Load flow analysis provides the key system performance parameters that are used to compare the performance of the power network for the two cases. Specifically, the power loss reduction is the key parameter used with the constraint that the voltage profile is within the acceptable range in all the buses.

3. RESULTS AND DISCUSSION

The results of the loads flow analysis of the IEEE 33-bus network for the case without DG integration is given in Figure 6, Figure 7, Figure 8 and Figure 9. The mean voltage of the buses in Figure 6 is 0.98648 p.u. and the minimum is 0.9812 p.u. while the maximum is 0.9989 p.u. The mean VSI of the buses in Figure 7 is 0.9928 .and the minimum is 0.982 while the maximum is 0.9997. As shown in Figure 8 and Figure 9, the top 10 buses based on the VSI includes bus 3,4,2,6,10,13,25,7,11, and 16.

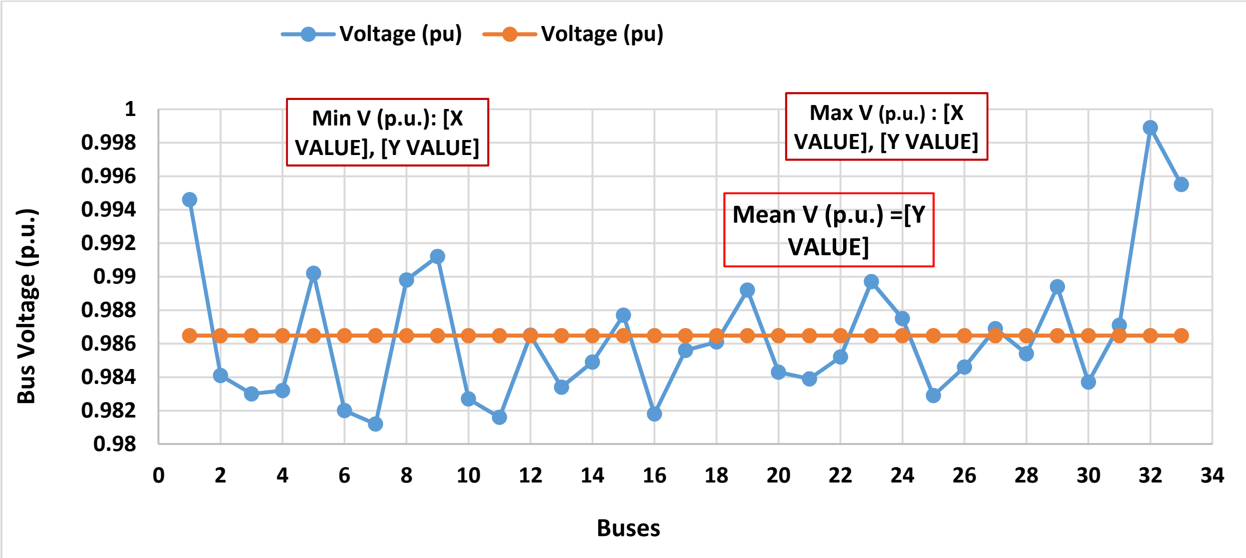

Figure 6 The voltage profile of the IEEE 32-bus when the flow analysis is considered without DG integration

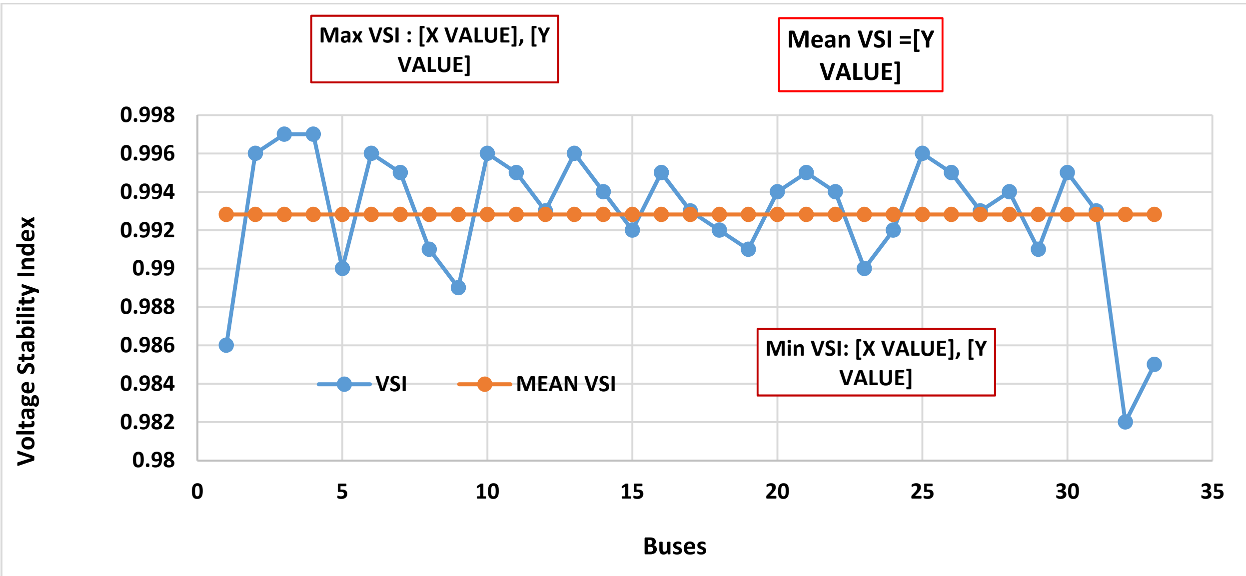

Figure 7 The voltage stability index profile of the IEEE 32-bus when the flow analysis is considered without DG integration

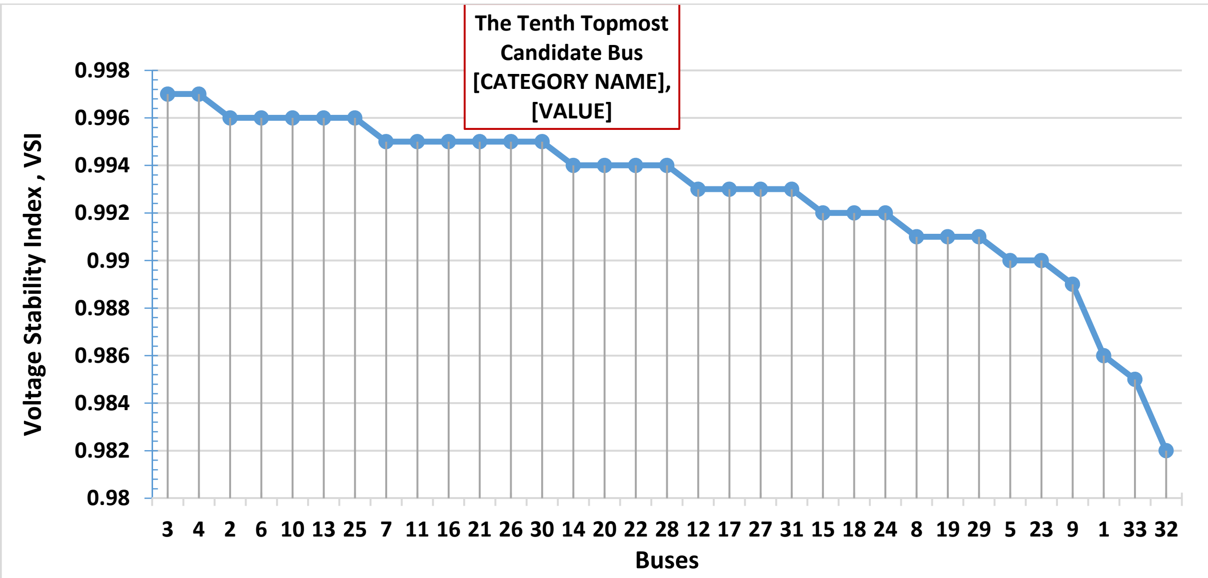

Figure 8 The voltage stability index profile of the buses arranged in descending order when the flow analysis is considered without DG integration

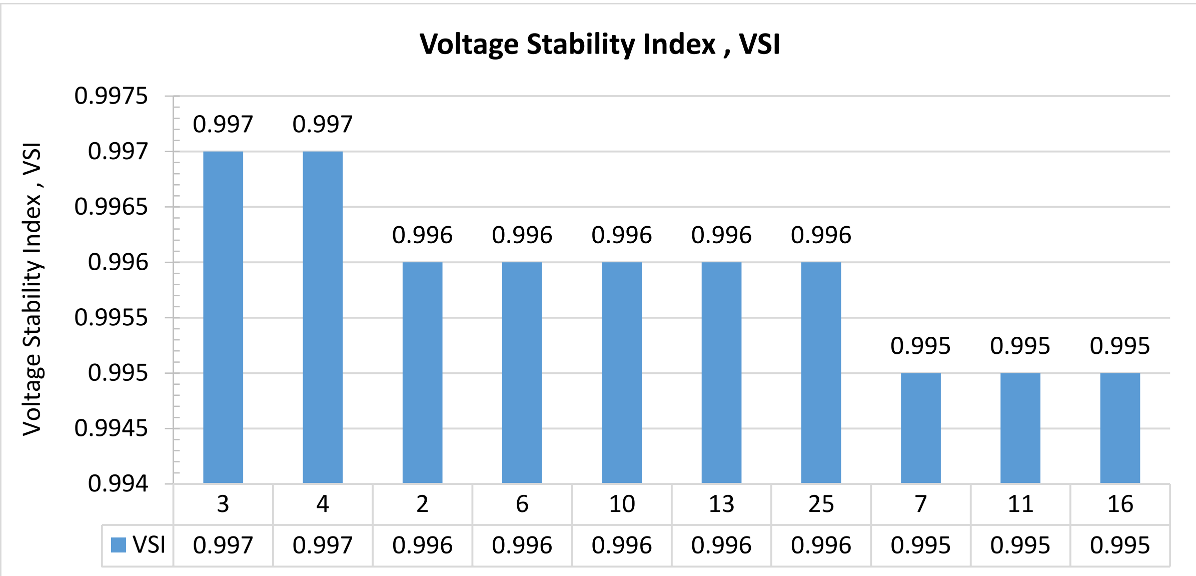

Figure 9 The voltage stability index profile of the top ten VSI buses arranged in descending order when the flow analysis is considered without DG integration

The candidate bus ranking of the buses using the VSI and also using the XGBoost Regressor Model is presented in Table 1 and Figure 10. The DG size on each of the buses using the VSI and XGBoost Regressor Mod and also using the XGBoost Regressor Model alone is presented in Table 2 and Figure 11. Again, the line graph of the percentage loss on each of the buses using the VSI and XGBoost Regressor Mod and also using the XGBoost Regressor Model alone is presented in Table 3 and Figure 12. In addition, the comparison of the mean of the various performance parameters for the DG placement and sizing when using the VSI and XGBoost Regressor Mod and also using the XGBoost Regressor

Model alone is presented in Table 3. The results show that the use of the VSI and XGBoost Regressor resulted in power loss of 7.92 % while the use of XGBoost Regressor Model alone resulted in power loss of 8.1245 %. About 0.2028 % reduction in power loss is achieved by using the VSI in the optimal placement of the multiple DG installation.

Table 1 The candidate bus ranking of the buses using the VSI and also using the XGBoost Regressor Model

Candidate Bus Ranking	Candidate Bus Ranked by the XGBoost Regressor Model	Candidate Bus Ranked by the VSI	Candidate Bus Ranking	Candidate Bus Ranked by the XGBoost Regressor Model	Candidate Bus Ranked by the VSI
1	27	4	18	13	11
2	10	25	19	14	12
3	4	17	20	15	14
4	1	13	21	17	15
5	25	2	22	19	16
6	9	9	23	20	18
7	16	32	24	21	19
8	18	30	25	22	20
9	3	24	26	23	21
10	32	22	27	24	23
11	2	1	28	26	26
12	5	3	29	28	27
13	6	5	30	29	28
14	7	6	31	30	29
15	8	7	32	31	31
16	11	8	33	33	33
17	12	10			

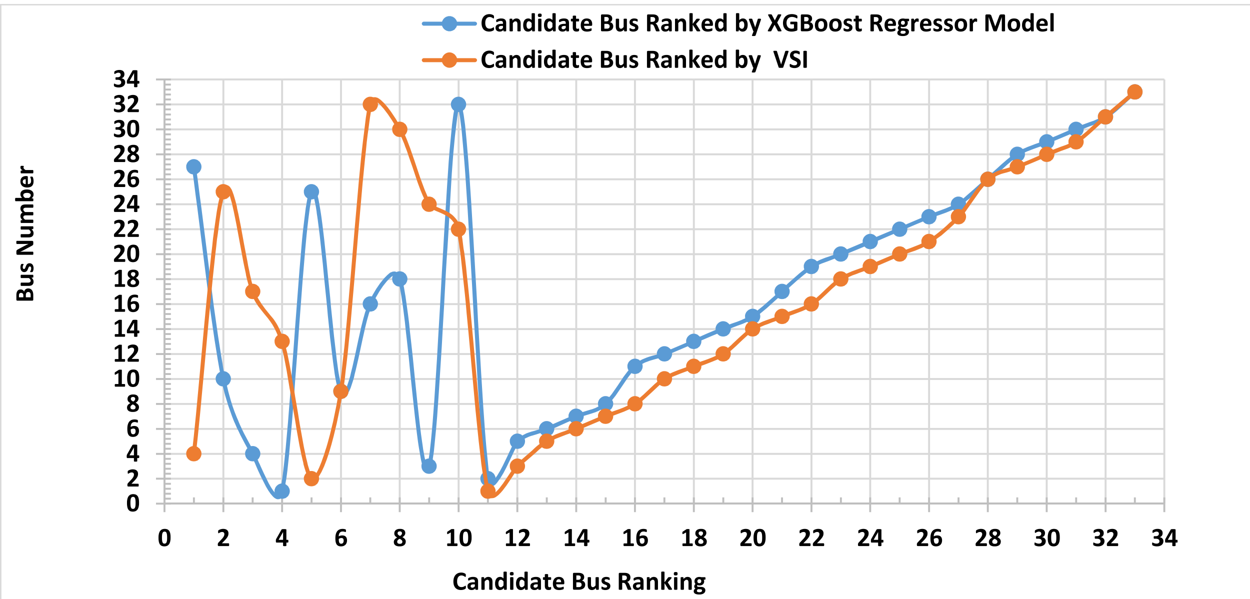

Figure 10 The line graph of the candidate bus ranking of the buses using the VSI and also using the XGBoost Regressor Model

Table 2 The DG size on each of the buses using the VSI and XGBoost Regressor Mod and also using the XGBoost Regressor Model alone

Candidate Bus Ranking	DG Size (kW) by XGBoost Regressor Model Alone	DG Size (kW) by VSI and XGBoost Regressor Model	Candidate Bus Ranking	DG Size (kW) by XGBoost Regressor Model Alone	DG Size (kW) by VSI and XGBoost Regressor Model
1	162.9	164.2	18	130.9	139.7
2	158.1	162.7	19	130.2	138.3
3	154.3	161.1	20	129.4	137
4	149.8	159.4	21	128.7	135.6
5	147.2	157.8	22	127.9	134.4
6	145.9	156.2	23	127.2	133
7	143.3	154.9	24	126.6	131.7
8	141.6	153.4	25	125.8	130.3
9	140.4	152	26	125.1	129
10	138.7	150.5	27	124.5	127.8
11	136.9	148.8	28	123.8	126.6
12	135.2	147.6	29	123.2	125.3
13	134.5	146.2	30	122.5	124
14	133.8	145	31	121.8	122.8
15	133	143.7	32	121.2	121.6
16	132.2	142.3	33	120.6	120.3
17	131.6	141			

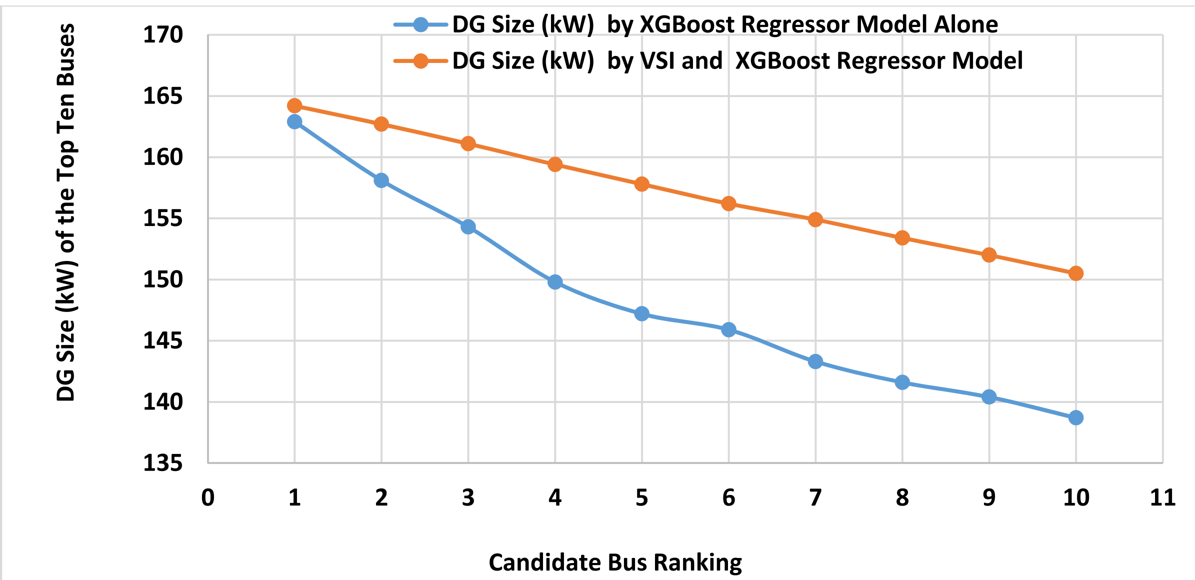

Figure 11
The line graph of the DG size on each of the buses using the VSI and XGBoost Regressor Mod and also using the XGBoost Regressor Model alone

Table 3 The percentage loss on each of the buses using the VSI and XGBoost Regressor Mod and also using the XGBoost Regressor Model alone

Candidate Bus Ranking	Loss % by XGBoost Regressor Model Alone	Loss % by VSI and XGBoost Regressor Model	Candidate Bus Ranking	Loss % by XGBoost Regressor Model Alone	Loss % by VSI and XGBoost Regressor Model
1	7.76	7.67	18	8.19	7.96
2	7.8	7.69	19	8.2	7.97
3	7.84	7.71	20	8.2	7.98
4	7.88	7.73	21	8.21	7.99
5	7.92	7.75	22	8.22	8
6	7.96	7.77	23	8.22	8.01
7	7.99	7.79	24	8.22	8.02
8	8.03	7.81	25	8.23	8.03
9	8.06	7.83	26	8.23	8.04
10	8.1	7.84	27	8.23	8.05
11	8.12	7.86	28	8.24	8.06
12	8.14	7.87	29	8.24	8.07
13	8.15	7.89	30	8.24	8.08
14	8.17	7.91	31	8.25	8.09
15	8.18	7.92	32	8.25	8.1
16	8.18	7.94	33	8.25	8.015
17	8.19	7.95			

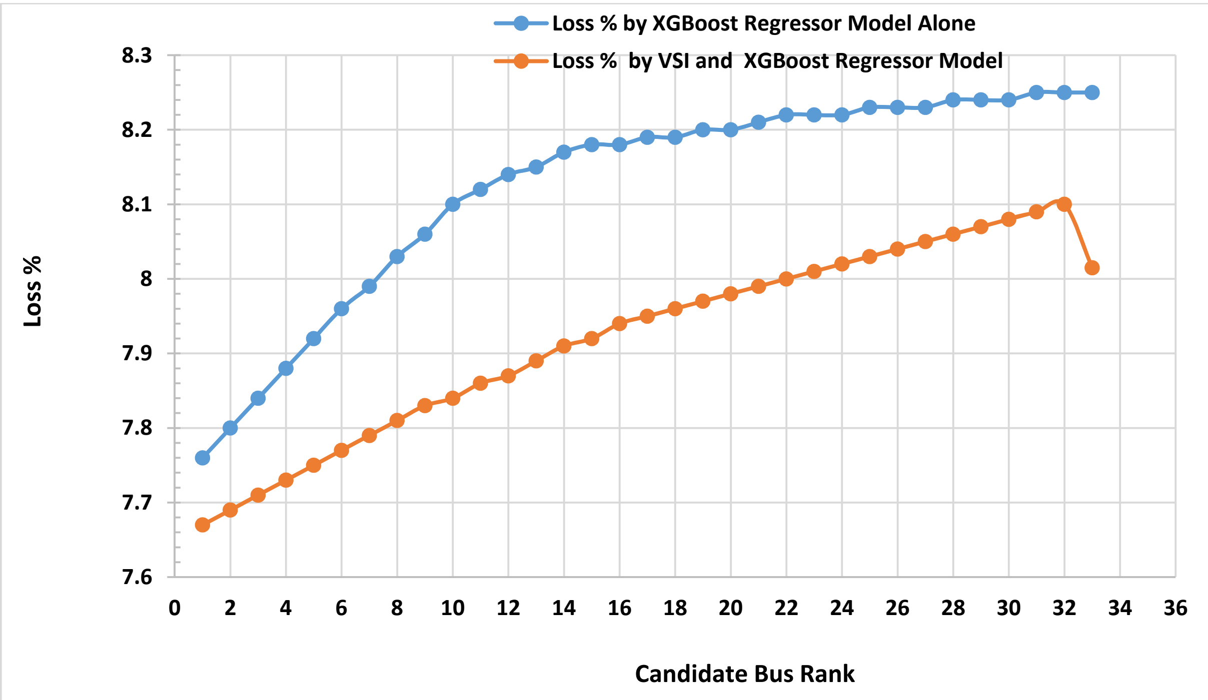

Figure 11 The line graph of the percentage loss on each of the buses using the VSI and XGBoost Regressor Mod and also using the XGBoost Regressor Model alone

Table 4 Comparison of the mean of the various performance parameters for the DG placement and sizing when using the VSI and XGBoost Regressor Mod and also using the XGBoost Regressor Model alone

Mean of the key Performance Metrics	**Value for the case of VSI and XGBoost Regressor Model**	**Value for the case XGBoost Regressor Model alone**	Improvement achieved by using VSI (%)
Mean of the Active Power Loss (kW)	112.1261	120.6618	7.07407
Mean of the Reactive Power Loss (kVAR)	165.5455	163.9091	-0.99836
Mean of the Voltage Deviation Index (VDI)	0.0054	0.0053	-1.88679
Mean of the Bus Voltage (pu)	0.9998	0.9998	0
Mean of the Phase Angle Spread (deg)	7.7452	7.7461	0.011619
Mean of the Power Loss Percentage (%)	7.9211	8.1239	0.2028

4. CONCLUSION

An approach is presented for using voltage stability index (VSI) to determine the best locations for multiple Distributed Generators (DG) installations on IEEE 33-bus network. The DG capacity is further determined using the XGBoost regression model. The study considered the case where the XGBoost alone is used to determine the DG location and capacity without involving the use of the VSI. Next, the VSI is first used to determine the candidate buses and then the XGBoost model is used to determine the DG capacity for each of the buses identified by the VSI. The results showed that the use of the VSI reduced the power loss by about 0.2 %.

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