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Effects of Dispersed Generation on Voltage Profile and Power Losses

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Abstract— With the rapid increase in need of electricity, electric power system is becoming complex day by day. Different types of generating units and loads are connected with one another to form a huge generating, transmitting and distributing network. Pakistan is being confronted with acute shortage of electric power and measures need to be taken on short terms to tackle these problems. In Distributed generation, DG can be utilized efficiently in such cases due to the reason that DG can be on site generation with less time of installation and generating electricity. However, integrating a DG unit with a distribution system causes some disparities if some issues like proper sizing, capacity and location are not taken into consideration. Theses disparities can be related to voltage profile, stability, power losses, harmonics etc. which can cause damage to different electrical devices and units. Particularly, this research work covers the adverse effects on voltage profile when a DG unit is being integrated with the distribution system without taking its size, capacity and location into consideration together with the methods for alleviating these effects. A 132 kv residential feeder has been taken as a test case. Which is further modeled in Electrical Transient Analyzer Program ETAP. Various tests are taken into consideration to analyze the effects of DG on distribution system. Different cases are being analyzed taking system with and without DG unit installed at different busbars. It has been observed that significant improvement in voltage profile occurred when DG is inserted in system with proper consideration of size location and capacity.This research work can help expanding power system in future and tackling different issues related to voltage profile in distribution sector worldwide and particularly in Pakistan**.**

Keywords— Renewable Distributed Generation, Distribution System Operators, Cross-Linked Polyethylene, Load Tap Changing, Combined Heat and Power.

I. Introduction

Electrical Power system comprises of three subsystems i.e. a generating system, transmission system and distribution system. Demand for electrical power has increased up to great extent and usually this demand is fulfilled by electricity generating stations i.e. Hydro, thermal and nuclear power stations etc. Figure 1.1 shows a brief presentation of electrical generating station, then a transmission system and at the end a distribution system. [1]. Capacity of Electricity generating stations can vary from micro to macro [2]. In order to transmit electrical power from generation point to the consumer, several transmission systems are being used. [3].

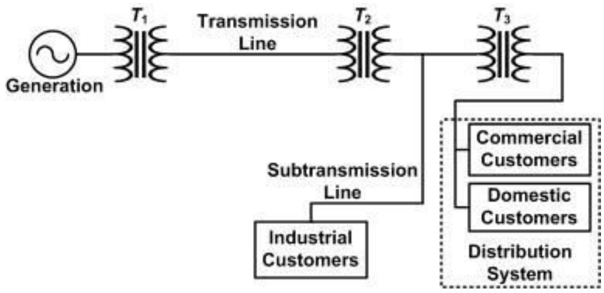

Figure 1. Electrical Power system [1]

The data revealed by the renewable global status report declares that the total electrical power comprises of 79.5% fossil fuels and remaining percent is non-fossil fuels. About 2.2% of electrical energy is being generated from nuclear sources, nearby 11% from non-conventional sources such as geothermal, wind0and solar0etc. Figure 2, [4] [5] shows the energy production from different sources.. Due to these reasons, generation of electricity must also be increased according to the needs. According to energy data source, demand for electricity is mounting at the rate of 1.4% annually and being assessed to increase till 2020 [6]. However, it requires a numerous time for construction and a massive investment too. To overcome these problems there should be a fast and improved solution that will take minimum time to be in service [7].

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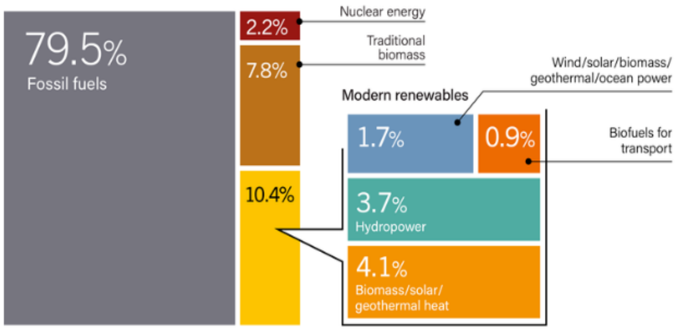

Figure 2. Distribution of power generation from various sources [5]

To overcome the gap between electrical energy supply and demand, Dispersed Generation has become the most suitable option. Small generating units that can generate electricity on-site, when joined within the distributed system is known as Distributed generation [8]. DG comprises of enormous technologies, like Wind Turbine system, Gas Turbines, Photovoltaic cells etc. If power is being generated by a DG unit through non-traditional or renewable energy source it can be mentioned as a renewable dispersed power generation [9] [10]. Together, traditional and non-traditional (renewable) energy can be utilized for generation of electrical power [4]. Conventional energy resources can be Combustion engine, fuel cells etc., while non-conventional energy can be the energy obtained from sun, wind or heat from inside of the earth etc. A DG unit along with the capability of energy storing capability is known as Distributed source of electrical energy. Proper study and mechanism is needed to gain out the maximum efficiency from DG. Location of installation, size and type must be chosen accordingly [4]. Some worse conditions might also occur if theses parameters are not considered properly like false triggering (flow of power back into the transmission system) [11] [12]. Some of the positive effects that are entitled with the DG when integrated with a distributed system are improved voltage profile, power losses reduction, improved transmission and the of distribution congestion, security enhancement and in achieving the aim to use a green and environment friendly energy resources [13]. On the other hand, injection of DG in distribution system has also some negative impacts if its size and proper installation location is not considered. These can be voltage rise, flow of power from distribution network back into transmission network, worst power value when islanding (network is being cut down from the utility but distributed resources are still connected) which can harm the consumer's appliances [14].If a un-deterministic DG unit of larger capacity is linked to the network, it may have bad impact of voltage rise. To overcome this problem different alternative approaches are anticipated in this research work.

II. Methodology

For load flow analysis, the loads are being considered at different intervals.To make the system at steady state i.e. at static position, very short intervals are being chosen because in such a short interval the load change cannot be too much and can be chosen a constant. Such kind of discrimination is known as Quasi static operating condition i.e. considering that the load and power flow on a transmission line remain constant for very short interval of time [26].

A. Voltage Controlled Bus

A specific kind of bus, explicitly preferred and detailed on the basis of voltage0magnitude and real power0is called PV0bus or voltage-controlled0bus. In this kind of bus, reactive0power and phase angle0are not being taken into attention. At some per-defined0points, voltage0regulators are installed0which continuously0keep on checking0the voltage0levels.

B. Mathematical Modeling

For various outcomes and calculations, Newton Raphson method can be used along with the Gauss Seidel iteration method.

$$I_{Bus} = Y_{Bus} \times V_{Bus}$$

Also for any specific Bus \K"

$$I_K = \sum_{n=1}^{N} Y_{Kn} V_n$$

Complex Power

$$S_K = V_K I_K^*$$

$$P_K + jQ_K = V_K [\sum_{n=1}^{N} Y_{Kn} V_n]^*$$

Where K = 1, 2, 3 ...N

For Complex Power

$$I_K = \frac{P_K + jQ_K}{V_K^*}$$

Also, $I_K = \sum_{n=1}^{N} Y_{Kn} V_n$

$$I_K = Y_{K1}V_1 + Y_{K2}V_2 ++ Y_{KK}\, V_K ++ Y_{KN}\, V_N$$

From the above equation

$$V_K = \frac{1}{Y_{KK}[I_K - (\sum_{n=1}^{K-1} Y_{Kn}V_n + \sum_{K+1}^{N} Y_{Kn}V_n)]}$$

$$V_K = \frac{1}{Y_{KK}[\frac{P_K+jQ_K}{V_K^*} - (\sum_{n=1}^{K-1} Y_{Kn}V_n + \sum_{K+1}^{N} Y_{Kn}V_n)]}$$

Where K = 1, 2, 3... N

Gauss-Seidel Iterative Procedure

Typically initially a is used i.e. j V_i j= 1 and $i_{(0)} = 0$. For estimation of V_K, this particular method is utilized.The results being obtained in the first iteration are used further to have a more accurate result in the second iteration.

$$V_K^{i+1} = \frac{1}{Y_{KK}[\frac{P_K+jQ_K}{V_K^{i*}} - (\sum_{n=1}^{K-1} Y_{Kn}V_n^{i+1} + \sum_{K+1}^{N} Y_{Kn}V_n^{i})]}$$

III. SYSTEM ANALYSIS AND MODELING

ETAP software is operated for making the test model of Rahman baba feeder and then analysis is being made for the voltage profile and power reduction. Figure 3, shows a single line diagram for the trial-based distribution feeder taken. The particular 11KV feeder being taken into account is situated at Rahman baba grid station Dora road, Peshawar, Pakistan, being energized from a bus bar of 132KV in compliance with a 31.5/40 MVA transformer. The energizing basis for this particular feeder is 132 KV bus bar being taken by means of a power grid with a short circuit measurement of 1800.00 MVA.100 MVA is chosen as a base for this data. A lumped load with a power factor of 0.85 lagging is taken and this load is being energized from seven different distribution transformers of various capacities. A particular category of cable being utilized for the analysis is 3-phase overhead aluminum conductor with insulation of cross-linked polyethylene. Span of every single cable is being chosen 700 meters, having a cable class percentage of 100%.

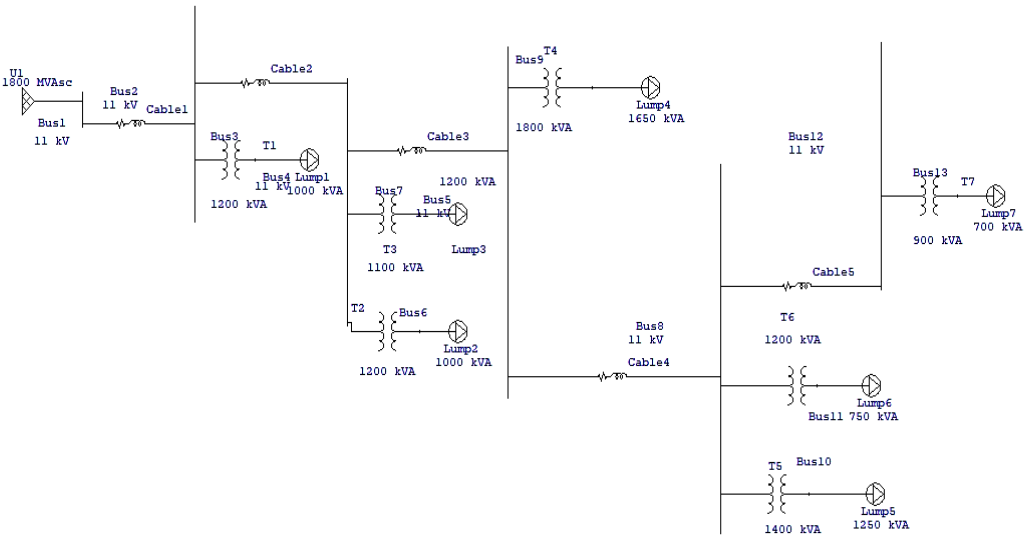

Figure 3. Circuit diagram of the Test feeder

IV. CASE-I

Three scenarios are taken into consideration in this research work regarding the size, type0and location0of DG unit with reference to the impact on voltage profile and system losses. Similarly, along with these three scenarios, five different cases are discussed. In this particular case, analysis of the system is being made without integrating a DG unit into the system. This case will be considered as a base or reference case for studying all other cases. Practically picked data will be used and the results so far gained will be used for understanding the other cases.

D. CASE-II

In the second case, two categories of DG units are opted for analyzing the impact on voltage profile and losses of the scheme i.e. a synchronous generator and induction generator. Two sub scenarios are taken as follows

E. Scenario-1

Synchronous generator is being chosen as a DG unit. A synchronous generator acting as a DG unit having generating capacity of 2 MW will be installed at different locations or buses of the distribution system. It will inject only real power and we will consider power factor to be unity. Such type of sources occurs in the first category. This particular type of DG unit will be injected at various locations, these are, first, this synchronous generator acting as a DG scheme will be connected with bus-4. In second case, the same DG component is added at bus 8.

F. Scenario-II

Induction generator being chosen as a DG component. Induction generator acting in place of DG component having same capacity as in the above case i.e. 2 MW owing lagging power factor of 0.85 is installed at various locations or bus bars of the distribution hub. In this case, reactive power is being engrossed by the arrangement. Such natures of sources occur in third category i.e. different induction generators used in generation of electricity from wind. Two different locations are selected for installation of such DG unit, these are , At first, this DG component will be added at bus-4. The same DG component will be added at bus-8 like the previous case.

TABLE 1. SYNCRONIOUS AT BUS NO.4

CKT/Branch	From To Bus Flow		To from Bus Flow		Losses		% Bus Voltage		% drop in voltage magnitude Vd
ID	MW	Mvar	MW	Mvar	KW	KVAR	From	To	
Cable 1	6.538	4.405	-6.465	-4.353	72.4	52.3	100.0	98.9	1.13
Cable 2	5.623	3.785	-5.568	-3.745	84.3	42.5	98.9	97.9	0.98
T1	0.843	0.568	-0.836	-0.518	7.1	50.1	98.9	95.6	3.23
Cable 3	3.723	2.481	-3.675	-2.463	37.4	18.8	97.9	96.8	1.09
T2	0.839	0.567	-0.832	-0.516	7.2	51.1	97.9	94.6	3.25
T3	1.006	0.697	-0.995	-0.616	11.5	81.4	97.9	93.6	4.31
Cable 4	2.297	1.522	-2.247	-1.513	36.6	8.4	96.8	95.2	1.62
T4	1.379	0.940	-1.366	-1.846	13.3	94.3	96.8	93.2	3.62
Cable 5	0.585	0.392	-0.582	-0.391	3.3	0.6	95.2	94.8	0.42
T5	1.038	0.708	-1.028	-0.637	10.0	70.7	95.2	91.6	3.56
T6	0.624	0.413	-0.620	-0.384	4.1	29.3	95.2	92.7	2.46
T7	0.582	0.391	-0.576	-0.357	5.9	34.4	94.8	91.6	3.20

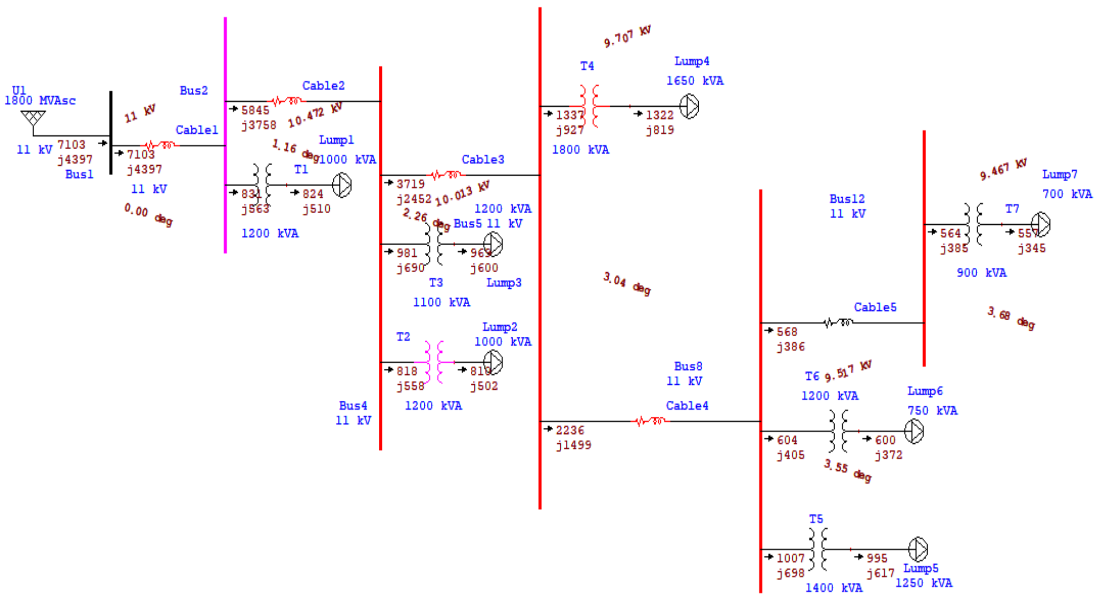

Figure 4. Without DG Component

G. Scenario-IIA

A DG unit having capacity of 2.00 MW is integrated with the system and connected at bus-4 with a unity power factor.The calculations and outcomes from this scenario are depicted in figure 5.3. A DG component having capacity of 2.00 MW is added with the network at bus-4 with a unity power factor. In this case, the load being connected with the feeder is fed mutually by power grid and DG unit. The voltage levels and other conditions are taken in real time. After simulation and analysis, when results are compared with the previous case, an improvement has been noticed in voltage concerned with bus number 4, 5, and 8. Table 1, illustrates the losses. The voltage changes and drops that occurred during this analysis from bus to bus is also described.

H. Scenario-IIB

In this scenario, A DG component having capacity 2.00 MW is being added with bus-8 and power factor is chosen unity. The results after the simulations and analysis for scenario-1B of case-2 at busbar-8 are shown in figure 5.4. A DG component with capacity 2.00 MW is being integrated to system at bus-8 with power factor of unity. Same as the previous case, the load is being handled through power grid and the DG unit jointly. After the analysis of this case and comparing the results with the previous case, it has been noted that a better voltage profile along with less losses have been observed once the same DG component is installed at bus-8. During these calculations, the power depreciation being occurring at several positions like transformers, cables and various lines of distribution system. A detailed description of the power flow direction is also being shown i.e. flow of power from and towards the branch. Different voltage drops from bus to bus are also shown along with the bus voltages.

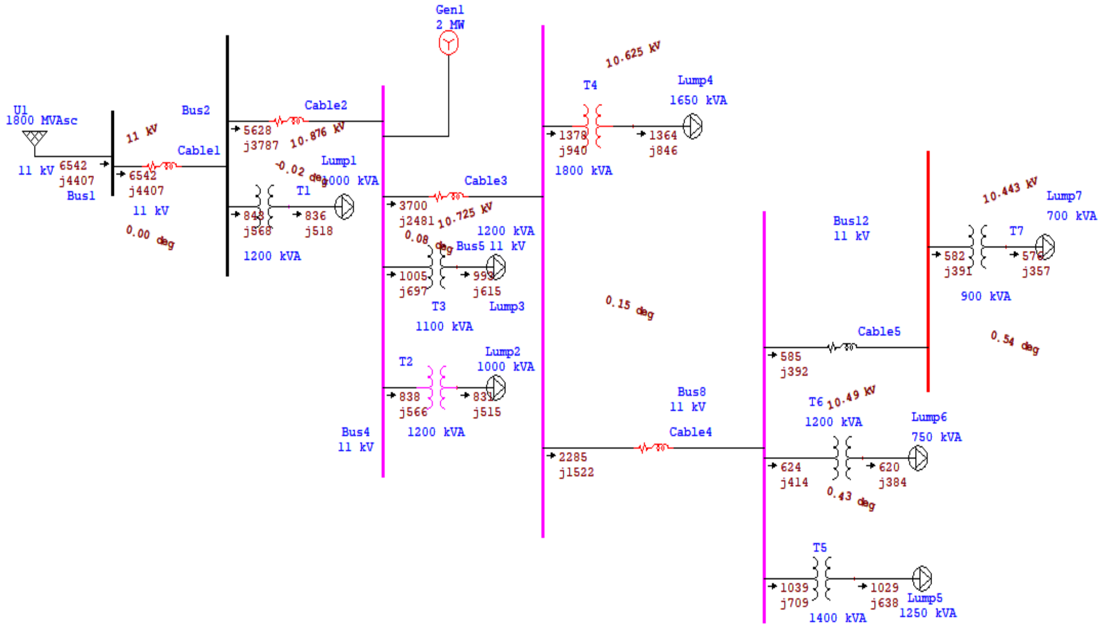

Figure 5. DG component added at bus 4 contributing solitary Active power

I. Case-III

In this scenario, an induction generator is taken as a DG component. Taking this particular case into consideration, an induction generator is being chosen for DG unit owing a power factor, 0.85 lagging. As usual, induction generator works with lagging power factor and absorbs reactive power, same is the case here, reactive power is absorbed and active power is being provided with the system. Two buses are in critical state, i.e. bus 4 and 8, DG unit is integrated at these two buses.

J. Scenario-IIIA

In this case a WTG having capacity 2.00 MW is being added at Bus-4 taking power factor of 0.85. Figure 6, shows the results of load flow analysis from this scenario when a WTG is being added to the distribution network. A DG unit of capacity 2.00 MW is added at bus 4 having power factor of 0.85 lagging. Same as the previous case, real power is being given to the system while reactive power in the same manner is being taken owing to the reason that induction machines work with lagging power factor. After the analysis and results, it can be clearly observed from the results that the voltage profile is very much better as compared with the scenario-1, Scenario-IIA and scenario-IIB. In this particular case, the WTG is connected with bus-4. Power flow can also be seen from and towards different busses. Different voltage drops are also shown i.e. from bus to bus and bus voltages also. Table 2, shows the outputs from this particular case.

TABLE 2. INDUCTION GENERATOR AT BUS NO.4

CKT/Branch	**From To Bus Flow**		**To from Bus Flow**		**LOSSES**		**% Bus Voltage**		**% drop in voltage magnitude Vd**
ID	MW	Mvar	MW	Mvar	KW	KVAR	From	To	
Cable 1	4.473	5.634	-4.412	-5.59	60.2	43.5	100.0	99.0	0.99
Cable 2	3.569	5.023	-3.524	-4.990	45.0	32.5	99.0	98.2	0.85
T1	0.843	0.568	-0.836	-0.518	7.0	50.0	99.0	95.8	3.22
Cable 3	3.677	2.486	-3.653	-2.469	23.8	17.2	98.2	97.5	0.65
T2	0.840	0.567	-0.833	-0.516	7.1	50.6	98.2	94.9	3.24
T3	1.007	0.698	-0.996	-0.617	11.4	80.6	98.2	93.9	4.30
Cable 4	2.271	1.527	-2.261	-1.520	9.2	6.6	97.5	97.1	0.40
T4	1.383	0.942	-1.369	-0.849	13.1	93.1	97.5	93.9	3.60

Cable 5	0.587	0.394	-0.587	-0.393	0.6	0.4	97.1	97.0	0.10
T5	1.046	0.711	-1.036	-0.642	9.7	69.0	97.1	93.6	3.51
T6	0.628	0.415	-0.624	-0.387	4.0	28.5	97.1	94.7	2.42
T7	0.587	0.393	-0.581	-0.360	5.8	33.4	97.0	93.9	3.15

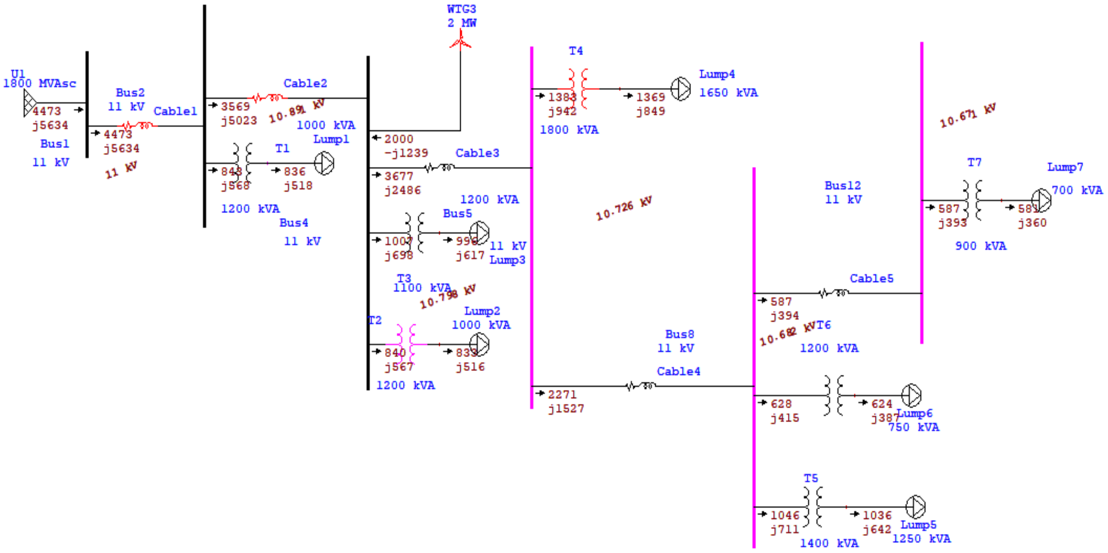

Figure 6. WTG component 2.00 MW added at busbar 4

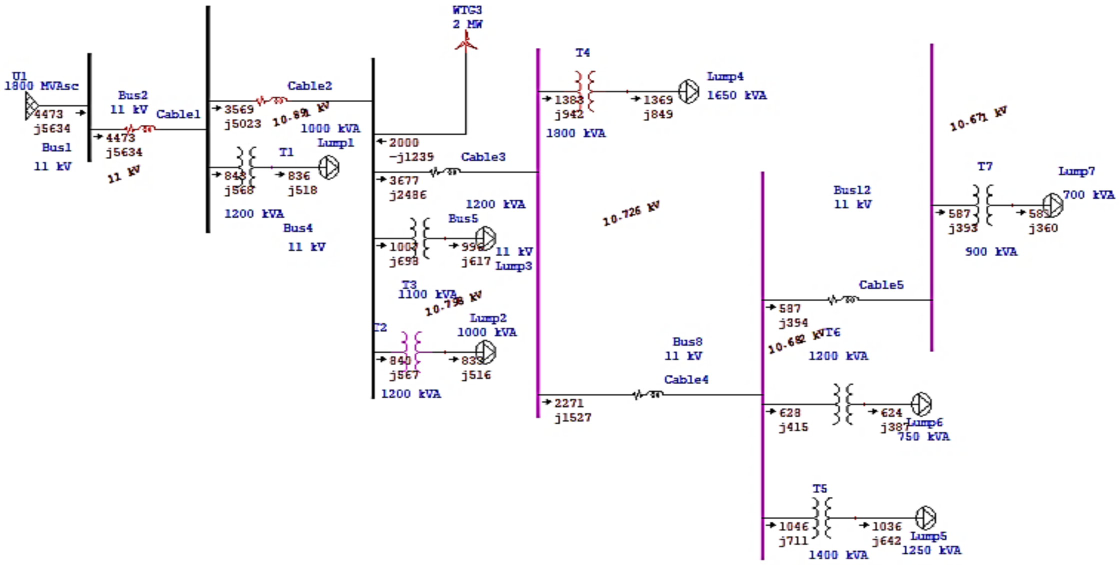

Figure 7. WTG0component 2.00 MW added at busbar 4

K. Scenario-IIIB

In this scenario, a wind turbine generator of 2.00 MW is integrated with the system and installed at bus-8 taking the power factor of 0.85. The busbar used in this case is busbar-8. The results and different outcomes from this particular case are shown in Figure 7, Load is being suckled commonly by the power grid and the DG unit integrated with the system.

L. output results from different cases

Results and outcomes from various cases has been analyzed and sorted out for a best possible scenario. Table 3, is presenting the power given and taken from the system.

TABLE 3.POWER GIVEN BY DG

Case	Scenario	DG Inoculated Power		Grid Inoculated Power	
		MW	MVAR	MW	MVAR
1	1	0	0	7.03	4.39
2	2A	2.00	0	6.538	4.405
2	2B	2.00	0	6.553	4.406
3	3A	2.00	-1.550	4.473	5.634
3	3B	2.00	-1.550	4.587	4.355

M. Investigation of Voltage Profile

Voltage profile varies accordingly with the type of DG unit integrated with the system. Various type of voltage profile occurs for various type of DG units. A detailed description about the voltage levels with DG units installed at various buses is given in Table 4.

TABLE 4. VOLTAGE LEVELS WITH DG UNITS INSTALLED AT VARIOUS BUSES

Bus number	Case-1	Case-II		Case-III	
		Case-IIA	Case-IIB	Case-IIIA	Case-IIIB
1.	11	11	11	11	11
2.	10.472	10.876	10.875	10.891	10.723
3.	10.013	10.725	10.725	10.798	10.557
4.	9.707	10.625	10.625	10.726	10.472
5.	9.517	10.49	10.446	10.682	10.454
6.	9.467	10.443	10.4	10.671	10.442

N. Case-1

While taking this particular situation into consideration, not any DG unit is inserted in to the network. Figure 8, gives a block and graphical appearance while Table 5, gives numerical depiction of the depreciation in voltages along with the route from power source to load in different buses. The reason that the depreciation in voltages occur is because of the impedances.

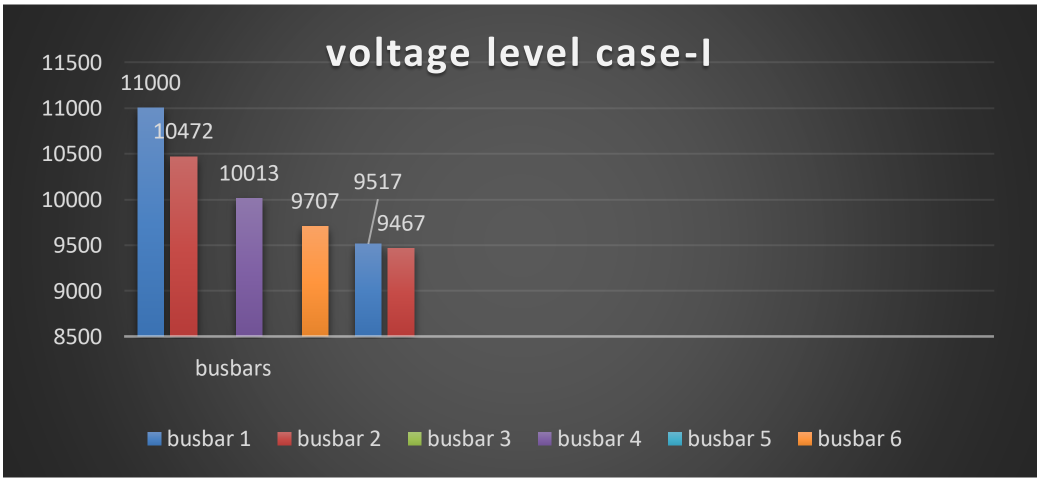

Figure 8. Volatge level at case-1

TABLE 5. VALUES OF VOLTAGE LEVELS FOR CASE-1

S. No	Busbar	Voltage (kv)
1.	1.	11
2.	2.	10.472
3.	3.	10.013
4.	4.	9.707
5.	5.	9.517

O. Case-II

Two unlike type of states are considered and discussed in this particular case Scenario-IIA and Scenario-IIB. A DG unit of 2.00 MW is integrated at two buses i.e. bus-4 and bus-8.

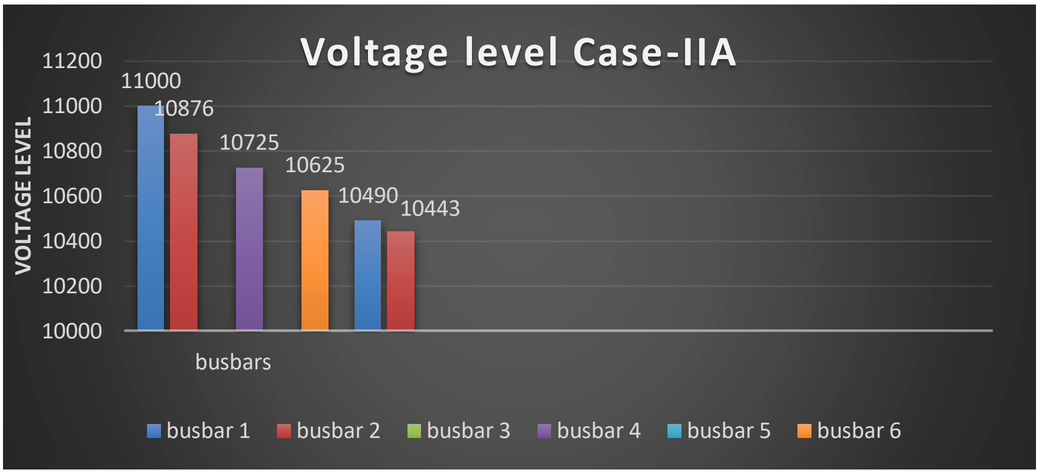

Figure 9. Voltage level at case-II A

Operating power factor of these buses is taken as unity in order to have only active power integrated in to the network with no reactive power being captivated from the system. When a DG unit is installed at these two specific locations, it has been observed that the voltage profile has been improved in both of the buses i.e. bus-4 and bus-8, but busbar-4 depicts a more positive image. So, a suitable location for putting in DG unit is bus-4. Figure 9, represents Case-IIA along with the comparison with topmost case in which no DG is added to the network depicted in Figure 10.

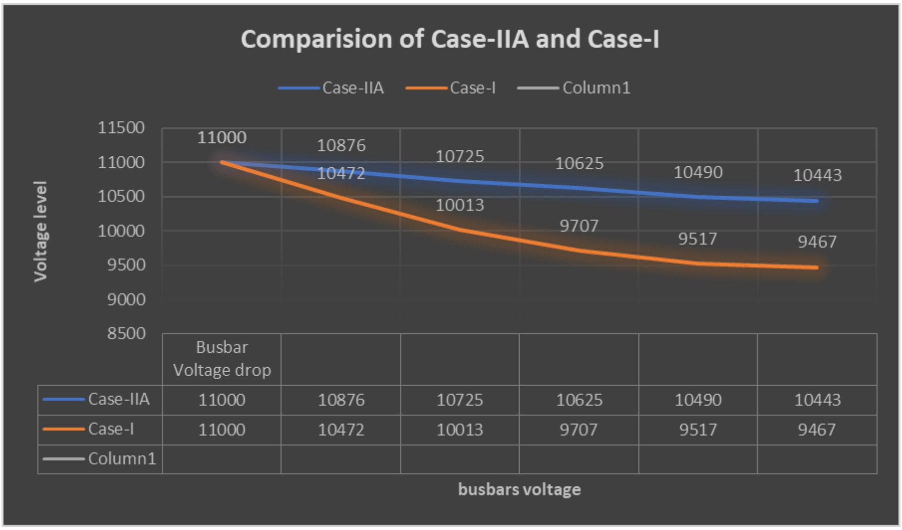

Figure 10. Comparison of Voltage levels at case-1 and case-II.

Similarly, as discussed earlier, two buses were noted in critical condition i.e. bus 4 and 8. Formerly bus 4 was chosen for the addition of DG, in this particular Case-IIB , bus 8 is opted, Figure 11, depicts Case-II

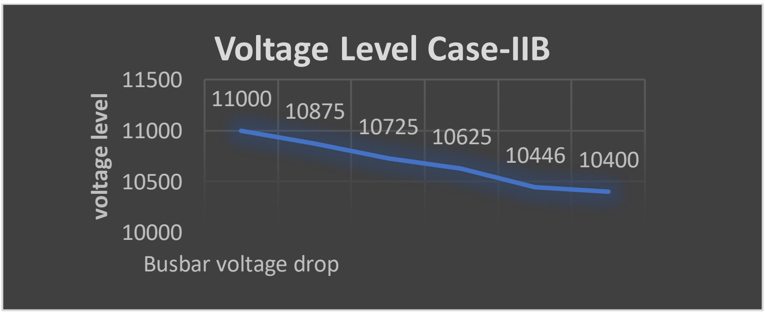

Figure 11. Voltage levels for Case-IIB

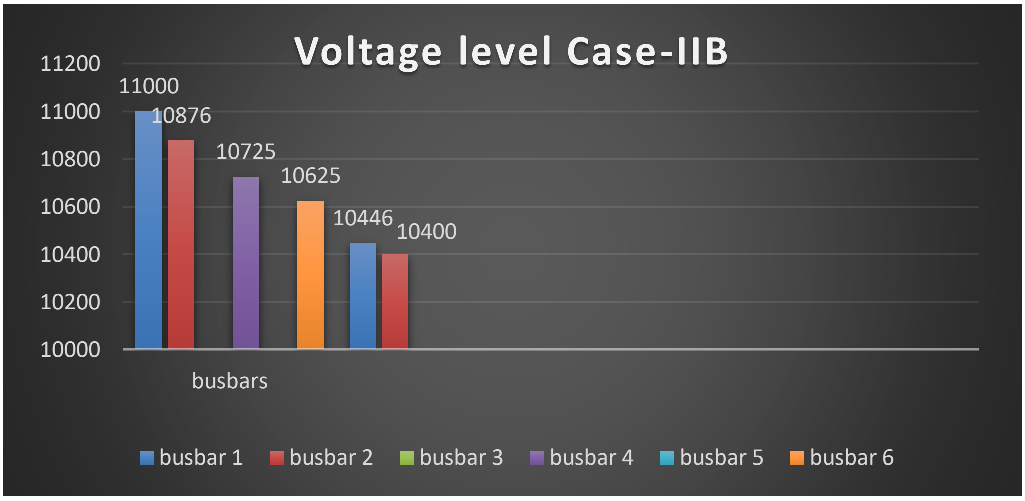

Figure 12. Voltage level for Case-IIB

After comparing case-I and both situations of Case-II in Figure 13, it can be noted that opting a proper location, size and busbar has significantly improved the voltage profile in comparison with the case where no DG was added in to the system.

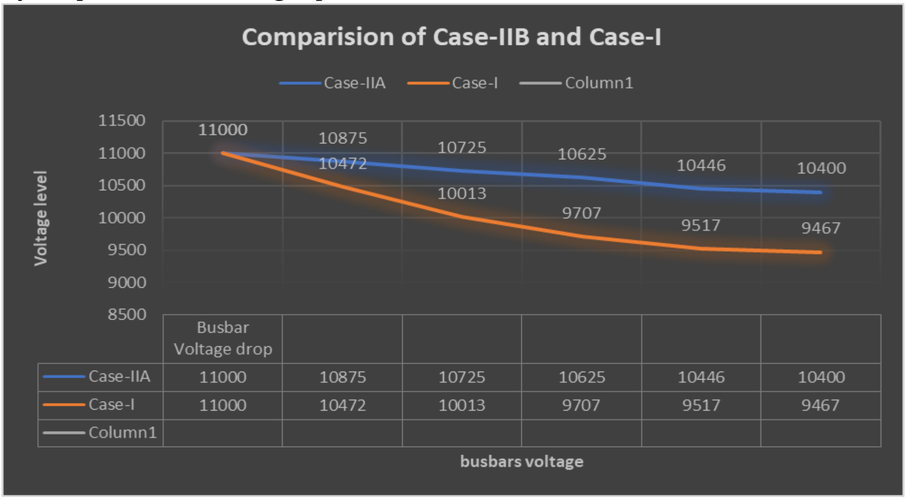

Figure 13. Comparison of Voltage levels at Case-IIB and Case-1

P. Case-III, (Scenario-IIIA And Scenario-IIIB)

In scenario-IIIA and Scenario-IIIB, a DG unit having capacity of 2.00 MW and a specific type i.e. WTG is being integrated with the system. In the previous case, only active power was being inserted and no reactive power was taken, here, reactive power is also taken by the system due to the nature of WTG. Figure 14,15 and 16 depicts the outcomes when a WTG is added at busbar-4 and bus-8 respectively. It can be noted that busbar-4 has more positive impacts if compared with the former bus bar.

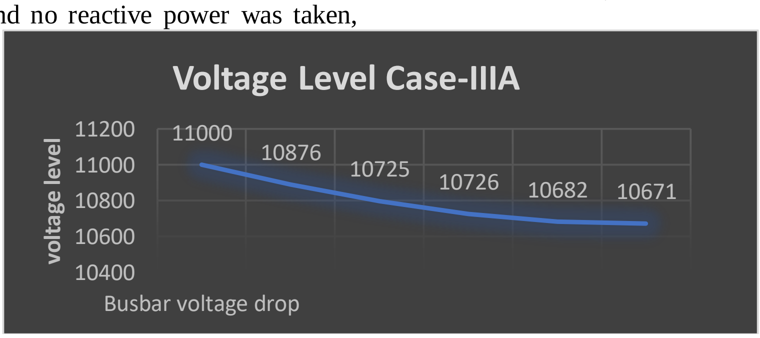

Figure 14. Volatge levels for case-IIIA

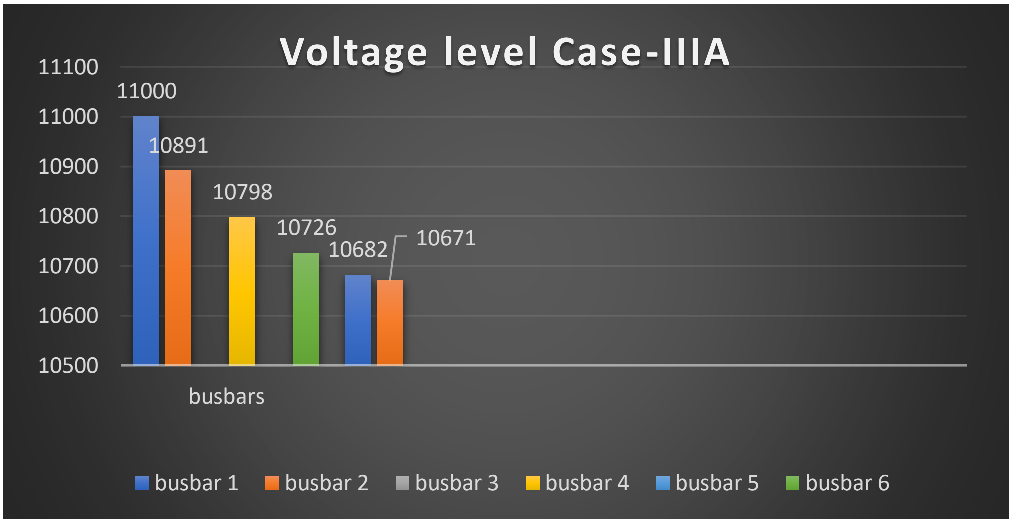

Figure 15. Volatge levels for case-IIIA

After the outcomes being gained from the simulations and ETAP software, a comparison has been made between Case-I and Case-III being depicted in Figure 16, it can be noted that the best suitable location for this particular type and capacity of DG is busbar 4.

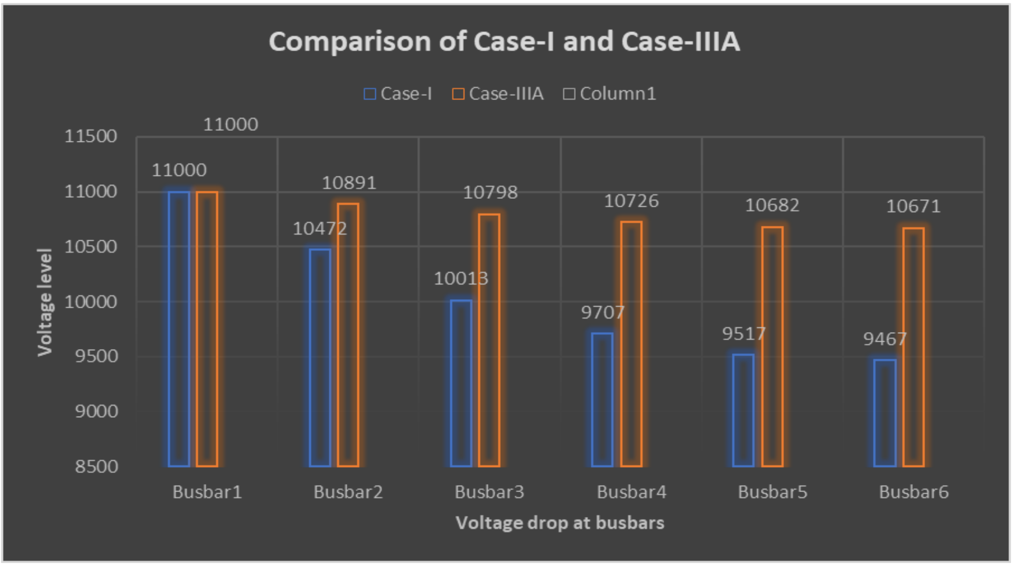

Figure 16. Voltage comparison values of Case-1 and Case-IIIA

Q. Investigation of Power Losses

Power losses varies with the type of DG used and also with the location of installation of DG i.e. minimum losses has been noted when a wind turbine generator of 2MW is installed at busbar 4. Similarly, the case where no DG has been injected is noted to have maximum losses. The following cases shows different types of losses occurring in this analysis.

R. Case-1

While taking this particular situation into consideration not any DG has been integrated in to the grid. The depreciation being noted in this particular case is about 1026KW. The impedance of different lines, current flow and some constant losses i.e. transformer losses contribute to the total losses.

S. Case-II

Case-II comprise of sub two cases i.e. in one case synchronous generator being used as DG unit has been integrated at bus 4 and then at bus 8. It has been observed that losses have been depleted if compared to the previous case. Case-IIA and Case-IIB has 293.1KW and 361KW power reduction respectively.

T. Case-III

Case-III, just like the previous case consists of two cases. In one case a WTG has been installed at busbar 4 and in the other case the same wind turbine generator has been integrated with the grid through busbar 8. Load is being mutually fed by grid and DG unit both. After comparison, busbar 4 shows less amount of losses compared to bus 8. The following figure illustrates these losses. Case-IIIA and Case-IIIB has 196.9KW and 362.9KW losses respectively.

U. Comparison of power Losses

By comparing all cases i.e. the one in which no DG has been inserted into the system, the other one in which a synchronous generator is used as a DG and similarly the third and last case which consists of a Wind Turbine Generator, it has been noted that power reduction can be lessened if a DG unit is implanted at appropriate site (in this particular situation Case-IIIA). Similarly, the size and type of DG must be nominated in accord to system necessity. The table 6 and Figure 17 show the different losses combined.

Figure 17. Different power losses

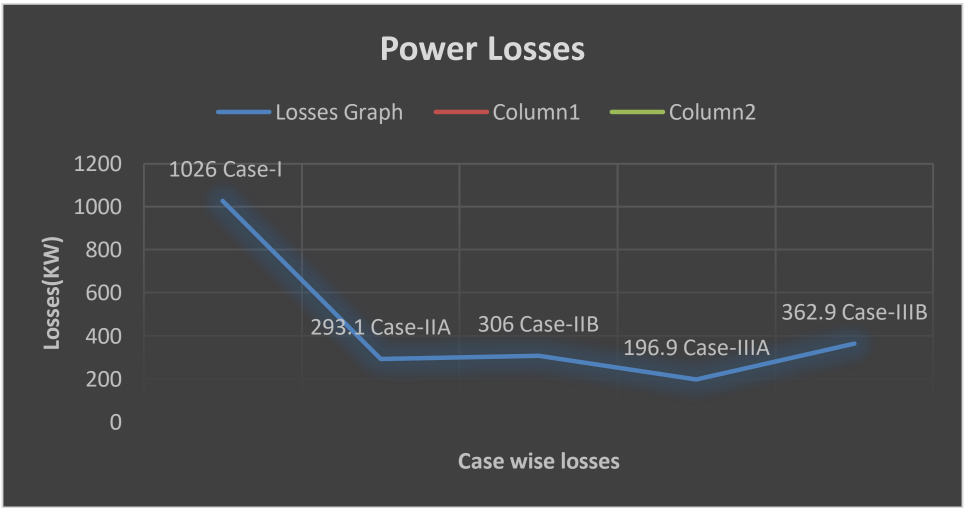

Figure 18. Comparison of power Losses in all Cases

TABLE.6 DIFFERENT POWER LOSSES

Case Number	Power losses (KW)
1.Without DG	1026
2.DG unit with unity power factor at busbar 4 and 8	293.1
	306
3.A wind turbine Generator installed at busbar 4 and 8	196.9
	362.9

CONCLUSION AND FUTURE WORK

Demand for electrical energy is increasing day by day due to rapid increase in population and their increased requirements. Electrical energy flows from generating power stations to load centers through different channels which makes the system more complicated and lots of power losses occur through these channels. Due to the vast gap between the generated electrical power and consumer's demand , load is being shed off from the generation. To tackle this gap, electricity generation must be increased. Keeping in view these circumstances, DG is a feasible and optimal alternative to tackle these problems. In order to have maximum outcome from the installation of DG in a distribution system, some parameters must be analyzed properly. If appropriate location, type and size of DG unit are not assessed, then problems like eccentricity of voltage from its demarcated extent and power losses can happen. Voltage regulation must remain minimum in order the appliances to work efficiently. This research work represents and evaluate the impacts of DG integrated with a distribution network. Various scenarios are taken with and without DG units, analyzed and evaluated for the results. From the analysis and study of case 1, when there was no DG unit integrated with the system, from the outcomes of the losses, voltage deviation has been noticed which caused a low voltage at various buses and links, in addition to some buses that are noted in critical codition.When Wind Turbine generator acting as a DG unit was injected in the same case keeping proper location, size and capacity into consideration as discussed, it was noticed from the results that the voltage profile has become better comparatively and the optimum site for induction of DG unit is bus-4. This research work covers an important and most occurring problem in a distributed system i.e. deviation of voltage pattern after a DG unit is inducted within the system. Today, our country is confronted with a dire need of electricity generation. Different alternatives can be used to tackle this problem. But most of them are time consuming and cannot start their generation in less time. DG can be used as an alternative to overcome this problem. DG is being used widely throughout the world for generation of electricity on a smaller as well as larger base, prominence has been made to improve and make the voltage profile better and the losses be minimized. In addition, this research can be advanced by considering harmonica, protection and short circuit analysis into consideration.

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