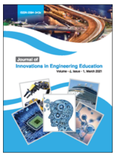

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Impact analysis of residential induction cooking on medium voltage distribution network system: A case study of Nagarkot feeder, Bhaktapur, Nepal

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Abstract

Electricity is mostly used for cooking purposes in developed countries for a long time. Electricity could be used for cooking in Nepalese residential areas by transfering from Liquifty Petroleum Gas (LPG) to Induction Cooking(IC). Significant use of IC to the distribution feeder can increase the losses of the feeder, reducing the voltage profile at the buses, which in fact increases the current-carrying conductor. So, the grid impact analysis by IC loading to the distribution feeder is necessary. The study is carried out by performing technical analysis by load flow analysis on the feeder by calculating current, voltage profile, and power losses. The load flow has been performed for different loading of IC, and optimized Distributed Generation (DG) size is calculated. The bundling of the conductor is performed to reduce the loss at the feeder. This can be performed by checking the rated current of the conductor used (i.e., the branches where the rated current limit violates then that branches need bundling). The power loss at a different penetration level of IC is calculated. The IC power rating of 1500 Watts at each residential consumer when total 4924 number of the consumer is loading to Nagarkot feeder, active power loss increases to 1887.013 kW from 469.443 kW, and reactive power loss increases to 943.507 kVar from 234.722 kVar. The Minimum voltage is 0.664 Per unit (pu) at bus number 104 (Halede bus) which violates the voltage stability limit. The optimal penetration level of IC can be done up to 25% of total peak load by DG integration of 5965 kVA at 0.8 Power Factor (pf) lagging. This will give an active power loss of 530 kW. The next method, i.e., bundling of the conductor in 9 number of branches (at branch number 1, 2, 31, 34, 36, 38, 78, 79, and 86), should be done to improve the IC loading level. The maximum IC loading can be done up to 40% of the total peak load with a power loss of 477.7 kW by this bundling technique.

1. Introduction

Electricity is one of the most important things that human beings need. It is used for lighting rooms, working fans, and domestic appliances like induction cooking, air conditioners, and more providing comfort to people. The National statistical data of 2012 shows that about 80% of the national energy consumption is used in the residential sector in Nepal, out of which 60% of energy is used for cooking applications[1]. This designates that cooking is one of the most energy-intensive applications. In the urban residential sector of Nepal, cooking is highly dominated by LPG, whereas, in rural residential sectors, cooking is dominated by biomass. Moreover, LPG shortage is the most common and frequently faced problem of the urban people. According to NEA annual report of about distribution consumer services the most connected consumers are from the residential consumers and is around 93.24% [2] so, it could be possible option to check the grid feasibility to connect IC.

The principle of working of an induction cooking stove is to stimulate a coil of wire and induce a current into a pot made of a material that must have high magnetic permeability and stands in the coil [3]. Induction heating means producing high frequency eddy current on

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metallic object which will produce heat on the object. Induction heating is most commonly used electric cooking in domestic sector [4].

Induction cooking is often measured as one of the most efficient cooking technologies globally. In this technology, up to 90% of the energy transformed into heat is transferred to the utensils, compared to about 74% for traditional electric systems and 40% for gas [5]. However, the usage of induction cooking has been seen in the European market. Nepalese people are still resistant to the change in cooking habits. Several market barriers exist for this technology in the case of Nepal, counting the high initial cost, the requirement of magnetic cookware, unreliable power supply, and lower perceived reliability of induction stoves among the people [5].

Though usage of induction is both beneficial to consumers and the nation. The penetration of large-scale induction stoves may arise problems on the distribution feeder. Some of the problems can be mitigated by various techniques like installing distributed generation in the distribution system, bundling of the conductor, upgradation of feeder and many more [6, 7]. To determine the technical impact to the grid load flow is necessary. The distribution load can be carried out using different methods like Newtons-Raphsons and Fast Decoupled methods, but they are not efficient as the R/X ratio of distribution feeder is high [8]. For distribution load flow the major techniques are ladder theory and backward forward sweep methods. Due to fast conversion rate and efficient computation Backward /forward sweep algorithm is genererally preferred [9].

Installing distributed generation (DG) in the distribution system has positive and negative effects on the system. There is a need to adequately choose the acceptable amount of DG penetration such that the advantages are not turned into disadvantages. Improvement in voltage profile resulting from installing DG can help mitigate the voltage drop along the feeder; however, increasing the penetration level above a specific limit might cause overvoltage or other problems. The advantage of DG installation is the reduction in overall system losses. Careful sizing and placement are needed, as high penetration may increase losses in some cases [10]. On the other hand bundling of lines reduces the line reactances, which improves the line performance and increases the power capability of the line [11]. The combination of more than one conduction in parallel in a phase is termed as bundling.

On [12] it was suggested that, electric grid parameters are within the limit of regulation of the country (Ecuador). It was also suggested that, the registered coincidence factor of induction stoves utilization was 0.16. On [13] the work done was on induction cooking based on grid connected solar PV system. The result suggested that the integration of solar PV up to 3 kW are capable to run the IC. On [14] the study of efficiency between induction cooking, natural gas and traditional cooking stoves was studied and the most efficient was found to be induction cooking. So, out of all induction cooking is the most motivating factor.

This research focuses on examining the technical impacts of the induction cooker in a medium voltage residential distribution feeder system. In many households, if the induction cooker is simultaneously switched ON, it may affect the distribution feeder's conductor and transformers, which ultimately increases power loss, decrease voltage which is violated beyond the limit.

2. Methodology

This study is to analyze the technical impact on the grid due to the use of residential IC. The overall step-wise flow diagram is shown in Figure 1.

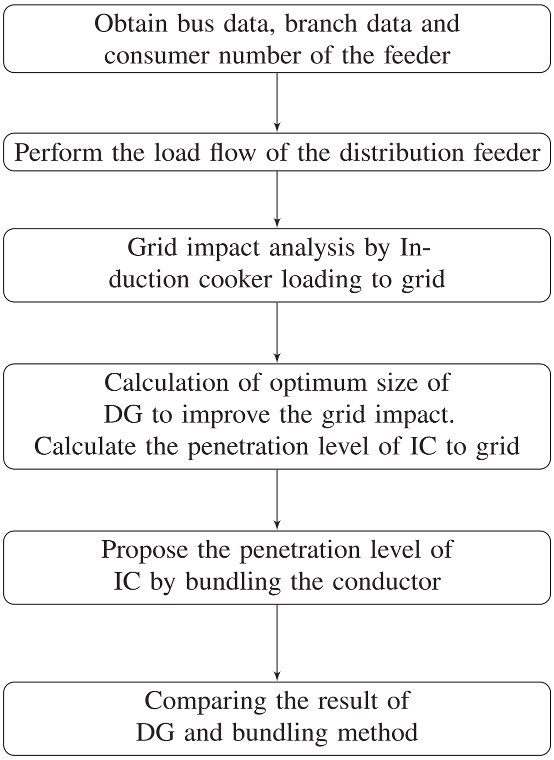

Figure 1: Block diagram of methodology

The grid impact studied in the research were power loss and voltage profile. By performing load flow analysis which calculates power loss at each branch, current at each branch and voltage at each bus. The load flow was carried out by using Backward/Forward sweep algorithm. The load flow was performed for different loading of IC, and optimized DG size was calculated. The optimized DG size was calculated using analytical method [15] using Equation 1, 2, 3 and 4. Further analyzing the penetration level of IC on the basis of loss was determined. For the analysis, the area selected was the Nagarkot feeder, at Bhaktapur, Nepal.

$$\mathrm{P_{DG}} = \frac{\mathrm{P_{Lk,\,eff}} + \alpha \times textQ_{\mathrm{Lk,\,eff}}}{1 + \alpha^2} \tag{1}$$

$$\mathrm{Q_{DG}} = \frac{\mathrm{P_{Lk,\,eff}} + \alpha \times \mathrm{Q_{Lk,\,eff}}}{\alpha + \beta} \tag{2}$$

$$\alpha = \tan(\theta) = \frac{\mathrm{Q_{DG}}}{\mathrm{P_{DG}}} \tag{3}$$

$$\beta = \cot(\theta) = \frac{\mathrm{P_{DG}}}{\mathrm{Q_{DG}}} \tag{4}$$

Where,

θ : Power factor of DG size to be calculated

$\mathrm{P_{DG}}$: Size of DG to be placed at $\mathrm{k^{th}}$ bus

$\mathrm{Q_{DG}}$: Size of DG to be placed at $\mathrm{k^{th}}$ bus

$\mathrm{P_{Lk,\,eff}}$: Real loads beyond $\mathrm{k^{th}}$ bus

$\mathrm{Q_{Lk,\,eff}}$: Reactive loads beyond $\mathrm{k^{th}}$ bus

Firstly the data's required for study was taken from Nepal Electricity Authority office. Then load flow analysis of radial distribution feeder is to use backward/forward sweep algorithm [16], which calculate branch current and voltage at each bus. Induction cooker (IC) can be used as active power consuming load. It was considered that one IC of capacity 1500 Watt (i.e. 80% loading of IC) can be used at each household. Only active power of IC was taken for the study because according to [17] the power factor of IC is above 0.98. For optimal DG placement at optimal location analytical method was done [18].

Another method to reduce the loss, bundling of conductor method was also studied. The branches to be bundled was determine by the current carrying capacity of conductor used. The used conductor in Nagarkot feeder was DOG conductor. Bundling was done with the same conductor. The specification of DOG conductor is shown in Table 1.

Table 1: DOG conductor specifications [19]

S.N.	Components	Description
1.	Type	ACSR
2.	Cross section	100 mm^2
3.	Ampacity	229 A at 65°C

3. Result and discussion

3.1. IEEE 33 test bus system

Voltage profile and power loss was carried out for the base case. To verify the code standard IEEE 33 test bus system was taken with the base voltage of 12.66 kV and base power of 100 kVA. The software simulation for the impact anlaysis was carried out in Code environment of MATLAB.

3.2. Current status of Nagarkot feeder

The Nagarkot feeder with 104 buses have the total active power demand of 8344 kW and total reactive power demand of 6258 kVar. Here, the base voltage of 11 kV and base power of 500 kVA was taken for studying load flow at different case. Maximum voltage of 1 pu was obtained at bus number 1 and minimum voltage of 0.818 pu at bus number 104. The active power loss is found to be 469.44 kW and reactive power loss to be 234.722 kVar. The voltage profile at base case is shown in Figure 2.

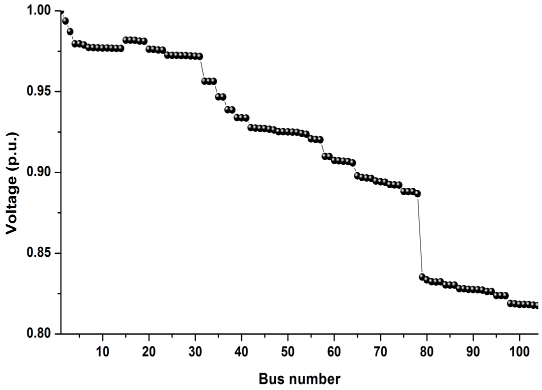

Figure 2: Voltage profile at base case of the feeder

3.3. Impact of induction cooker injection to the Nagarkot feeder

An induction cooking (IC) of 1.5 kW (Philips) was taken for each household. The injection of IC. was only taken for residential consumers. The feeder has altogether 4924 numbers of domestic consumers connected at the different bus. It was considered that one domestic consumer uses only one IC and uses in its rated capacity.

There are altogether 70 buses from where the domestic loads were connected. Some buses have only one consumer connected to them, so these types of buses were neglected due to less impact for IC injection. The total active power increment if 100% of the consumers use the IC for cooking is around 7386 kW. The feeder should withstand this additional power. If 100% IC injection is done in this feeder then, active power loss increase to 1887.013 kW and reactive power loss increase to 943.507 kVar. The total power losses were increased by 300%. The loss at the base case and after IC integration of the Nagarkot feeder is shown in Figure 3.

There are voltage profile changes after use of IC in the grid. The minimum voltage decreases from 0.818 pu to 0.664 pu at bus number 104, as shown in Figure 4. This violates the voltage stability limit. It is seen that the voltage drop increases and power loss increase significantly. So, to overcome this loss optimized DG integration is necessary.

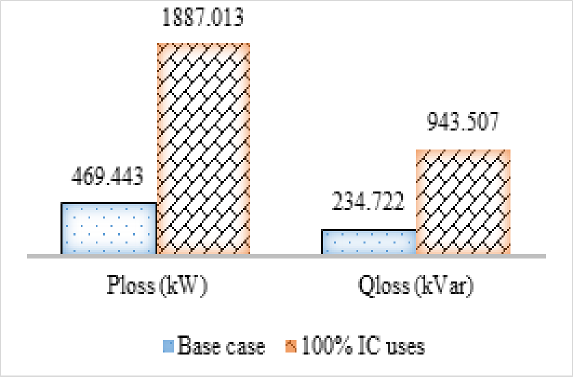

Figure 3: Loss at base case and after IC integration of the Nagarkot feeder

3.4. Impact of induction cooker in the grid at different case

Due to the cooking habits of consumers all the consumers may not using IC at a time, so the usage rate of IC increases 5% at a certain specified time. It can be seen that the voltage at bus number 104 changes from 0.818 pu to 0.664 pu from base case to 100% consumers IC in the grid. Active power loss increases from 469.443 kW to 1887.013 kW and changes approximately linearly with the regression coefficient of 0.98. Similarly, reactive power loss increases from 234.772 kVar to 943.507 kVar; this also changes approximately linearly with the same regression coefficient. This shows the linear increment in IC load may decrease voltage profile, and power loss increases linearly.

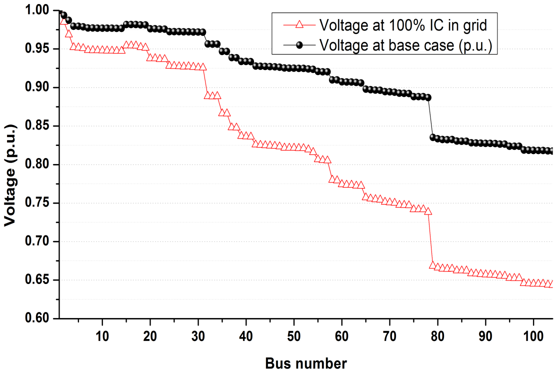

Figure 4: Voltage profile at base case and 100% IC integration in grid

3.5. Optimum DG placement at Nagarkot feeder after IC connection in grid

The analytical method was used to calculate the optimum size of DG at the different bus. This method is an efficient technique for approximating the appropriate size of DG if there are fewer variables. Here, the main objective is minimizing loss as much as possible. One DG integration to the grid was calculated at each of the buses for 100% IC uses in the grid.

DG penetration at bus number 2 to 19, 22, 23, 32 to 76 and 78 have active power loss lesser than loss when 100% consumers use IC in the grid at the current situation. Out of these buses, the penetration on bus number 39 gives the optimum place having minimum loss. But the size of the DG on that bus required is large. It can be seen that the size of DG on this bus is around 12650 kVA on 0.8 pf lagging. So, this large size may not be technically feasible. So, moving toward to bus number 69 can have the optimum size of around 10780 kVA at 0.8 pf lagging. Which is around 65% of total demand size. On DG penetration on other buses except mentioned above the losses were increased more than the losses before penetration of DG So, other buses were neglected. The size of the DG at the bus seems quite larger. So 100% IC on grid 'doesn't seems a good penetration level. Therefore it is better to determine the penetration level of IC on grid first. Although it is no feasible but, the voltage profile improvement after the placement of DG at bus number 69 after 100% IC on the grid is shown in Figure 5.

The voltage profile at each buses were improved as compared to base case voltage. Although, voltage profile seems quite improved the loss at branches increases. The total active power loss is shown in Figure 6.

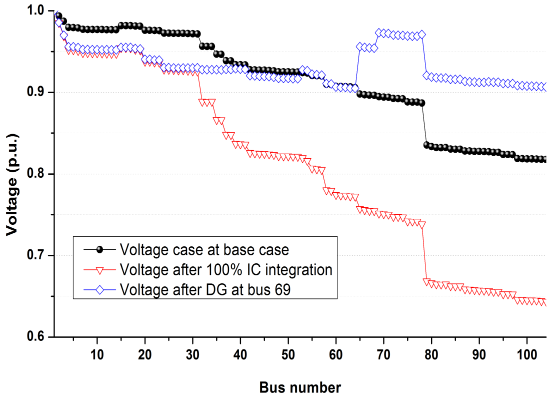

Figure 5: Comparison at Base case, 100% IC integration and with DG at bus 69

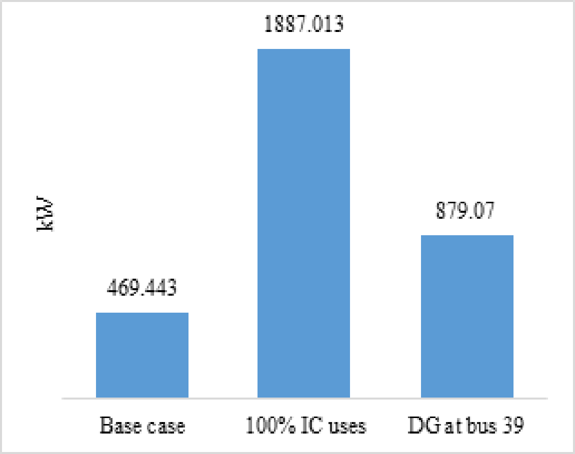

Figure 6: Loss at different cases

After optimal DG placement at 69 number bus the loss decreases up to 879.07 kW. But it is already double than the base case. So, this analysis shows that, 100% of consumers IC uses in the grid is technically not viable. Therefore it is necessary to calculate the sizes of DG and power loss reduction at different percentage loading if IC sizes.

3.6. Optimal placement at different IC loading

Optimal placement of DG from the result shows that the maximum size of 25% can be penetrated in the grid for effective DG size.

It can be noted that, for 5% loading of IC in grid, the active power loss increases to 508.596 kW. This loss can be reduced to 403.56 kW after the placement of optimal DG of size 5646 kVA at 0.8 pf lagging at optimal bus number 87. This means that loading 5% of IC to grid can be technically feasible. In the same manner for 10% IC loading the loss power increases to 550.3 kW and it could be reduced to 432.81 kW after placement of DG at bus number 87 with a size of 5726 kVA at 0.8 pf lagging. Here the amount of DG is around 55% of total base demand of the feeder. It could also be taken as technically feasible. For 15% loading the loss could be reduced from 594.83 kW to 456.45 kW after placement of 9443 kVA at 0.8 pf lagging at optimal bus number 39. Although the power loss was reduced below base power loss the loading of DG is found to be around 90.5% of total base demand. So, this value is not feasible for DG placement. To overcome this problem, another optimal bus was determined as bus number 87 with an optimal DG size of 5807 kVA at 0.8 pf lagging. After injecting this DG (loading size of 55.7% of total base demand), the loss reduced to 463.72 kW, which is also below base power loss. Therefore IC penetration of around 15% is also technically feasible.

Now for 20% penetration, the optimal size of DG was found to be 5886 kVA at 0.8 pf lagging. This is around 56.4% DG loading of total base demand of feeder. The loss after injecting this size at optimal bus number 87 could reduce the active power loss to 496.21 kW from 642.116 kW. Although the loss was reduced than the IC loading loss, the loss after DG injection is still found to be more than the base power loss. This could be considered as short time loading loss. If dynamism could be considered then, this level could be considered as technically fine for utility. Similarly, for IC loading of amount 25% the same situation arises. The power loss reduces from 692.298 kW to 530 kW after injecting 5965 kVA DG size at optimal bus number 87. The power factor of DG is 0.8 lagging. The power loss increase by 13% than before. If we could consider for short time loading, then it could be considered as marginally feasible. For the size above 25% of IC loading the optimal size of DG was found to be greater than 90% of the base load demand of feeder so, it cannot be taken as technically viable.

With all the analysis the most technically feasible IC loading level is found to be 20%. The datas' for calculation is shown in Table 2. But considering load dynamism it could be taken up to 25% loading. To improve the loss, the fraction of DG was found to be around 57.2% of total baseload demand. The voltage profile of different loading of IC up to 25% and after DG placement at the optimal bus is shown in Figure 7.

The voltage profile does not deflect negatively than the base voltage profile. Voltages were improved on some of the buses than base voltage profile. Therefore, it can be noted that IC loading up to 25% can be considered

Table 2: Optimal placement of DG at different loading of IC

S.N.	IC Loading (%)	Optimum bus	Optimum size (KVA) at 0.8 pf	Loss after DG (kW)
1.	5	87	5646	403.56
2.	10	87	5726	432.81
3.	15	39	9443	456.45
	15	87	5807	463.74
4.	20	39	9644	472.65
	20	87	5886	496.21
5.	25	39	9837	489.14
	25	87	5965	530.55
6.	30	39	10022	505.87
7.	35	39	10201	523.04

as technically viable.

3.7. Technical viability by bundling of conductor

A bundle of two conductors was carried out for the branches, which exceed the current limit of 229 Ampere for DOG conductor.

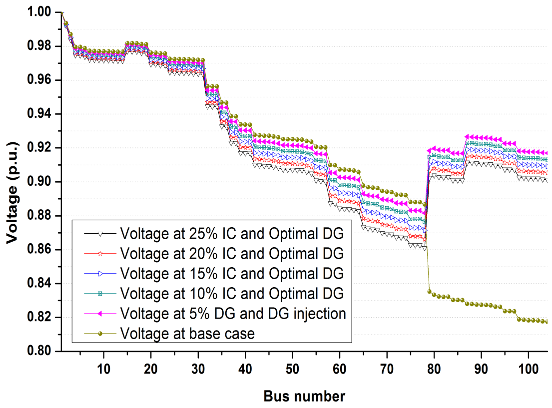

Figure 7: Voltage Profile of different loading of IC upto 25%

Maximum of 14 branches to be bundled and minimum of 9 branches. For the range of 5% to 45% of IC loading there are only nine branches to that exceeds the current limit of 229 Amperes. Then from 50% to 65% loading there are 10 branches to be bundled. Similarly from the range of 70% to 80% of loading the number of branches to be bundled are 11 and rest of the loading above 80% are 14 branches. Since, 100% loading of IC for the distribution feeder may be impossible so firstly 9 number of branches (1, 2, 31, 34, 36, 38, 78, 79 and 86) were taken for the study. In total of 9.992 Km of the line should be bundled in average.

After the bundling on nine number of branches the load flow to calculate the loss was conducted for different loading of IC to get the penetration level of IC The Figure 8 shows the total active power loss versus percentage loading of IC for the bundled conductor.

The active power loss at base case is 469.44 kW. From Figure 8 it can be seen that by bundling the 9 branches, the active power loss below the base case loss is found up to 35% of IC loading (i.e. at 35% loading the active power loss is 445.2 kW). For 40% loading of IC the active power loss was found to be 477.7 kW, which could be considered technically viable if it could be considered. Therefore, it could be found that 35% of IC loading is technically feasible by bundling and may go up to 40% of IC loading if needed. The loss will be further reduced if bundling on more branches could be done but should be checked for the economic point of view as well.

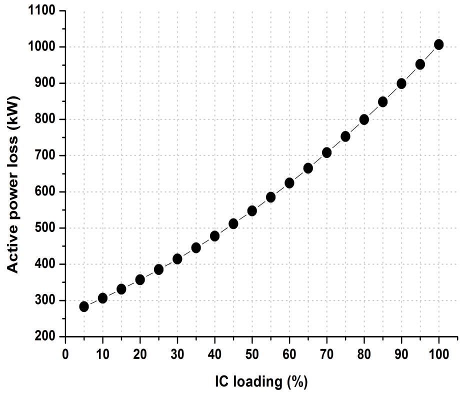

Figure 8: Total active power loss versus percentage loading of IC for the bundled conductor

4. Conclusions

After the IC loading in the Nagarkot feeder, the active power loss changes from 469.44 kW to 1887.01 kW with a significance voltage drop. This loss and voltage drop could be improved by a DG penetration is of large size as compared to total power of demand of grid. This concludes that 100% IC loading is not technically feasible. The feasible penetration level of IC to grid was found to be 25% of the household number. Up to this level the DG can improve the power loss and voltage drop to a acceptable limit. This improvement was also carried out using bundling method in which bundling of 9 branches (in around 9 Km) can reduce the impact up to penetration level of 45% of IC to grid. On comparing between DG penetration and bundling method, the impact of IC penetration is reduced more on bundling method.

5. Recommendations

Following recommendations have been drawn from the study:

- Dynamic consumption pattern of consumer could be implemented in the study on grid impact analysis more reliable.
- Use of decentralized DG placement at the distribution feeder can be suggested for reducing loss.

6. Limitation

- Only technical analysis was carried out for the impact analysis at grid.

7. Acknowledgment

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