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Grid parameters analysis of 11 kV radial feeder on residential areas based on forecasted emerging load: A case study of Tarkeshwor Municipality, Nepal

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Abstract

The study focuses on the technical performance analysis of a radial distribution network in a rapidly urbanising area under the current, future, and optimised scenarios. The control area in this research is Tarkeshwor Municipality, Nepal, which lies in the outer stretch of Kathmandu, representing the urbanising loads. In this paper, the electric cooking load has been added to the long term forecasted load up to ten years from now, representing emerging technology and load that adds to the peak load in the daily load curve of the control area. The placement of reactive power suppliers (i.e. Capacitor placement) in optimal network buses is also proposed as an optimisation tool that exhibits improved power quality and reliability with the forecasted load. The peak load is found to be increased to 21.93 MVA at the tenth year's end including targeted emerging load due to which the voltage profile also goes out of the limits. Optimal placement of capacitor on optimal buses results in improved voltage profile and also reduces active power loss of the distribution network in the control area. The analysis and discussion in this research will be helpful to the policymakers as well as the electric utility for planning the supply and utilisation pattern of electricity in the future.

Keywords: *radial distribution network, emerging loads, capacitor placement, optimisation*

1. Introduction

Energy is essential for the well-being and prosperity of people, the economy, and infrastructural development. Energy consumption patterns and per capita energy consumption are increasing due to urbanization (Rajbhandari et al., 2019). Electricity has been the primary demanded form of energy, not only in conventional stationary lighting and industrial load but also in the technologies like cooking and transportation. Electricity is distributed to the consumers through radial feeders emerging from substations (Atteya et al., 2016). The distribution network in the context of Nepal has been in a continuously improving scenario to manage the current and future loading in the feeders.

In Nepal, electric cooking has been recognised as a critical factor increasing electricity demand in the domestic sector. Various factors such as reducing the dependency on imported Liquefied Petroleum Gas (LPG) fuels, environmental benefits, commitments in the national and international arena, and the excess of electricity in the national grid have urged the government to come up with different plans and policies to prompt the consumers to shift the energy for cooking from petroleum energy and biomass to electricity (Ministry of Forests and Environment, 2021), (Dahal & Poudyal, 2020).

The trend shift in cooking is still predicted to increase in alignment with various governmental strategies and policies. In this context, Nepal also has submitted its Second Nationally Determined Contribution - 2020, to United Nations Framework Convention on Climate Change, where it is targeted that 25% of households use the electric stoves as their primary means of cooking by 2030 from 6% in the current scenario of 2020 (Government of Nepal, 2020). Similarly, other emerging technologies could account for the increase in electrical demand in the future. The planning for the future scenario of the distribution network would have to include the electrical market by the technologies and the shift of energy use in the future.

Electricity is distributed in Nepal through 11kV network feeding to 11/0.4kV distribution transformer and supplying from 400 L-L voltage for all residential or domestic consumers whereas for the industrial consumers through higher voltage level also as per their requirement. Most of the 11kV distribution feeders are radial in nature, some being upgraded to ring main topology but the feeders described in this study are entirely in radial topology. The penetration of significant demand in the future with increasing base loads and peak loads may cause problems with loading the distribution feeder. Some of the issues can be solved by various optimisation techniques like installing distributed generation in the distribution system, bundling the conductor, up gradation of feeder, and many more (Carvalho et al., 2008).

This research is divided in to the following three sections with clear specific objectives. The first specific objective of load forecasting, in which, the load is forecasted for up to ten years based on the historical five years data of energy consumption and developing scenarios for consumers with the addition of targeted emerging load as electrical cooking. The second one is to study the load flow and impact analysis, in which technical impacts in the medium voltage residential distribution feeder system are examined with future loading conditions, which could affect the distribution feeder's conductor and transformers, which ultimately increases power losses and decreases voltage beyond the limit. Then after, as per the specific objective of loss reduction in the distribution network, such distribution feeders are optimised through optimal placement of capacitor on optimal buses to reduce loss and improve the voltage profile. Finally, it concludes with some future work and limitations.

2. Materials and Methods

The study site for this research is taken as major parts of Tarkeshwor Municipality in Kathmandu district, including growing sub-urban areas like Dharmasthali, Goldhunga, Manamaiju, and Phutung, which falls under the distribution area of Balaju Distribution Center, Nepal Electricity Authority. These areas are fed by feeders emerging from the Bajalu substation, namely the Dharamsthali feeder, Goldhunga feeder, and Jarankhu feeder. Dharamsthali was the only feeder here up to 2019, but now new feeders have been added due to increasing consumers, spread in the distribution area, and increasing electricity consumption pattern.

2.1 Load forecasting

Historical data about the number of consumers, electricity consumption, and the feeders' hourly ampere (A) loading have been collected over the last five years. The data were made available from Balaju Distribution Centre log sheets and Balaju Substation, Nepal Electricity Authority. From the historical hourly load demand curve for the last five fiscal years, we can see that the base load increases with the peak load. The valley created by the differences between the base and the peak load increases with passing years. The increase in the use of electrical load is influenced due to significant factors such as growing growth in the purchasing capacity of the consumers, growth in the use of electrical technologies, and trend shift in electricity as the primary form of energy (Omer, 2008). All these factors can be summarised as the cause of rapid urbanisation, reflected explicitly in this research. The control area selected is the outer stretch of the capital city, Kathmandu. Filling the valley between the base load and peak load, may it be by the massive use of emerging technologies with a shift of energy use or change in the behavior of consumers using the existing calculated loads is still a matter of discussion that would justify the optimisation and rearrangement of distribution network (Balasubramanianab & Balachandraa , 2021). The increasing trend of past average hourly load demand is fitted to a curve using the Sine summation function. For hourly load demand curve fitting, the sum of the sine algorithm was performed using the inverse linear least square method (Irfan Ahmed, Mohammad Aslam, & Bhawani Shankar, 2014). For checking the goodness of fit, R-Square was determined. After curve fitting was performed and checking the goodness of fit, the peak load of the forecasted data was extrapolated using a polynomial trend line. The polynomial trend line can be used for predicting the future value from the past trend (Heiko, Silja, & Stefan, 2009). Some assumptions are taken for forecasting the load. Demand forecast was carried out for the next 10 years from the Fiscal Year 2021/2022 to 2031/2032. As electrical cooking load is studied here as the emerging load in the future and its impact on the grid has also been analysed, the peak load for the forecasted has been extrapolated with the targeted electric cooking load as well without including the cooking load. In contrast, within the ten years, this will amount to 25% of the targeted consumers. Also, the size of electric cooking was taken as an average size of 1500 Watts for each domestic consumer.

2.2 Load flow and impact analysis

The grid impact analysis was then carried out for the business as usual (BAU) scenario and the future plan by load flow analysis. The load flow is performed using the backward/forward sweep algorithm. This algorithm is the best, easy and efficient approach to perform load flow, especially, in radial feeders (Rupa & Ganesh, 2014). The load flow was carried out with two propagation. On backward propagation, the branch currents are calculated with the initial bus voltage set to 1 p.u. On forward propagation, the bus voltages at each bus are calculated. Load flow was carried out separately for all three feeders. The load flow starts with the radial distribution feeder's input of line data and bus data. Then after, the branches were arranged using the breadth-first search method which helps in finding the end node of the feeder. After setting the nodes and branches as per our requirement (as shown in Figure 1), further analysis were performed.

In this method, the load current is calculated for the first initial guess and branch current is computed using the backward sweep method. This is calculated using Equations (1) and (2) below (Eminoglu & Hocaoglu, 2008).

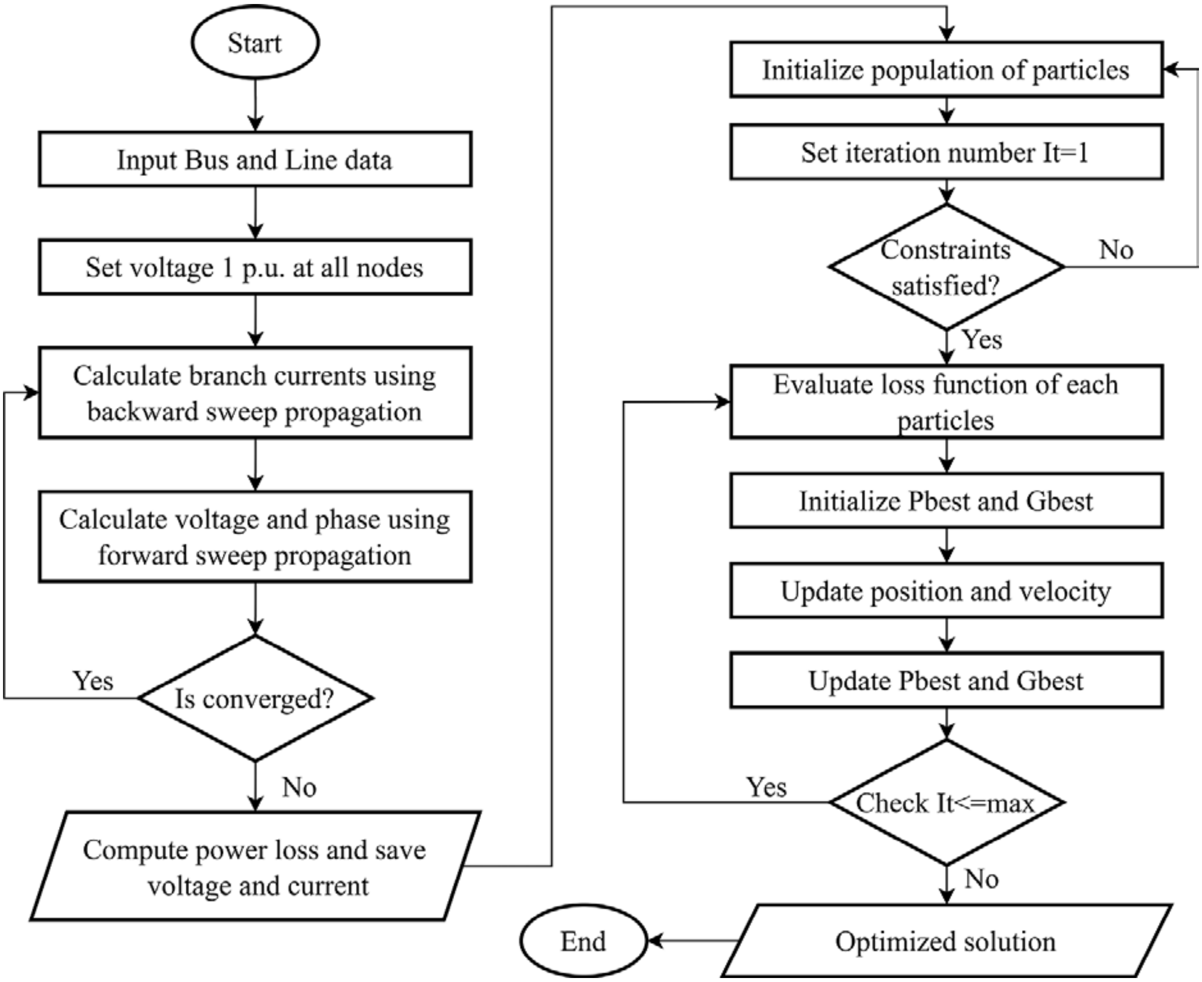

Figure 1: Flowchart of PSO with sweep algorithm

$$I_i^{(k)} = \left(\frac{S_i}{V_i^{(k)}}\right)^* - y_i V_i^{(k-1)} \quad (1)$$

$$J_l^{(k)} = -I_{lr} + \sum J_{lr} \qquad (2)$$

where, S_i = power output at node *i*, V_i = voltage at node *i*, y_i = shunt admittance at node *i*, I_{lr} = current injection of node *lr* calculated from step 1, ∑J_lr = currents in branches emanating from node *lr*, *i* = 1, 2, 3,..., *n* and *lr* = 1, 2, 3,..., b.

Then in forwarding sweep method, the calculation of voltages at each bus is carried out. The bus voltages are calculated using the Equation (3).

$$V_{lr}^{(k)} = V_{ls}^{(k)} - Z_l J_l^{(k)} \qquad (3)$$

where, *ls* and *lr* denote the sending end and receiving end of the branch *l* and Z_l = series impedance of branch *l*.

These backward and forward sweep methods are continuously iterated until the convergence criteria are met. Here, the convergence criteria are checking the voltage difference at each bus of two successive iterations (Dilek, Leon, Broadwater, & Lee, 2010). The difference in voltage between two consecutive iterations should be less than 0.0001. After the iteration criteria are met, the voltage and the branch currents are saved and power loss at each branch is calculated. The branch losses are calculated using the equations (4) and (5) shown below (Eminoglu & Hocaoglu, 2008).

$$P_l = \sum \left(\frac{P_i^2 + Q_i^2}{V_i^2} \times R_i \right) \qquad (4)$$

$$Q_l = \sum \left(\frac{P_i^2 + Q_i^2}{V_i^2} \times X_i \right) \qquad (5)$$

where, P_i and Q_i are the total real and reactive power fed through i^{th} node, R_i = resistance of i^{th} branch and X_i = inductive reactance of i^{th} branch.

2.3 Loss reduction in distribution network

After load flow is carried out in BAU and in future scenarios, the feeders should handle the load in present as well as in future. With increasing load demand, the voltage drop increased, the current in the branches seems to exceed the limits, and the power loss in the network increases (Efkarpidis et al., 2016). So, to ensure a secure and economically optimal electricity supply, it is essential to use distribution network reconfiguration or optimisation to find the optimum solutions based on the requirements and constraints defined by the operators (Abdelaziz et al., 2009). Distribution network reconfiguration can be the cost-effective and most efficient way to increase system reliability. There are many types of compensating methods available to be connected to the grid. All these types have their specifications and purpose (Olamaei, Niknam, & Gharehpetian, 2008). Among various distribution network optimisation/reconfiguration methods, this research proposed optimal placement of capacitor in various buses and techniques for optimisation used is particle swarm optimisation (PSO).

The main objective function of the proposed research is to minimise the total active power loss under given constraints and conditions. The objective function is the sum of unlimited losses of the radial distribution system and is provided in Equation (6).

$$Objective\ function = minimize \sum_{i=1}^{total\ branch} P_{i,loss} \qquad (6)$$

Where, P_{loss} is the active power loss in a bus. The constraints (Singh et al., 2018) for the given equation can be regarded as,

$$0.95\ Pu \le V_{bus} \le 1.05\ Pu$$

$$0 < Q_{Cap,\ Size} \le 60\% * Q_{total}$$

$$N_{CP} \le 4$$

where, V_{bus} is the bus voltage, Q_{CP} is the sizes of capacitor units and Q_{total} is the sum of the total reactive power load of buses. Reactive power supplied by the capacitor unit is less than or equal to 60% of the entire load with D.G. N_{CP} is the total number of capacitor banks at different buses.

To reduce the grid impact due to forecasted load, optimal placement of capacitor as reactive power supplier was considered using PSO algorithm. The PSO algorithm is most appropriate for locating the optimal size of capcitor at the optimal location, particularly when continuous data are available (Kahouli, Alsaif, Bouteraa, Ali, & Chaabene, 2021). This algorithm firstly generates the population of the solution. The objective function defined in Equation (6) is evaluated for each particle of the population and after the initialisation of personal best (P_{best}) and global best (G_{best}), the position and velocity of a particle are updated using the given Equations (7) and (8) below, and then P_{best} and G_{best} are updated. The optimised solution is evaluated after a defined number of iterations. The algorithm is shown in Figure (1) above.

The optimal solution gives the minimum loss under subjected constraints, position of D.G. with its size and individual bus voltages and losses (Naik et al., 2013).

$$V_{id} = w * V_{id} + c_1 * rand(\quad) * (p_{id} - x_{id}) + c_2 * rand(\quad) * \left(p_{gd} - x_{id}\right) \qquad (7)$$

$$x_{id} = (x_{id} + V_{id}) \qquad (8)$$

In the proposed methodology, the size of the population is assumed to be 200 and the maximum number of iterations to be 100. The value of constants c_1 and c_2 both are assumed to be 2. The inertia weight (w) is updated by the Equation (9) as:

$$w = w_{max} - \frac{w_{max} - w_{min}}{Maximum\ Iteration} * Iteration_{number} \qquad (9)$$

3. Results

As per the available data of domestic consumers, energy use, and loading of the feeders of the control area, the consumer growth rate at the end of fiscal year (F/Y) 2015/16 was around 9.93% and at the end of F/Y 2019/20 was 7.16%. Considering the linear growth rate, the growth of consumers can be linearised as in Equation (10).

$$N_{DC}=1600.9\times X+12354 \qquad (10)$$

where, N_{DC} is the number of domestic consumers and X is the F/Y in number, i.e. x=1 is F/Y 2015/16. From this linearisation, we can assume that the number of domestic consumers increases by 1600 per year approximately.

Similarly, the unit energy consumption at the end of F/Y 2015/16 increased by 22.9% and by 33.9% at the end of F/Y 2019/20. The energy consumption rate can also be linearised by the Equation (11) shown below. R-square is measured as the goodness of fit for linearisation and found to be 0.93 which can be considered good for approximation.

$$E_C=267424\times X+862225 \ \# \qquad (11)$$

where, E_C is the total energy consumption in kWh and X is the number of F/Y, i.e. if X=1 then it represents F/Y 2015/16. From this linearisation, as shown in Equation (11), the energy consumption rate can be assumed as 267424 kWh per year for approximation.

The total average load demand for five fiscal years throughout the day is shown in Figure 2. This graph shows domestic consumers' yearly average load demand of the feeders combined in the control area. As shown in Figure 3, it can be seen that there are two peaks, one starting from 6th hours to 9th hours and the other starting at 17th hours to 22nd hours.

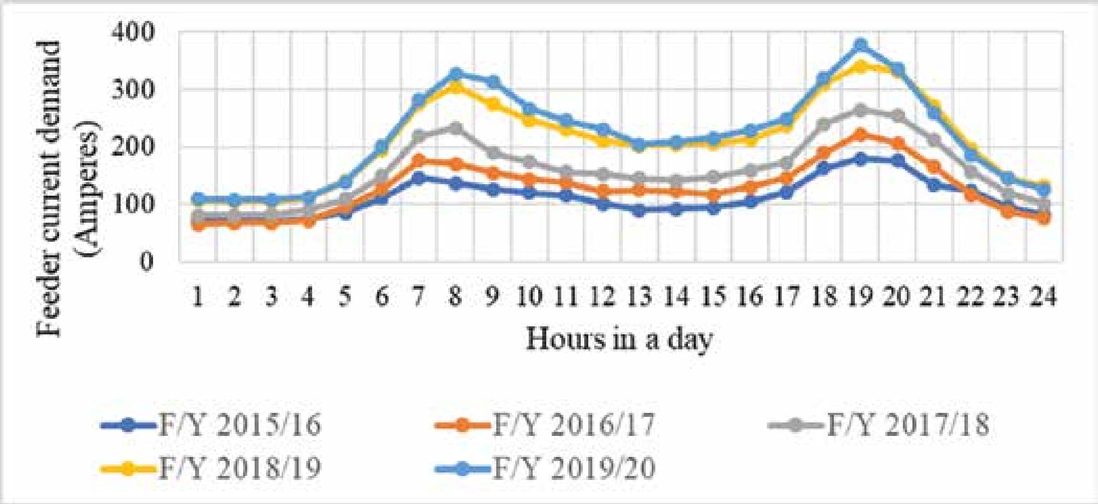

Figure 2: Hourly load demand for different fiscal years

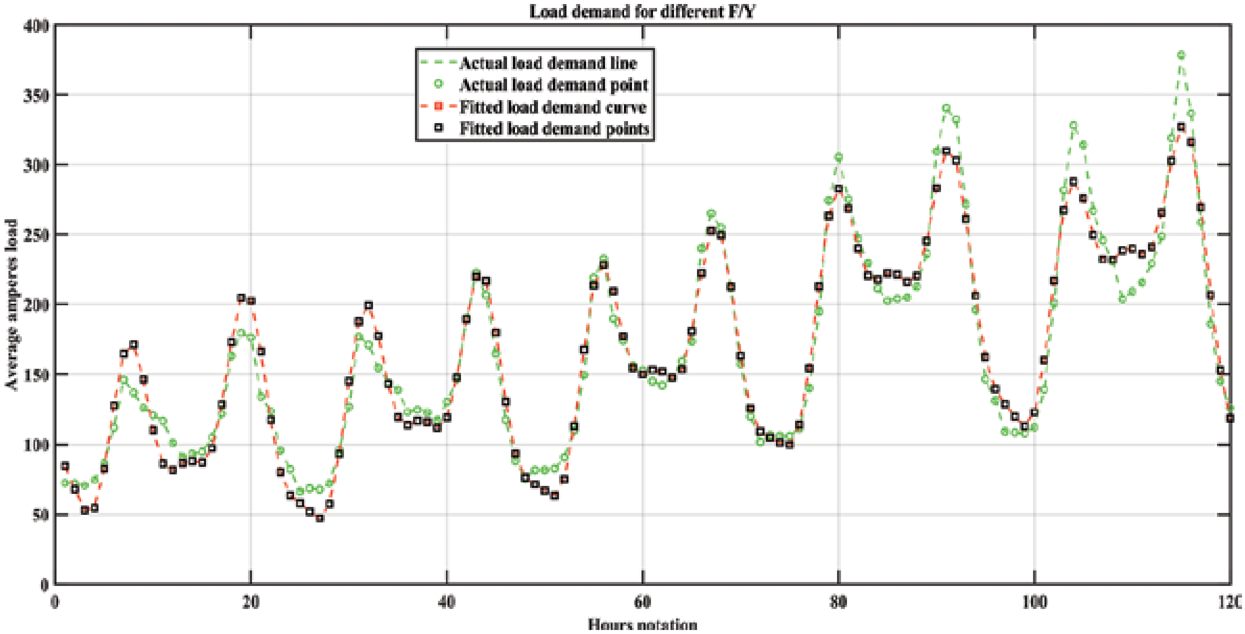

Figure 3: Comparison between actual demand vs. average demand

3.1 Load forecasting

The increasing average hourly load demand trend was fitted to a curve using the sine summation function. Figure 3 shows the actual demand and fitted demand of the hourly demand for the distribution feeders. For checking the goodness of fit, R-Square was determined and found to be 0.95009 for eight summation terms of sine function. All the coefficients of sinusoidal function are specified with 95% confidence bounds which are found by using the nonlinear least square method. As the R-Square is around 95%, the fitted data with the sum of sine wave can be taken for approximation for the further years (Ahmed, 2005).

The curve fitted demand, and the actual average demand is the current (amperes) of feeders of the domestic consumer is shown in Figure 3, where the demands are of five F/Y with 24 hours load (each hourly load). Demand from 1 to 24 shows the first F/Y i.e. 2015/16, and demand from 25 to 48 shows the hourly demand form first hour to 24th hour for 2nd F/Y, i.e. 2016/17 and so on.

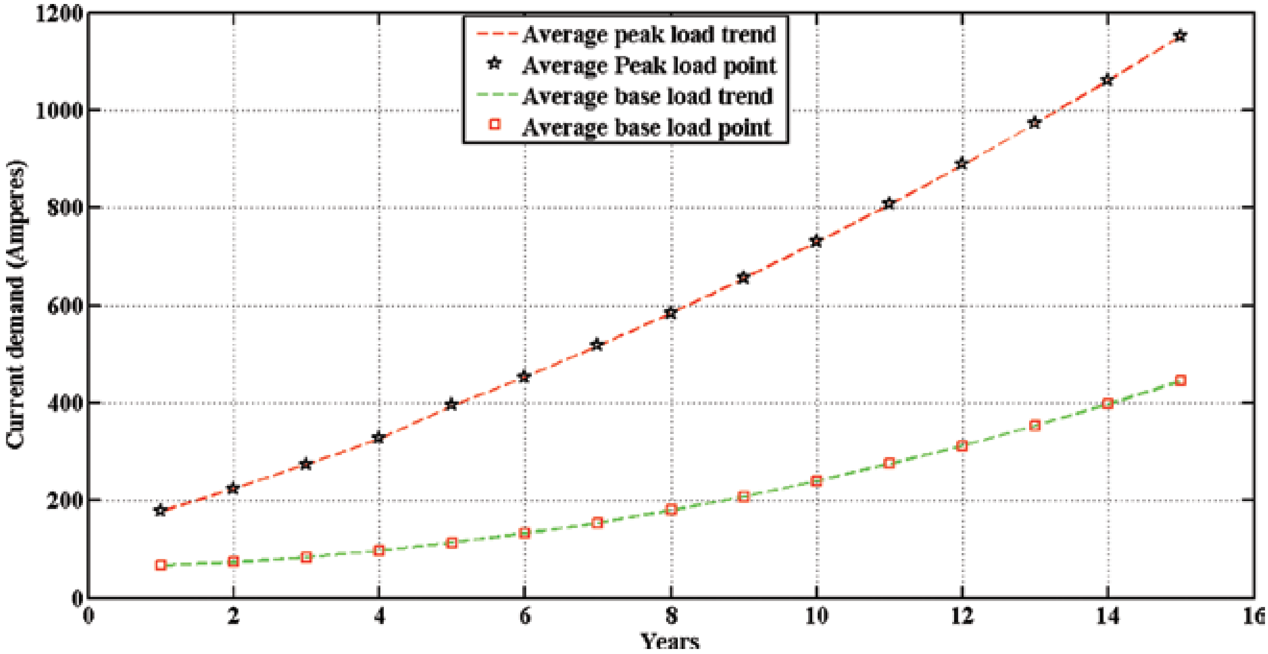

Figure 4: Peak load and base load forecasting for the next 10 years with and without E.C.

Long term load forecasting was carried out which shows the average yearly amperes load is forecasted using the sum of sine function with eight terms. The growth rate of domestic consumers was considered as increased by about 1600 numbers each year in equation 10. The peak load and base load forecasting for ten years from now is shown in Figure 4

As shown in Figure 4, the forecasted value using the sum of sine wave fitting trend lines gives the peak load demand as 452.048 amperes for the first forecasted year and at the end of the tenth year, the forecasted peak load demand would be 1151.31 amperes increasing by almost three times from the current scenario. Similarly, for base load demand, forecasted values will be 131.584 amperes for the first indicated year, and at the end of the tenth year, the forecasted base load demand would be 443.89 Amperes. The peak load here considers a load of electrical cooking (E.C.) as well. Table 1 shows the apparent power forecasted demand for peak load (with and without E.C.) and base load for ten years.

As shown in Table 1, it can be seen that the load demand will increase by three times in ten years from now and there will be around 2.6 MVA more load while considering the electric cooking.

Table 1: Forecasting demand for the next ten fiscal years

F/Y (B.S.)	Peak Load with E.C. (MVA)	Peak Load without E.C. (MVA)	Base Load (MVA)
2021/22	8.613	7.17723	2.507
2022/23	9.837	8.19756	2.932
2023/24	11.125	9.2712	3.416
2024/25	12.478	10.3982	3.959
2025/26	13.894	11.5784	4.561
2026/27	15.374	13.5657	5.222
2027/28	16.919	14.9283	5.942
2028/29	18.527	16.3473	6.721
2029/30	20.199	17.8228	7.560
2030/31	21.935	19.3548	8.457

3.2 Loading of the distribution feeders

The load flow study was carried out for three feeders of Balaju Distribution Center. The three feeders outing are Dharmasthali feeder, Goldhunga feeder, and Jarankhu feeder, supplying significant portions of Tarkeshwor Municipality. The substation currently delivers the total demand of 8.613 MVA through these feeders. All three feeders deliver power to domestic consumers with a base voltage of 11 kV. The total load is shared as 30.81% by Dharmasthali feeder, 33.84% by Goldhunga feeder, and 35.34% by Jarankhu feeder. With this ratio, the increased load at the end of tenth year was distributed as 6.75 MVA by the Dharmasthali feeder, 7.422 MVA by the Goldhunga feeder, and 7.75 MVA by the Jarankhu feeder. The grid impact study for three feeders for the base case and the future case is performed where the load flow is done using the sweep algorithm with a base voltage of 11 kV and a base power of 100 MVA.

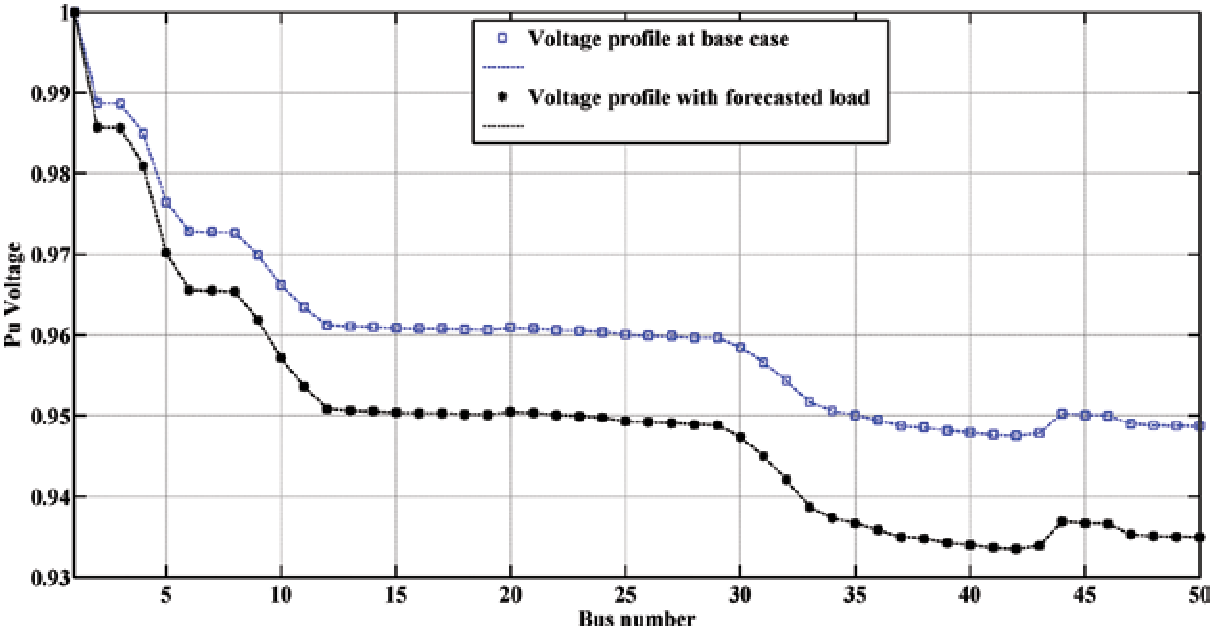

Figure 5: Comparison of voltage profile of Dharmasthali feeder

As shown in Figure 5, the addition of load after the tenth year will result in a voltage drop in Dharmasthali feeder. After forecasting, the predicted voltage drop was found to be 0.933 Pu at bus number 42, and the maximum voltage was 0.985 Pu at bus number 2, excluding the slack bus. The minimum voltage was changed from 0.947 Pu to 0.933 Pu, and the maximum voltage changed from 0.988 Pu to 0.985 Pu at the respective buses 42 and 2. The predicted active power loss increased to 392.2 kW (increased from 122 kW, i.e., by 221%) and reactive power loss increased to 196.1 kVAR (increased from 61 kVAR). The current rating at each branch is calculated, and it was found out that branch numbers 1, 3, 4, 5, 8, 9, 10, and 11 have a high current rating that a current 0.1 sq. mm ACSR conductor cannot support (Alawar, Bosze, & Nutt, 1995) as shown in Table 2.

Table 2: Branch current of Dharmasthali feeder

Branch number	**Current (A)**	**Branch number**	**Current (A)**	**Branch number**	**Current (A)**	**Branch number**	**Current (A)**
1	**429.43**	14	13.83	27	10.388	40	35.194
2	3.3335	15	6.9151	28	6.9255	41	14.079
3	**412.76**	16	27.663	29	210.49	42	14.073
4	**406.06**	17	13.832	30	203.55	43	63.195
5	**399.29**	18	6.9164	31	196.6	44	14.032
6	6.8063	19	13.829	32	182.65	45	7.0161
7	13.614	20	6.915	33	168.65	46	35.136
8	**372.06**	21	49.493	34	91.432	47	21.084
9	**356.69**	22	42.576	35	84.417	48	14.057
10	**349.82**	23	41.539	36	77.395	49	7.0285
11	**336.04**	24	38.079	37	70.366		
12	27.656	25	6.923	38	63.337		
13	20.743	26	17.312	39	56.303		

As shown in Figure 6, the addition of load after the tenth year will result in a voltage drop in Goldhunga feeder. After forecasting, the predicted voltage drop was found to be 0.929 Pu at bus number 41 and the maximum voltage was found to be 0.99 Pu at bus number 2 excluding slack bus. The minimum voltage was changed from 0.936 Pu to 0.929 Pu and the maximum voltage didn't change at the respective buses 41 and 2. The predicted active power loss increased to 364.6 kW (increased from 151.37 kW, i.e., by 241%) and reactive power loss increased to 145.84 kVAR (increased from 60.54 kVAR). The current rating at each branch is calculated and branch numbers1, 2, 3, 4, 7, 8, and 9 have high current ratings that a current 0.1 sq mm ACSR conductor cannot support as shown in Table 3.

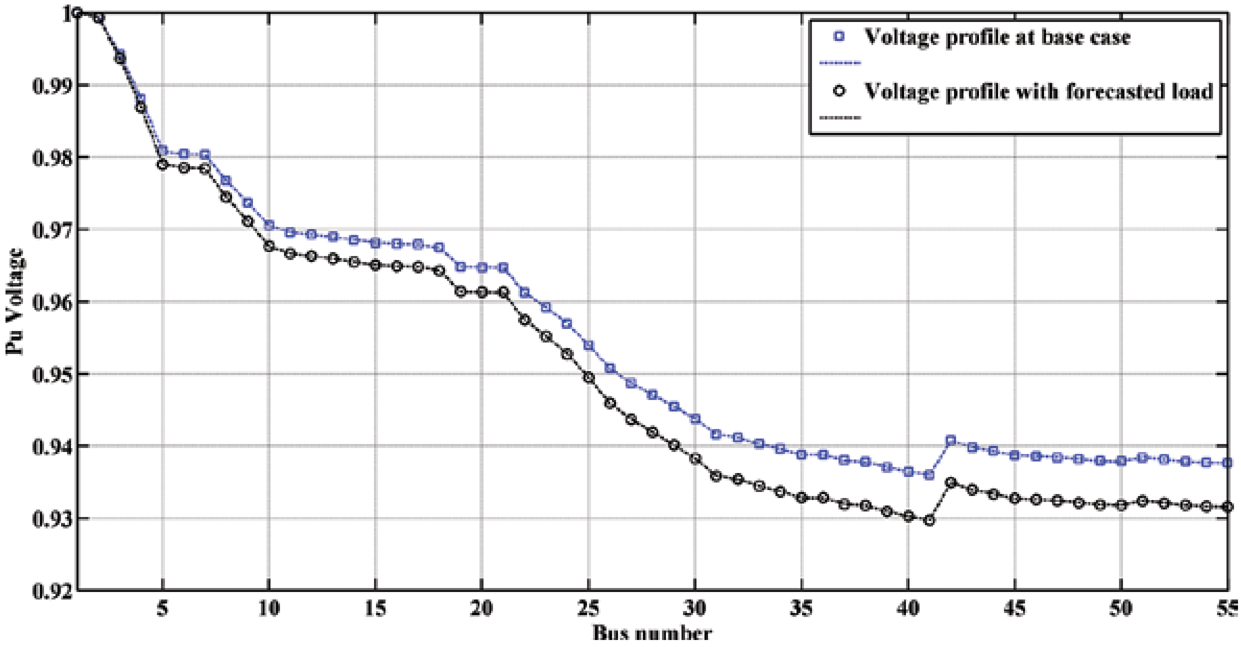

Figure 6: Comparison of voltage profile of Goldhunga feeder

Table 3: Branch current of Goldhunga feeder

Branch number	Current (A)	Branch number	Current (A)	Branch number	Current (A)	Branch number	Current (A)
1	**409.52**	15	17.813	29	172.08	43	73.749
2	**398.06**	16	5.9382	30	169.03	44	67.611
3	**392.29**	17	268.35	31	76.894	45	30.73
4	**386.49**	18	262.41	32	75.363	46	24.587
5	17.566	19	11.92	33	69.232	47	18.442
6	11.711	20	5.96	34	63.097	48	12.296
7	**363.07**	21	238.57	35	1.5354	49	6.1483
8	**351.31**	22	235.58	36	55.419	50	30.739
9	**339.52**	23	223.58	37	49.272	51	24.594
10	59.326	24	211.56	38	43.123	52	18.448
11	47.472	25	205.52	39	36.969	53	12.3
12	35.614	26	199.47	40	30.811	54	6.15
13	29.683	27	193.4	41	86.011		
14	23.75	28	187.31	42	79.883		

Similarly, as shown in Figure 7, the addition of load after the tenth year will result in a voltage drop for Jarankhu Feeder. After forecasting, the predicted voltage drop was 0.94 Pu at bus number 33 and the maximum voltage was 0.977 Pu at bus number 2 excluding the slack bus. The minimum voltage was changed from 0.959 Pu to 0.94 Pu and the maximum voltage changed from 0.984 Pu to 0.977 Pu at the respective buses 33 and 2. The predicted active power loss increased to 306.4 kW (increased from 109.28 kW, i.e., by

280%) and reactive power loss increased to 122.5 kVAR (increased from 43.7 kVAR). The current rating at each branch is calculated and branch numbers 1, 2, 4, 5, and 7 have high current ratings that a 0.1 sq mm ACSR conductor cannot support, as shown in Table 4.

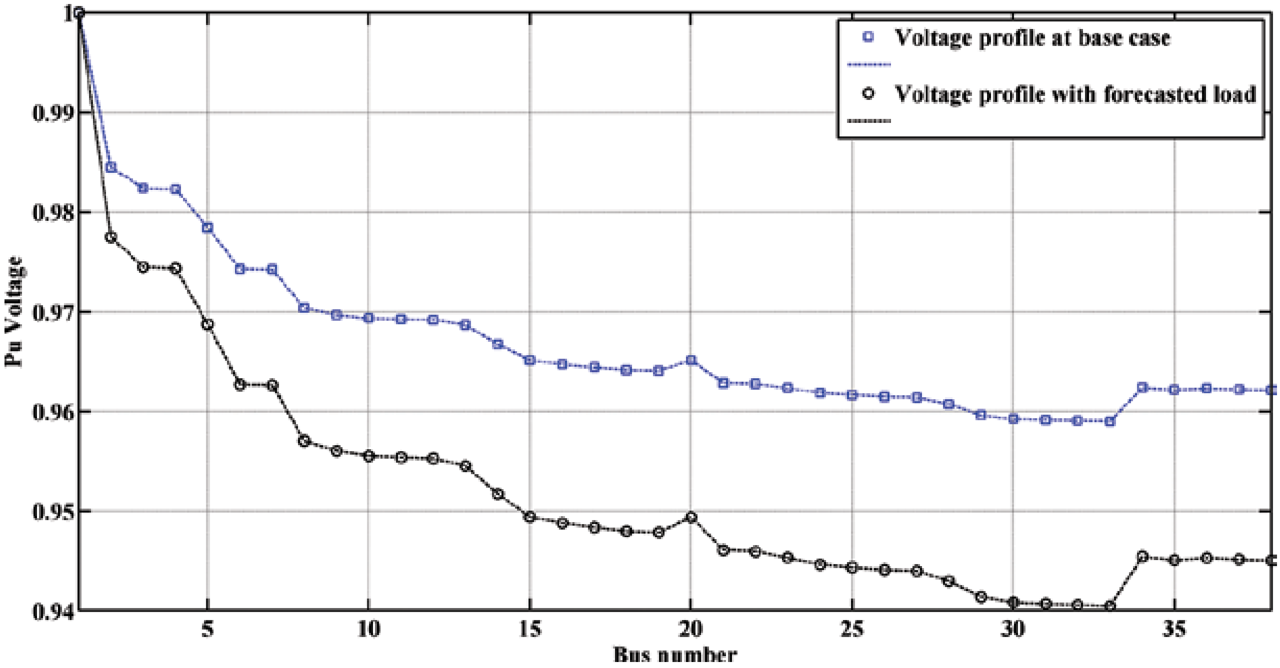

Figure 7: Comparison of voltage profile of Jarankhu feeder

Table 4: Branch current of Jarankhu feeder

Branch number	Current (A)	Branch number	Current (A)	Branch number	Current (A)	Branch number	Current (A)
1	**371.4**	11	10.457	21	10.561	31	13.277
2	**320.3**	12	211.31	22	87.419	32	5.3111
3	10.253	13	200.85	23	31.738	33	42.276
4	**299.8**	14	198.22	24	21.163	34	10.57
5	**284.33**	15	31.606	25	15.873	35	5.284
6	10.378	16	26.342	26	10.583	36	15.855
7	**263.57**	17	15.808	27	45.113	37	5.2854
8	47.042	18	5.2696	28	39.816		
9	31.369	19	5.2612	29	29.204		
10	20.914	20	156.09	30	18.587		

As seen from the above analysis, the active power loss was increased by more than 200% for all three feeders. It was also noticed that the branch currents for some of the feeders mentioned above at the mentioned feeders also exceed the ampacity rating of the existing conductor. So, now the grid analysis is done with reactive power supplier as distributed generation.

3.3 Optimal location and sizes of capacitors in the network

The PSO algorithm converges before 100 iterations, as shown in Figure 8. The plot is between the number of iterations versus the best power loss per iteration

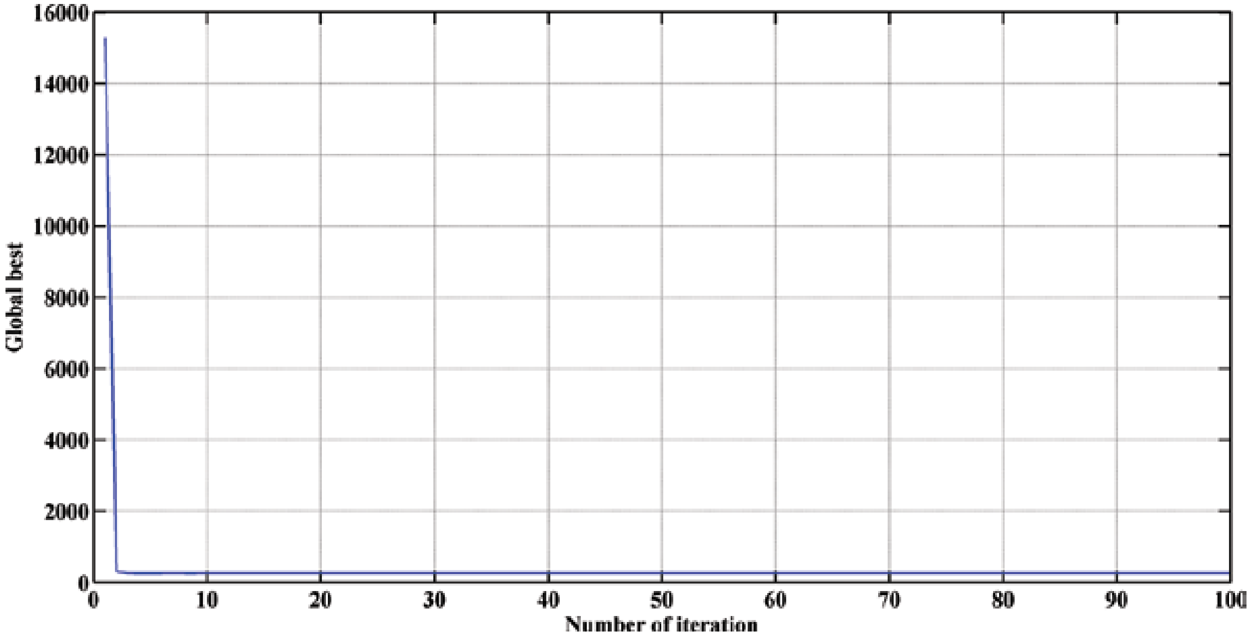

Figure 8: Convergence curve of PSO of the Dharmasthali feeder

The optimal size of the capacitor with the respective optimal bus number obtained through the PSO algorithm for the Dharmasthali feeder along with the other two feeders is shown in Table 5 below. With the placement of capacitor bank in the respective buses shown, the active power loss of the feeder after the forecasted load was found to be 253.84 kW (which is around 35% less than the increased load).

Table 5: Optimal sizes of Capacitors at different feeders

Dharmasthali Feeder		**Goldhunga Feeder**		**Jarankhu Feedeer**	
Optimal buses	**Capacitor size (kVAr)**	**Optimal buses**	**Capacitor size (kVAr)**	**Optimal buses**	**Capacitor size (kVAr)**
34	1125	41	750	2	1200
2	3000	23	1500	21	1500
41	750	43	1500	30	600
31	1500	37	375	10	900

Optimal placement of D.G. reduces active power loss and improves the voltage profile (Bawan, 2012) The voltage profile improvement after the placement of D.G. to the Dharmasthali feeder is shown in Figure 9.

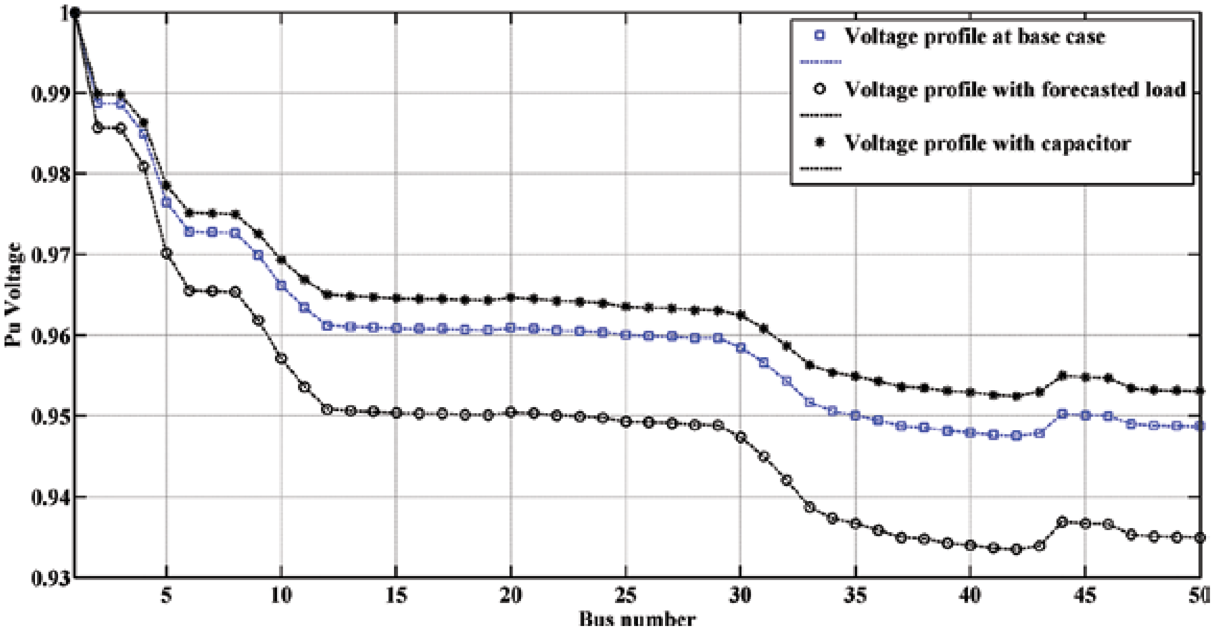

Figure 9: Voltage profile improvement of Dharmasthali feeder

The minimum voltage after placement of D.G. was found to be 0.952 Pu at bus number 42 and the value of maximum voltage at bus number 2 was 0.991 Pu. The voltages were within the limit and power loss was reduced. Moving towards the branch current in the feeder, Table 6 shows the branch current after optimisation.

Table 6: Branch current of Dharmasthali feeder after optimisation

Branch number	Current (A)	Branch number	Current (A)	Branch number	Current (A)	Branch number	Current (A)
1	**338.31**	14	13.626	27	10.235	40	34.494
2	3.3195	15	6.8132	28	6.8232	41	13.799
3	**325.43**	16	27.255	29	165.5	42	33.402
4	**319.92**	17	13.629	30	159.86	43	61.995
5	**314.42**	18	6.8145	31	154.3	44	13.765
6	6.739	19	13.625	32	143.51	45	6.8831
7	13.48	20	6.8131	33	133.25	46	34.468
8	292.91	21	48.763	34	73.066	47	20.683
9	281.21	22	41.948	35	66.938	48	13.789
10	276.11	23	40.926	36	60.967	49	6.8948
11	266.12	24	37.517	37	55.208		
12	27.248	25	6.8208	38	49.736		
13	20.437	26	17.056	39	44.658		

As seen from Table 6, only the branch numbers 1, 3, 4, and 5 still exceed the current limit of the 0.1 sq mm ACSR conductor used for distribution compared to the scenario without D.G.

The optimal size of the capacitor with the respective optimal bus number obtained through the PSO algorithm for Goldhunga feeder is also shown in Table 5. With the placement of these values of reactive power supplier, the active power loss of the feeder after the forecasted load was found to be 237.67 kW (which is around 35% less than the increased load).

Optimal placement of D.G. reduces active power loss and improves the voltage profile of Goldhunga feeder as in harmasthali feeder. For the voltage profile improvement after placement of D.G. in Goldhunga feeder, the minimum voltage after placement of DG was 0.95 Pu at bus number 41 and the maximum voltage at bus number 2 with a value of 0.999 Pu. The voltages were within the limit, and power loss was reduced. Moving towards the branch current in the feeder after optimisation, only the branch numbers 1, 2, 3, and 4 still exceed the current limit of the 0.1 sq mm ACSR conductor used for distribution compared to the scenario without D.G.

Similarly, for Jarankhu feeder, the optimal size of the capacitor with the respective optimal bus number obtained through the PSO algorithm is also shown in Table 5 above. With the placement of these reactive power supplier after the forecasted load was found to be 194.94 kW (which is around 36% less than the increased load).

Optimal placement of D.G. reduce active power loss and improves the voltage profile of Jarankhu feeder as in previous feeders. For Jarankhu feeder, the minimum voltage after placement of capacitor was found to be 0.954 Pu at bus number 33 and the maximum voltage with a value of 0.982 Pu at bus number 2. The voltages were within the limit and power loss was reduced. After optimisation, about the branch current in this Jarankhu feeder, all the branches are under the current limit of the 0.1 sq mm ACSR conductor used for distribution compared to the scenario without D.G.

4. Discussion

As the valley created between the base and peak load is getting deeper with increasing years, we can picturize that the accumulation of emerging technologies or even the shift of energy use is being loaded to the electricity distribution network in the peak hours, i.e., 6th hours to 9th hours and 17th hours to 22nd hours of a day. Cooking in an induction stove is cheaper than cooking in LPG. Hence, electric cooking in city areas like Kathmandu with increasing reliability and availability of power being supplied (Leary, Menyeh, Chapungu, & Troncoso, 2021), electrical cooking is the most suitable emerging load that adds in the peak hours which is selected and is added up to the forecast with the current loading scenario. The share of electric cooking is added as per the Nepal Government's targets through N.D.C. which seems practical enough.

In the load forecast up to ten years ahead, it can be observed that the differences between the base load and peak load are still increasing in exponential proportion, and at the end of the tenth year, there in 13.478 MVA load difference in the base load and peak load, which is 6.106 MVA in the base year. Peak load increases by 2.5 times in 10 years, whereas base load increases by 3.4 times. The load forecast for the coming ten years has been differentiated with and without electric cooking, symbolising an emerging electrical technology and the shift in energy use to electrical source.

When we neglect the load due to electrical cooking, the forecasted load curve offsets from the current year but rises linearly with the peak load in the coming years. There is undoubtedly some share of the load in the historical and current scenarios due to e-cooking. Neglecting it would create another curve if extrapolated from the previous years. From the forecast, it is seen that the total share of load the distribution network should bear due to the addition of e-cooking is 2.6 MVA which is undoubtedly a significant amount. This load, certainly, is a considerable part of the discussion as a substantial part of fossil fuel energy is being replaced by electrical energy. (Veldman, Gibescu, Slootweg, & Klinga, 2013).

The major part of the research is the analysis and technical arrangement of the distribution network of the control area after the forecasted load for which the grid impact performance analysis is done. From the load flow analysis done using backward forward sweep algorithm for BAU as well as future scenarios, we can see that the voltage profile degrades, active and reactive power losses increase, and the current exceeds the limit of the presently used conductor in the distribution network after the addition of forecasted load in the control area. Load flow is carried out with a base voltage of 11 kV and base power of 100 MVA. The minimum voltage of the control area has been degraded from 0.936 p.u in the BAU scenario to 0.929 p.u in the future forecasted scenario. The total active loss in the BAU condition is 383.65 kW (4.76%) whereas in the forecasted case, it amounts to 1063.2 kW (6.05%).

Similarly, the reactive power loss in the control area, currently, is 165.26 kVAR, whereas it is 464.44 kVAR at the end of the tenth year from now. On the other hand, the current flowing through the branches of the feeders, which are currently within the limit of the conductors, have exceeded in various branches in the future case. So, it can be seen that the addition of future load in the current arrangement of the distribution network would degrade the quality of the power supply and reliability of the distribution network adversely affecting the consumers and the distribution system operators.

This outcome is verified by the load flow in the forecasted distribution network incorporating the optimally installed reactive power suppliers in all the studied feeders. The minimum voltage of the control area has been upgraded to 0.95 p.u, which is even better than the BAU scenario. Similarly, the active power loss has reduced to 3.9% at the end of the tenth year, which is also much less than the BAU case, and most of the branch currents are within the limits of the current-carrying capacity of the conductor used. For the case of the Jarankhu feeder, which is the newest of the three feeders, all the branch currents are within limits by the installation of D.G. in the forecasted scenario, which indicates that this particular feeder has been appropriately planned and loads are distributed evenly than the other two feeders. For the cases of the Dharmasthali and Goldhunga feeders, few branches still have a current higher than the capacity of the conductor, which can be solved by the twinning of conductors in the same branches, creating new branches or splitting the branches to share the portion of current flow.

5. Conclusions

Electrical energy is the most versatile form of energy; with emerging technologies and an increasing share of electricity in the spectrum of energy use among domestic consumers in the modern era; thus, the electricity distribution network requires frequent optimisation. In this research, the optimised structure of the distribution network supplying load to the consumers of Tarkeshwor Municipality as a control area ten years from now is analysed. The way the government is committed to increasing clean and modern cooking and the trend that electric cooking is taking on the market as an emerging technology is seen to have a considerable share of the electricity load in the coming days such that the existing distribution infrastructure is thoroughly exhausted and highly unstable. With the increasing load in the distribution network, the optimum placement of reactive power suppliers (i.e. capacitor placement) in various branches helps to maintain the grid's power quality and reliability. The placement of capacitor used in this research as a form of distributed generation improves the voltage profile of the distribution network, decreases the losses and allows more current to flow through the same network. The study, concludes that optimisation of capacitor bank, at its current status, can improve the power quality and decrease power loss. Similarly, with the increased use of electricity in the coming days, the gap between the base load and the peak load in the hourly load curve will also grow, which needs to be financially fulfilled to justify the technical arrangements made to the distribution network in consideration of the peak loading. The gap can be minimised by changing the behavior of the time of electricity use or the development of sectors like enterprises that smoothen the load curve, which further needs to be studied through social and economic lenses.

One of the limitations is this study is only limited to the peak loading condition to find the maximum ampacity limits of the radial distribution feeder ten years from now. The switching methods of the capacitor and its economic aspects is still the case to study shortly.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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