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Enhancing Voltage and Minimizing Losses in Power Distribution Systems Using Fuzzy Based DG Integration

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ABSTRACT

In modern electrical distribution systems, addressing issues such as high losses and maintaining voltage in acceptable limit is crucial. One effective approach is integrating small-scale, decentralized generation units, known as Distributed Generation (DG), directly into the network. These DG units, placed closer to the end consumers, help reduce power losses and improve voltage profiles. This paper explores how installing DG units affects a distribution circuit, focusing on how it impacts the network's performance, particularly in terms of voltage and power losses. It introduces Fuzzy Algorithm for finding the optimal size and placement of DG units in a specific area, Phyu Township, to minimize losses and enhance bus voltage. Using MATLAB software for simulation, the study demonstrates that with careful placement and sizing of DG units, it's possible to significantly cut system losses and maintain bus voltage within acceptable ranges.

KEYWORDS: *Distribution system, DG (Distributed Generation), Fuzzy, Voltage improvement, Power losses*

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I. INTRODUCTION

Power utilities today face significant challenges, including growing electricity demand, dwindling fossil fuel reserves, and rising environmental concerns. As transmission and distribution networks approach capacity, this increased demand causes voltage drops and higher power losses, occasionally resulting in blackouts. One potential solution is to construct new power plants to boost voltage levels, reduce losses, and ensure a reliable power supply. However, relying on aging, overloaded networks ultimately degrades system performance. Furthermore, building new plants or upgrading existing infrastructure proves both costly and environmentally burdensome. Consequently, power companies are increasingly focusing on improvements in distribution systems through the integration of Distributed Generation (DG).

DG units are frequently incorporated into power distribution systems to lower energy losses and maintain voltage levels within acceptable limits. The effectiveness of DG integration depends on various factors, including location, size, type, and quantity of the units. A range of techniques has been developed to solve the challenges of DG placement and sizing, from analytical methods to more advanced approaches like evolutionary computing. Methods such as Genetic Algorithms and Ant Colony Optimization are known for delivering strong results, but they often involve heavy computational efforts. To address this, engineers have long pursued simpler, more intuitive solutions that, while easier to implement may not always produce optimal results. Fuzzy logic-based methods offer a middle ground, reducing computational complexity by using fuzzy membership functions to model the system. The most challenging aspect of these methods lies in selecting the appropriate membership functions. Typically, these approaches rely on indicators like node voltage levels and power loss to guide the optimal placement of DG units in distribution networks.

II. A CASE STUDY OF DISTRIBUTION SYSTEM

Phyu Township is experiencing ongoing power disruptions due to frequent scheduled and unscheduled load shedding, which are a result of an insufficient power supply and low voltage levels. The imbalance between the growing electricity demand and the limited capacity of the power infrastructure leads to frequent disruptions in scheduled electricity and occasional power outages. Causing these difficulties is by the township's geographic location, nestled between two edges of 33 kV power lines, making it harder to maintain voltage stability for its residents and businesses.

As Phyu Township is on the point of significant growth, with numerous restaurants and electric vehicle (EV) charging stations being established, the demand for electricity is set to rise even further. This growth highlights the urgent need to upgrade the power infrastructure to support the town's increasing energy needs. Addressing the issues of low voltage and inadequate power supply is crucial to ensuring the electricity network meets the demands of this development.

To tackle the ongoing challenges of load shedding and voltage instability, strategically integrating Distributed Generation (DG) at optimal locations and sizes within the township is essential. By doing so, Phyu Township can bolster its power supply, reduce the strain on the existing infrastructure, and improve bus voltage and reduce power losses. Proper placement and sizing of DG units provides electricity more efficiently, ensuring that the growing demands of the community are met. In this way, incorporating DG is a key step toward solving the township's electricity challenges and supporting its long-term growth and prosperity.

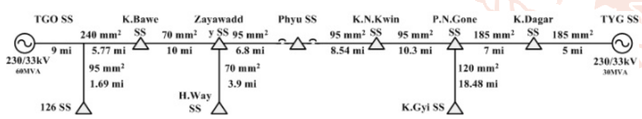


Figure. 1: Single line diagram of 33kV distribution system.

III. METHODOLOGY

This paper explores the use of MATLAB to model and simulate a 33 kV distribution system, focusing on how Fuzzy logic is used to optimize the placement and sizing of distributed generation (DG) units. The Fuzzy algorithm helps pinpoint the best locations and capacities for these units, all with the goal of boosting the system's performance. By carefully placing DG units, the method aims to cut down on power losses and improve voltage stability throughout the distribution network. A comparison of system performance for both with and without DG integration shows that when DG units are placed and sized optimally, there is a noticeable improvement in bus voltage and a marked reduction in power losses. These results highlight how important precise optimization techniques are for enhancing the efficiency of modern power distribution systems.

IV. MODELLING OF DISTRIBUTION SYSTEM

Figure 2 illustrates the modeling of the distribution system. The simulation began by analyzing the radial distribution network without any distributed generation (DG) connected. This initial step was conducted to determine the voltage profiles at each bus within the system. Following this, the model was tested under four distinct conditions:

Condition 1: Simulating the power flow from the Taungoo substation to the Phyu substation under minimum load conditions.

Condition 2: Simulating the power flow from the Taungoo substation to the Phyu substation under maximum load conditions.

Condition 3: Simulating the power flow from the Tharyar Gone substation to the Phyu substation under minimum load conditions.

Condition 4: Simulating the power flow from the Tharyar Gone substation to the Phyu substation under maximum load conditions.

These conditions is used to evaluate how different load conditions affect the voltage profiles and overall performance of the distribution network.

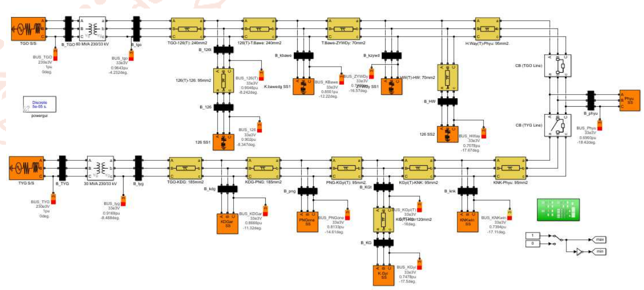
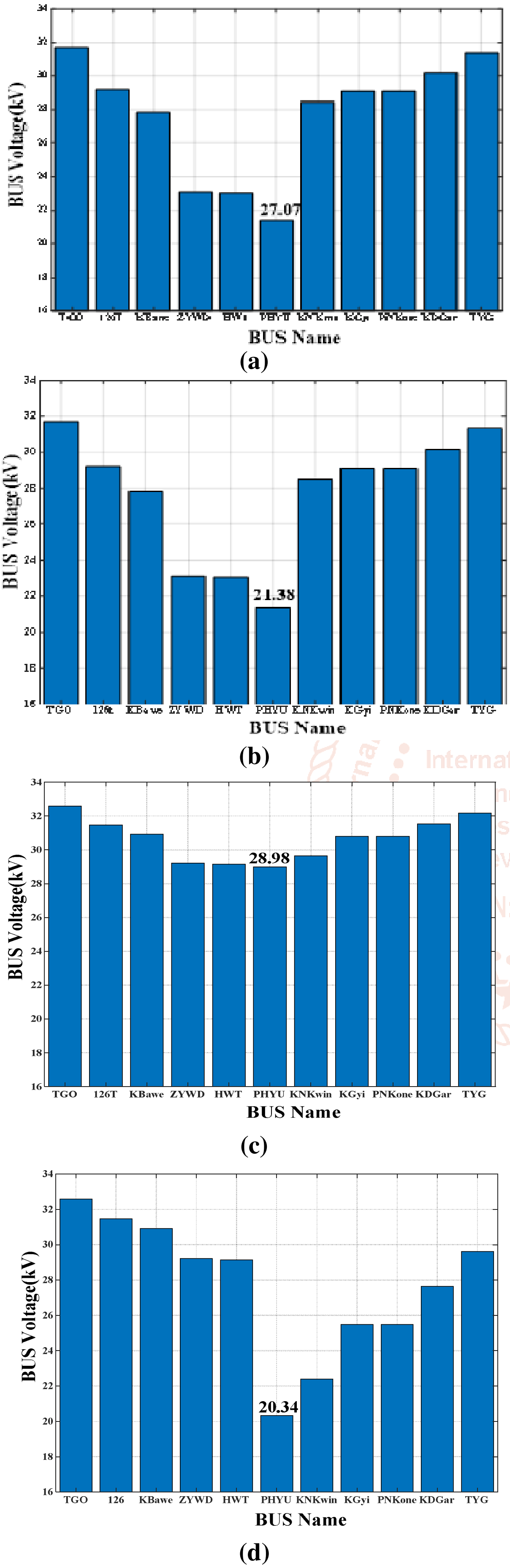


Figure.2: The modelling diagram of the power system

V. LOAD FLOW ANALYSIS OF DISTRIBUTION SYSTEM (WITHOUT DG)

The simulation results are displayed in Figures 3(a), (b), (c), and (d), which show the voltage levels at each bus under the different conditions mentioned earlier. These graphs provide a clear visual representation of how voltage is distributed across the network, making it easier to analyze and compare the system's performance under varying load scenarios.



Figures 3: Bus voltage under (a) condition 1, (b) condition 2, (c) condition 3 and (d) condition 4

In Conditions 1 and 2, the Phyu bus voltage starts at around 27.07 kV when the load is minimal but drops significantly to 21.38 kV under maximum load. This sharp decline suggests that the system faces higher losses or struggles with voltage regulation as the load increases. On the other hand, in Conditions 3 and 4, the voltage at the Phyu bus is higher under minimal load, around 28.98 kV, but drops even more, down to 20.34 kV, under maximum load. While the voltage is better under light load compared to Conditions 1 and 2, it suffers a steeper drop when the system is heavily loaded.

When considering where to place and size DG units, it's important to look at both the voltage levels and the power losses in each condition. Tables 1 to 4 provide a detailed breakdown of the power losses for each scenario.

Table I. Loss Report for Min Load (TGO-Phyu)

SN	Name	P (MW)	Q (MVAR)
1	Total generation	7.71	3.14
2	Total PQ load	0	0
3	Total Z shunt	7.26	2.47
4	Total losses	0.45	0.67
5	Loss percentage	5.84	21.34

Table II. Loss Report for Max Load (TGO-Phyu)

SN	Name	P (MW)	Q (MVAR)
1	Total generation	15.58	7.41
2	Total PQ load	0	0
3	Total Z shunt	13.46	3.46
4	Total losses	2.12	3.95
5	Loss percentage	13.61	53.31

Table III. Loss Report for Min Load (TYG-Phyu)

SN	Name	P (MW)	Q (MVAR)
1	Total generation	12.82	4.93
2	Total PQ load	0	0
3	Total Z shunt	12.35	4.18
4	Total losses	0.47	0.74
5	Loss percentage	3.67	15.01

Table IV. Loss Report for Max Load (TYG-Phyu)

SN	Name	P (MW)	Q (MVAR)
1	Total generation	27.26	12.18
2	Total PQ load	0	0
3	Total Z shunt	25.06	6.42
4	Total losses	2.19	5.76
5	Loss percentage	8.03	47.29

The active power losses on the Taungoo to Phyu line are about 5.84% under minimum load and rise to 13.61% under maximum load. In comparison, the Tharyar Gone to Phyu line experiences lower losses, around 3.67% at minimum load and 8.03% at maximum load. This shows that the Taungoo to Phyu line consistently has higher losses under both loading conditions.

Integrating Distributed Generation (DG) into the Taungoo to Phyu line could help improve the system by reducing these power losses and stabilizing voltage, especially when the load is high. With strategic placement and sizing of DG units, along with careful coordination with the existing grid, the overall performance of the line could be greatly improved.

VI. LOCATION AND SIZING OF DG BY USING Fuzzy Algorithm

This paper presents a fuzzy logic approach to determine the optimal placement and sizing of Distributed Generation (DG) units in a distribution system. The fuzzy algorithm is designed to handle the uncertainties and variability in system parameters such as load demand, voltage levels, and power losses. It works by taking into account multiple input variables, such as the Voltage Stability Index (VSI), Power Loss Index (PLI), and Power Generation Index (PGI). These variables are modeled using fuzzy membership functions to reflect the imprecision inherent in the system.

The core of the method is a Fuzzy Inference System (FIS) that applies a set of rules to evaluate the suitability of each bus in the distribution network for DG integration. The primary objectives of this approach are to minimize real power losses and maintain voltage levels within permissible limits. The FIS generates a ranking of candidate nodes, identifying the most suitable locations for DG placement, along with the optimal DG size. By achieving a balance between voltage stability and reduced losses, this fuzzy approach offers a flexible and adaptive solution for DG integration, even in complex and dynamic operational environments. For instance, it is logical to prioritize sections of a distribution system that exhibit high losses and low voltage for the placement of Distributed Generation (DG). In contrast, sections with low losses and stable voltage levels are generally less suitable for DG integration.

VII. IMPLEMENTATION OF FUZZY METHOD

This paper examines two input variables and one output variable to determine DG placement suitability. The first input variable is the Power Generation Index (PGI), while the second is the per-unit nodal voltage (V), which represents the proportion of received voltage relative to a reference voltage and is also known as the Voltage Stability Index (VSI). The output variable is the DG Suitability Index (DGSI). The Power Loss Index (PLI) ranges from 0 to 1, the per-unit nodal voltage spans from 0.9 to 1.1, and the DG Suitability Index also falls between 0 and 1. The formulation of the PGI is provided below.

$$PGI(i) = \frac{X(i) - Y}{Z - Y}$$

Where, X = Power Generation improvement at bus i
Y = Minimum generation improvement
Z = Maximum generation improvement
n = Number of nodes

For the PGI, we have defined seven triangular membership functions: Very Low (VL), Low (L), Low Medium (LM), Medium (M), High Medium (HM), High (H), and Very High (VH), as illustrated in Fig. 4. Similarly, the voltage has its own set of seven triangular membership functions: Very Low (VL), Low (L), Low Normal (LN), Normal (N), High Normal (HN), High (H), and Very High (VH), depicted in Fig. 5. Finally, for the DG Suitability Index, we also use seven membership functions: Very Low (VL), Low (L), Low Medium (LM), Medium (M), High Medium (HM), High (H), and Very High (VH). However, these membership functions are defined as Gaussian, as shown in Figure 6.

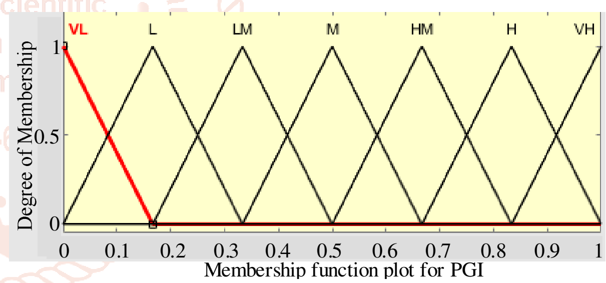


Figure. 4, Input 1 PGI Membership function

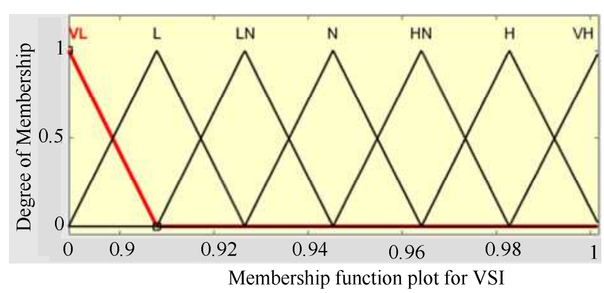


Figure. 5, Input 2 VSI Membership function

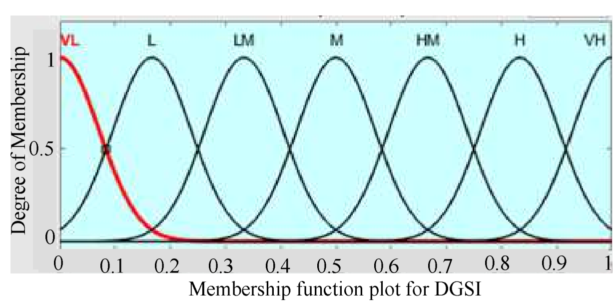


Figure. 6, Output DGSI Membership function

To assess the suitability of DG placement at a specific node, a set of fuzzy rules with multiple antecedents has been formulated. These rules are summarized in the fuzzy decision matrix in Table 5. In this study, 49 rules have been constructed.

Table V. Fuzzy Decision Matrix

VSI / PGI	VL	L	LN	N	HN	H	VH
VL	M	LM	LM	L	L	VL	VL
L	HM	M	LM	LM	L	L	VL
LM	HM	HM	M	LM	LM	L	L
M	H	HM	HM	M	LM	LM	L
HM	H	H	HM	HM	M	LM	LM
H	VH	H	H	HM	HM	M	LM
VH	VH	VH	H	H	HM	HM	M

Optimal locations for DG placement are identified based on DGSI values. For this system, optimal locations have been determined, with candidate locations and their corresponding DGSI values presented in Table 6.

Table VI. Buses with DGSI values

Bus No	PGI (Input 1)	VSI (Input 2)	DGSI (Output)
1	0.000	0.897	0.427
2	0.220	0.938	0.395
3	0.197	0.933	0.375
4	0.340	0.953	0.346
5	0.730	1.002	0.340
6	1.000	0.989	0.605
7	0.614	0.993	0.270

When integrating DG into a power distribution system, it is essential to size the DG units to meet the local power demand. To achieve this, the fuzzy algorithm is used to determine optimal DG sizing, taking into account the connected load at each bus in the simulation model. For instance, the total demand at bus 6 is set to 0.8 MW.

VIII. DISTRIBUTION SYSTEM WITH DG INTEGRATION

Figure 7 show the modelling of DG integration in the distribution system.

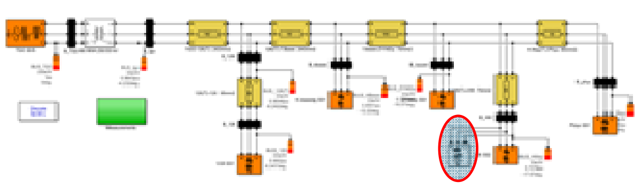
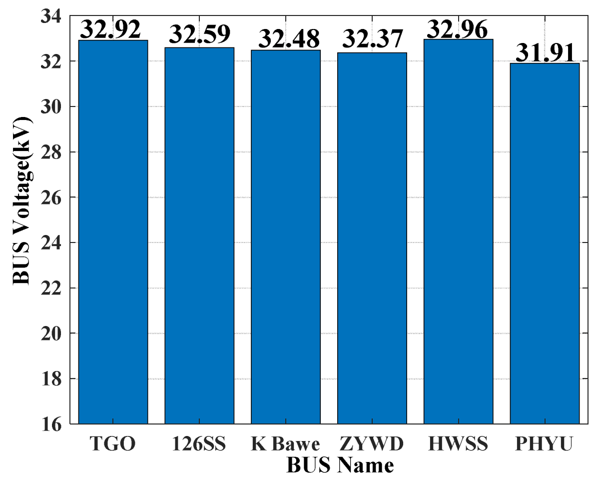
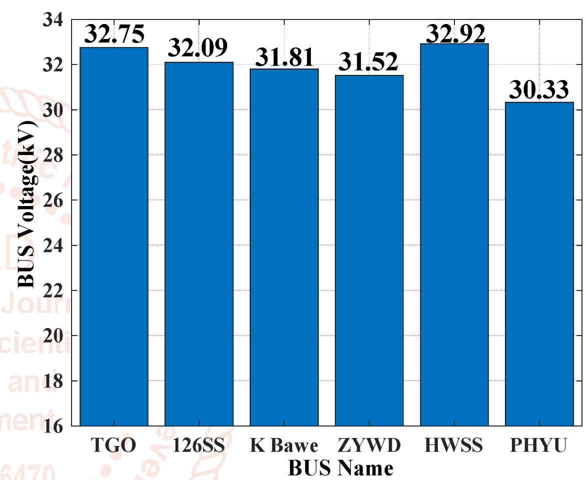


Figure 7: The modelling of DG integration in the distribution system

The simulation results include the bus voltage profiles for the distribution system with DG, showing both minimum and maximum load conditions. These profiles are depicted in Figures 8(a) and 7(b), respectively.



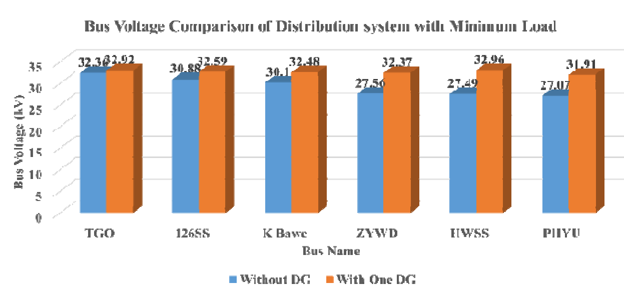
(a)



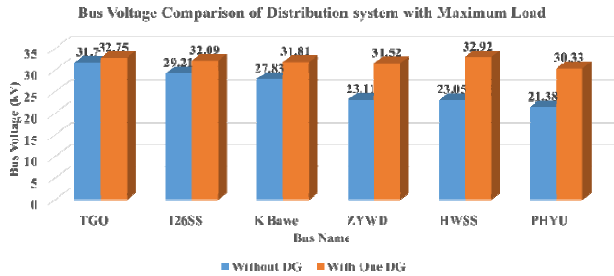
(b)

Figure 8; Bus voltage of power distribution system after DG integration (a)with minimum load (b)with maximum load

The simulation results for the 33 kV Taungoo to Phyu line reveal a substantial improvement in bus voltage levels following DG integration. Specifically, the voltage at the Phyu bus increases from 27.01 kV to 31.91 kV under minimum load conditions and from 21.38 kV to 30.33 kV under maximum load conditions. Figures 9(a) and 9(b) illustrate the comparison of bus voltages before and after DG integration for both loading scenarios.



(a)



(b)

Figure 9; Bus voltage comparison of power distribution system with and without DG integration (a) minimum load condition (b) maximum load condition.

Additionally, a detailed analysis of system losses was conducted, comparing the results before and after the integration of DG. The impact of DG on overall system efficiency and performance is clearly outlined in Tables 7 and 8.

Table VII. Load Flow and Losses Report Comparison for Minimum Load

Name	Minimum Load Condition			
	Without DG		With DG	
	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)
Total generation	7.71	3.14	7.73	3.00
Total PQ load	0.00	0.00	0.00	0.00
Total Z shunt	7.26	2.47	7.37	2.51
Total losses	**0.45**	**0.67**	**0.36**	**0.50**
Loss percentage	**5.80**	**21.46**	**4.61**	**16.62**

Table VIII. Load Flow and Losses Report Comparison for Maximum Load

Name	Maximum Load Condition			
	Without DG		With One DG	
	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)
Total generation	15.58	7.41	15.66	7.09
Total PQ load	0.00	0.00	0.00	0.00
Total Z shunt	13.46	3.46	13.75	3.54
Total losses	**2.12**	**3.95**	**1.91**	**3.55**
Loss percentage	**13.59**	**53.27**	**12.18**	**50.12**

The integration of Distributed Generation (DG) into the power distribution system significantly reduces total power losses, as evidenced by the load flow analysis under minimum load conditions. As shown in the comparison table, the total active power losses decrease from 0.45 MW to 0.36 MW after DG integration. Additionally, the reactive power losses also reduce from 0.67 Mvar to 0.50 Mvar. This improvement reflects a reduction in loss percentages from 5.80% to 4.61% for active power and from 21.46% to 16.62% for reactive power, demonstrating the positive impact of DG on system efficiency during minimum load conditions.

The results for maximum load conditions also demonstrate the positive effect of DG integration in reducing system losses. As shown in the comparison table, the total active power losses decrease from 2.12 MW without DG to 1.91 MW with DG integration. Similarly, the reactive power losses reduce from 3.95 Mvar to 3.55 Mvar. This reduction in losses translates to a decrease in loss percentages, from 13.59% to 12.18% for active power and from 53.27% to 50.12% for reactive power. These results confirm that DG integration enhances system efficiency even under maximum load conditions, contributing to both active and reactive power loss reductions.

IX. CONCLUSION

In conclusion, this research demonstrates the significant benefits of integrating Distributed Generation (DG) into the 33 kV Taungoo to Phyu line, utilizing MATLAB software and a Fuzzy algorithm for optimal placement and sizing of DG. The simulation results reveal substantial enhancements in the performance of the power distribution system, with the voltage at the Phyu bus increasing notably from 27.01 kV to 31.91 kV under minimum load conditions and from 21.38 kV to 30.33 kV under maximum load conditions. These improvements underscore the effectiveness of DG in stabilizing and enhancing voltage profiles across varying load scenarios.

Additionally, load flow analysis indicates a significant reduction in total power losses due to DG integration. Under minimum load conditions, active power losses decreased from 0.45 MW to 0.36 MW, while reactive power losses were reduced from 0.67 Mvar to 0.50 Mvar, resulting in percentage reductions from 5.80% to 4.61% for active power and from 21.46% to 16.62% for reactive power. Similarly, under maximum load conditions, active power losses decreased from 2.12 MW to 1.91 MW and reactive power losses from 3.95 Mvar to 3.55 Mvar, translating to loss percentage reductions from 13.59% to 12.18% for active power and from 53.27% to 50.12% for reactive power.

Overall, the integration of DG not only enhances bus voltage stability but also significantly reduces both active and reactive power losses across different loading conditions. These findings highlight the critical role of DG in improving the efficiency and reliability of power distribution networks, presenting a viable solution to modern energy challenges. Future studies should investigate additional optimization strategies and the impacts of various DG technologies to further maximize these benefits.

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