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A New Approach to Quantify the Loss Reduction Due to Distributed Generation

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Abstract: This paper is an intent to quantify and analyze the impact of distributed generation (DG) in Tamil Nadu, India to examine what the benefits of decentralized generation would be for meeting rural loads. In this paper, the total loss of a practical distribution system is calculated with and without distributed generation and an index, quantifying the total line loss reduction is proposed. Simulation tests have been carried out on a practical distribution system and the proposed index is evaluated for various ratings, locations of distributed generation.

Key words: Distributed generation · Load flow analysis · Power losses

INTRODUCTION

The presence of Distributed Generation (DG) has been shown to be beneficial in many respects like voltage profile improvement, line loss reduction, improvement in reliability etc. The evaluation of these benefits is very critical in assessing the merit of DG. The quantification of the benefit of line loss reduction was proposed in [1], which evaluated the line losses both with and without DG and the benefit index was defined as the ratio of line loss with DG and that without DG. The subsequent researches also defined the quantification in a similar way and the benefits of DG were defined. These works, however, considered only the losses in the lines and the quantification was defined for the line losses only.

Description of the System: A simple distribution system shown in fig 1, is considered for analysis. The system consists a number of identical distribution transformers, the secondary of which supply power to the consumers at low voltage (440V).

The major problem today in Power sectors is losses in distribution network. In Tamil Nadu Electricity Board the Transmission and Distribution (TandD) losses is around 18% and Aggregate Technical and Commercial (AT and C) losses is around 19.,3%. In India the TandD losses around 31.25%. The Transmission and distribution losses in the advanced countries of the world have been ranging between 6 to 11%. So the Tamil Nadu Electricity Regulatory Commission (TNERC) insisted the TNEB to reduce and brought the TandD losses below 10% as per standard [2].

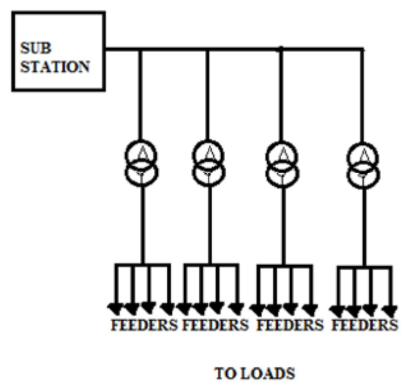

Fig. 1: The single line diagram of a standard distribution system

Decentralized power generation close to the rural load centers using renewable sources appears to have the potential to address at least some of the problems including reduction of line losses in rural electrification.

Simulation and Analysis

Methodology: The approach of this study is to conduct a three-phase AC load flow analysis [3, 4] of a rural distribution feeder (Kattakudy feeder) in Tiruvarur district of Tamil Nadu India (Fig 1). This is representative of a typical rural distribution feeder and the results will therefore have a wider applicability. The crude hand

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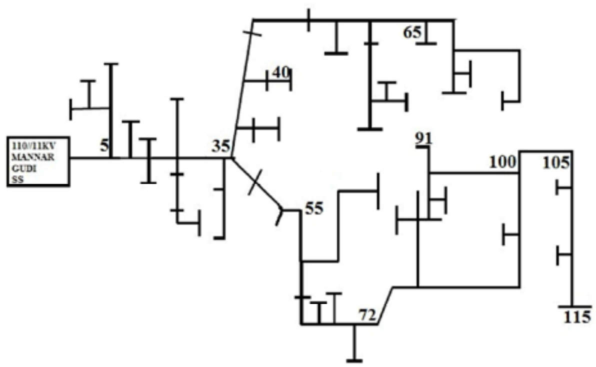

Fig 2: Sketch of the Rural feeder(Kattakudy #) in Thiruvarur district, TamilNadu (Peak demand 3 MW, 115 buses, Substation 110/11 kV).

Table 1: Details of the Kattakudi Distribution Feeder

Substation Transformer	110/11 kV
Total number of buses	115
Number of Load buses	70
Peak Load	3 MW
Transformers in the feeder	25 KVA, 63 KVA, 100 KVA

sketch of the distribution feeder, taken from a field line inspector, is often the best data available on rural power distribution networks. The lack of reliable power data is a handicap in planning for rural electricity supply.

The feeder begins with a 110/11 kV sub-station Mannargudi. There are 115 buses out of which there are 70 load buses, each roughly supplying a village or hamlets. Each load bus has a step-down transformer for 415V/240V and the transformer ratings are 25 KVA, 63 KVA, or 100 KVA. The distance between the sub-station and the tail end bus is about 17 km and the peak demand is 3 MW (Table 1). The feeder's load is mostly agriculture pumps and motors that are inductive and often operate at power factor as low as 0.75.

The buses are numbered in a sequential manner, but due to the branching of the network, higher numbered nodes are not necessarily further away from the substation. The present annual consumption of the feeder is 48 Lakhs Units (kWh). Since Agriculture pumps are not metered, there is no data available on their annual power consumption and it is estimated by computed consumption.

$$\text{Total KWh}_{\text{feeder}} = \text{KWh}_{\text{Metered}} + \text{KWh}_{\text{Unmetered}} + \text{Losses} \quad (1)$$

Where Losses=TandD losses+Theft

Table 2: Assumptions for the three-phase AC load flow analysis

Variable	Value or Range
On-Line Load	40% - 80% of the sanctioned load
Theft	13% of on-line load
Power Factor	0.70 – 0.90 lagging

The only known quantities in (1) are the total kWh at the feeder level in sub- station and the kWh consumed by the metered consumers. It is therefore impossible to know precisely the three unknowns from a single equation. The recent tariff order of the Tamil Nadu Electricity Regulatory Commission (TNERC) explains a rough procedure adopted by the utilities to estimate these numbers.[5, 6, 7] The utility makes an assumption of the annual kWh consumed by an Agriculture pumps by sampling a few predominantly agricultural feeders (clearly this is a crude exercise at best). This results in an estimate of the total losses: technical losses and theft. The utility then makes an assumption of the technical losses based on statistical data of a few feeders to obtain the commercial losses. Clearly, there is great subjectivity in such calculations and they could be easily challenged or manipulated. Often, the utilities lump theft with the Agriculture pump consumption thus overstating the actual kWh consumed by the pumps.

B.A.C Load Flow Analysis: The approach is to conduct a three-phase AC load flow analysis for this feeder using the Gauss-Seidel algorithm. It was first carried out a base case scenario (without DG) to obtain the voltage profiles and distribution losses and then considered the impact of a DG installed in the feeder, [8, 9].

For simplicity, the following assumptions are made. (Table 2):

- On-line load: This is defined as the fraction of sanctioned load that is connected at any instant. This is varied between 0.40 and 0.8, parametrically.
- Power Factor: The load power factor is not known and we varied it parametrically between 0.7 and 0.90. This appears reasonable given the majority of the load are irrigation pump sets.
- The ftisde finedas the fraction of on-line consumption that is unauthorized. We have fixed this at 13% of the on-line load.
- Transformer Losses: We have ignored the losses in each of the transformers because of non-availability of data.
- DG unit is capable of supplying power at both leading and lagging power factors.

RESULTS

Voltage Profiles and Distribution Losses

Current System: Fig 3 shows the voltage profiles (per unit basis, or *pu*) under heavy load conditions (75%) with a theft of 13%, with the power factor varying between 0.7 and 0.9. The horizontal line is the acceptable voltage level i.e. within 6% of the specified voltage level. Under heavy load conditions and when the power factor is 0.7, the voltage at far-off buses drops to as low as 0.75 pu, which is severely damaging to the equipment. Even when the power factor is 0.9, the voltage at far-off buses is still below the acceptable norm.

Proposed system: Now we consider the impact of a decentralized generator located in the middle of the feeder.

Fig 4 shows the impact of a decentralized power generation source placed in the feeder at Bus # 57. The choice of the bus was made on the basis of it being centrally located in the feeder and almost equidistant from all the branches. The generator power varied from 0 to 3 MW with a power factor of unity. As expected, the voltage profiles improve considerably throughout the feeder the power factor is 0.85 to 0.9. For most of the buses, even with just a 1 MW plant, the voltages fall within acceptable norms. The same effect is also seen when a bank of capacitors is installed, which supplies only reactive power. Reactive power is therefore very important for voltage support in the context of rural feeders that have low power factors. This becomes relevant in the following sections as the generators could also act as sources of reactive power.

Fig 5 shows the technical distribution losses as a function of the generator MVA rating. There is a dramatic reduction in the losses from the base case of 10% without the decentralized generator. The losses keep on decreasing until a minimum is reached corresponding to a critical generator rating. At this point, the feeder is virtually drawing no current from the grid and therefore losses are very low. As the MVA rating is increased further, there is surplus power generation in the feeder and there is a net export of real power to the grid. As a result, there is a subsequent increase in the distribution losses.

Therefore, appropriate sizing and locating a decentralized generator improves the quality of power supplied to the feeder and also reduces the distribution losses. Using photovoltaic generation and wind power, other researchers have reported similar results that reduce distribution losses [10]. The above discussion

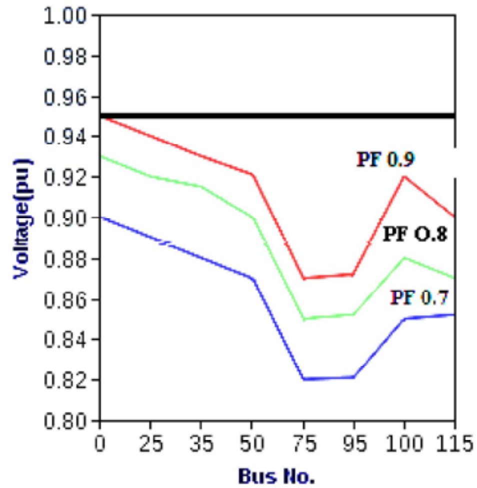

Fig. 3: Voltages (pu basis) at different buses in the 115 bus feeder in Kattakudy, Tamil nadu under heavy loads. On-Line load is 75% of the sanctioned load, theft is 13% of on-line load and power factor is varied parametrically between 0.7 – 0.9. The horizontal line is the acceptable voltage of 0.95 pu.

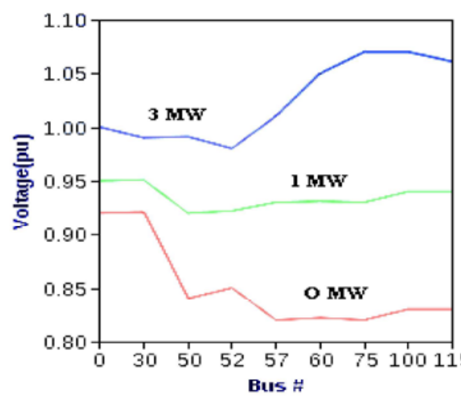

Fig. 4: Impact of a decentralized generator placed centrally at Bus # 57 on the voltage profiles. The generator is varied from 0 MW to 3 MW. (On-Line load is 60%, theft 13%, power factor 0.9)

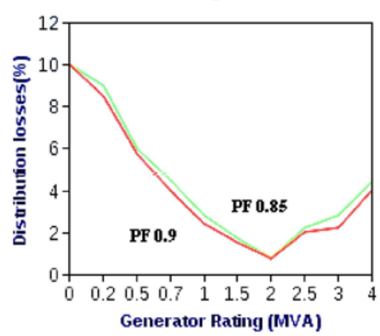

Fig. 5: Technical distribution losses for different MVA ratings of the generator (0-4 MVA) and for two generator power factors of 0.80 and 0.95.

suggests that distributed generation close to the rural load centers benefits both the local consumers (improved power quality) as well as the utility (lower losses). It opens the possibility of creating rural micro-grids, or regions of stable and good quality power supply within the utility's network. Improved quality of power also creates incentives for tariff reforms in the agricultural sector and thus breaks the vicious circle. Rural electricity cooperatives can be formed at a district level, wherever decentralized generation is possible. In this context, biomass and natural gas based distributed generators can play an important role. The farmers get paid for the biomass they supply to the power plant and in return, they pay for the power consumed.

CONCLUSION

In this paper we examined opportunities for distributed power generation in rural Tamil Nadu India. The results obtained show that power losses of the system is considerably reduced and the power quality enhanced by finding optimum location of a decentralized power generator. There is a significant improvement in the voltage profiles and reduction of technical distribution losses. This creates a possibility of setting up rural micro-grids or rural electricity cooperatives with Gas based and non conventional power generators. From the experimental and practical implemented proposed system, clearly identified that the percentage reduction in line loss and voltage improvements were achieved. Our study is limited to only in Tamil Nadu state in India.In future work our study will be expanded to all states in India using the above techniques to reduce the line losses and improve the power quality in whole country and increase the revenue of the utilities.

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