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Reduction of Line Losses in Presence of Distributed Power Generation: India- A Case Study

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Abstract: Attempts to reduce electricity cost, together with improving the efficiency of power distribution systems, have led power sectors to dealing with the problem of power loss minimisation. Although losses in the system can never be entirely eliminated, they can be controlled and minimised in several ways. Research conducted in the last few decades has proven that an inclusion of Distributed Genaration (DG) into distribution systems considerably lowers the level of power losses. Moreover, the choice of DG is even more attractive since it provides not only benefits in power loss minimisation, but also a wide range of other advantages including environment, economic, power qualities and technical issues. This paper is an intent to quantify and analyse the impact of distributed generation(DG) in tamilnadu, India to examine what the benefits of decentralized generation would be for meeting rural loads. Use load flow analysis to simulation over a quantify the loss reduction and system improvement by having decentralized generation available line conditions for actual rural feeders in tamilnadu, India. Reactive and voltage profile was considered. This helps utilities to better plan their system in rural areas to meet dispersed loads, while optimizing the renewable and decentralised generation sources.

Key words: Distribution system · Power distribution economics · Distributed generation · Load flow analysis · Optimal Location · Power losses

INTRODUCTION

Electricity supply in rural area of Tamilnadu india has been lagging in terms of service (measured by hours of supply) as well as penetration. Eventhough 85% of the rural households have access to electricity, but the supply suffers from frequent power cuts and high fluctuations in voltage and frequency, with so-called break downs and load sheddings [1]. The demand-supply gap is currently 28% of average load and 38.5% of peak demand at current prices, which are heavily subsidized, on average. In order to bridge this gap and meet anticipated growth, it is necessary to double the present capacity, i.e., install an additional generation capacity of 10,000 MW by 2017. This would require an investment of Rs. 70000 crors (approximately) for generation and Rs 85000 crore including investments in transmission & distribution. A major bottleneck in the development of the power sector is the poor financial state of the utilities, which can be attributed to the lack of adequate revenues and state subsidies for supply to the rural subscribers. Of the total power distributed, only 93% of the kilowatt-hours are billed and only 80% of this is collected in time. The average cost of supply is Rs. 5.98/kWh and the average revenue is only Rs.3.79/kWh [2].

This is due to a skewed tariff policy of subsidizing the power supplied to agricultural consumers (in Tamilnadu the power is free to agricultural subscribers!) at the cost of commercial and industrial consumers [3]. This, coupled with the fact that the electricity supplied to Agriculture pumps is not metered, provides for wasteful consumption and theft. Agricultural consumption, to the extent estimated, is over 30% of total consumption in the state [4]. The Tamilnadu Electricity Regulatory

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Commissions (TNERC) in this state have attempted to rectify these tariff imbalances by increasing the agricultural tariff, only to have the governments reverse these steps due to strong opposition from farmers. The farmers also complain that the electricity supplied to the rural areas is intermittent and of poor quality leading to high implicit costs because of damage to their motors and equipments.

The major problem today in Power sectors is losses in distribution network. In Tamilnadu Electricity Board the Transmission & Distribution (T&D) losses is around 18% and Aggregate Technical and Commercial (AT & C) losses is around 19.,3%. In India the T&D losses around 31.25% [5, 6]. The Transmission and distribution losses in the advanced countries of the world have been ranging between 6 to 11%. So the Tamilnadu Electricity Regulatory Commission (TNERC) insisted the TNEB to reduce and brought the T&D losses below 10% as per standard.

For reducing losses the TNEB implementing various methods with the fund of Rural Electric corporation(REC) and Power Finance Corporation(PFC) like, Network Reconfiguration, link lines, Strengthening of conductor, Capacitor installation, increase the HT:LT Ratio, Erection of Distribution Transformer at load center, Load Balancing, Adoption of HVDS, Energy Conservation & Energy Efficiency, Rural load management system, But duet to some more reasons the line losses not yet reduced as per the standard (below 10%) [7, 8]

The present policies of building large centralized generation and extended distribution networks are clearly unlikely to solve the problems of rural electricity supply, at least in the near future. 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 described in the earlier section.

Distributed Generation

Rationale for Distributed Generation: Distributed generation is currently being used by many customers to provide some or all of their electricity needs. The vast majority of DG units are operated to provide emergency back-up and are unlikely to ever operate in parallel with the distribution system [9]. There are also some customers that use DG to reduce their demand charges and others that use DG to provide premium power or reduce the environmental emissions from their power supply.

Distributed generation (DG) is attracting a lot of attention worldwide. Several potential applications of DG are standby power, combined heat and power (CHP), peak shaving, grid support and stand-alone power. Widespread use of DG provides an alternate system architecture for the generation and delivery of heat and electricity with cost savings [10].

In the context of Tamilnadu (india), or other developing countries with similar needs, decentralized power generation in rural areas can improve voltage profiles, lower distribution losses and supply reactive power locally. Improved quality of power supply also can assist in creating incentives for tariff reforms.

Planning for Decentralized Generation: The conventional wisdom has indicated that large generation stations offer significantly better economies of scale. However, such calculations must be recalibrated when faced with the state of the power grid in many emerging economies in the states in India, viz., large distributed (rural) load, high T&D losses (including theft), limited capacity availability and dramatically poor supply conditions. In such cases, a thorough analysis should be made for the policies, technical specifications and economic analysis behind use of DG [11-13].

Current System: The utilities interconnect with the renewable DG generators at high voltages (> 66 kV, > 33 kV or, > 11 kV, depending on the state lowest "transmission" voltage level). This gives the utility the flexibility to divert the power in the grid. However, the local area does not benefit significantly from decentralized generation and moreover, there is no discernible improvement in the power supply or in utility's revenues even though the utility purchases expensive power from the DG units. The generator pays for the wiring necessary to connect to the nearest sub-station.

Proposed System: The utilities' policy for DG units appears to be one-sided and overlooks the possible benefits of decentralized power generation in remote rural feeders. In this paper we examine the opportunities with decentralized power generation in rural areas and attempt a more rational basis for framing utilities' policies towards the DG units. In particular, we address the following issues:

- Impact of DG on the voltage profiles and technical distribution losses.
- Options for economic valuation of reactive power supplied by the DG.
- Balanced approach to estimating wheeling charges.

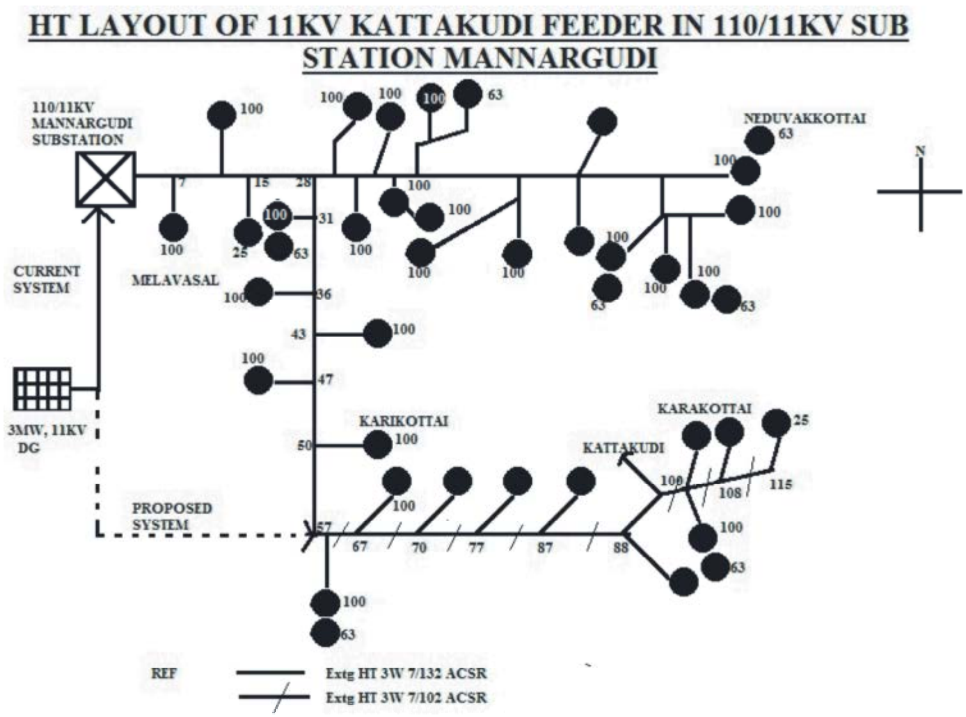

Fig. 1: Sketch of the Rural feeder (Kattakudy #) in Thiruvarur district, Tamilnadu (Peak demand 3 MW, 115 buses, Substation 110/11 kV). This crude sketch, taken from field line inspector, is often the best data available on power distribution networks, which are often unmapped and largely unknown

Simulation and Analysis

Methodology: The approach of this study is to conduct a three-phase AC load flow analysis [14, 15] of a rural distribution feeder (Kattakudy feeder) in Tiruvarur district of Tamilnadu in (Fig. 1). This is representative of a typical rural distribution feeder and the results will therefore have a wider applicability. The crude hand 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 0.70.

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). Table 2 gives the break-up of the kWh consumed. There are four main categories of consumers: Domestic, commercial, industrial and agricultural (irrigation pumps). The kWh consumed by the first three categories are metered and they are charged on a per kWh basis, while agricultural consumers are not metered and they pay on a flat rate basis(Rs 1750/ /HP/Annum) [16, 17]. Table 2 shows that the metered consumers account for a very small fraction (~5%) of the total consumption. Agricultural consumption, technical distribution losses and theft account for the balance. This is typical of most rural distribution feeders in Tamil nadu. The tariff levied on domestic consumers is significantly lower (subsidiary) than that levied on commercial and industrial consumers.

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 = T&D losses+Theft

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

Table 2: Categories of Consumers, Sanctioned Connections, Annual Kwh Consumption and Tariffs (Total Annual Consumption Is 48 Lakhs kWh)

Consumer	Sanctioned Load Connections	Annual kWh	Annual kWh /connection	Tariff
Domestic	2135	1979258	927	Rs1.10/Unit 1.20/kWh
Commercial	90	117000	1300	Rs.7.00/Unit 4.75/kWh
Industrial	22	94600	4300	Rs. 5.50/Unit 5.00/kWh
Agriculture Pumps	730	-	-	Rs 1750/HP

Table 3: 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 Tamilnadu Electricity Regulatory Commission (TNERC) explains a rough procedure adopted by the utilities to estimate these numbers. The utility makes an assumption of the annual kWh consumed by an Agriclture 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.

AC Load Flow Study: The approach is to conduct a three-phase AC load flow analysis for this feeder using the Gauss-Seidel algorithm (Appendix I). 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. The assumptions made in the analysis are as follows (Table 3):

- 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.
- Theft is defined as 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.

RESULTS

Voltage Profiles and Distribution Losses

Current System: Fig. 2 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.

Fig. 3 shows the current system the decentalised power generation source placed in the beginning of the feeder ie at sub-station the calculated distribution losses as a function of the power factor under moderate loading condition of 60% with 13% theft. Depending on the power factor, the technical distribution losses are between 8% and 12%. In most rural feeders, the power factor is 0.75 – 0.8 and therefore distribution losses are likely to be at least 10% under normal loading conditions. The commercial losses (theft) were assumed to be 13% and hence the total losses (or unaccounted energy) in the feeder are 20%. When adding the technical transmission losses, estimated over 9%, it was see that the total losses are unacceptably high (29%). One contribution of this

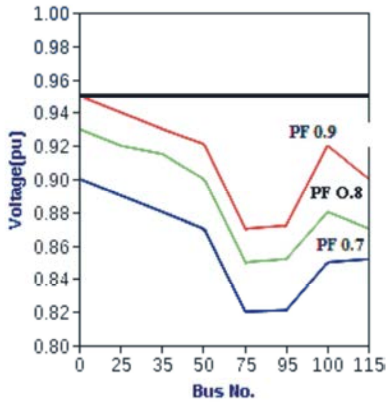

Fig. 2: Voltages (pu basis) at different buses in the 115 bus feeder in Kattakudy, Tamil nadu under heavy loads. On-Line load is 75% of the sanctioned load, theft is 13% of on-line load and power factor is varied parametrically between 0.7 – 0.9. The horizontal line is the acceptable voltage of 0.94 pu

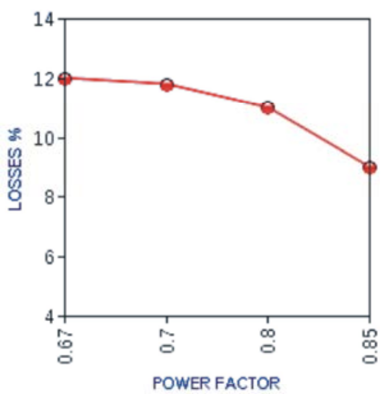

Fig. 3: Technical Distribution Losses (I^2R) in the feeder under moderate loading of 60% as a function of the overall power factor. The losses are 8% to12%. Thus the total losses after accounting for theft (13%) are 23% - 27% in just the distribution portion of the network

study is therefore to quantify the technical distribution losses for rural feeders from first principles, something not shown in publications before.

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

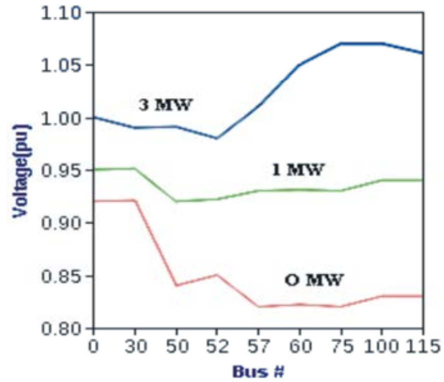

Fig. 4: Impact of a decentralized generator placed centrally at Bus # 57 on the voltage profiles. The generator is varied from 0 MW to 3 MW. (On-Line load is 60%, theft 13%, power factor 0.9)

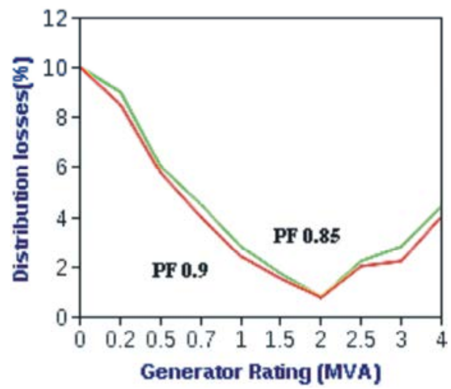

Fig. 5: Technical distribution losses for different MVA ratings of the generator (0-4 MVA) and for two generator power factors of 0.80 and 0.95

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 [18]. The above discussion 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 Tamilnadu india. The results obtained show that power losses of the system is considerably reduced 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. These can further extended for more complicated system for system expansion planning.

Appendix 1: Gauss seidel Algorithm

The algorithm literatively solves for the voltage at each bus by equating the total complex power at each bus with the product of the voltage and the complex conjugate of the current entering that bus, until convergence.

$$V_k Y_{kk} [(P_k - jQ_k)\overset{N}{\underset{i=1}{/}} V_k) - \Sigma Y_{ki} V_i] \tag{2}$$

$$Y_{ij} = 1/R + j\varpi L \tag{3}$$

where Y_{ij} is an element of the admittance matrix, This is the admittance (reverse of impedance) of the distribution line connecting i^{th} and j^{th} buses (if connected).

R = Resistance of the connecting line (0.25 Ω/km)
L = Inductance of the line (1.62×10^{-3} Henry/ km)
Ω = Angular frequency (rad/s)
P_k = Real power demand at k^{th} bus (kW)
Q_k = Reactive power demand at k^{th} bus (kVAR)
N = Total number of buses (115)

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