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Research Article

Peak Clipping in Power Lines using Distributed Generation

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Abstract: This real time study is intent to analyze the impact and role of Distributed Generation (DG) in Tamil Nadu, India to examine what the benefits of decentralized generation would be for peak clipping. Using 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 Tamil Nadu, India. In order to realize the energy efficiency potential and upscale the implementation of DSM program by utility, load research should be the starting point. One of the key objectives of load research is to understand and analyze the utility's system load profile and Peak clipping. This helps utilities to better plan their system in Demand side Management.

Keywords: Distributed generation, demand side management, load flow analysis, peak clipping

INTRODUCTION

India is witnessing a tremendous growth in the demand of electricity. This increased demand has outpaced supply, leading to significant overall energy and peak shortages. Energy and peak shortages across India stood at 8.6 and 9.7%, respectively in 2013-14. Increasing supply is an option, but inadequate capacity additions in the past and associated environmental concerns merit the promotion of energy efficiency and Demand Side Management (DSM) as an important strategy to reduce the peak demand, our approach in this study how that DG will help for DSM and improve the power quality. Distributed generation technologies have emerged against bad environment and energy crisis and they have been developed well in recent years (GOI, 2012). Lots of people have paid more and more attention to smart grid at home and abroad. This study analyzes the important role of the distributed power generation in the modern network's security and reliability, particularly the application and development of Distributed Generation (DG) in the smart grid. Demand Side Management (DSM) must balance the contradictions between the supply system and consumption, as an emerging power generation industry, the main feature is that they are close to the users and can operate independently or grid-connected. In addition to emphasizing the importance of DGs in DSM, paper demonstrates the importance and necessity of DGs and DSM's coordinated operation in the smart grid (Tan *et al*., 2005). This real time study conducted in a typical rural feeder of 110/11 KV substation Mannargudi (Tamil Nadu) and analyzes how the peak demand reduced to helps to DSM.

Demand side management:

DSM in India: The historic problems of the Indian power sector can be traced to three root issues-unacceptably high T&D losses, large commercial losses due to poor billing, metering, collection and energy theft and, low end-use efficiency of energy use specifically in agriculture. There is now widespread agreement that restoration of the financial health of the sector can be only enabled by demand side initiatives. To be specific, the electricity distribution area is where the historic problems converge. This convergence is most felt in the agricultural sector where the water-energy nexus is a major root cause for the precarious financial condition of the power sector in India today. Water withdrawal is an energy intensive operation throughout the agricultural sector, with the result that 30-40% of India's power consumption is used for irrigation. The irrigation pumping electricity use is at the heart of the subsidy issue and along with electricity theft and T&D losses, comprise the root cause for the sector's financial crisis (Nezhad and Sarkar, 1997).

The reasons a power utility in India may undertake DSM include:

- Demand outstripping the capability to provide supply, particularly peak supply
- Improve the cash flow revenues of the utility
- Improve the quality and reliability of power supply

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- Mitigate the impact of rising tariffs to the subsidized customers. For agricultural sector particularly, utility DSM is highly beneficial because of the subsidized prices and high costs of supply resulting from technical and commercial losses.

DSM in Tamil Nadu: Tamil Nadu Electricity Board (TNEB) was functioning as a vertically integrated utility responsible for generation, transmission and distribution of electricity until 2010. In 2010, it was restructured into a holding company, viz., TNEB Ltd and two subsidiary companies-TANGEDCO responsible for generation and distribution and Tamil Nadu Transmission Corporation Limited (TANTRANSCO) responsible for transmission of electricity. The utilities are under the regulatory purview of the Tamil Nadu Electricity Regulatory Commission (TNERC).The policies and guidelines for power sector development are framed by the Department of Energy, Government of Tamil Nadu (GoTN). In addition, there are agencies such as Electrical Inspectorate Department responsible for electrical safety and energy conservation and Tamil Nadu Energy Development Agency (TEDA) responsible for renewable energy development in the state.

The total installed capacity in Tamil Nadu is about 10124 MW as on 31st March 2013 (including share from Private generators and central generating stations), of which thermal constitutes the highest share (46%), followed by renewable (37%), hydro (14%) and nuclear (3%). Of the total installed capacity in the state, TANGEDCO's own capacity is to the tune of 5750 MW As on 31st March 2013, Tamil Nadu ranks first in wind-installed capacity of 4101 MW contributing around 47% of the country's total share. In terms of the sector-wise breakup, the private sector contributes the highest share of installed capacity (44%), followed by the state and central sector with a share of 37 and 19%, respectively (TNEB, 2013-14).

Electricity supply in rural area of Tamil Nadu India has been lagging in terms of service (measured by hours of supply) as well as penetration. Even though 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 shedding. 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. 75000 crore (approximately) for generation and Rs 90000 crore including investments in transmission and 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 83% of this is collected in time. The average cost of supply is Rs. 5.97/kWh and the average revenue is only Rs.3.78/kWh (MOP, 2013).

The major problem today in Power sectors is losses in distribution network. In Tamil Nadu Electricity Board the Transmission and Distribution (T&D) losses is around 18% and Aggregate Technical and Commercial (AT and C) losses is around 19.3%. In India the T&D 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 Tamilnadu Electricity Regulatory Commission (TNERC) insisted the TNEB to reduce and brought the T&D losses below 10% as per standard.

For reducing the peak demands and 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 peak demands and line losses not yet reduced as per the standard (below 10%) (TNERC, 2013; Ramesh *et al*., 2008).

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 and reduce the peak demand in rural electrification described in the earlier section.

DSM techniques: DSM works to reduce electricity consumption in homes, offices and factories by continually monitoring and actively managing how appliances consume energy. It consists of DR programs, smart meters, dynamic electricity pricing, smart buildings with smart appliances and energy dashboards. DSM manipulates residential electricity usage to reduce cost by altering the system load shape.

Common techniques used for load shaping are peak clipping, valley filling, load shifting, strategic conservation, strategic load building and flexible load shape as shown in Fig. 1 (Koutroumpezis *et al*., 2010).

DSM and power quality: The link between quality and reliability of power supply and energy efficiency is self

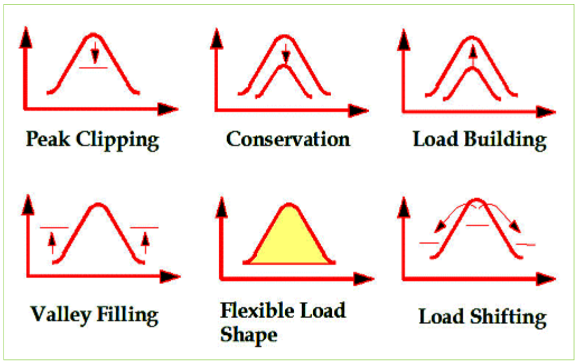

Fig. 1: Common techniques used for load shaping

evident. The primary casualty on account of indifferent power supply is reduced end-use efficiency. The use of voltage stabilizers, battery powered inverters and robust yet low efficiency irrigation motor-pump sets point out to the coping strategy employed by urban and rural power consumers at the cost of efficiency. Improvement in quality of power supply is sine qua non to achieving higher end-use efficiency. Quality improvement also has its own positive implications. Anecdotal evidence tells us that consumers are willing to pay higher prices provided there is commensurate improvement in the quality and reliability of power supply.

The improvement in power quality and hence energy efficiency has major socio-political implications. A subject of considerable political sensitivity is that associated with tariff increases for power supply to agriculture and the urban poor. DSM and energy efficiency has the inherent potential to mitigate the rising impact of such politically sensitive tariffs through an integrated program of metering, installation of energy conservation devices and efficient system operation and maintenance.

All around the world, there is increasing use of renewable energy sources and more efficient use of energy. These are motivated by a will to reduce Green-House Gases (GHG) emissions and the increase of fuel prices that drives up the prices of energy.

Behind the will to reduce GHG large number of countries have ratified the Kyoto protocol which has, in turn, been transposed into national laws and energy policies. At the same time the role of electricity as an energy carrier is increasing and the construction of new transmission lines and large central power plants is becoming more and more difficult.

Importance of Renewable Energy Resources is increasing with every passing day. The International Renewable Energy Agency (IRENA) is an intergovernmental organization for promoting the adoption of renewable energy worldwide. It aims to provide concrete policy advice and facilitate capacity building and technology transfer and promote DG (Ieadsm, 2010).

The Peak clipping is one of the methods for reduction of grid load mainly during peak demand periods. Our aim is by optimization of distributed generation in the rural feeder and analyzes how the peak demand and losses will be reduced.

DISTRIBUTED GENERATION

Rationale for distributed generation: Distributed Generation (DG) systems are small-scale power generation technologies (typically in the range of 3 kW to 10,000 kW) used to provide an alternative to or an enhancement of the traditional electric power system. The usual problem with distributed generators is their high cost Distributed generation is currently being used by many customers to provide some or all of their electricity needs. The vast majority of DG units is operated to provide emergency back-up and is unlikely to ever operate in parallel with the distribution system. 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 (Caamano-Martin *et al*., 2008).

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 alternate system architecture for the generation and delivery of heat and electricity with cost savings.

In the context of Tamil Nadu (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 and reduce peak demands.

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 (Ackermann *et al*., 2001).

Current system: The utilities interconnect with the renewable DG generators at high voltages (>110 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 and reduction of peak demand 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 (Nara *et al*., 2001).

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 study 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.
- Peak clipping approach to reduce peak demand.

MATERIALS AND METHODS

Methodology: The approach of this study is to conduct a three-phase AC load flow analysis (Datas) of a rural distribution feeder (Koraiyaru feeder) in Tiruvarur district of Tamilnadu in (Fig. 2). This is representative of a typical rural distribution feeder and the results will therefore have a wider applicability (Koutroumpezis and Safigianni, 2010).

The feeder begins with a 110/11 kV sub-station Mannargudi. There are 120 buses out of which there are 75 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 7.6 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 57 Lakh Units (kWh). 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). Since Agriculture pumps are not metered, there is no data available on their annual power consumption and it is estimated by sample metering:

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

where,

$$\text{Losses} = \text{T\&D losses} + \text{Theft}$$

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 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.

AC load flow study: The approach is to conduct a three-phase AC load flow analysis for this feeder using

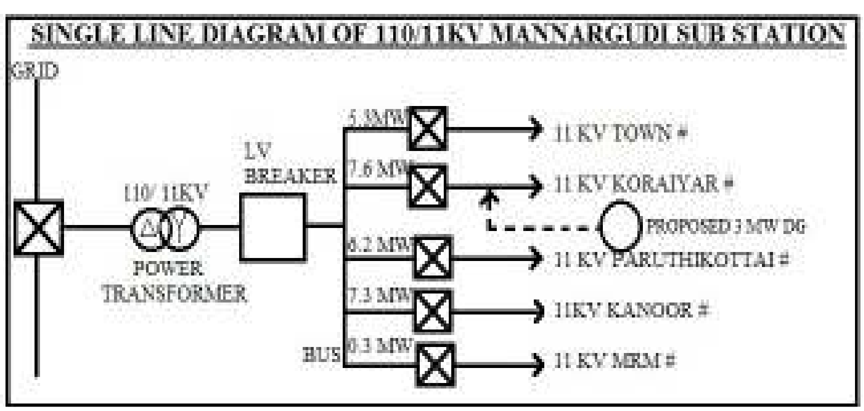

Fig. 2: Single line diagram of 110/11 KV Sub-Station Mannargudi in Thiruvarur district, Tamilnadu (Peak demand 27MW)

Table 1: Details of the Koraiyaru distribution feeder

Substation transformer	110/11 kV
Total number of buses	120
Number of load buses	75
Peak load	7.6 MW
Transformers in the feeder	25 KVA, 63 KVA, 100 KVA

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	14% of on-line load
Power factor	0.70–0.90 lagging

the Gauss-Seidel algorithm. It was first carried out a base case scenario (without DG) to obtain the voltage profiles, distribution losses and then considered the impact of a DG installed in the feeder (El-Khattam *et al*., 2004).

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.
- Theft is defined as the fraction of on-line consumption that is unauthorized. We have fixed this at 14% 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 AND DISCUSSION

Peak demand and distribution losses:

Current system: Figure 3 shows the current system the decentralized power generation source placed in the beginning of the feeder i.e., at sub-station the calculated distribution losses as a function of the power factor under moderate loading condition of 60% with 14% theft. Depending on the power factor, the technical distribution losses are between 8.5 and 12.5%. 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 including theft were assumed to be 14% 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 (30%). One contribution of this study is therefore to quantify the technical distribution losses for rural feeders from first principles, something not shown in publications before.

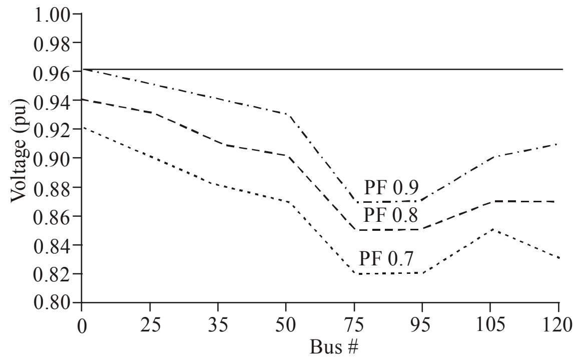

Fig. 3: Shows the voltage profiles (per unit basis, or *pu*) under heavy load conditions (75%) with a theft of 13%, with the power factor varying between 0.7 and 0.9. The horizontal line is the acceptable voltage level i.e., within 6% of the specified voltage level

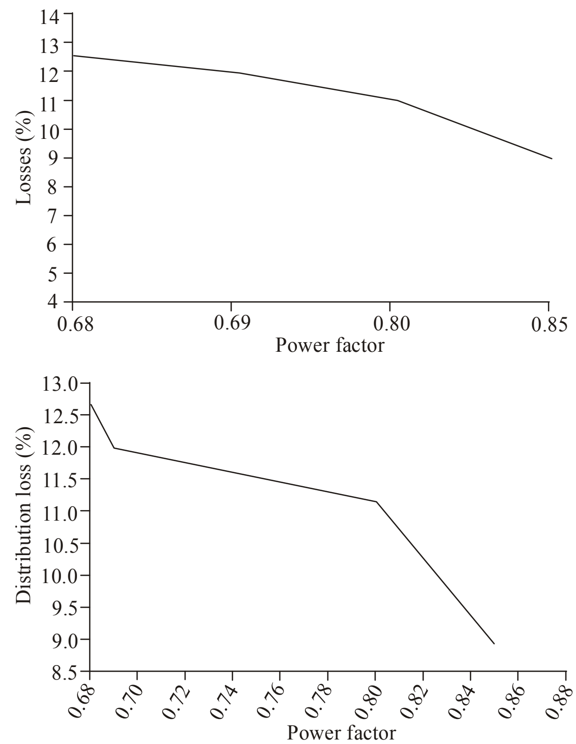

Fig. 4: Technical Distribution Losses (I^2R) in the feeder under moderate loading of 60% as a function of the overall power factor. The losses are 8% to12%. Thus the total losses after accounting for theft (14%) are 23%-27% in just the distribution portion of the network

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

Figure 4 shows the impact of a decentralized power generation source placed in the feeder at Bus # 60. 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 4 MW with a power factor of unity. As expected,

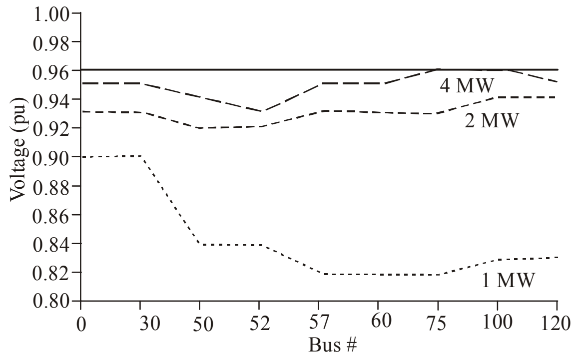

Fig. 5: Impact of a decentralized generator placed centrally at Bus#60 on the voltage profiles. The generator is varied from 1 MW to 4MW. (On-Line load is 60%, theft 14%, power factor 0.8)

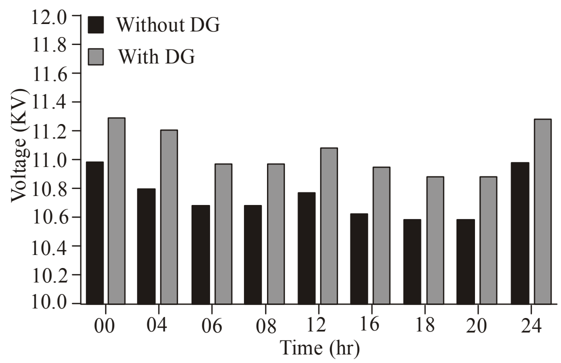

Fig. 6: Daily voltage of 11KV Koraiyar feeder in Mannargudi Sub-station

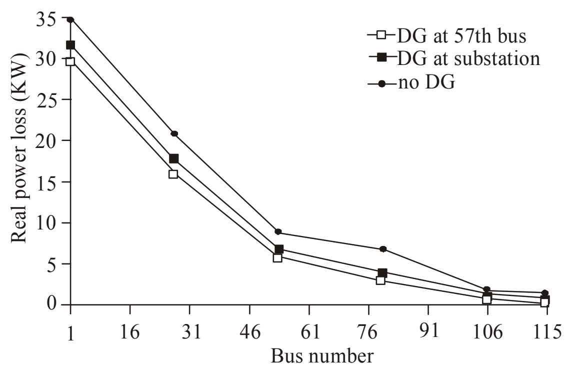

Fig. 7: Real power loss vs bus

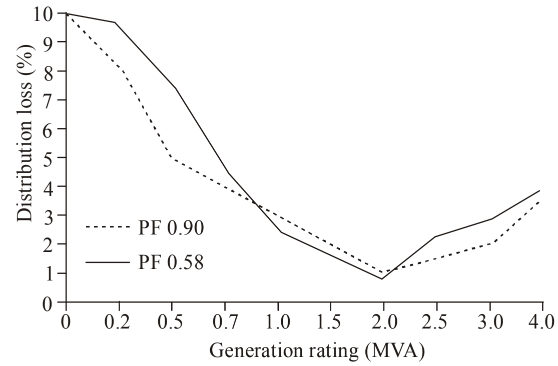

Fig. 8: Technical distribution losses for different MVA ratings of the generator (1-4 MVA) and for two generator power factors of 0.80 and 0.95

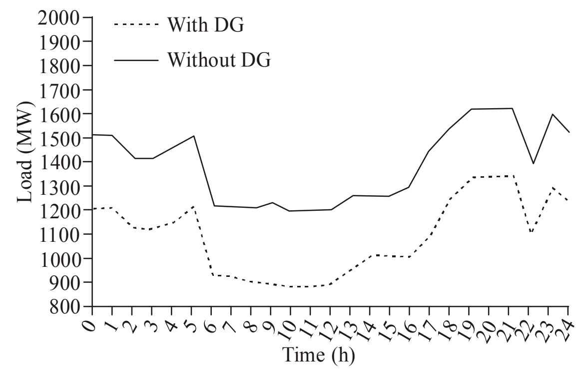

Fig. 9: Daily load profile of 120 bus feeder in Koraiyar, Mannargudi substation Tamil Nadu. Peak reduction of 30% achieved with DG

the voltage profiles improve considerably throughout the feeder. 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.

The voltage of the system under study will increased when the DG is connected in the middle of the feeder. Hence the feeder load is 7.6 MW. When we connect 4 MW DG in the middle of the feeder is optimum to maintain the feeder voltage within the accepted level.

Figure 5 shows the simulated result of Real power loss and bus. The loss is minimum when the DG is connected in the middle of the feeder (Fig. 6).

Figure 7 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 (Keane and Malley, 2005). 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) and helps to reduce peak demands. It opens the possibility of creating rural micro- grids, or regions of stable and good quality power supply within the utility's network (Kuri *et al*., 2004; Safigianni *et al*., 2014) 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 (Fig. 8 and 9).

CONCLUSION

In this study 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, the power quality enhanced and peak load 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, voltage improvements and peak clippings 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 for demand side management in whole country and increase the revenue of the utilities.

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