Pricing of Distributed Resources

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Abstract— **As a result of restructuring in the electric power sector economic as well as environmental issues have led increased interest in distributed resources. Distributed generation (DG) is not entirely new concept but it is emerging approach for providing electric power in the heart of power system. It mainly depends upon the installation and operation of a portfolio of small size, compact, and clean electric power generation units at or near the load (customer). The increased penetration level of DG in the distribution network has changed its characteristics from passive to active .Therefore it is relevant to consider the applicability of some pricing mechanism in distribution network that are finding application in short term operation of transmission networks. In this paper a methodology is proposed for nodal pricing of distributed resources for different type of loads. The method recommends significantly greater revenue under nodal pricing reflecting its contribution to reduced losses. The profit as a result of reduced cost of electricity is also calculated.**

Keywords —**Distributed generation (DG), Nodal pricing.**

λ	Real power price at power supply point.
P_{kt}	Real power supplied by DG
Q_{kt}	Reactive power supplied by DG
∂P_{kt}	Incremental real power
∂Q_{kt}	Incremental reactive power
Pnpi	Real power nodal price index
Qnpi	Reactive power nodal price index
R_{λ}	Revenue paid to DG through normal pricing
Rn	Revenue paid to DG using nodal pricing
C_{WDG}	Cost of Electricity with DG
C_{WODG}	Cost of Electricity without DG

1. Introduction

Distributed generation is an emerging approach for providing electric power at or near the load. Distributed generation also called on-site generation, dispersed generation, embedded generation or decentralized generation, generates electricity from many small energy sources. The distributed technologies have many benefits, such as high fuel efficiency, short construction lead time, modular installation, and low capital expense, which all contribute to there growing popularity. The decentralization of power system and liberalization of the electricity sector, along with dramatically growing demand for electricity in developed countries has made DG an attractive that has been reconsidered by various entities such as customers, distributors, power producers, regulators and researchers as well [1].

Use of Distributed generation reduces the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used. This also reduces the number of power lines that must be constructed. As distributed generators benefits are site specific, Various Distributed generation (DG) devices can be strategically placed in power system for grid , reducing power losses , improving voltage profile and load factors, eliminating for system upgrades and improving system integrity, reliability and efficiency [2]. Placement of multiple DGs of small capacities are more beneficial than the placement of a huge capacity single DG.

As distributed generation (DG) becomes more widely deployed in distribution networks, distribution network takes on many of the same characteristics as transmission in that it becomes active rather than passive. Consequently pricing mechanisms that have been employed in transmission, such as nodal pricing as first proposed in [3] can be used.

Pricing generally refers to the way a particular load (customer) is charged for the electricity it consumes to pay the Gencos (Generating Companies). The pricing of DG resource is the key issue to run it on economical lines and to maintain the equilibrium between the Gencos and customers as well. The pricing model should be such that it

- ✓ Should benefit both Gencos and customers.
- ✓ Should play a vital role in popularizing the concept of Distributed resources.
- ✓ Should be readily understood and accepted by the customers.

The two basic ways in which we can do the pricing (revenue given) of a particular DG are i) Normal Pricing: The current existing method of pricing in which revenue is calculated traditionally. The two major problems associated with the normal pricing are that the introduction of DG will result in low line losses and normal pricing has no provision for this compensation, introduction of DG will result in economical power and a part of the net savings due to DG should be made available to the customer and Gencos as well. Normal pricing has no such provision. And ii) Nodal Pricing: The method which is presented in this paper.

2. NODAL PRICING

Nodal pricing is most often associated with pricing congestion as discussed in [4], The pricing of line losses at the margin, which can be substantial in distribution networks with long lines and small voltages, is equally important. In this paper, we propose using nodal pricing in distribution networks to send the right price signals to locate DG resources and to properly reward DG resources for reducing line losses through increased revenues derived from prices that reflect marginal costs. The concept of active and reactive nodal pricing index is introduced. The revenue is also affected by the nature of load. A standard voltage dependent mathematical load model is considered and all the analysis is done for time invariant load.

3. PROBLEM FORMULATION

In this paper we have considered the IEEE-37 bus distribution network to calculate the losses and other profiles at different buses.

Define the net withdrawal position for real and reactive power. Nodal prices are calculated using power flows .λt corresponds to the real power price at power supply point.

Revenue given to DG can be calculated by

$$R_{\lambda} = \lambda t * P_{kt} \quad \text{.......................................} 1$$

For proper rewarding to DG for reduction of losses following indices can be defined

Real power nodal price index

$$\text{Pnpi} = 1 + \frac{\partial Loss}{\partial P_{kt}}$$

Reactive power nodal price index

$$\text{Qnpi} = \frac{\partial Loss}{\partial Q_{kt}}$$

Using (Pnpi) and (Qnpi) following prices for real and reactive power can be calculated

Real power price = $\lambda t * (\text{Pnpi}) * P_{kt}$

Reactive power price = $\lambda t * (\text{Qnpi}) * Q_{kt}$

Nodal price is given as

$$Rn = \lambda t * (\text{Pnpi}) * P_{kt} + \lambda t * (\text{Qnpi}) * Q_k \text{...........................} 2$$

Nature of load would also affect the nodal pricing. Different types of load models are present in the literature. A voltage dependent load model is mathematically expressed as

$$P_i = P_{0i} |Vi|^a$$

$$Q_i = Q_{0i} |Vi|^b$$

Where a and b are the real and reactive power exponents. The different values of a and b for different types of load are given in Table-1

Load Type	a	b
Constant	0	0
Residential	0.92	4.04
Industrial	0.18	6.00
Commercial	1.51	3.40

Table 1: Load type and exponent values

Power flow solution is run to calculate the Pnpi and Qnpi for a particular location of DG and for a specific value of P_{kt}, Q_{kt}, ∂P_{kt}, ∂Q_{kt} .Then revenues obtained by equation-1 and 2 can be compared. Furthermore the difference in the cost of electricity with and without DG is calculated for constant power load and hence the net profit in the cost of electricity as a result of DG installation is calculated.

4. CASE STUDIES & DISCUSSIONS

In this paper the above presented methodology is implemented in MATLAB code was employed for a case study. A typical 37 bus standard IEEE distribution network with DG taken from reference [11] was used and the following studies were made:

- Study of the impact of Load models on revenue.
- Study of DG power factor on revenue.
- Calculation of profit in the cost of electricity.

The problem is formulated with two distinct objectives, namely, loss minimization and profit maximization.

For the complete analysis following parameters are being taken into account

- Standard IEEE-37 bus distribution system taken as test system
- DG is applied at bus number 10.
- MVA Base=100.
- Base voltage=22KV.
- λt = 45 $/MWh

To study the effect of load model the losses of the test system with out DG and with DG are calculated for various types of load which are further used for nodal pricing of DG located at bus 10. it is assumed that true and reactive power supplied by DG is 0.5 pu. And all the system load requirements are met by DG.

Constant power load

In case one the constant power load is assumed by taking a=0 and b=0

LWODG= 0.3149

LWDG = 0.2033

$C_{WODG} - C_{WDG} = 44.64$ %

Residential load

In case two Residential load is assumed by taking a=0.92 and b=4.04.
LWODG= 0.2769
LWDG = 0.1863
$C_{WODG} - C_{WDG}$ = 36.24 %

Industrial load

In case three Industrial load is assumed by taking a=0.18 and b=6.00
LWODG= 0.2765
LWDG = 0.1855
$C_{WODG} - C_{WDG}$ = 36.40 %

Commercial load

In case four Commercial load is assumed by taking a=1.51 and b=3.40
LWODG= 0.2736
LWDG = 0.1855
$C_{WODG} - C_{WDG}$ = 35.24 %

All above results are tabulated in Table -2 and then the variation is plotted in figure-1

LOAD TYPE	Loss WODG(p.u.)	Loss WDG (p.u.)	Diff. in Revenue $C_{WODG} - C_{WDG}$
Constant Power Load	0.3149	.2033	44.64%
Industrial Load	0.2769	0.1863	36.24%
Residential Load	0.2765	0.1855	36.40%
Commercial Load	0.2736	0.1855	35.24%

Table 2: Variation in losses for different load models

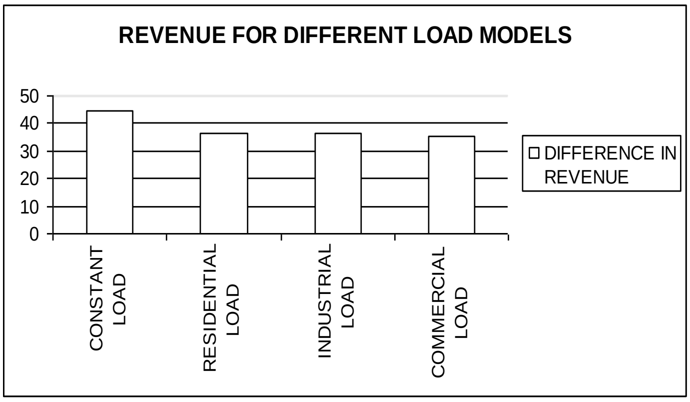

Figure 1: Revenue for different load models

To study the impact of power factor at which DG is supplying Various cases are considered for investigation with DG supplying constant true power but the reactive power supplied is varied and hence varying the power factor of the DG. Incremental increase in true are reactive power is 0.1 pu. .The difference in the revenue obtained by DG is calculated by using equation 1 and 2.

Case-1

In case one the true power supplied is 0.5 pu and reactive power is 0.2 pu
Dg_val_p=0.5 pu
Dg_val_q=0.2 pu
Power factor = 0.92
$R_{\lambda} - Rn$ = 13.78 %

Case-2

In case two the true power supplied is 0.5 pu and reactive power is 0.3 pu
Dg_val_p=0.5 pu
Dg_val_q=0.3 pu
Power factor = 0.85
$R_{\lambda} - Rn$ = 14.22 %

Case-3

In case three the true power supplied is 0.5 pu and reactive power is 0.4 pu
Dg_val_p=0.5 pu
Dg_val_q=0.4 pu
Power factor = 0.78
$R_{\lambda} - Rn$ = 14.36 %

Case-4

In case four the true power supplied is 0.5 pu and reactive power is 0.5 pu
Dg_val_p=0.5 pu
Dg_val_q=0.5 pu
Power factor = 0.707
$R_{\lambda} - Rn$ = 14.40 %

Case-5

In case five the true power supplied is 0.5 pu and reactive power is 0.6 pu
Dg_val_p=0.5 pu
Dg_val_q=0.6 pu
Power factor = 0.64
$R_{\lambda} - Rn$ = 14.30 %

All above results are tabulated in Table-3 and the variation is plotted in figure-2

S.No	***DG location***	***DG_val_p***	***DG_val_q***	***Power factor***	***%age increase in revenue***
1	10	0.5	0.2	0.92	13.78%
2	10	0.5	0.3	0.85	14.22%
3	10	0.5	0.4	0.78	14.36%
4	10	0.5	0.5	0.71	14.40%

5	10	0.5	0.6	0.64	14.30%

Table 3: Variation in revenue with power factor

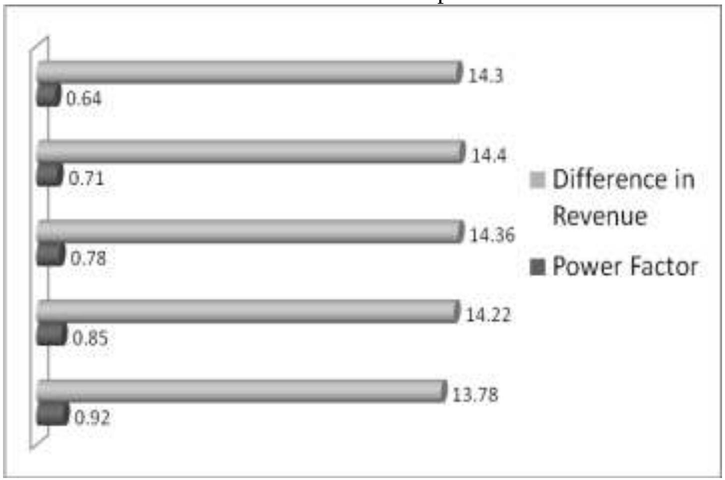

Figure 2: Difference in revenue with power factor

From table 2 and 3 the profit in the cost of electricity is calculated with variation in power factor for constant power load model. Corresponding results are tabulated in Table-4.

Power factor	Profit
0.92	30.86 %
0.85	30.42 %
0.78	30.28 %
0.71	30.24 %

Table 4**:** Variation in Profit with p.f.

5. CONCLUSIONS

From the above case studies, it is observed that a significant difference in revenue is rewarded to DG as its contribution in loss reduction. The difference in revenue is maximum for constant power load, while a small variation for other type of loads. For a given DG location the difference in revenue is increasing with decrease in power factor while the active power supplied by DG is assumed to be constant. There is no considerable difference if DG is supplying only active power. So there is no need of nodal pricing if DG is supplying only active power. R_{λ} – Rn keep on increasing till true and reactive power supplied becomes equal after that it starts decreasing i.e. the DG gets the maximum benefit if true and reactive power supplied by DG are equal.

The difference in the cost of electricity calculated in Table-2 is the combination of two segments one which gives the additional revenue to DG as a reflection to loss reduction (Table-3) and another appears as profit in the cost of electricity as a result of DG installation in the distribution network.

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