Nodal Price Analysis for Radial Distribution System with Probabilistic Load and Wind Power Integration

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Abstract. In power industry the upshot of deregulation has reformed the electricity prices of the electric distribution system where pricing schemes are controlled by rules and regulations of market operation. Nodal price is a method to determine the prices at which the market clearing prices are calculated for various locations of the transmission network called nodes, it can also be implemented to distribution systems. This paper depicts the study of nodal pricing in power distribution system with probabilistic load and the impact of wind power assimilation on nodal prices is perceived. The current method utilizes marginal loss coefficients(MLC) technique to obtain nodal prices, and compares the results with deterministic and probabilistic loads, these are again examined with wind power integration. The whole study is carried out on a IEEE 69 bus radial distribution system using MATLAB 7.0.4

Keywords: Distribution System, Nodal Price, Probabilistic Load, Wind Power integration , Marginal Loss Coefficients, .

1 Introduction

Deregulation of the energy industry is the restructuring of the rules and economic incentives governments have decided to manage and promote the energy industry. Nodal pricing is a mechanism of determining the prices charged at certain clearing prices at multiple locations in the transmission network [1]. It is seen that this technique can also be employed to distribution network [2].Nodal pricing is an economically efficient pricing mechanism to determine marginal energy costs and loss costs. The different technical and economical advantages of integration of distributed generation into distributed system has been studied in the past [3].In [4] Renewable energy is preferred among various DGs due to its cost-effectiveness and inherent environmental feasibility. The effect of penetration of renewable energy on the nodal price is studied in [5].In [6] with nodal price and amp-mile method, the systemic impact of intermittent wind power on distribution system economy was analyzed.

The behavior of nodal prices with ZIP load is studied in [7] with the formulation of load flow. In order to make the analysis of the distribution system pragmatic, instantaneous dynamics of the system must be considered when conducting load flow study. The probabilistic load flow studies can incorporate the random behavior of the distribution system [8]. Where deterministic load flow studies do not consider the randomness of load power requirements. In this paper extension of [7] is done where nodal price analysis is described considering wind power integration with probabilistic load. This paper is structured into 5 different sections. 2nd Section narrates the methodology of nodal pricing technique with the use of marginal loss coefficients (MLCs) where 3rd section narrates probabilistic load and wind power source modeling. 4th section gives the results and discusses the comparison of nodal prices considering wind energy penetration with Deterministic and probabilistic load, where the 5th section gives the conclusion of the paper. IEEE 69 bus RDS system is taken as test system in this paper and corresponding program was instigated and run in MATLAB 7.0.4.

2 Nodal Pricing Methodology

The distribution system's nodal prices can be obtained in the same way as the transmission system. MLCs are calculated first to get the nodal prices on each distribution system bus. MLCs are those coefficients that show incremental or marginal deviation of net active power loss as a result of variations in active and reactive power injections in certain network nodes [9]. Jacobian matrix method is used to determine the MLCs [10]. It is considered that there is no direct link between the power injections and the power losses. So that the intermediary variable as magnitude of bus voltages and bus angles which are attained from AC load flow, are used to calculate the MLCs.

$$\rho_{Pi} = \frac{\partial L}{\partial P_i} \quad [1]$$

$$\rho_{Qi} = \frac{\partial L}{\partial Q_i} \quad [2]$$

W here L is the net power loss, ρ_{Pi} is active power MLC and ρ_{Qi} is reactive power MLC at node i.

The point of connection between the transmission and distribution networks is termed as power supply point. λ is defined as active power electricity price (USD/MWh) at power supply point, so the nodal prices of active and reactive power at different nodes are:

$$C_{Pi} = \lambda + \lambda.\ \rho_{Pi} = \lambda(1 + \rho_{Pi}) \quad [3]$$

$$C_{Qi} = \lambda.\ \rho_{Qi} \quad [4]$$

Where C_{Pi} and C_{Qi} is the nodal prices for the active and reactive power respectively at node i. The reactive power nodal price is considered zero at power supply point.

3 Probabilistic Load and Wind Power Source Modeling

3.1 Probabilistic Load modeling

The load requirements of the distribution system are undetermined, and this unpredictability is treated with probability distribution functions. The probabilistic pattern of the load on each bus can be integrated with load flow studies by visualizing loads as distributed random variables with a variance around a mean value. Loading demands on each bus involve random variables with Gaussian or normal distribution [11].

$$f(P_{L,i}) = \left(\frac{\mathbf{1}}{\boldsymbol{\sigma_{PL,i}}\sqrt{\mathbf{2}\boldsymbol{\pi}}}\right) exp - \frac{(\boldsymbol{P_{L,i}} - \mu_{\boldsymbol{PL,i}})^{\mathbf{2}}}{\mathbf{2}\boldsymbol{\sigma_{PL,i}}^{\mathbf{2}}} \quad [5]$$

$$f(Q_{L,i}) = \left(\frac{\mathbf{1}}{\boldsymbol{\sigma_{QL,i}}\sqrt{\mathbf{2}\boldsymbol{\pi}}}\right) exp - \frac{(\boldsymbol{Q_{L,i}} - \mu_{\boldsymbol{QL,i}})^{\mathbf{2}}}{\mathbf{2}\boldsymbol{\sigma_{QL,i}}^{\mathbf{2}}} \quad [6]$$

Where $P_{L,i}$ is the active and $Q_{L,i}$ is the reactive load demands at i[th] bus. Parameters $\boldsymbol{\sigma_{PL,i}}$ $\boldsymbol{\sigma_{QL,i}}$and $\boldsymbol{\mu_{PL,i}}, \boldsymbol{\mu_{QL,i}}$ are standard and mean deviations of active and reactive power respectively.

3.2 Probabilistic substation voltage modeling

Similar to the load modeling substation voltage is also modeled as normally distributed random variable [12].

$$f(V_{s/s}) = \left(\frac{1}{\sigma_{Vs/s}\sqrt{2\pi}}\right) exp - \frac{(V_{s/s} - \mu_{Vs/s})^2}{2\sigma_{Vs/s}{}^2} \quad [7]$$

Where $\boldsymbol{V_{s/s}}, \mu_{\boldsymbol{Vs/s}}, \boldsymbol{\sigma_{Vs/s}}$ are nominal, mean and standard deviations of substation voltages respectively.

3.3 Wind power source modeling

Because of the frequent change of wind speed everywhere, it is assumed that it is a random variable. This paper uses the Weibull distribution function [13] to model the wind speed which is described as:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \ exp\left(\frac{-v}{c}\right)^k, 0 \leq v \ \leq \infty \quad [8]$$

where $\boldsymbol{c}$ is the scale parameter, k is the parameter of shape and v is the wind speed in m/s.

The power output from awind turbine is given [13]:

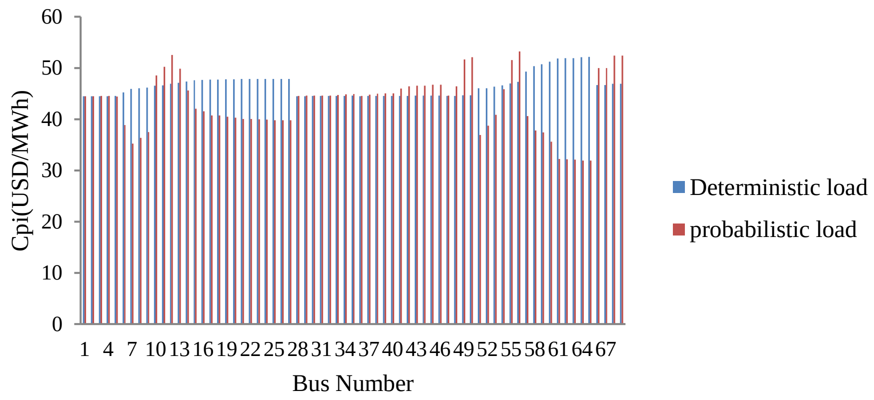
$$P_w = \begin{cases} 0, v \le v_{ci} \\ k_1 v + k_2, v_{ci} < v < v_r \\ P_r, v_r < v < v_{co} \\ 0, v > v_{co} \end{cases} \quad [9]$$

Where Pw, Vci, Vco, Vr are power output(MW),cut in, cut out and rated wind turbine speed in m/s respectively. $k_1 = \frac{P_r}{v_r - v_{ci}}$ and $k_2 = -k_1 * v_{ci}$,where Pr is rated wind turbine power output in MW.

4 Results and Discussions

The IEEE 69 bus RDS is simulated in MATLAB 7.0.4.The real and reactive prices for probabilistic load models described in section 3.1 are calculated and compared with deterministic load. Again impact of penetration of wind power on the nodal prices for real and reactive power are examined. The selected wind turbine has given parameters: Vco =25 m/s,Vci=2.5m/s, Vr= 13m/s and Pr=0.6MW [14].The wind farm is integrated into 61th bus of the distribution test system since this is the optimal location found from GAMS 23.4 CONOPT MINLP solver calculations. It is assumed that a total of 20 wind turbines are integrated to the distribution test system. The mean value and standard wind speed deviation for each hour of 24 hours a day is derived from historical wind speed data collected over the year [15].

(a)



(b)

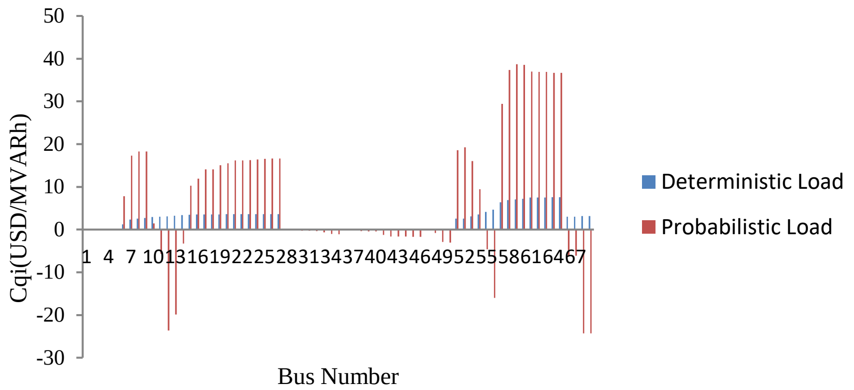


Fig.1.(a) Active and (b) reactive power nodal price comparison without wind

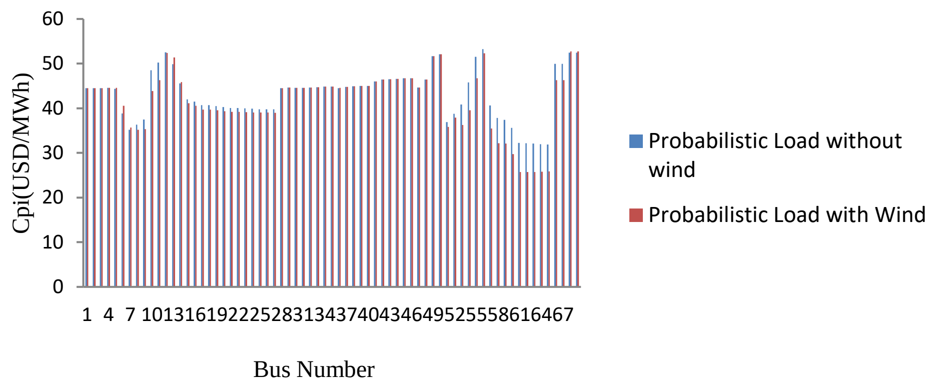


Fig.2. Active power nodal price comparison without and with wind

Fig. 1(a) and Fig. 1(b) show the active power and reactive power nodal price comparison without wind power integration .It can be seen that there is noticeable difference in nodal prices with deterministic load compared to probabilistic load which is considered more realistic. In Fig.2 impact of wind power integration in nodal prices for probabilistic load is shown as the penetration of wind energy significantly decreases the active power nodal prices in the distribution system. The maximum active power nodal price is observed at bus number 56 and the value is 53.1023 USD/MWh, this value is reduced to 46.7 USD/MWh with wind power integration. In Fig. 3(a) and Fig. 3(b) comparison of ,active and reactive power nodal prices for deterministic and probabilistic load with wind energy penetration is done respectively.

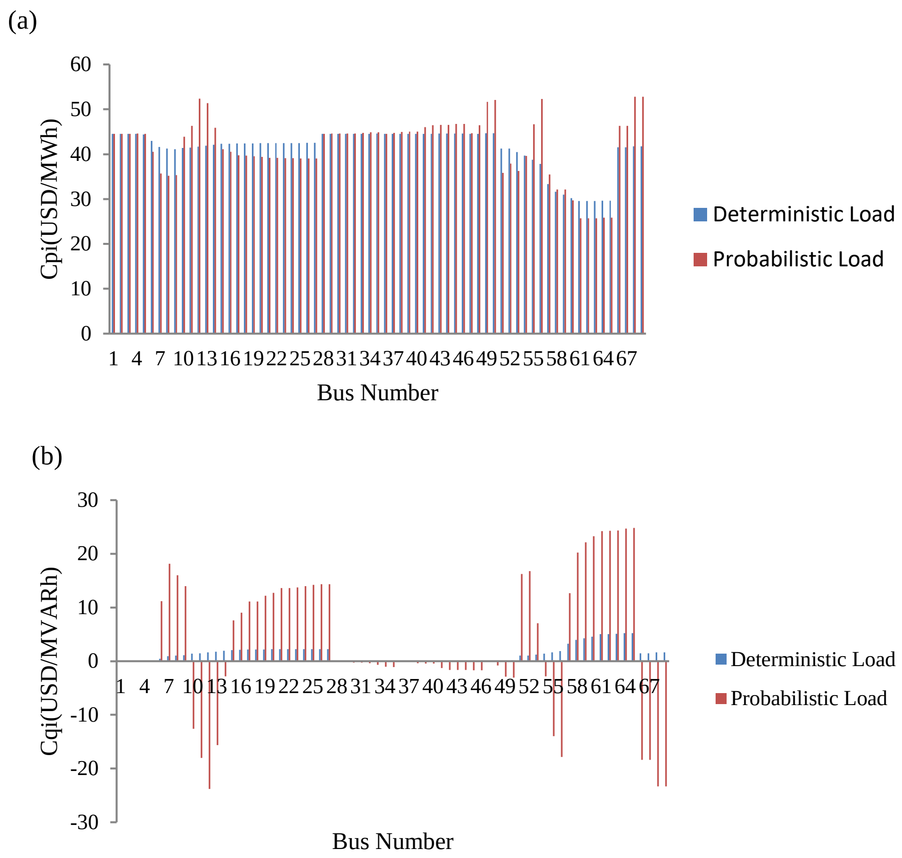


Fig. 3. (a) Active and (b) reactive power nodal prices comparison with wind

5 Conclusion

This paper depicts the method for obtaining nodal prices in radial distribution systems, taking into account wind power integration and probabilistic load. Nodal prices comparison is calculated for deterministic and probabilistic load without and with wind energy penetration. Since the probabilistic load includes the realistic haphazardness of the various fickleness of the system, obtained result for nodal prices for probabilistic loads are more accurate than the Deterministic load. It is observed that nodal prices are significantly reduced with the integration of wind power. So it is advantageous to include wind power source into distribution system.

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