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Loss Reduction in a Probabilistic Approach for Optimal Planning of Renewable Resources

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Abstract

Clean and sustainable renewable energy technology is going to take responsibility of energy supply in electrical power systems. Using renewable sources improve the environment and reduce dependence on oil and other fossil fuels. In distribution power system, utilizing of wind and solar DGs comprises some advantages; consist of loss and emission reduction, and also improvement of voltage profile. So, in expansion planning of distributed generations, improvement of each of these parameters can be the objective of planner. In this paper, a mathematical model for sizing and placement of wind and solar DGs is proposed. The formulation is based on a probabilistic load-generation model. The stochastic nature of the wind and solar resources are considered in the proposed scenario-based model. This mathematical framework is used to minimize total annual loss as an objective function. All the network constraints in different operational conditions are regarded. The model is applied on a typical rural distribution network using GAMS software which illustrated the effectiveness of the model.

Keywords: Sustainable recourses, Wind and solar DGs, Loss reduction, Uncertainty.
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1. Introduction

Now, interest rates have started to rise to move toward distributed energy resources which are connected to distribution networks. Locally supplying the loads by renewable DGs, imposes loss reduction in both transmission and distribution system. Of course, a non-optimal expansion solution may cause inverse results. So, a mathematical probabilistic planning framework to develop the network condition is proposed in this paper.

A good availability of renewable resources in the network has facilitated installation of these DGs in different nodes. High Speed of Technological Advancement in renewables, made them competitive in the marketplace, so plenty of environmental and economical benefits are brought about the system [1-3]. However, to have a reliable operational condition in the network, the stochastic nature of renewable sources should be modeled in the simulations [4].

DG planning can be modeled as a single or multi – objective problem. Mainly in single objective modeling, loss reduction [5-7] is considered. Whereas other objectives like cost [8], reliability [9], and stability [10] parameters are also optimized. On the other hand, multi-objective models are proposed in [11-12] which optimize voltage, loss, cost, reliability etc. of the system, simultaneously.

It is obvious that a non-optimal planning of DGs avoid some of the benefits. So various optimization methods for DG planning exist, which are classified into three major groups: conventional techniques [13], artificial intelligent optimization techniques [14], and other heuristic methods [15].

In this paper, we propose a novel mathematical model for the optimization for renewable DGs planning in distribution network. Due to determinative role of wind and solar power generation in future, a precise modeling of their output power considering the uncertain nature of wind speed and solar radiation is presented. The model is solved by The *General Algebraic Modeling System* (*GAMS*) using a nonlinear modeling system.

This paper is organized as follows: load and generation modeling considering uncertainties are outlined in Section 2. Mathematical model for renewable distributed generation planning is proposed in Section 3. A case study based on the Ontario-41 bus system is presented in Section 4. The study conclusions are summarized in Section 5.

2. Load and Generation Modeling

In this section, to avoid probable misleading solutions resulted from deterministic programming, we modeled stochastic nature of wind and solar-based DG units through scenario based uncertainty modeling. For all time segment, the hourly solar irradiance and wind speed data of the site under study [16], are modeled by Beta and Weibull probability density functions (pdf), respectively. Finally, for each time segment and in different states a combined renewable generation model is generated, which contain the output power of renewable resources and probability of associated state. In addition, IEEE-RTS [17] system for load behavior modeling is utilized.

A)*Historical Data Analyse*

Beta and Weibull probability density functions (pdf) are needed for prediction of solar irradiance and wind speed, respectively. The mentioned pdfs are produced from three years of historical data from site under study. Four typical day from four seasons are selected as the study period. This way, we have 96 time segment, that for each one of them 270 data (3 year* 3 month in a season* 30 day in a month) is analyzed to develop the pdfs. For each time segment, using mean and standard deviation of data, the Weibull and Beta pdfs are generated.

B)*Solar Modeling*

Solar irradiance in a time segment usually behave like a beta pdf which is calculated as:

Here, to describe the stochastic nature of the solar irradiance data, a Beta pdf is utilized [18], as set out in the following:

$$f_b(s)=\begin{cases}\dfrac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}*s^{(\alpha-1)}*(1-s)^{(\beta-1)} & for\ 0\le s\le 1, \alpha\ge 0, \beta\ge 0\\ 0, & otherwise\end{cases} \quad (1)$$

Where

s solar irradiance

$f_b(s)$ Beta distribution function of S

α , β parameters of the Beta distribution function

β and α are calculated using the following:

$$\beta=(1-\mu)*\left(\frac{\mu*(1+\mu)}{\sigma^2}-1\right) \quad (2)$$

$$\alpha=\frac{\mu*\beta}{1-\mu} \quad (3)$$

Where μ and σ are the mean and standard deviations of the random variable, respectively.

Output power of PV modules depends on solar irradiance, environmental temperature, and technical characteristic of the modules. Therefore, output power of the a solar based DG is calculated as:

$$T_{C_y}=T_A+s_{ay}\left(\frac{N_{OT}-20}{0.8}\right) \quad (4)$$

$$I_y=s_{ay}\left[I_{sc}+K_i\left(T_c-25\right)\right] \quad (5)$$

$$V_y=V_{oc}-K_v*T_{C_y} \quad (6)$$

$$P_{Sy}\left(s_{ay}\right)=N*FF*V_y*I_y \quad (7)$$

$$FF=\frac{V_{MPP}*I_{MPP}}{V_{oc}*I_{sc}} \quad (8)$$

Where

T_{C_y} cell temperature ^{0}C during state (y) ;

T_A ambient temperature ^{0}C

K_v voltage temperature coefficient V/^{0}C;

K_i current temperature coefficient A/^{0}C;

N_{OT} nominal operating temperature of cell in ^{0}C;

FF fill factor;

I_{sc} short circuit current in A;

V_{oc} open-circuit voltage in V;

I_{MPP} current at maximum power point in A;

V_{MPP} voltage at maximum power point in V;

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P_{Sy} output power of the PV module during state (y);

S_{ay} average solar irradiance of state (y);

C) *Wind Modeling*

Weibull probability density function (pdf) has been considered as a proper expression to model wind speed [19]. Weibull pdf for wind speed prediction is recommended because of some results from comparing between real site data and predicted ones by Weibull pdf.

$$f_w(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{9}$$

Where k and c are shap and scale index, respectively. If shape index k = 2, the probability density function is called Rayleigh $f_r(v)$, which is a special case of Weibull pdf, as in (5). This pdf is in accordance with most of wind speed profiles, so that, in this paper is utilized for wind speed modeling in all time segments.

$$f_r(v) = \left(\frac{2v}{c^2}\right)\exp\left[-\left(\frac{v}{c}\right)^2\right] \tag{10}$$

Weibull pdf with different shape and scale indexes are shown in Fig.1 and Fig.2 respectively.

Rayleigh scale index is calculated as follow:

$$v_m = \int_0^\infty v.f(v)dv$$

$$= \int_0^\infty \left(\frac{2v^2}{c^2}\right)\exp\left[-\left(\frac{v}{c}\right)^2\right]dv = \frac{\sqrt{\pi}}{2}c \tag{11}$$

$$c \approx 1.128\, v_m$$

Where, v_m is mean wind speed in each time segment.

Output power of a wind based DG is dependent on wind speed in site, and turbine power efficiency curve. So, having the pdf in each time section, the output power of wind based DG is calculated as:

$$P_{Vw}(v_{aw}) = \begin{cases} 0 & 0 \le v_{aw} \le v_{ci} \\ P_{rated} * \dfrac{(v_{aw} - v_{ci})}{(v_r - v_{ci})} & v_{ci} \le v_{aw} \le v_r \\ P_{rated} & v_r \le v_{aw} \le v_{co} \\ 0 & v_{co} \le v_{aw} \end{cases} \tag{12}$$

Where v_{ci}, v_r and v_{co} are the cut-in speed, rated speed and cutoff speed of the wind turbine, respectively.

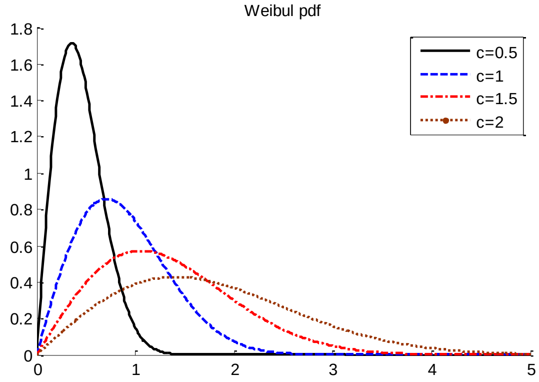

Fig. 1. Weibull pdf with different scale index (k=2)

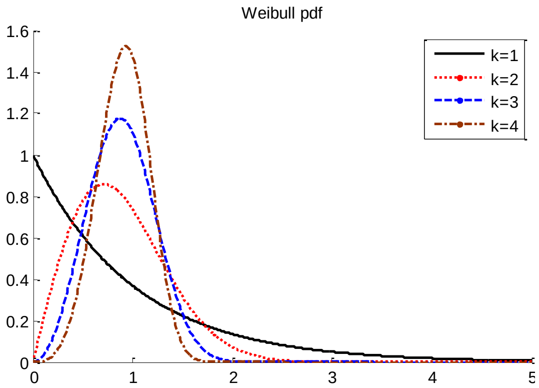

Fig. 2. Weibull pdf with different shape index (c=1)

The continuous wind speed pdf is divided into some states. Here, each step for wind speed states is 1m/s.

D) *Load Modeling*

Load profile [20] is considered as a percentage of peak load as IEEE-RTS system.

E) *Combined Load-Generation Model*

Using the pervious described models in this section, an annual load-generation model is resulted. Since the probability of constant load is 1, and assuming independency of wind and solar states, probability of each combination of them ($P\{G_g\}$) is calculated as in (13):

$$P\{G_g\} = P_v\{G_w\} * P_s\{G_y\} \tag{13}$$

In each time section, renewable DGs output power and load, have some different states with different probabilities. The complete load-generation model can be formulated as in (14):

$$R = \left[\left\{C_{tg}, P\{C_{tg}\}\right\} : g = 1:N, t = 1:T\right] \tag{14}$$

R Complete annual generation-load model;

C Matrix of three columns that include all possible combinations of the wind output power states and solar output power states as well as the load states (i.e., column 1 represents the output power of wind-based DG as a percentage of the rated power, column 2 represents the output power of the solar DG as a percentage of the rated power, and column 3 represents the different load levels), this matrix in each of 96 time section has different values;

$P\{G_{tg}\}$ 96-Columns matrix that represents the probability corresponding to matrix C in each time section;

N Total number of discrete states in model.

3. Mathematical Model

Mathematical formulation of renewable DG planning is proposed in this section. First, the objective function is presented.

A)*Objective Function*

Distributed generation in distribution system cab increase or decrease the power loss, depending on the placement and sizing of units. Objective function in (15), computes the total annual loss of energy in distribution network.

$$F_{loss} = \sum_t \sum_g \left[P_{loss,tg} \right] * P\left\{ G_{tg} \right\} * 90 \tag{15}$$

Here, $P\{G_{tg}\}$ is the probabality of state g in time section t. $P_{loss,\,tg}$ is calculated as in (16).

$$P_{loss,tg} = \sum_{i=1}^{L} R_l . \left(\left(I_{l\ tg}^{Re} \right)^2 + \left(I_{l\ tg}^{\mathrm{Im}} \right)^2 \right) \tag{16}$$

Where, R_l, I_l^{Re} and I_l^{Im} are resistant, real and imaginary part of the current in line l.

B)*Power Flow in Distribution Power System*

As you know, routine power flow method in transmission power system is not executable in distribution system, so, a novel single line power flow model based on the power network elements is presented in this paper.

For each series element, a set of equations based on ABCD parameters, corresponding to the sending and receiving ends of the elements is modeled, which is as (17).

$$\begin{bmatrix} V_{ltg}^{s} \\ I_{ltg}^{s} \end{bmatrix} = \begin{bmatrix} A_l & B_l \\ C_l & D_l \end{bmatrix} \begin{bmatrix} V_{ltg}^{r} \\ I_{ltg}^{r} \end{bmatrix}, \quad \forall l,t,g. \tag{17}$$

ABCD parameters models the series elements and are calculated as follows.

$$A_l = D_l = \frac{Z_l Y_l}{2} + 1, \quad \forall l. \tag{18}$$

$$B_l = Z_l, \quad \forall l. \tag{19}$$

$$C_l = Y_l \left(1 + \frac{Z_l Y_l}{4} \right), \quad \forall l. \tag{20}$$

Where, Z_l and Y_l are respectively impedance and admittance of π model for line l.

Constant load and renewable power generation units are modeled as in ().

$$\begin{aligned} &V_{ntg} I_{ntg}^{*} = Cl_{tg} * P_n^{L} - P_{ntg}^{Sub} - Cw_{tg} * P_n^{W} \\ &- Cs_{tg} * P_n^{S} + j\left(Cl_{tg} * Q_n^{L} - Q_{nt}^{Sub} \right), \quad \forall n,t,g. \end{aligned} \tag{21}$$

Cw_{tg}, Cs_{tg}, and Cl_{tg} are two dimension matrixes in state g and time section t, representing all different states of wind and solar output power and load, respectively.

Power balancing equations in each node is satisfied in (22).

$$\sum_l I_{ltg}^{r_n} = \sum_l I_{ltg}^{s_n} + I_{ntg}, \quad \forall n,t,g. \tag{22}$$

And of course voltage in each node is equal in all elements connected to that node, so we have (23).

$$V_{ltg}^{s_n} = V_{ltg}^{r_n} = V_{ntg}, \quad \forall n,t,g. \tag{23}$$

Elements of the distribution network are modeled in equations (17)-(21) while (22) and (23) apply circuit laws to the network. So, we present a novel load flow model in distribution system through (17)-(23). Moreover, operational constraint of distribution network like voltage limit and capacity of each feeder in the network, are essential in this DG planning program.

Maximum renewable penetration limit in each node and also in distribution network, is considered in the following equations.

$$P_n^W + P_n^S \le P^{bus} \quad \forall n \in B \tag{24}$$

$$\sum_{n=1}^{N} CF_w * P_n^W + \sum_{n=1}^{N} CF_s * P_n^S \leq x * \sum_{n=1}^{N} P_n^l \tag{25}$$

Where B is set of candidate nodes for placement of DGs. CF_w and CF_s are 0.2209 and 0.174, respectively.

4. Case Study

In this section, the effectiveness of the proposed method for planning of renewable DG units in distribution network is illustrated. Here, general data, wind and solar data for the system under study is presented.

A)*System Under System*

The system under study [20], shown in Fig. (3), is a typical network with 16.18 MW. The network is connected to the sub-transmission system via bus 1. Load profile is presented as a percentage of reference peak load [20] for 96 time section.

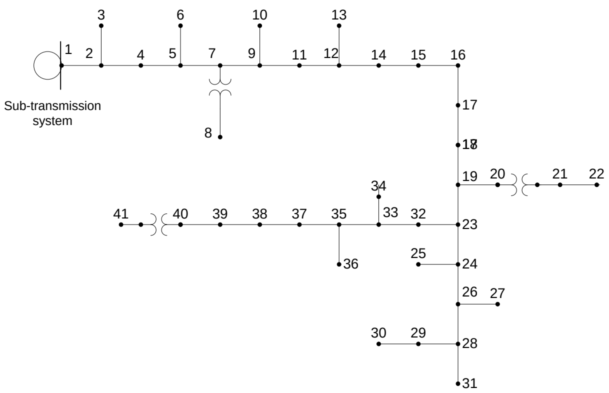

Fig. 3. System under study

For this study, set of candidate buses for DG placement is: {19, 23, 24, 26, 28, 32, 33, 35, 37, 38, 39, 40}, which is based on Ontario's standard offer program [21]. Maximum DG penetration limit on each bus and in all the distribution system is respectively 10 MW and 30%.

B)*Wind and Solar Data*

Wind and solar data of the site under study is gotten from Waterloo University [1]. This data is utilized to generate a Beta and Rayleigh pdf for each time segment. In each time segment, three scenarios are generated for wind speed and three scenarios for solar irradiance. Here, we considered that wind and solar DG unit sizes can be found in a continuous rang of values.

C)*Results*

Result of the optimized planning of wind and solar DG units is proposed in table 1. This planning reduced the annual energy loss from 1507 MWh to 1113 MWh, which demonstrate 26% loss reduction in the distribution system.

Table.1.
Planning RESULTS

Candidate bus	**Renewable DG Units (in kW)**	
	Wind based DG Capacity	***Solar DG Capacity***
19	0	0
23	0	0
24	250	160
26	130	0
28	630	390
32	0	0
33	180	110
35	0	0
37	90	60
38	0	0
39	0	0
40	1900	1180

5. Conclusion

In this paper, an efficient optimization technique is proposed for optimally allocating renewable DGs into the distribution system in order to minimize annual energy losses. This model is based on a deterministic distribution optimal power flow which uses the probabilistic generation-load model, including all operating conditions. The optimization problem is formulated as MINLP, under GAMS environment. A rural distribution system has been used to illustrate the performance of the proposed planning technique. The results reveal that 26% of loss reduction can be obtained by the proposed method.

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