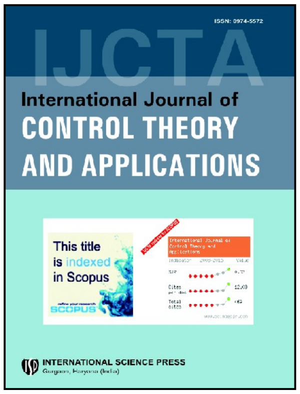

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Optimal Placement of Non-dispatchable Distributed Generation in Radial Distribution System

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Abstract: This paper presents an optimum placement of Non-dispatchable Distributed Generation (NDG) in Radial Distribution System. The present analysis of non-dispatchable nature of wind is based on modified Weibull probability distribution function. Furthermore, the beta probability distribution function is applied for modeling of solar irradiance. The voltage stability index (VSI) based methodology is used for optimal placement of NDG. Moreover, the modeling of load which includes residential, industrial and commercial is voltage dependent in this analysis. The Bus-Injection to Branch-Current (BIBC) and Branch-Current to Bus Voltage (BCBV) based method is applied for load flow analysis. The proposed technique is applied on IEEE-69 bus system. The present technique is very much effective as far as system loss reduction is concern.

Keywords: NDG, voltage stability index, BIBC, BCBV, optimal placement and radial distribution system.

I. INTRODUCTION

The growing electricity demand, environmental concern, uncertainties associated to fuel prices, liberalization of electricity markets and advances in technologies has motivated power system planner to use small scale generation instead of large centralized power plants. Such small scale electric power generation is termed as distributed generation (DG) and is directly connected to loads or customer side of meter [1]. The DG size typically varies in the range few kWs to several MWs [1], [14]. DGs are ever beneficial when integrated with existing distribution network provided their sizing and siting is planned strategically. Moreover, DG unit offer several benefits such as environmental, economical and technical to utilities and consumers [1], [3], [4], [14], [19] and [20]. These benefits are reduction of system energy and power losses; improvement of system voltage profile, voltage stability margin, loadability, and reliability [1], [14] and [16]. Further, the generation of green power using renewable energy sources enhances the quality of power supply [4] and [14]. Considerable work has been carried out by the authors for loss reduction using analytical method as in [6]. In [24] a fuzzy Genetic algorithm method is proposed to minimize power losses.

On the other hand non-optimal placement of DG units may lead to increase system losses, system cost and voltage in some load buses. As a consequence performance of system get deteriorates [3], [4], [14] and [19]. Therefore, optimal placement of DG in distribution systems is an extremely important aspect of DG planning.

Hung *et al.* [8] applied an analytical formulation based on multi-objective index to put up the unification of energy storage battery and solar photovoltaic based DG units for minimizing energy loss and improvement of voltage stability of the system with time-varying load and non-dispatchable DG using self-correction algorithm. Kayal and Chanda [13] and Kansal *et al.* [15] highlighted the classification of diversified group of DG units those are operated by non-conventional energy source such as, biomass, solar and wind to reduce system losses by optimum allocation and sizing of DG. Hung and Mithulananthan [16] suggested a multi-objective dual index (IMO) based analytical technique for optimum size and power factor of DG unit to reduce the system power loss and improvement of system loadability. Beta and Rayleigh modeling is used for modeling of solar and wind power [23].

The loss reduction is extremely important in case of distribution system due to their inherent properties. Therefore, the reduction of losses in distribution system is a matter of great concern for researchers and analysts. Hence, as per available literature, the authors are motivated to analyze the proposed technique.

The rest of the paper is organized as: section 2 describes the modeling of wind and solar operated DG along with proposed methodology, section 3 explains the selection of optimum locations for NDG placement, section 4 presents results and discussions and finally, section 5 describes the conclusions.

II. MODELING OF NDG AND PROPOSED METHODOLOGY

(A) Non-dispatchable DG (Solar and Wind) modeling

DG whose output power is not predictable may be termed as non-dispatchable type DG such as wind and solar irradiance operated DG. The solar photovoltaic may be installed at rooftop under control of local owner of utility. The modeling of wind speed and solar irradiance is as follows

(B) Modeling of Wind speed

Many experiments have demonstrated that a good expression for modeling the stochastic behavior of wind speed is the Weibull probability density function (PDF) but the modified PDF of Weibull distribution function that is Rayleigh distribution function when k=2, is also very much effective . The PDF of wind speed is given by Atwa et al [21] and [23].

$$f(v)=\frac{k}{c}\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^{k}} \tag{1}$$

If the value of $k = 2$, then above expression reduces to Rayleigh distribution function,

$$f(v)=\left(\frac{2v}{c^2}\right)e^{-\left(\frac{v}{c}\right)^{2}} \tag{2}$$

And power output of wind generator is given as

$$W_{wind}=\begin{cases}0 & 0\le v\le v_{ci}\\ \left(\frac{v_{ci}-v}{v_{ci}-v_r}\right)W_w^{rated} & v_{ci}\le v\le v_r\\ W_w^{rated} & v_r\le v\le v_{co}\\ 0 & v_{co}\le \mathrm{v}\end{cases} \tag{3}$$

Where v, v_{ci}, v_r, v_{co} are the nominal, cut-in, rated and cut-out speed of the wind respectively

(C) Modeling of solar photovoltaic cell

The uncertainty of solar irradiance is given by beta PDF,

$$F(x)=\frac{x^{\alpha-1}\times(1-x)^{\beta-1}}{\Gamma(\alpha)\times\Gamma(\beta)}(\Gamma(\alpha+\beta)) \tag{4}$$

Here

$$\alpha=\frac{\mu\times\beta}{1-\mu} \tag{5}$$

$$\beta=(1-\mu)\times\left(\mu\times\left(\frac{1+\mu}{\sigma^2-1}\right)\right) \tag{6}$$

Where, x is solar irradiance in kW/m^2. Further, α and β are the shape parameters of beta PDF, μ and σ are mean and standard deviation of solar irradiance respectively.

Solar module output power W_{pv} is given as

$$W_{pv}=n\times FF\times V\times I \tag{7}$$

$$FF=\frac{V_{mp}\times I_{mp}}{V_{oc}\times I_{sc}} \tag{8}$$

$$V=V_{oc}-K_v\times T_c \tag{9}$$

$$I=x[I_{sc}+K_i(T_c-25)] \tag{10}$$

$$T_c=T_a+x\left(\frac{N_{OCT}-20}{0.8}\right) \tag{11}$$

Where FF is the fill factor, n is the number of modules; V and I are the voltage and current of cell at specified state, T_a and T_c are ambient and cell temperature respectively and N_{OCT} is nominal operating cell temperature in ^0C .

(D) Load Modeling

In traditional power flow investigations, it was assumed that active and reactive power loads are constant, irrespective of the magnitude of voltages in the same bus. A voltage dependent load model is a static load model that represents the power relationship to voltage as an exponential equation, which can be mathematically expressed as

$$P_l=P_{\ln}V^{a_p} \tag{12}$$

$$Q_l=Q_{\ln}V^{a_q} \tag{13}$$

Where a_p and a_q are active and reactive power exponents respectively given in Table 1, P_{ln} and Q_{ln} are active and reactive powers at nominal voltage respectively. If p, q and r represent percentages of residential, commercial and industrial load at each bus respectively then equations which will describe the load model is given by

$$P_l=pP_{\ln}V^{a_{pr}}+qP_{\ln}V^{a_{pc}}+rP_{\ln}V^{a_{pi}} \tag{14}$$

$$Q_l = pQ_{\ln}V^{a_{qr}} + qQ_{\ln}V^{a_{qc}} + rQ_{\ln}V^{a_{qi}} \tag{15}$$

Table 1
Type of load and exponent values

load	*Time*	*Residential*		*Commercial*		*Industrial*	
		a_{pr}	a_{qr}	a_{pc}	a_{qc}	a_{pi}	a_{qi}
Summer	day	0.72	2.96	1.25	3.50	0.18	6.00
	night	0.92	4.04	0.99	3.95	0.18	6.00
Winter	day	1.04	4.19	1.05	3.15	0.18	6.00
	night	**1.30**	**4.38**	**1.51**	**3.40**	**0.18**	**6.00**

III. SELECTION OF OPTIMAL LOCATION FOR NDG PLACEMENT

(A) Voltage stability index (VSI)

The *VSI* is given as

$$VSI = \sum_{i=1}^{nb-1} \left(2V_{i+1} - V_i\right) \tag{16}$$

Where '*nb*' is total number of buses in given system. The bus which will have lowest *VSI* will be more sensitive to stability and DG can be placed at this node to preserve the stability criterion

IV. RESULTS AND DISCUSSIONS

The coding for the results is developed in MATLAB environment. Table 2 [23] and Table 3 [25] provides specifications used for this analysis. The Fig.1 shows the VSI profile for IEEE-69 bus test radial distribution system. It is evident, that VSI profile is lowest for bus 61; therefore the NDG will be placed at bus 61. Furthermore, the losses are determined for three different cases. First Case represents the base case i.e. without DG, in Case 2 only Wind operated generator NDG is installed, for Case 3 solar based NDG is taken. It is assumed that all above discussed NDG's are operated at unity power factor. Fig.2 and Fig.3 represents active and reactive power losses for summer season respectively. Active and reactive power losses for winter season are represented by Fig.4. and Fig.5 respectively. Solar based NDG is working for 12 hours (during day time) only while wind operated NDG is working for 24 hours. Therefore from Fig.2 to Fig.5 it is observed that during night hours losses are less for wind operated NDG than base case, while for that of solar based module losses are equal to base case; on the other hand for the period of sunny hours losses are less for solar based NDG as compared to wind operated NDG and base case.

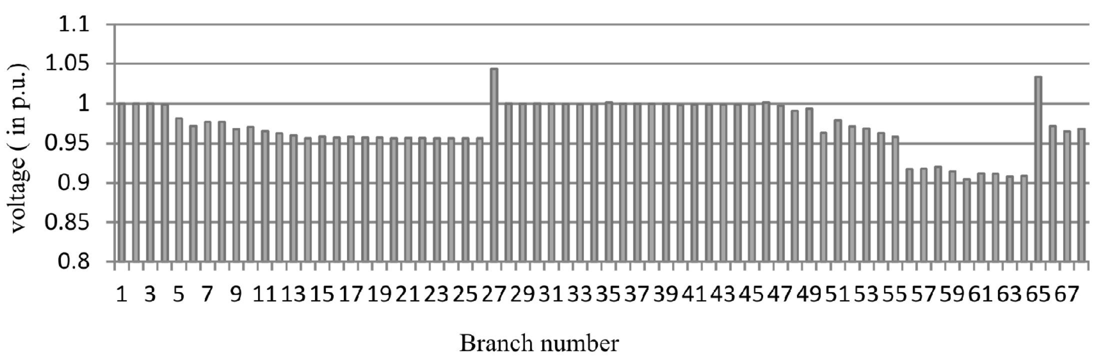

Figure 1: VSI for IEEE-69 bus system

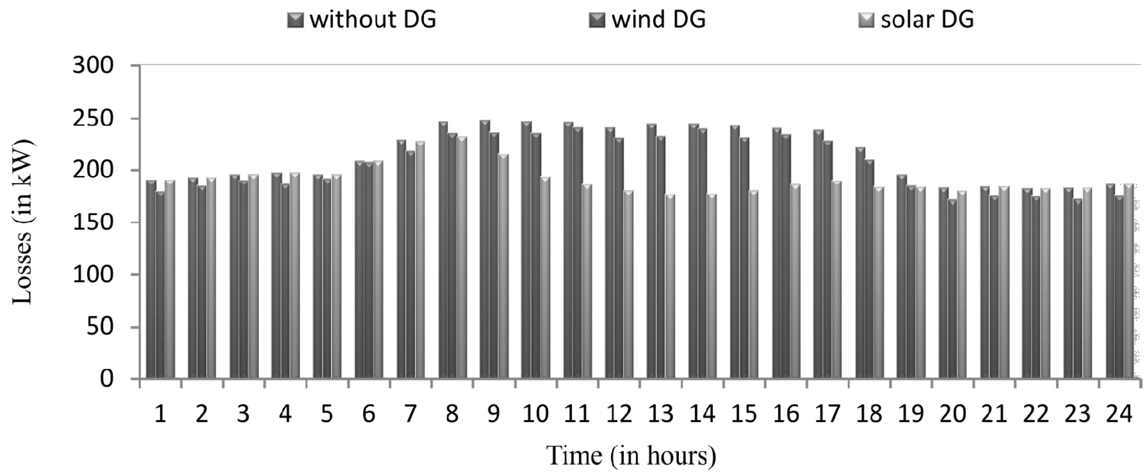

Figure 2: Active power losses for summer

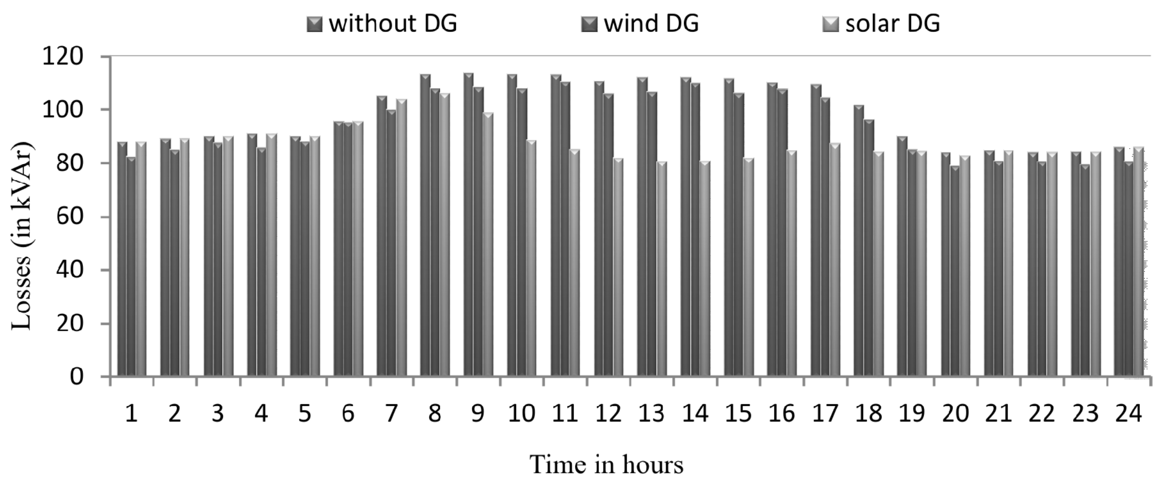

Figure 3: Reactive power losses for summer

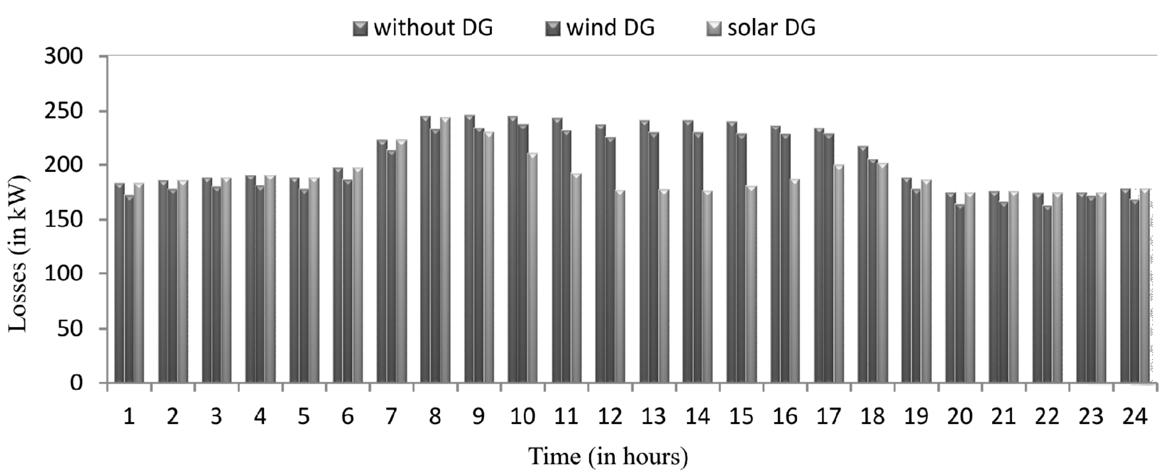

Figure 4: Active power losses for winter

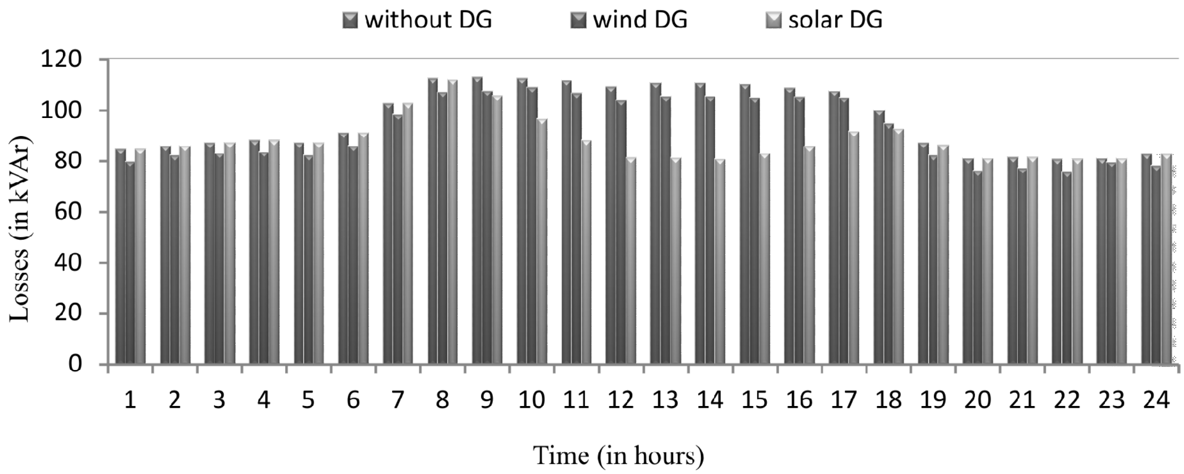

Figure 5: Reactive power losses for winter

Table 2
Specifications of solar photovoltaic

Module specifications	*values*
Watt peak(*W*)	50.0
V_{oc} (Open circuit voltage in *V*)	55.5
I_{sc} (Short circuit current in *A*)	1.80
V_{mp}(Voltage at maximum power in *V*)	38.0
I_{mp} (Current at maximum power in *A*)	1.32
K_v (Voltage temperature coefficient in *mV/°C*)	194
K_i (Current temperature coefficient in *mA/°C*)	1.40
N_{OCT} (Nominal cell operating temperature in °C)	43.0

Table 3
Specifications of wind generator

W_w^{rated} *(Rated power in kW)*	*4.0*
v_{ci} (Cut in speed in m/s)	2.5
v_r (Rated speed in m/s)	12.5
v_{co} (Cut out speed in m/s)	**20**

V. CONCLUSIONS

It is observed that system losses get reduced significantly when solar and wind based DG is placed at identified locations in an IEEE 69 bus system. The VSI based methodology is adopted for placement of NDG in radial distribution system. In this paper three scenarios have been considered such as base case i.e. system without DG. Further, remaining two scenarios wind and solar operated DG has been considered with voltage dependent load model. Such load models are close to real time practical load. Three different types of load residential, commercial and industrial are used for analysis

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