

# Optimal Placement and Sizing of Dg Units in Distribution Network Considering Uncertainties

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*Abstract*— Global environmental problems associated with traditional energy generation have led to a rapid increase in the use of renewable energy sources (RES) in power systems. This paper proposes an application of Differential Evolution (DE) algorithm for determining the optimal allocation of PV based distributed generation (DG) units in the distribution network (DN) with the aim of minimizing the total power and energy losses.

**Keywords**— uncertainties; photovoltaic array; differential evolution algorithm; distribution network

## 1. INTRODUCTION

In the last few years, considerable attention has been paid to the usage of RES (such as PV, wind, etc.) to minimize power losses due to global environmental problems associated with traditional generation. Many countries have been introduced or are proceeding towards the implementation of renewable energy policies like the Renewable Energy Portfolio Standard (RPS) [1]. Accepting an RPS is a production obligation of a certain percentage of the total electricity production from RES for a specific date. However, available PV energy is unstable and variable. However, high PV integration can lead to large power fluctuations, which may risk the provision of continuous power supply. In addition, the amount of PV energy that can be absorbed by the power system at a particular time may be significantly limited, since the available traditional units may not be able to respond to changes caused by PV units' fluctuations [2].

PV produces energy when exposed to sunlight, and several other components are needed to properly conduct, control, convert, distribute and store the energy produced by the array. In restructured power systems, the use of distributed generation energy resources, including photovoltaic (PV), fuel cells, small wind turbines, etc. The advantage of distributed generation energy resources includes reducing power losses, improving voltage profile (VP), and increasing network reliability. To achieve the advantages of DG units, the choice of the optimal location and size becomes a major problem [3-4].

## 2. PROBLEM FORMULATION

The objective of this article is to minimization the real power loss and improve the DN voltage [3,9].

The first term of the objective function is the real power loss, which is determined by equation (1)

$$P_{LOSS} = \sum_{j=1}^{n_f} \sum_{k=1}^{n_s} R_k |I_k|^2 \quad (1)$$

Accordingly, minimizing the total active power losses in the DS leads to reduce the total active energy losses  $E_{loss}$  during 24 hrs as:

$$E_{loss} = \sum_{t=1}^{24} P_{loss}(t) \Delta t \quad (2)$$

The second goal of this work is to improve the VP, which is represented by the VP index in equation (3) [2].

$$VP = \sum_{j=1}^{n_f} \sum_{k \in lb} |V_k - V_{ref,k}| \quad (3)$$

### 2.1 PV and Load models

#### 2.1.1. Solar radiation model

It is considered that the probabilistic nature of solar radiation follows the Beta PDF [5]. The Beta PDF of solar radiation 's' (kW/m<sup>2</sup>) in the time interval 't' is defined as:

$$f_b(s^t) = \begin{cases} \frac{\Gamma(\alpha^t + \beta^t)}{\Gamma(\alpha^t)\Gamma(\beta^t)} s^{t(\alpha^t-1)} (1-s^t)^{(\beta^t-1)}, & 0 \leq s^t \leq 1, \quad \alpha^t, \beta^t \geq 0 \\ 0, & otherwise \end{cases} \tag{4}$$

where,  $f_b(s^t)$  is the Beta PDF of  $s^t$ ;  $\alpha^t$  and  $\beta^t$  are the shape rates of Beta PDF,  $\Gamma$  is depict Gamma function. The shape rates can be found based on the mean ( $\mu$ ) and SD ( $\sigma$ ) of radiation for a suitable time interval.

$$\beta^t = (1 - \mu^t) \left( \frac{\mu^t (1 + \mu^t)}{\sigma^{t2}} - 1 \right), \quad \alpha^t = \frac{\mu^t * \beta^t}{1 - \mu^t}.$$

A) PV array power generation model

The PV array hourly average power output corresponding to an exact time interval ‘t’ ( $P_{PV}^t$ ) is expressed as (5). A typical day for three years is generated in p.u., as shown in Fig 1.

$$P_{PV}^t = \sum_{g=1}^{n_s} P_{PV_o}(s_g^t) f_b(s_g^t) \tag{5}$$

where ‘g’ denotes a stage factor and  $n_s$  is the solar radiation discrete stage number.  $S_g^t$  is the  $g^{th}$  stage of solar radiation at  $t^{th}$  time interval.

Solar radiation and ambient temperature are the basic dominant factors that affect the PV array power output. The PV power generation with average solar radiation ( $s_{ag}$ ) for the  $g^{th}$  stage is estimated as [6]:

$$P_{PV_o}(s_{ag}) = N_{PV\text{mod}} * FF * V_g * I_g \tag{6}$$

where:

$$FF = \frac{V_{MPP} * I_{MPP}}{V_{OC} * I_{SC}}; \quad V_g = V_{OC} - K_v * T_{cg}; \quad I_g = s_{ag} [I_{SC} + K_i(T_C - 25)]; \quad T_{cg} = T_A + s_{ag} \left( \frac{N_{OT} - 20}{0.8} \right)$$

Here,  $N_{PV\text{mod}}$  is the PV modules total number;  $T_A(^{\circ}C)$  is ambient temperature;  $V_{MPP}$  and  $I_{MPP}$  are maximum power tracing voltage (V) and current(A), respectively;  $V_{OC}$  and  $I_{SC}$  are voltage of open-circuit and current of short circuit, respectively;  $K_i$  and  $K_v$  are the current and voltage temperature coefficients ( $A/^{\circ}C$  and  $V/^{\circ}C$ ), respectively;  $FF$  is the fill factor;  $T_{cg}$  is PV module temperature at  $g^{th}$  stage ( $^{\circ}C$ ).

2.1.2 Load model

The load demand for the system is modelled corresponding to the normalized daily 24- hours load curve with a peak of 1 pu, as shown in Fig. 1 [7]. The load factor (LF) can determine as the field beneath the load curve, the load curve in p.u. subdivide by the sum of time interval [8]

$$LF = \sum_{t=1}^{24} \frac{\text{per.unit. Demand}(t)}{24} \tag{7}$$

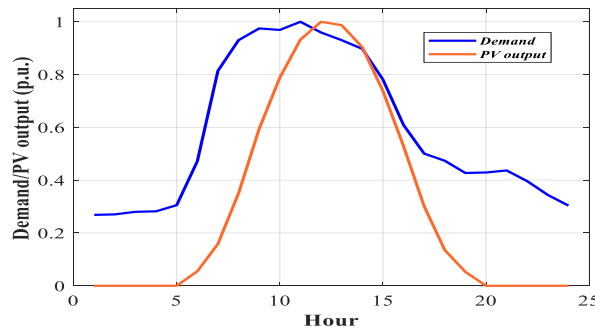


Fig 1. Normalized daily active load curve and PV output

The voltage-dependent load demand model, which includes variable load over time, can be calculated as [3]:

$$P_k(t) = P_{ok}(t) * V_k^{n_p} \\ Q_k(t) = Q_{ok}(t) * V_k^{n_q} \tag{8}$$

where,  $P_k$  and  $Q_k$  represent active and reactive power injected at node  $k$ .  $P_{ok}$  and  $Q_{ok}$  represent the active and reactive power loads injected at nodes  $k$ .  $V_k$  represents the voltage value at node  $k$ , and  $n_p$  and  $n_q$  represent active and reactive load demand voltage indexes, respectively [3], where  $n_p = 1.51$  and  $n_q = 3.4$ .

3. NUMERICAL RESULTS AND DISCUSSION

Based on the proposed methodology, a program was written in MATLAB software. To evaluate the effectiveness of the proposed approach, the program was applied to test systems at nominal load. The test system is a standard 33-bus DN with a total load of 3.7 MW and 2.3 MVar as shown in Fig.2. The power flow is performed using  $S_{base} = 100MVA$  and  $V_{base} = 12.66 kV$  [3]. The power losses in the base case are 210.986 kW. The VP index is 0.90378 pu.

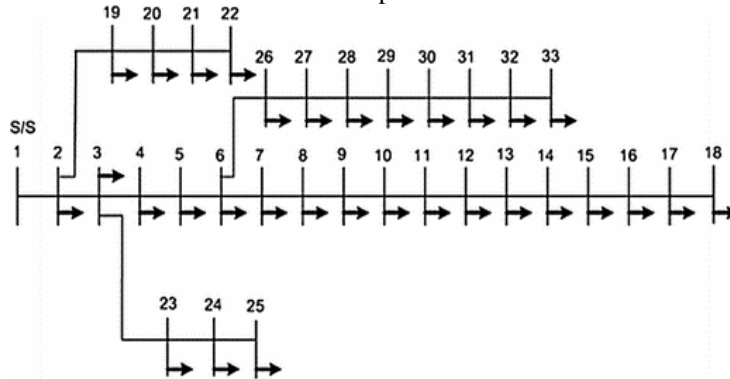


Fig. 2. Single line diagram of standard 33-bus system.

In this paper, the power flow is analyzed using the reverse / forward sweep algorithm in the base case. Without PV array allocation and with optimal PV array allocation. The observed results are presented in Table 1 and Table 2. It can be seen from the results that the integration three PV based DG units improve DN performance.

Table 1: The observed results for 33-bus system

PV- location	PV- size/PF	Power loss	Voltage profile (minimum voltage at the bus)
13	801.71/1	72.790	0.96 @ bus 33
30	1053.6/1		
24	1091.3/1		

Table 2 Daily energy loss for 33-bus system

Scenario	Energy loss (kW h)	Loss reduction %
Base case	2044.796	-
With PV	1036.09	49

4. CONCLUSION

The proposed approach is used to reduce power losses, energy loss and improve VP in the distribution network. To test the effectiveness of the proposed approach was tested on a test system with a standard 33 bus system. For the 33-bus system, the loss reduction is 53% and energy loss reduction is 49%. In addition, the VP performance is improved over the base system.

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