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Optimal Integration of Wind Turbine based DG Units in Distribution System 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. The integration of renewable energy technologies is commercially available nowadays, and the most common of such RES technology is wind turbine (WT). This paper proposes an application of Salp Swarm Algorithm (SSA) for determining the optimal allocation of WT based distributed generation (DG) units in the distribution system (DS) with the aim of minimizing the total power and energy losses.*

Keywords—uncertainties; wind turbine; differential evolution algorithm; distribution system

1. INTRODUCTION

In the last few years, considerable attention has been paid to the usage of RES (such as WT, 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 WT energy is unstable and variable. However, high WT integration can lead to large power fluctuations, which may risk the provision of continuous power supply. In addition, the amount of WT 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 WT units' fluctuations [1-3].

WT produces energy when exposed to wind speed, and several other components are needed to properly conduct, control, convert, distribute and store the energy produced by the turbine. In restructured power systems, the use of distributed generation energy resources, including wind turbine (WT), fuel cells, small micro turbines, etc. The advantage of distributed generation energy resources includes reducing power and energy 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 [3-5].

2. PROBLEM FORMULATION

Objective function

The objective of this article is to minimization the real power and energy losses and improve the DS voltage [6-7].

Real power loss

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

$$P_{LOSS} = \sum_{j=1}^{n_f} \sum_{k=1}^{n_s} R_k \, |{I_k}^2| \tag{1}$$

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

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

where,

I_k − Is the current passing through line k

n_f − Is the total number of branches

n_s − Total number of sections in the system

R_k −Resistance of the line section between buses k and $k + 1$

Voltage Profile improvement

The second goal of this work is to improve the VP, which is represented by the VP index in equation (3) [8].

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

where,

$lb -$ Collection of the load buses

$V_{ref,k} -$ Nominal voltage at load bus k.

$V_k -$ Voltage amplitude at bus k.

3. WT AND LOAD MODELS

3.1.1 Wind speed modeling: Weibull PDF was chosen to evaluate the stochastic behavior of wind speed at a predetermined duration of time [9]. Weibull PDF for wind speed v_t (m/s) at the t-th time interval can be calculated as:

$$f_v(v^t) = \frac{k^t}{c^t} * \left(\frac{v^t}{c^t} \right)^{k^t - 1} * \exp\left(- \left(\frac{v^t}{c^t} \right)^{k^t - 1} \right) \quad for \quad c^t \succ 1; \quad k^t \succ 0 \tag{4}$$

The shaping rate (k^t) and scale rate (c^t) at tth time interval are expressed as [9]:

$$k^t = \left(\frac{\sigma^t}{\mu_v^t} \right)^{-1.086} \tag{5.1}$$

$$c^t = \frac{\mu_v^t}{\Gamma(1 + 1/k^t)} \tag{5.2}$$

where, μ_v^t and σ^t are mean and Sd of wind speed at time interval 't'.

3.1.2 WT power generation: The hourly WT average output power corresponds to a specific time interval 't' (P^t_{WT}) can be expressed as (6). A typical day for three years is generated in p.u., as shown in Fig. 4.

$$P_{WT}^t = \sum_{g=1}^{n_s} P_{WT_o}(v_g^t)\, f_b(v_g^t) \tag{6}$$

where 'g' denotes a stage factor and n_s is the number of wind speed discrete stage. v^t_g is the gth stage of wind speed at tth time interval.

The WT power generation [9] with an average wind speed (v_{ag}) for stage "g" is expressed as:

$$P_{WT_o} = \begin{cases} 0 & v_{ag} \prec v_{cin} \quad or \quad v_{ag} \succ v_{cout} \\ (A * v_{ag}^3 + B * P_r) & v_{cin} \le v_{ag} \le v_r \\ P_r & v_r \le v_{ag} \le v_{cout} \end{cases} \tag{7}$$

where P_r is the nominal power rate that WT can be generated; v_{cout} is cut-out; cut-in (v_{cin}) and nominal (v_r) wind speed, respectively, constants A and B are achieved as 9]:

$$A = \frac{P_r}{(v_r^3 - v_{cin}^3)} \tag{8.1}$$

$$B = \frac{v_{cin}^3}{(v_r^3 - v_{cin}^3)} \tag{8.2}$$

3.2 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 [10-11]. 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 [10]

$$LF = \sum_{t=1}^{24} \frac{per.unit. \quad Demand(t)}{24} \tag{9}$$

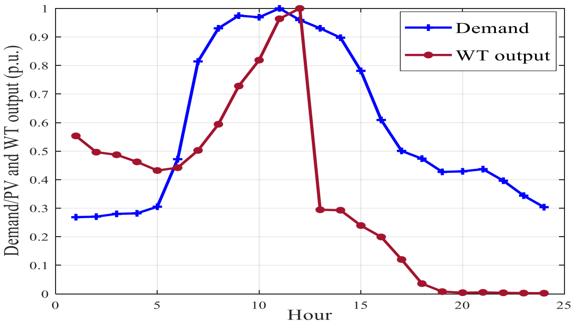

Fig 1. Normalized daily active load curve and WT output

The voltage-dependent load demand model, which includes variable load over time, can be calculated as [10-11]:

$$\begin{aligned} P_k(t) &= P_{ok}(t) * V_k^{n_p} \\ Q_k(t) &= Q_{ok}(t) * V_k^{n_q} \end{aligned} \tag{10}$$

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 [10-11], where $n_p = 1.51$ and $n_q = 3.4$.

4. SALP SWARM ALGORITHM (SSA)

4.1 Source of inspiration.

Salps are barrel-shaped, planktonic tunicate. They move by contracting, thus pumping water through its gelatinous body. Salps jet propulsion are one of the most efficient in the animal kingdom. However, the salp strains the pumped water through its internal feeding filters, feeding on phytoplankton. This swarming behavior is considered the main inspiration of this optimizer which some researchers believe that this behavior is done for achieving better movement using rapid assortment changes and foraging [11].

4.2 Mathematical model of SSA

In the SSA, the possible solutions of optimization problem are represented by positions of multiple salps (salp chain), the proposed salps can be divided to leader that represents the salp located in the beginning of the chain and followers that represent the rest of salps in the swarm. The best solution (best salp) is considered as the food source to be pursue by the salp chain. After the first iteration the leader changes its position with respect to the food source, so the leader explores and exploits the space around the best solution also the follower salps move gradually towards the leader. Hence, it can prevent from being trapped in local optima stagnation and converge it to globally optimum results in proper time. The salps move and search food source in the oceans and aggregated together forming swarm (chain) as shown in Fig. 2. The flow chart of SSA is shown in Fig.3.

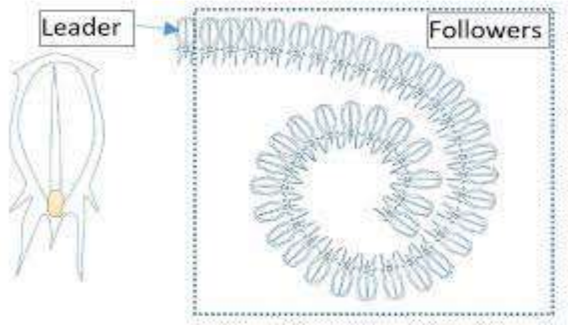

Fig. 2 Swarm of aggregation slaps

Fig. 3. Flow chart for SSA

5. SIMULATION AND RESULTS

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 69-bus DN with a total load of 3801.5 kW and 2694.6 kVAr as shown in Fig.4. The power flow is performed using S_{base} = 100MVA and V_{base} = 12.66 kV [12]. The power losses in the base case are 224.98 kW. The minimum voltage of this test system is 0.90919 pu.

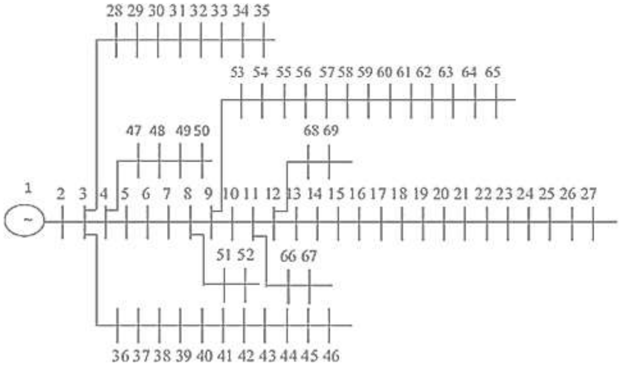

Fig.4. The standard 69-bus distribution system

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

Table 1: The observed results for 69-bus system

WT-location	WT- size/PF	Power loss	Voltage profile (minimum voltage at the bus)
61 18 11	2113/0.82 458/0.83 668/0.82	4.48	0.99427 @ bus 50

Table 2 Daily energy loss for 69-bus system

Scenario	Energy loss (kW h)	Loss reduction %
Base case	2044.796	-
With WT	727.47	66

6. CONCLUSION

The proposed approach is used to reduce power losses, energy loss and improve VP in the distribution system. To test the effectiveness of the proposed approach was tested on a test system with a standard 33 bus system. For the 69-bus system, the loss reduction is 98% and energy loss reduction is 66 %. In addition, the VP performance is improved over the base system.

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