OPTIMAL SITTING AND SIZING OF RENEWABLE ENERGY RESOURCES IN DISTRIBUTION NETWORK WITH BI-LEVEL OPTIMIZATION

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ABSTRACT

This paper proposes a Bi-Level optimization to determine the optimal size and location of wind turbine (WT) and photovoltaic (PV) generator in distribution network. At first level of optimization the optimal capacity in each bus is determined without consideration of kind of technology by maximizing the profit. At second level of optimization the number of WT and PV in each bus is determined by minimizing the cost. The minimum cost is used at first level of optimization to calculate the profit.

INTRODUCTION

In the last decade, the electric power industry has shown a renewed interest for distributed generation (DG). DG can provide benefits to the distribution utility such as loss reduction, emission reduction, reducing the cost of curtailed energy, increasing the reliability of power supply, voltage profile improvement, reducing the risk of overloading the distribution feeders, maximizing the DG penetration level enhancing the social sustainability, reducing the construction period and reducing the cost of energy purchased from power market and investments deferral[1]. Due to various environmental problems and increasing in fossil fuel cost as well, the significant amount of DG units in distribution systems are renewable energy based [2]. Also, as the potential benefits of DG largely depend on its location and size, many of the studies regarding DG address the problem of its optimal placement and size [3-4].

Due to stochastic nature of renewable distributed resources, sitting/sizing of these resources is difficult. Despite this, due to environmental impact of these resources, there is a trend to use of these resources in distribution networks. So, in this paper with regard to wind turbine (WT) and photovoltaic (PV) generators, a bi-level optimization is used to optimal sitting/sizing of these resources. At first level of optimization, particle swarm optimization (PSO) algorithm is used to find the optimal size and location of renewable resources by maximizing the profit is achieved due to loss reduction, deferral of investments, and reliability improvement. At another level of optimization, with knowing optimal size and location of renewable resources, mixed integer non-linear optimization is used to determine the optimal hybrid of PV and WT with consideration of maintenance, installation and operation costs.

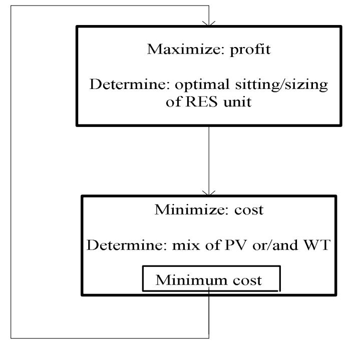

Figure 1: Bi-level programming .

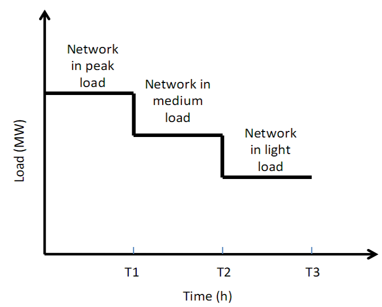

Figure 2: three stages load.

BILEVEL FORMULATION

The proposed bi-level optimization is shown in figure 1. It can be seen that at first level of optimization optimal size and location of RES is determined by maximizing profit. At another level of optimization the hybrid of WT and PV is determined by minimizing maintenance, installation and operation costs. The proposed method is presented in the following section.

Load modeling

Accurate optimization of objective function is resulted based on input data and correct analysis of this data. One important data is definition of load pattern. Distribution system load varies in different time of day, therefore in this paper, load condition is considered in three stages (light, medium and peak load) (figure 2). Passed time in these three stages is registered and maximum load consumption in each load point is considered as input data for RES allocation algorithm [4].

First level optimization:RES sitting/sizing

For optimal sitting/sizing of RES, economical benefits and RES cost are considered. It is supposed that distributions system companies are responsible for providing customer demand, RES operation and distribution system management. All of these responsibilities are based on cost reduction and improving quality and reliability of customer service[4]. Therefore costs and benefits of RES allocation in network can be expressed as follows.

RES benefit evaluation

1-Loss reduction

With presence of DG in distribution network, utilities can supply portion of their demand with considering DG and gets lower electric power from transmission grid. This can cause loss reduction. Loss reduction based on presence of DG can be formulated as following equation.

$$\Delta P_{loss}^{h} = P_{loss,h}^{no-DG} - P_{loss,h}^{DG}(P^{DG1}, P^{DG2}, ...P^{DGn}) \qquad (1)$$

Where, $P_{loss,h}^{no-DG}$ is network loss at load level-h when not considering DG in network (MW), $P_{loss,h}^{DG}$ is network loss at hour-h when considering DGs with capacity of ($P^{DG1}, P^{DG2}, \ldots P^{DGn}$)in network buses 1 to n ,and ΔP_{loss}^{h} is loss reduction due to DGs installation at load level-h.

Based on above mentioned notes, loss reduction benefit for each year that utility can achieve is evaluated by:

$$B_{lr} = \sum_{h=1}^{3} \lambda^{h} \times \Delta P_{loss}^{h} \times T_{h} \qquad (2)$$

Where λ^{h} is wholesale market price at load level-h, and T_{h} is passing time (h/year). Presence value of (2) is calculated as follow.

$$BPV(B_{lr}) = B_{lr} \sum_{t=1}^{T} (\frac{1+\inf R}{1+\operatorname{int} R})^{t} \qquad (3)$$

Where, $\inf R$ is the annual inflation rate, $\operatorname{int} R$ is the annual interest rate, and BPV is the function of cost into equivalent present value[5].

2-Reliability improvement

If RES is sited in distribution system, it is used as alternative source to restore power to part of the loads that are failed based on faults on transmission grid and distribution system and system reliability is improved. Energy not supplied index (ENS) is used to evaluate the reliability improvement. Reliability enhancement benefit that Distribution Company can reach is expressed by equation (4).

$$B_{re} = \lambda^{'} \times (ENS^{no-DG} - ENS^{DG}) \qquad (4)$$

$$ENS = \left[\sum_{b=1}^{N_b} \gamma_b \times L_b \times (\sum_{res=1}^{Nres} p_{res} t_{res} + \sum_{rep=1}^{Nrep} p_{rep} t_{rep}) \right] \qquad (5)$$

Where, ENS^{no-DG} is energy not supplied without DG, ENS^{DG} energy not supplied with presence of DGs with capacities [$P_{DG,1}, P_{DG,2}, ..., P_{DG,n}$] in buses 1 to n , $\lambda^{'}$ is price of energy not supplied (\$/MWh), N_b is the number of branches in network, γ_b is branches failure rate(f/km.year), L_b is branch length (km), N_{rep} is number of nodes isolated during fault location, P_{res} is load s which are restored during fault, P_{rep} is loads are not restored during fault, t_{res} is duration of the fault location and switching time, and t_{rep} is duration of the fault repair [4]. Presence worth value of (4) is calculated as follow.

$$BPV(B_{re}) = B_{re} \sum_{t=1}^{T} (\frac{1+\inf R}{1+\operatorname{int} R})^{t} \qquad (6)$$

3-investment deferral

Network current peak load ($SD_{\max}$) reaches to its maximum loading ($SS_{\max}$) after N years due to annual load growth. So, the network should be developed to supply load after that year. With installation of DG in network, and assuming the same load growth, network peak demand will be reduced and reached to its' maximum loading after M years. So, the investment of the network will be deferred for $\Delta T = M - N$ years. In the state of presence of no DG in network,

$$SD_{\max}(1+\alpha)^{M} = SS_{\max} \qquad (7)$$

After installation of DG,

$$SD_{\max}(1-\gamma)(1+\alpha)^{M} = SS_{\max} \qquad (8)$$

$$\gamma = \frac{\sum_{i=1}^{n} P^{DG,i}}{SD_{\max}} \qquad (9)$$

Where, α is annually load growth and $P^{DG,i}$ is DG capacity at bus-i. With regard to equation (7) and (8), equation (10) is achieved as follows.

$$\Delta T = N - M = \frac{\log(\frac{1}{1-\gamma})}{\log(1+\alpha)} \qquad (10)$$

The economical benefit of investment deferral is obtained according following equation.

$$B_{id} = C_{invT} \left(1 - \left(\frac{1+\inf R}{1+\operatorname{int} R} \right)^{\Delta T} \right) \qquad (11)$$

$$BPV(B_{id}) = B_{id} \left(\frac{1+\inf r}{1+\operatorname{int} r} \right)^{M} \qquad (12)$$

Where C_{invT} is the cost of investment,

RES cost evaluation

The cost of RES unit (C_T) is determined in second level of optimization and used in this level of optimization to determine optimal sitting/sizing of RES units.

Objective function

Benefit and cost terms which have been described in previous sections are considered in an objective function as formulated as follows.

$$\begin{aligned}\max Z &= profit = benefit - \cos t \\ &= BPV(B_{lr}) + BPV(B_{re}) + BPV(B_{id}) - C_T\end{aligned} \tag{13}$$

Therefore, RES allocation problem can be solved by using particle swarm optimization (PSO) which is appropriate optimization technique for the proposed function. Given function have been optimized considering constrains include voltage limits, capacity of feeder limit, and penetration rate limit in accordance with [4].

Second level optimization: determination of technology (WT and/orPV)

In this level of optimization, by determined optimal RES capacity in each bus, the optimal hybrid of WT and/or PV is determined with consideration their cost, sun radiation and wind velocity.

The output power of the PV generator P_{pv} is given by the following equation [6].

$$P_{pv} = \eta_g . A_g . G_\beta = \eta_g . P_r \tag{14}$$

Where, η_g is the PV generator efficiency, A_g is the total area of the PV generator (m^2), G_β represents the solar radiation on tilted module plan (W/m^2) and P_r is rate power. It should be noted that the efficiency of the PV will increase in higher irradiation and lower temperature.

The wind power output is modeled as follow [7]

$$P_{wt} = \begin{cases} P_r \dfrac{V^2 - V_{cin}^2}{V_{rat}^2 - V_{cin}^2} & V_{cin} < V < V_{rat} \\ P_r & V_{rat} < V < V_{cou} \\ 0 & V \le V_{cin} \ and \ V \ge V_{cou} \end{cases} \tag{15}$$

Where, P_r is the rate power, V_{cin} is the cut-in wind speed, V_{rat} is the rated wind speed and V_{cou} is the cut-off wind speed.

Cost component

The unit cost, installation cost, and even maintenance cost of renewable energy unit should be considered in the planning stage. The objective function is achieved by summation of above mentioned terms as follows:

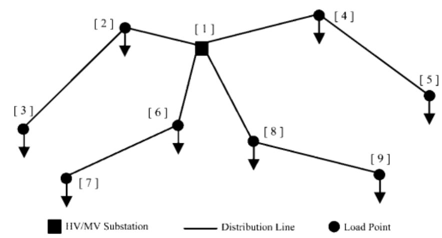

Figure 3: distribution network under study

$$\begin{aligned}&\min C_T = \\ &\sum_{i=1}^{n} N^i_{pv} . \alpha^i_{pv} (CPV(C^i_{pv}) + C^{in,i}_{pv} + CPV(C^{main,i}_{pv})) \\ &\quad + N^i_w . \alpha^i_w .(CPV(C^i_w) + C^{in,i}_w + CPV(C^{main,i}_w))\end{aligned} \tag{16}$$

$$\alpha^i_w = \frac{P^{w,i}_r}{P^{w,i}_{av}} \quad \&\& \quad \alpha^i_{pv} = \frac{P^{pv,i}_r}{P^{pv,i}_{av}} \tag{17}$$

$$\sum_{i=1}^{n} N^i_w . P^{w,i}_r + N^i_{pv} . P^{pv,i}_r = \sum_{i=1}^{n} P^{DG,i} \tag{18}$$

Where N^i_w and N^i_{pv} represent the number of WT and PV at bus- i with rate power $P^{w,i}_r$ and $P^{pv,i}_r$ respectively. C^i_w and C^i_{pv} denotes the cost per unit ($/kW) for WT and PV technologies respectively. $C^{in}_{w,i}$ and $C^{in}_{w,i}$ are the installation costs for WT and PV respectively. $C^{main}_{w,i}$ and $C^{main}_{PV,i}$ are the maintenance costs for WT and PV. And finally $P^w_{av,i}$ and $P^{pv}_{av,i}$ are average power of WT and PV which are determined according equation (14) and (15) with consideration of historical data of wind velocity and sun radiation. $P^{DG,i}$ is determined in first level of optimization. It should be noted that all costs are related to rated power. Non-linear mixed integer optimization is used to solve this problem. In this level of optimization N^i_w , N^i_{pv} , $P^{w,i}_r$, and $P^{pv,i}_r$ are determined.

CASE STUDY

The proposed methodology for RES placement has been implemented in the MATLAB environment and tested on the modified primary distribution network [3]. Technical information of the test network and loads has been shown in table 1. Minimum and maximum loads of the network are 48.15 and 68.2 MW, respectively. Therefore load demands of the network in this study changes from 70.6% to 100% of the peak load. Required information for reliability evaluation has been mentioned in table 2. All PV and WT data are in accordance with [8]. Interest rate

Table 1: network and load data

section from	section to	R (Ω)	X (Ω)	Max load in level 1 (MW)	Max load in level 2 (MW)	Max load in level 3 (MW)
1	3	1.4	1.5	5	6	8
3	7	2.78	5.5	7.5	8.8	9.2
1	2	2	4	8.3	11.2	9
2	6	2.8	5.5	4	5	7
1	5	1.7	1.7	7.5	8.8	9.2
5	9	2.1	4	7.3	10.2	8
1	4	2.26	4.5	6	7	9
4	8	2.4	5	7.5	8.7	9.2

Table 2 : Required information for reliability evaluation.

Load type	Price of not supplied energy ($/kWh)
Light load	2
Medium load	2.8
Peak load	3.6

Table 3:optimal number of WT and PV at each bus.

Bus	Peak load		Medium load		Light load	
	N_w	N_{pv}	N_w	N_{pv}	N_w	N_w
1	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	4	5	5	5	4	5
6	8	8	8	8	8	8
7	-	-	4	5	4	4
8	12	11	8	8	7	8

and inflation rate are considered 9% and 20% respectively. The rated power of WT and PV is considered 200-kW 40-kW respectively.

Table 3 illustrates the optimal hybrid of WT and PV for each load condition. As can be seen, the number of WT and PV generator are equal in almost all buses. But according to rated power of each technology, the optimal capacity of WT is more than PV optimal capacity at each bus. It is because that cost of WT turbine technology is greater than costs of PV technology.

Table 4 shows economical cost and benefit of allocation of hybrid WT and PV in the network. Benefit of loss reduction, reliability improvement, and investment deferral is illustrated in this table for each load condition. As can be seen benefit of reliability at peak load is greater than at other load condition, because at peak load DGs have a greater effect on ENS reduction. Loss reduction benefit at medium load is higher than at other load condition which means that DGs effect on loss reduction at medium load condition is higher than the other load conditions. Also, since the benefit resulting from investment deferral just depends on the amount of DGs capacity, this benefit is higher at medium load condition, because the optimal capacity at this load condition is greater.

Table 4: Economical costs and benefit for allocation of hybrid WT and PV in the network.

Network condition	Peak load	Medium load	Light load
Benefit of reliability improvement ($)	246,211	198,362	146,144
Benefit of loss reduction($)	1,346,746	2,341,425	424,836
Benefit of investment deferral($)	198,432	112,325	85,346
Total costs($)	12,710,210	14,441,236	8,214,012

CONCLUTION

In this paper a Bi-Level optimization has been proposed to determine the optimal size and location of wind turbine WT and PV generator in distribution network. At first level of optimization the optimal capacity at each bus is determined by maximizing benefits, while at second level of optimization hybrid of WT and PV is determined by minimizing costs. From studied results it has been derived that due to considered wind velocity, sun radiation, and cost of each technology optimal capacity of WT is greater than PV at all optimal buses.

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