
Optimization Modelling for Renewable Energy Resources based Distribution Generation

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Abstract

Moving towards sustainable development, the inclination towards the use of renewable sources of energy has tremendously increased. The energy losses in transmission and distributed system can significantly be reduced by adopting the appropriate size of DG technology (renewable sources of energy) as they can benefit environment and be economical. For instance, we may need to combine the different renewable sources for satisfying the demand of the region. Here specifically focus is laid on solar energy system with different ranges of energy production. This paper presents the mathematical formulation of a multi objective optimization problem which helps in determination of optimal size of solar panels to be used which can satisfy the current demand. The problem is focused on catering two diverse objectives of attaining highest level of energy saving at the same making use of least investment. For illustration purpose, a numerical example based on different ranges of solar panels has been examined.

Keywords: Renewable Sources, Solar Energy System, DG Technology, Energy Saving, Aggregative Weighted Method, Multi-Objective Optimization Problem.

1. Introduction

Electric power is the key source for today world and is required for all activities of modern society. It should be available in right quantity and quality as life in today's society cannot be imagined without proper electricity. The quantity of the electric power delivered to consumers depends upon the transmission and distribution medium. The deviation in the transmitted and distributed electric power from the standard is due to different types of power losses in the surroundings. Adequate measures need to be taken to reduce power losses to its minimum value which should be less than 10%. In developing countries the power losses are around 20% while in developed countries it is less than 10%. In India,

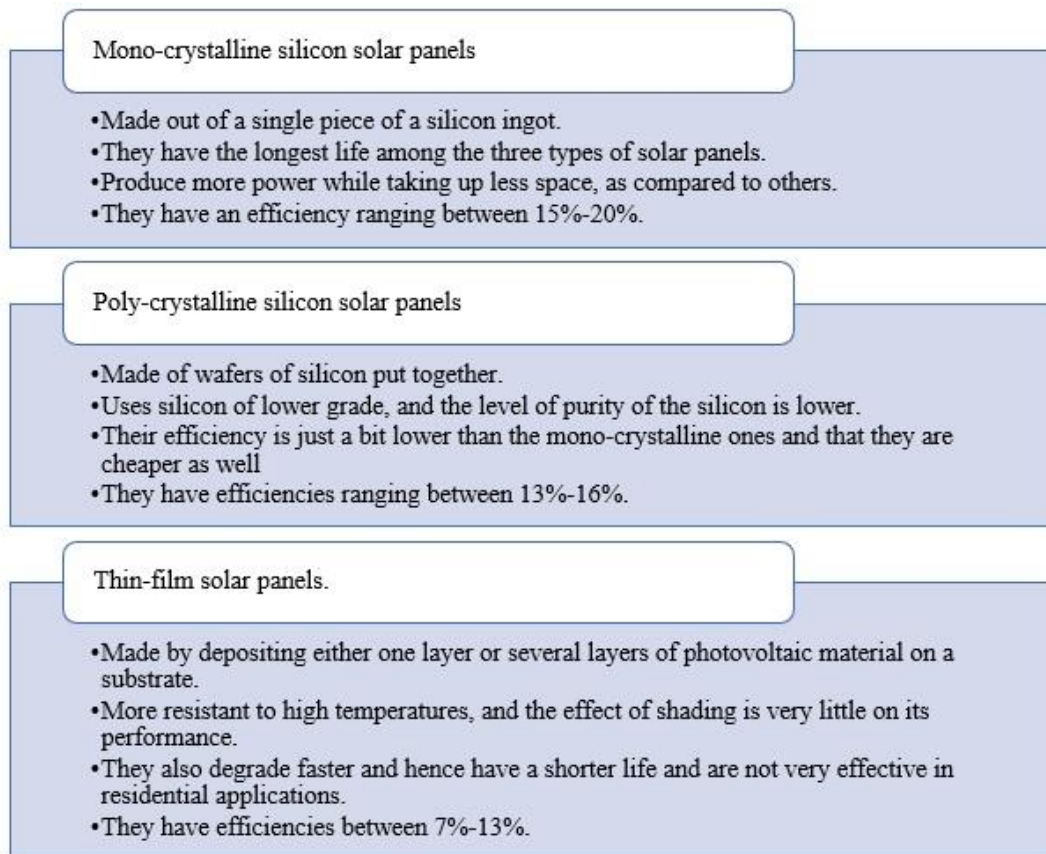
the T&D loss percentage of the power distribution utilities is very high and reported 20.9% during 2018-19. Therefore, Electric power generation companies are more concerned with improving the system performance using renewable distribution technologies and providing acceptable power quality by improving voltage support and increasing reliability of the electricity grid.

1.1 Renewable Distributed Generation Technologies

Distributed generation is an approach with range between 1 KW to 50 MW for decentralized electric power generations units which is allied to the distribution networks near the demand consumption rather than high voltage transmission network. Distributed generation can be done by implementing renewable resources like solar, wind, bio mass etc and from non-renewable like gas turbines, micro turbines, internal combustion engines, diesel engine etc Distributed generation has received attention and increasingly used due to environmental problem solutions and advances in electric power generation technology. Renewable resources based distributed generation is developing swiftly being small size, low cost and environmental benefits. The attention is averted towards using renewable DG units for distribution systems due to rising environmental worries and fuel uncertainties related to use of conventional energy sources. The distribution generation units can consist of wind generators, solar panel, biomass and many more. Due to certain limitations attached with their uses, specifically, the researchers have focused on the use of solar based energy generators which are also referred as solar panels or solar energy system. The core of solar energy system's lies in photovoltaic panels or modules which consists of number of solar cells, they are responsible for absorbing sunlight and converting it to generate electricity. At present there exists three generations of solar panel differentiable on the basis of technology being used. As with the passage of time, newer and newer techniques are available; the same can be experienced in the field of solar panels.

The earliest generation panels were made of silicon which made them quite efficient for domestic use but with the higher temperature such panels lose their efficiency. Later, technology evolved to thin film based solar panels as they consist of few micrometers thick semiconducting material. As the amount of material utilized in their development is significantly reduced in contrast to first generation solar panels, they tend to be cheaper. In present generation, apart from using silicon it is based on variety of constituents viz. nanotubes, solar inks, silicon wires, organic dyes, and conductive plastics. Current technology is still undergoing research and are expected to increase the efficiency substantially. Figure (1) shows the three categories of solar panels.

Figure 1 - Types of Solar Panels



This paper is organised as follows: section 1 gives introduction about the DG technology, section 2 describes the literature review. Section 3 discuss about Optimization model and related modeling framework. The aggregative weighted method as solution of multi-objective problem has been discussed in section 4. Optimal combination of number of solar panels that should be used has been elaborated and supplemented in section 5. Further the sensitivity analysis regarding demand and energy produced is elucidated. Finally conclusion in section 6 is discussed.

2. Literature Review

Numerous researchers analysed distribution generation problems in different aspects and for various geographical locations. Some of the work done in this arena is has been examined and discussed as follows:

Griffin et al. (2000) described an algorithm to find optimal location of disseminated fuel cell generation system so as to decrease losses and optimize capacity savings. Nara et al. (2001) discussed on reduction of distribution losses by proper placement of distributed generators. Tabu search algorithm

was designed to find optimal position for installing distributed generators on the demand side of power systems. Renewable distributed generation has become more important than traditional centralized generation power plant at international level because of increased demand of power, environmental concerns, energy security and economic challenge (Rahman (2003); Andrews & Weiner, (2004)).

Greatbanks et al. (2003), in his study used sensitivity analysis of power flow equations for network security and reliability to found the optimal location of distributed generators. Renewable resources being replenishable and widely available are prevalent for distributed generation as compared to non-renewable resources. Gandomkar et al. (2005), in their study discussed the use of Hereford Ranch Algorithm to determine optimal placement of renewable energy based DG units in existing distribution network so as to reduce losses and improve the performance index. Wang & Nehrir (2004) presented analytical approach to find best position for placing DG units and quantified benefit in terms of reduced losses. Genetic algorithm can be used to determine ideal position for distributed generator (Mithulananthan et al. (2004)).

Solar energy based distributed generators can assist in generating power and meeting the growing need in India (Phuangpornpitak et al. (2010)). Ghosh et al. (2010) discussed Newton Raphson method along with conventional iterative procedure for getting optimal position and size of renewable resources distributed generators so as to minimize losses, improve voltage and meet growing demand of electricity.

Many more researchers like Rau & Wan (1994), Keane & O'Malley (2005), Gautam & Mithulananthan (2007), Singh & Goswami (2010) have discussed optimal allocation of appropriate sizing distributed generation units with the objective of minimizing losses and cost and maximizing energy saving. Ahn et al. (2015) used cost-risk and least-cost optimization models for allocation of conventional along with renewable energy sources considering physical and policy constraints in accordance with Korean power generation circumstances. Ogunjuyigbe et al. (2016) described Genetic Algorithm (GA) to find optimal size and position of hybrid energy system for a distinctive residential building for achieving objective of reducing CO₂ emissions, Life Cycle Cost and dump energy.

The above literature clearly suggests the use of DG units for reducing the loses and for determination of their appropriate size. With this aim, the work presented in this article is focused on formulation of a multi-objective optimization model which can help in achieving the same. The focus has been laid on different ranges of solar panels, a variable for the generation of electricity by converting the solar energy.

We wish to determine the optimal combination of different ranges of solar panels that should be installed for satisfying the demand of electricity based on two contrasting perspective of maximizing the energy saving and at the same time minimizing the investments.

3. Optimization Model

Overall energy losses are currently very high and the overall objective is to reduce these power losses. The model formulated here is based on determining the combination of solar panel (varying w.r.t their ranges) that should be installed so the energy saving is maximum and at the same time we are able to minimize the total cost of installation. These objectives are to be attained based on the fact the total production of electrical energy should be able to meet the demand.

Notations:

η_{si} - Energy saving corresponding to size of different solar panels ($i = 1, 2, \dots, n$)

c_i - cost of installation of i^{th} type of solar panel

ω_i - No. of units of i^{th} type solar panel

ϵ_i - Energy produced by i^{th} solar panel per year

δ - Total energy demand per year

As η_{si} is the energy saving corresponding to i th type of solar panel and ω_i denotes the number of solar panel for i th type. Thus, energy saving for i th type of solar panel is $\eta_{si}\omega_i$. And overall energy saving is

$$\eta_s = \sum_{i=1}^n \eta_{si}\omega_i$$

The cost of installation corresponding to i th type of solar panel is c_i and ω_i denotes the number of solar panel for i th type. Thus, cost for i th type of solar panel is $c_i\omega_i$. The total cost is

$$C = \sum_{i=1}^n c_i\omega_i$$

The total production according to solar panel capacity of i th type be ϵ_i and ω_i is the number of units, then $\epsilon_i\omega_i$ is the total production of i th type of solar panel and overall energy produced is given by

$$\sum_{i=1}^n \epsilon_i\omega_i$$

The mathematical formulation of the problem as explained above becomes:

The bi-criterion problem for finding a tradeoff solution can be expressed as follows:

$$\left. \begin{array}{l} \max \eta_s = \sum_{i=1}^n \eta_{si} \omega_i \\ \max R = p \sum_{i=1}^n \epsilon_i \omega_i \\ \text{subject to } \sum_{i=1}^n \epsilon_i \omega_i \geq \delta \\ \sum_{i=1}^n c_i \omega_i \leq C_B \\ \omega_i \geq 0 \forall i \\ \text{and } \omega_i \text{ are integers} \end{array} \right\} (1)$$

The above problem can be solved for different combinations by using aggregative weighted method as discussed in next section.

4. Aggregative Weighted Method

In this paper a multi objective optimization problem has been formulated as it involves more than one objective function that are two be minimized or maximized or a combination. The aim is to adopt such a methodology which can work on providing a set of solutions that define the best tradeoff between competing objectives.

In order to determine tradeoff-based solution, we scalarize a set of objectives into a single objective by adding each objective pre multiplied with a suitably determined weight.

$$\left. \begin{array}{l} \min Z = \lambda_j C - (1 - \lambda_j) \eta_s \\ \text{subject to } \sum_{i=1}^n \epsilon_i \omega_i \geq \delta \\ \omega_i \geq 0 \forall i \\ \sum_{j=1}^m \lambda_j = 1 \\ \text{and } \omega_i \text{ are integers} \end{array} \right\} (2)$$

Being the simple and parsimonious approach it is being widely used even though the determination of weights is a cumbersome task.

5. Illustrative Example

To demonstrate the proposed problem solar panel (renewable energy source) with different capacities has been considered. For the ease of simplicity, we have considered the case of three different ranges of solar panels being categorized as: small, medium and high. The data given in Table (1) has

been taken from Das et al. (2017) and Zaatri & Allab (2012). The annual demand of energy production has been considered 3000 KW.

Table 1 - Data of solar panel with three different range

Solar Panel	Energy Savings (KW)	Cost of Installation (Rs)	Energy Production (KW)	Efficiency %
Small Range	1	87,000	25 (0.000025GW)	10
Medium Range	1.5	1,30,500	66 (0.000066GW)	14
Large Range	2	1,74,000	83 (0.000083GW)	17.5

The problem (1) can be formulated by using the data given in Table (1) as follows:

$$\begin{aligned}
 \max \eta_s = & \omega_1 + 1.5\omega_2 + 2\omega_3 \\
 \min C = & 87000\omega_1 + 130500\omega_2 + 174000\omega_3 \\
 \text{subject to} & 25\omega_1 + 66\omega_2 + 83\omega_3 \geq 3000 \text{ (0.003)} \\
 & \omega_i \geq 0 \forall i = 1,2,3 \\
 \text{and} & \omega_i \text{ are integers}
 \end{aligned} \quad (3)$$

To derive the compromise optimal solution of problem (2), an aggregative weighted method discussed in section 4 has been used. As a decision maker it is a tough task to identify the importance that should be associated with different objectives, therefore, here the equal weights are assigned to energy saving and cost of installation. Hence, the weighted mathematical model of problem (2) is as follows:

$$\begin{aligned}
 \min = & 0.5\eta_s + 0.5C \\
 \text{subject to} & 25\omega_1 + 66\omega_2 + 83\omega_3 \geq 3000 \\
 & \omega_i \geq 0 \forall i = 1,2,3 \\
 \text{and} & \omega_i \text{ are integers}
 \end{aligned} \quad (4)$$

The solution of problem (3) was obtained by an optimization software LINGO-13 as:

$$\omega_1 = 0, \omega_2 = 43, \omega_3 = 2 \text{ with } \eta_s = 68.5 \text{ KW and } C = \text{Rs. } 59,59,500$$

5.1 Sensitivity Analysis with Respect to Demand

In this section solution of the problem is checked for sensitivity with respect to small change in the annual demand of energy (δ). Table (2) presents the sensitivity of the solution with respect to δ .

Table 2 - Sensitivity Analysis w.r.t. δ

δ	ω_1	ω_2	ω_3	η_s	C
1000	0	14	1	23	2001000
1500	0	23	0	34.5	3001500
2000	1	30	0	46	4002000
2500	0	38	0	57	4959000
3000	0	43	2	68.5	5959500
3500	0	52	1	80	6960000
4000	0	61	0	91.5	7960500
4500	0	67	1	102.5	8917500
5000	0	76	0	114	9918000

From the Table (2) it can be seen that with the small change in demand, cost of installation will also change. Results of sensitivity analysis shows that annual demand of energy has linear relationship with the cost of installation as with the increase in demand the cost is also increases.

5.2 Sensitivity Analysis with Respect to Energy Produced

In this section solution of the problem is checked for sensitivity with respect to small change in the energy production by three solar panels (ϵ_i). Table (3) presents the sensitivity of the solution with respect to ϵ_i .

Table 3 - Sensitivity Analysis w.r.t. ϵ_i

ϵ_1	ϵ_2	ϵ_3	ω_1	ω_2	ω_3	η_s	C
20	60	78	0	50	0	75	6525000
22	63	80	0	48	0	72	6264000
25	66	83	0	43	2	68.5	5959500
30	70	87	0	43	0	64.5	5611500
35	75	92	0	40	0	60	5220000
40	80	98	1	37	0	56.5	4915500
45	85	105	1	35	0	53.5	4654500

Also, from the Table (3) it can be concluded that with the small change in energy production by three solar panels, cost of installation will also change. Results of sensitivity analysis proves that energy production also have the linear relationship with the cost of installation as with the increase in energy production the cost is also increases.

6. Conclusion

In the electrical energy saving environment, the companies wish to use those sources of energy which can reduce energy losses but these may not be economical. At the same time looking just for economical perspective does not suffice the aim of reducing losses or conserving electrical energy. We have formulated a multi objective optimization problem for determination of optimal size of solar energy system based on varying range of electricity production. The optimal problem has been modeled as integer programming based so that solution is purely integer. To illustrate the approach, a set of assumed parameters are considered. After solving the problem, the total energy conserved will be 68.5KW and the expenditure on solar energy system will be Rs. 59,59,500. For gaining the deeper insight to problem, sensitivity analysis on demand and the energy produced has been done. The above problem is indeed beneficial to decision makers due to its flexibility and straightforward manner in determination of sizing combination of solar panels.

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