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Economic Viability Solar PV Power Plant in Distribution System

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Abstract. Silicon is definitely, the most common substance used for manufacturing solar cells. Distributed Generation (DG) based on Solar Photo Voltaic (PV) cells enhance the voltage stability and economical profit as well as reduce the carbon emission. This manuscript optimized the location and size of PV base DG for the 13-Bus distribution network, using the nature base Particle Swarm Optimization (PSO) algorithm. This manuscript also gives an overview of the process of manufacturing of PV cell. The core intention of this manuscript is to demonstrate the economical benefits of optimal PV based generation unit. Results prove that the PV base power plant improves the technical performance as well as economical performance of the system.

1. Introduction

Now it is possible to generate solar energy competitively with the conventional source of electricity. Planners have recognized solar energy contribution to mitigating the difference between the energy demand and supply of power in India since long and overall target fixed is 17.5 GW by the year 2022 [1]. This requires mass production of commercially viable and cheaper solar panels. Silicon wafer is the most important and vital component in solar panel. The production cost of the solar cell is guided and influenced to a great extent by the cost of production of silicon wafers. Technology improvement in the process of getting raw silicon material, converting into wafers and technological advancement of tools and equipment, is the need of the hour to achieve the target. The refinement in processes of separation of pure silicon can improve and enhance mass production. Solar PV cells are categorized as organic photovoltaic and concentration photovoltaic[2]. Process of manufacturing both types of photovoltaic cells challenges the scientific community and investors to produce these in huge quantity. A photovoltaic cell is a tool which converts light into electricity. Photons of sunlight fall on the outer surface of the solar panel then electron are excited after gaining energy from a photon of sunlight. Once an excited electron breaks the valence bond and reaches the conduction band, then it is free to move[4]. Due to movements of electrons, current flow through the PV cells, i.e. DC electricity generated[4]. In this VP based Distributed Generation (DG) is sited at an optimal location to enhance the economics of utility. For optimization of place and size, the nature base algorithm is selected. To obtain the maximum benefit, an objective function is proposed with three objectives, namely minimization of cost, loss and voltage instability. The whole manuscript is prearranged in the six segments. Section 2 presents a summary of the materials and methods used for the fabrication of commercial solar cells. Section 3 shows the ability of inverters to control voltage. Section 4 develops a methodology to estimate the benefits of PV systems. Section 5 evaluates the proposed technique, and section 6 demonstrates the results of the proposed method.

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2. Methods and materials for the manufacturing of solar cells

Crystal Solar Approach simplifies the process of manufacturing silicon wafers for solar cells and eliminates the use of expensive technology and equipment. A Korean company has invented the first commercially viable solar panel by using new technology for producing silicon wafers[5]. Silicon wafer is the most expensive and important part of a solar cell (one third to half the cost of a solar panel). The technology help to make wafers that are less than one third the thickness of the conventional wafer[6]. The wastage of silica during the manufacturing process is reduced drastically as compared to that of conventional approaches, and requirement of equipment needed to make the wafers is also reduced. There are substantial saving wafer costs to almost half[7].

Given the high cost of manufacturing wafers, investors used to invest resources in thin-film solar panels, which are alternatives to silicon solar panels — the normal way to manufacture silicon wafers, which requires highly purified silicon (called poly-silicon)[8]. In the earlier conventional process, pure silicon was derived from a gas that contains silicon and other elements. Now a company has developed a process to create thin crystalline silicon wafers directly from that gas. In this process, the need to first make poly-silicon, then melt and sawing into wafers is not required. This version of a process is normally used in the chip industry. There is a further scope of improvement in this technology to bring down costs lower, which can be investigated to improve machine technology to produce in numbers with quality.

Solar cells are typically made of the semiconductor and named as per the material used to manufacture it. The semiconducting materials should have a suitable quality to absorb sunlight. Some cells are designed in such a way that these can handle sunlight reaching the Earth's surface, while some others are designed for use in space arena and other application[9]. Solar cells should be made of only one single layer or multiple layers (multi-junction) to take advantage of various absorption qualities and electrons separation technique.

Solar cells classified into first generation cells, second generation cells and third generation cells. These are described as under:

a) The first generation cells are also called conventional wafer cells. These are made of crystalline silicon. This crystalline silicon was the earliest commercially usable PV technology.

b) Second generation cells made of by thin film solar cells. Amorphous silicon, CdTe and CIGS cells also categorized as thin film solar cells.

c) Emerging photovoltaic is categorized as third generation solar cells. These are under process of development for commercial exploitation. Basic material for these experiments is organic materials, organo-metallic compounds and inorganic materials. There is a lot of research going on, and investment has been made to fine-tune processes and technologies as promises, these materials offer to achieve the task of producing low-cost and highly efficient solar cells.

Crystalline silicon is abundant material for solar cells. This material is also known as "solar grade silicon. Bulk quantity silicon separated into different categories as per crystalline and crystal size. Thes broadly called as ingot, ribbon and wafer. The function of this cell entirely based on p-n junction technique. The thickness of wafers used in Solar cells is between 160 and 240 micrometres

3. Formulation of economical benefits of a solar PV system

As per the latest bid on the provision of solar plant in Rajasthan, the purchased price of energy is INR 2.44 per unit. This bid is very cost effective. The purchased price of solar energy for grids will be higher than this price. This requires mass production of commercially viable and cheaper solar panels. Silicon wafer is the most important and vital component in solar panel. The production cost of the solar cell is guided and influenced to a great extent by the cost of production of silicon wafers. Technology improvement in the process of getting raw silicon material, converting into wafers and technological advancement of tools and equipment, is the need of the hour to achieve the target. The refinement in processes of separation of pure silicon can improve and enhance mass production.

3.1. Annual generation cost

Annual generation cost by solar PV units includes various cost such as the annual investment for installation, annual money required for operation and maintenance. The consideration of net worth is also essential to estimate in the current year.

Annual installation cost is a kind of fixed cost, which is the total cost of installation, divides by lifetime of PV panels. Annual fixed installation cost is given by equation (1)

$$AIFC = \frac{\sum_{j=1}^{n} Cpvj * ICj}{15} \qquad (1)$$

Annual operating cost is variable; its value depends on the salary and wages of employee engage in operation and control of a PV unit. It is given by equation (2)

$$AVOC = \sum_{j=1}^{n} (Cpvj * OCj) * \Delta T \qquad (2)$$

The annual cost of maintenance is also changeable; it comprises the daily expenses for renovation, cleaning etc. It expressed by equation (3)

$$AVMC = \sum_{j=1}^{n} (Cpvj * ICj) * MCj \qquad (3)$$

Current value depends on the interest rate of banks and the rate of inflation in the country's economy of the country. Present value index (π) is given by equation (4).

$$\textit{Present value index } (\pi) = \sum_{i=1}^{n} \frac{(1+IF)}{(1+IR)} \qquad (4)$$

The total annual cost of generation of power using an optimally placed PV based DG in an existing system is given by equation (5)

$$TAGC = (AIFC+AVOC) +AVMC)\ \pi \qquad (5)$$

3.2. Benefit due placement of PV power plant

Many benefits occur due to the optimization of placement and size of PV based distributed generation in a weak and overburdened power network Such as system loss reduction, reduction in carbon footprint and other green house gases. Congestion management, peak shaving, reliable supply are a few technical benefits of PV based DG the [10]. In this manuscript, only tangible benefits such as loss reduction and reduction of purchasing power considered.

Annual economic benefit due to the reduction in purchasing power is given by equation. Benefit due to a reduction in purchased power is the product of capacity of PV unit, rate of per unit energy and the duration of a generation of power.

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$$B1=\sum_{j=1}^{n} Cpvj * Pg * \Delta T \qquad (6)$$

Reduction in line loss is another benefit that occurs due to the optimal placement of the PV unit. This benefit is equal to unit saved because of loss reduction multiplied with the rate of energy per unit and given by equation (7)

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$$B2 = \sum_{j=1}^{n} \Delta Lj * Pg * \Delta T \qquad (7)$$

A net annual benefit is expressed by equation (8) with the inclusion of current value index.

$$NAB= \pi\ (B1+B2) \qquad (8)$$

Net annual economic profit due to the placement of the VP power plant in an existing system is given by equation (9)

$$Net\ economic\ profit = (NAB-TAGC) \qquad (9)$$

Where,

C_{pvj}	Capacity in MW of j^{th} PV unit
IC_j	Fixed Cost per MW
j	Number of PV unit in the distribution system
OC_j	Operating cost per MW of j^{th} DG
MC_j	Maintenance cost per MW of j^{th} DG
π	Current value index
IF	Rate of inflation
IR	Rate of interest
NAB	The net annual benefit accrued to utility
PP_g	The purchase price per KWH of electricity in the open market.
ΔT	Time Duration of power generation of DG
$B2$	Benefit due to loss reduction
$B1$	Benefit due to a reduction in purchasing power
ΔLR_j	Reduction in real power loss due to j^{th} DG.

4. Case study

In this section proposed a nature-inspired Particle Swarm Optimization (PSO) is applied in IEEE 13-Bus radial network. Data of this network is taken from[11]. Active power loss is 336.24 KW, and reactive power loss is 264.01 KVAr occurs with the integration of PV unit. The test distribution system considered is shown in figure 1. PSO was given by Kennedy and Eberhart in 1995[12]. To determine a suitable location, an objective function is proposed. Total annual generation cost *(TAGC),* power loss index (PLI) and voltage profile index (VPI). Proposed function is given by equation (10).

$$f = xTAGC + yPLI + zVPI \qquad (10)$$

Where,

x, y and z are the three weights

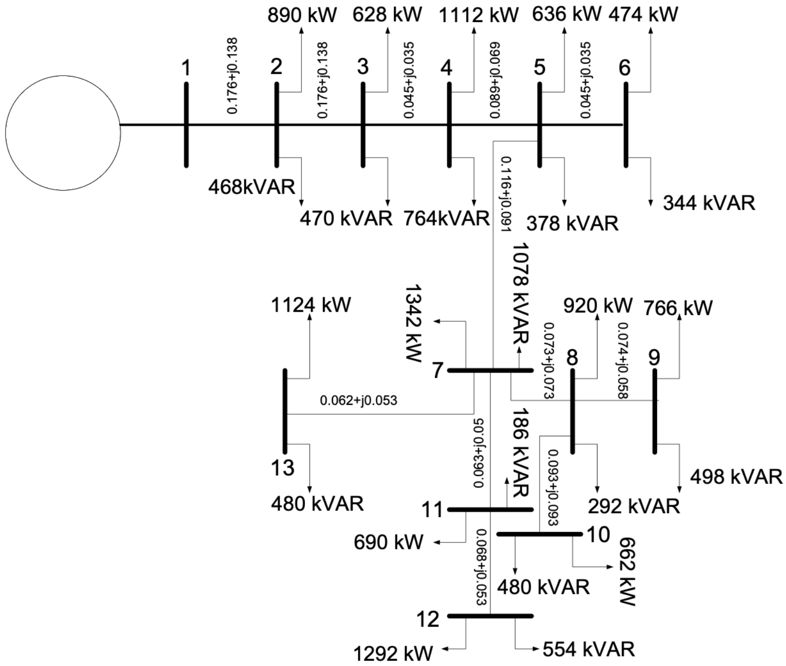

Figure 1. IEEE 13-Buses Distribution System

Calculation of net economical benefit:

Cost in Indian Rupees	
Investment cost / MW	$= 65\times10^6$
Operational Cost /yr	= 4% of Investment Cost/yrs
Maintenance Cost /yr	= 10,000 +4% of Investment cost/yr
Inflation Rate	= 4.97 % /yr (average of last 5 yrs figure)
Interest Rate	= 4.50 %
Present Worth Factor (π)	= (1+4.97)/(I+4.50)=1.085
Number of planning year	= 15
Purchase Price of Power from grid	= 3.50 / unit
DG Capacity	= 8.19 MW
Loss Reduction	= 0.756 MW
Investment Cost / yr	$= 35.49\times10^6$
Operational Cost / Yr	$=1.4196\times10^6$
Maintenance Cost / Yr	$= 1.4296\times10^6$
Total Cost/ yr	$=38.3392 \times10^6$
Benefits	
PWV (OC) / yr	$= 1.5402\times10^6$
PWV (MC) / yr	$= 1.5511\times10^6$
Benefit due to Less Demand /yr	$=251.1054 \times10^6$
Benefit due to Loss Reduction /yr	$= 23.1789\times10^6$
Total Benefit /yr	$= 277.3756 \times10^6$

5. Results and Discussion

The optimal size of PV based DG is 8.19 MW at the 7th bus. By the installation of the PV unit, the active loss and reactive loss are significantly reduced, as shown in figure 2 and figure 3, respectively. Active loss reduces to 44 KW from 336 KW, and reactive loss is reduced to 102 KVAr from 264.01 KVAr. PV based DG also improves the voltage profile of the system, as shown in figure 4. The optimally placed PV unit improves the technical and economic performance of the system.

Economical benefit is given in table 1, PV is a good alternative of the convention method of power generation.

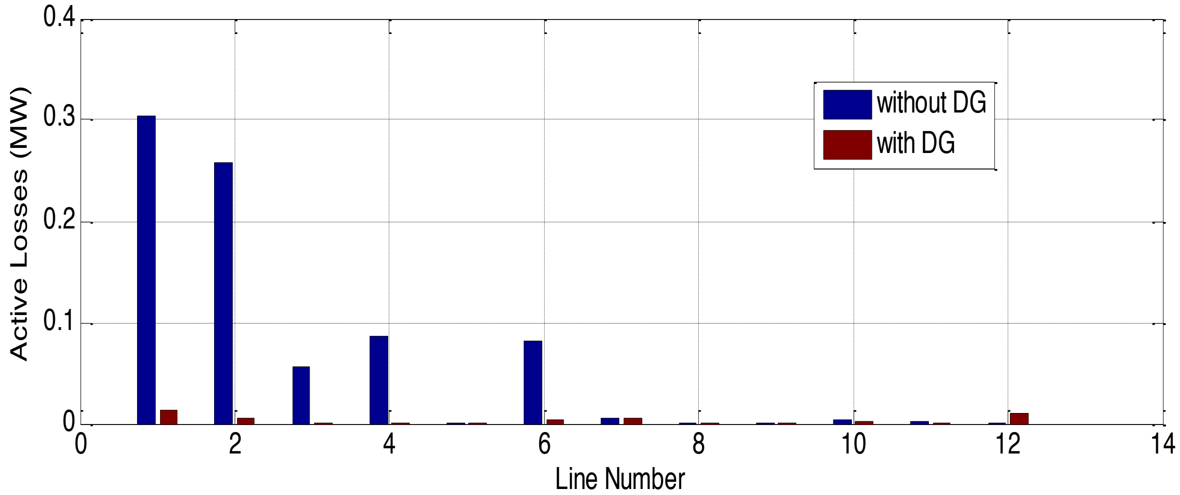

Figure 2. Active Line Losses Comparison in IEEE 13-bus System

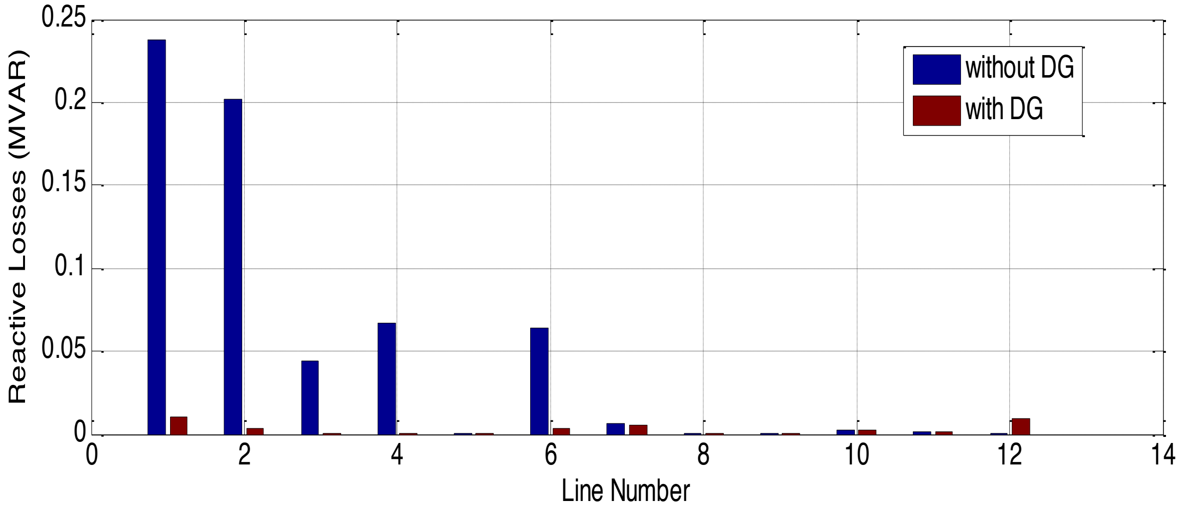

Figure 3. Reactive Line Losses Comparison in IEEE 13-bus System

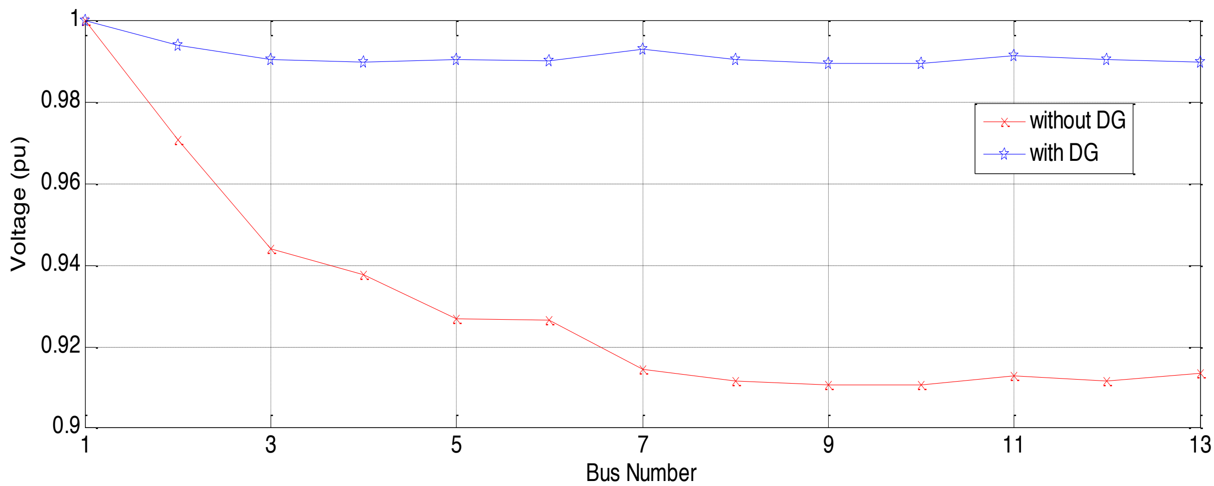

Figure 4. Voltage Profile Comparison in IEEE 13-bus System

Table 1.Performance PV based optimal DG

Technique	Objective Function	Size of DG (MW)	Location	Losses (MW)	Net economic benefit
PSO	Total losses and VPI	8.19	13	0.044	Rs. 277.3756 $\times 10^6$/yr

6. Conclusion

Demand for energy is increasing due to economical growth and technological development in the world. In the partial supply of power in the form of solar power, reduces environmental issues arising out of setting up conventional power plants. The latest research in the development of solar cell and improvement in manufacturing process promises the bright future of solar energy for humankind. The time is not far off when the majority component of supplied power will be solar energy and will be an inseparable part in Distributed Generation. As per the economic and technical analysis, as carried out above, it is found that research could be directed to enhance the efficiency of conversion of incident sunray into optimum solar power and in the manufacturing process to reduce capital cost in mass production. Society has to embark on the next great energy transition because of economic, environmental, and social limit which old system has imposed and is unsustainable and absolute. Authors opine that solar energy is sustainable energy which promises the cleaner and more secure energy for future generations.

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