Research Paper

Optimal Photovoltaic Cells Placement in Distribution System for Environmental Protection by CO$_2$ Emissions Reduction using Genetic Algorithm

Engineering

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ABSTRACT This paper proposes a genetic algorithm based approach to analyze the long-term benefits of Photovoltaic cells (PV) allocation at the demand side of a power distribution system. The benefits are evaluated based on the solar electricity generation and the avoidance of CO2 emissions. The objective function has been considered as total emission minimizing with considering economical parameters for optimal location of PVs for installation in distribution system.

1. Introduction-

Solar energy is expected to play an important role in the future global energy supply. The policy and challenges of solar power have been discussed in many countries for promoting the solar power technology industry. It is a universal problem that the investment of solar power technology requires support and incentives in most economies as long as prices for fossil fuels fail to reflect the negative externalities on the environment [1]. The characteristics of solar power include high capacity cost, and low CO$_2$ emissions as compared to fossil-fuel plants. If CO2 emissions could be charged in the future electricity market, the environmental benefits of solar power can be increased significantly [2].

Photovoltaic cells (PVs) are small plants that are properly located to provide an incremental capacity to power systems [3]. The integration of PVs into an existing distribution system, depending on the allocation of PVs, can result in several advantages, such as line loss reduction, peak shaving, emission reduction, and increased system voltage profile. Moreover, PVs can also relieve congestion and provide grid reinforcement. As a result, PVs have attracted more interests in the electricity industries.

This paper describes a benefit analysis when PVs are installed to meet load growth in a distribution system. A life time of 10 to 20 years is assumed for the solar-power installations. The benefits of PVs are evaluated by considering the power generation of PVs, electricity prices, and carbon trading prices. Distribution system planners must ensure the adequate capacity that meets the load growth within the planning horizon year. They are obligated to provide service reliability through planning, operation, construction, and maintenance with limited resources. In general, PVs are mostly installed in a demand system, and connected directly to distribution networks.

2. Photovoltaic array

PV technology is identified as most environment friendly technologies. It requires only sunlight and no other energy fuel.

A main feature of PV is low operation and maintenance cost. Therefore the PV energy cost is still higher than the utility energy price. Therefore, the PV applications have been limited to remote locations. However in this paper it is supposed that the PV is connected to power system and it is previously installed into system due to every reason such as reduction power loss, improvement voltage profile, improvement power quality or reliability indices. But in this paper only optimal operation of PV as grid connected based on optimum economical purpose are presented and considered.

Photovoltaic power output is depending on solar radiation.

The output power of photovoltaic array can be calculated using equation (1) [4]:

$$P_{PV} = A_{pv}x^2 + B_{pv}x + C_{pv} \qquad (1)$$

Where:

x = solar radiation (W/m^2) and P = power generation (W)

The power-radiation curve of PV, employed in this study, is based on the quadrate function shown in Figure 1.

3. Problem formulation

The benefit of PVs over its life time is calculated when the PVs are allocated based on the load growth. The benefit of PVs installed is determined by the net change in the total cost of electricity generation before and after the installation. The costs include investment cost and maintenance cost, and the benefits include the profit of electricity sold, CO$_2$ emissions sold, and loss reduction.

A better planning method is to locate the minimum cost solution where the total benefits can be maximized. Therefore, costs and benefits of PV allocation in the network can be expressed as follows, with the cash flows presented below in Figure 2.

3.1 Investment cost

The investment cost of PV units can b formulated as the following equation:

$$C_1 = \sum_{i=1}^{m} \text{Fix}_i \qquad (2)$$

Where, Fix is the investment cost of PVs installed ($NT\$ 5.2 \times 10^8 /unit$) [5].

3.2 Maintenance cost

The maintenance cost can be evaluated by:

$$C_2 = \sum_{i=1}^{m} \text{CM}_i \qquad (3)$$

CM is the maintenance cost of PVs (NT\$ $NT\$ 1.35 \times 10^7 /year$) [3-5].
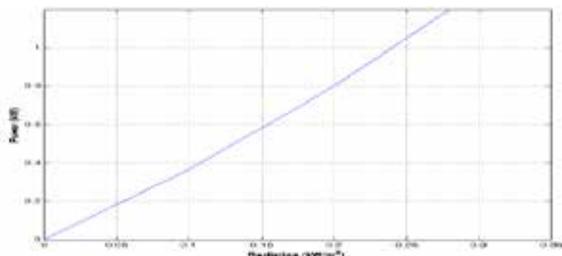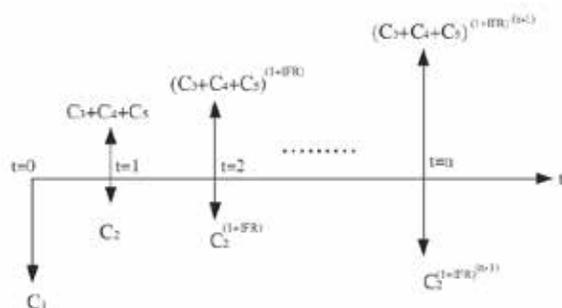
Figure 1 Power-radiation curve of PV

Figure 2 Cash flows of the PV project

Present value of this is:

$$PW(C_2) = C_2 \sum_{t=1}^{T} \frac{(1+IFR)^{t-1}}{(1+INR)^t} \qquad (4)$$

3.2 The Profit of CO_2 Sold
The main profit of PV installation is the profit of CO_2 sold which encourages engineering planers to employ the photovoltaic cells in distribution systems.

$$C_3 = 8760 \times CF \times \sum_{i=1}^{m} P_i \times \phi \times Cost_c \qquad (5)$$

Where, ϕ is the Carbon exhaust coefficient (0.612 kg CO_2 e/kWh) [4], Costc is the carbon trading price (NT\$/ton) and CF is the capacity factor of PVs.

Of course the other annual profit of PVs installed includes the profit of line loss reduction, C_4, the profit of power generation, C_5.The formulation is calculated as follows:

$$C_4 = 8760 \times CF \times P_{loss}^{r} \times Cost_e \qquad (6)$$

The profit of power generation:

$$C_5 = 8760 \times CF \times \sum_{i=1}^{m} P_i \times Cost_e \qquad (7)$$

Where, Coste the electricity price (NT\$), P_{loss}^{r} the loss reduction after PVs are installed (kW).

Present value of this annual profit is calculated by:

$$BPW(B) = (C_3 + C_4 + C_5) \sum_{t=1}^{T} \frac{(1+IFR)^{t-1}}{(1+INR)^t} \qquad (8)$$

The benefits of PVs can be calculated as:
$$benefit = BPW(B) - C_1 - PW(C_2) \qquad (9)$$

The benefits of PVs can be calculated as:
$$benefit = BPW(B) - C_1 - PW(C_2) \qquad (10)$$

4. Genetic Algorithm
Genetic Algorithm (GA) comprises three different phases of search. The first is the production operator which makes one or more copies of any individual that posses a high fitness value [6]. The second operator is the recombination or crossover operator. This operator selects two individuals within the generation and a crossover site and carries out a swapping operation of the string bits to the right hand side of the crossover site of both individuals. Crossover operations synthesize bits of knowledge gained from both parents exhibiting better than average performance. The third operator is the 'mutation', acts as a background operator and is used to explore some of the invested points in the search space by randomly flipping a 'bit' in a population of strings.

5. Simulation and Results
The proposed algorithm was applied to solve the 33-bus distribution system problem, as shown in Figure 3 [7].The total real and reactive power demand of the 33 bus system were 1470 kW and 1012 KVAR, respectively. The maximal power generation of PVs is set to 300kW.

**The GA parameter used in this paper was listed in Table 1.
Table 1 GA parameters**

Parameters	Value
Population size	80
Number of populations, generations	100
Probability of crossover	95%
Probability of mutation	5%
Solution precession	0.001

The power output for each PV ranged from 200kW to 300kW, while all network bus voltage magnitudes remained within 0.95-1.05/unit. The power factor for each PV was 0.82. The load growth rate was 3% in the distribution system, and the horizon years were set at 10, 20 and 30 years. Table 2 shows the summary of the simulation results.
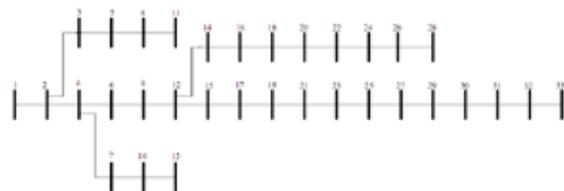

Figure 3 Single Line Diagram of the 33-Bus Radial Distribution System

Table 2 shows the summary of the simulation results.

Horizon year	10	20	30
Total real load demand (kW)	1470	1705	1980
Total reactive load demand (KVAR)	1012	1210	1400
The total power output of PVs(kW)	150.87	408.45	705.30
The average percentage of loss reduction (%)	13.70	25.46	30.80
The number of PVs installed	2	3	5
The location of PV(no. of bus)	5,11	7,11,19	7,15,19,23,28

Due to the load growth, the number of PVs installed was 2, 3 and 5 at 10, 20 and 30 horizon years in order to meet the load growth and operational constraints. The total power output of PVs was 150.87 kW, 408.45 kW and 705.30 kW at the different horizon years. Because the executed characteristics of GA might converge at different solutions for each test, the problem was solved 50 times by the proposed method. The best and worst system losses were found from the 50 trial tests.

The best percentage of loss reduction ranged from 13.8% to 31.15% at the various horizon years.

Figure 4 shows the convergent characteristics of the proposed method at the 10-thhorizon year. The convergent generation was about the 150-th generation.

The benefits sensitivity analysis of PVs contained two scenarios which varied with the electricity price, carbon price, and power generation after the PVs were installed. Table 3 shows the conditions of two scenarios in this study.

Table 3 The conditions of three scenarios in this study.

	Electricity price (NT\$/kWh)	Carbon price (NT\$/ton)
Case 1	1-10	800
Case 2	4	0-2000

In Case-1, the electricity price varied between 0-10 NT\$/kWh, if the carbon price is maintained at 800NT\$/ton. Similarly, Case-2 varied with the carbon price of PVs

Figure 5 shows the benefits of PVs installed in Case-1. In this study, the return time of PVs was 20 years. Based on different horizon years, the benefits of PVs installed were evaluated based on different electricity prices.

In Figure 5, when the electricity price was about 4 NT\$/kWh, the investment of PVs arrived at economical equilibrium. The benefits of the PV investment were directly proportional to the electricity price.

Figure 6 shows the benefits analysis of PVs installed in Case-2. The largest positive contribution to the PVs' benefit was from the reduction in CO_2 charges.

The investment in PVs arrived at economical equilibrium when the carbon prices were sold at 800 NT\$/ton in this case. When the carbon price was high, the benefits of the PV investment would increase.
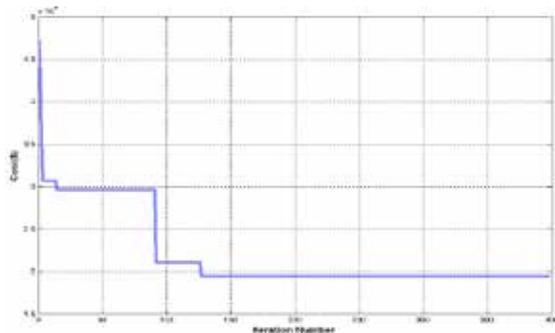

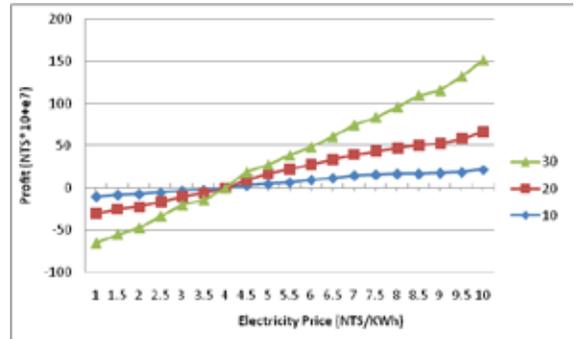**Figure 4 The convergent characteristics**

Figure 5 The benefits of PVs installed in Case-1 versus electricity price at the various horizon year
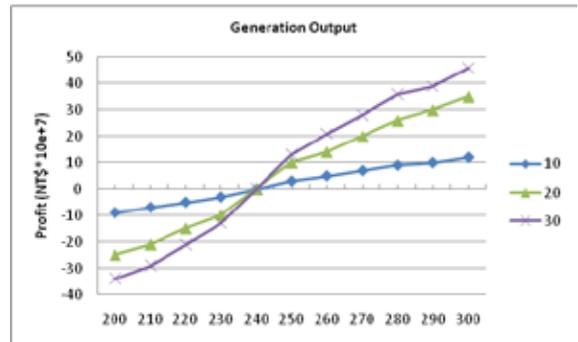

Figure 6 The benefits of PVs installed in Case-2 versus carbon price at the various horizon year

6. Conclusion

By considering electricity price and carbon price, the economical benefits of the installation of PVs were evaluated in two different scenarios. The effectiveness of the proposed algorithm was demonstrated and tested on the IEEE 33-bus distribution system. This study found that electricity price or carbon price is a key parameter in the development of PVs.

Simulation results also showed that optimal incorporating the PVs in the distribution system can reduce system losses, as well as improve the voltage profiles.

Since PVs reduces CO_2 emissions due to the use of solar generated electricity, the reduced emissions will turn into revenues in the carbon market. CO_2 emissions can be traded in the carbon market to gain further benefits.

From this study, it concluded that any variations including electricity price, carbon price, and generation output of PVs will affect the long-term benefits for PVs.

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