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Techno-Economic Analysis of Utilization Photovoltaic Cells in Distribution System with Considering Effects of Carbon Price Variation for Environmental Protection Purpose

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ABSTRACT

The characteristics of solar and wind power include high capacity cost, and low CO2 emissions as compared to fossil-fuel plants. If CO2 emissions could be charged in the future electricity market, the environmental benefits of solar and wind power can be increased significantly. It is a universal problem that the investments of solar power and wind power technologies as renewable energy resources (RES) require support and incentives in most economies as long as prices for fossil fuels fail to reflect the negative externalities on the environment. Photovoltaic cells (PVs) are small plants that are properly located to provide an incremental capacity to power systems. The integration of PVs into an existing distribution system, depending on the allocation of them can result in several advantages, such as line loss reduction, peak shaving, emission reduction, and increased system voltage profile.

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INTRODUCTION

The greenhouse gas (GHG) emission of electric power sectors around the world is about 1/3 of the total world GHG emission, indicating the significance of electric power sectors in the global warming issue. In recent years, climate change due to greenhouse gas (GHG) emissions has become a focus of international organizations and governments. In order to reduce GHG emissions, the aim has been placed on finding more environmentally friendly alternatives for electricity power generation. Renewable Energy (RE) is required for local energy markets, as an important alternative energy production option in the near future [1-3]. RE technologies may include solar energy, wind, fuel cells, micro-turbines, etc. Due to advances in solar energy technologies, solar power is currently considered one of the most rapidly increasing resources. There is no doubt that the benefit of PVs is beginning to attract many utilities in the electricity market [4].

1. *PV technology:*

PV technology is identified as most environment friendly technologies. It requires only sunlight and no other energy fuel. Being modular in design, the capacity can be increased to meet additional demand. It is easy to dismantle and configure these systems for other applications. PV systems require little maintenance [5]. In figure 1 the distribution system equipped with PV panels to support demand instead of fossil-fuel plants is presented.

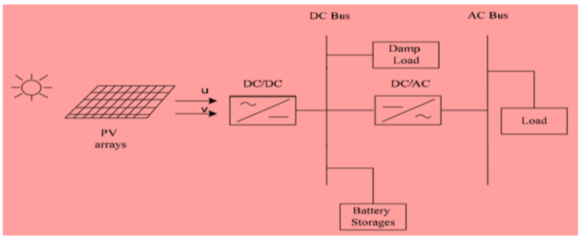

Fig.1: Distribution system equipped with PV panels.

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Output electric power from the photovoltaic generator is given by the following equation [6]

$$P_{pv} = \eta_{pv} A_{pv} I_r \tag{1}$$

Where η_{pv} is the power conversion efficiency of the module (power output from system divided by power input from sun); $A_{pv}(m^2)$ is the surface area of PV panels; $I_r(W/m^2)$ is the solar radiance. PV generator efficiency is given by [7].

$$\eta_{pv} = \eta_r \times \eta_{pc} \times [1 - \beta \times (Tc - NOCT)] \tag{2}$$

Where η_r is the reference module efficiency; it depends on cell material and η_{pc} is the power conditioning efficiency which is equal to 1 if a perfect maximum power tracker (MPPT) is used, β is the generator efficiency temperature coefficient, ranging from 0.004 to 0.006 per ◦C. **Tc** is the cell temperature **(◦C)**. For a PV module with polycrystalline silicon solar cells, it can be estimated from the ambient temperature **Ta** (◦**C**) and the solar irradiation $\mathbf{I_r}$ (W/m^2) as follows [8]:

$$Tc = 30 + 0.0175 \times (Ir - 300) + 1.14 \times (Ta - 25) \tag{3}$$

NOCT is the normal operating cell temperature (◦**C**) when cells operate under standard operating conditions: irradiance of 800 **W/m2,** 20 ◦**C** ambient temperature, average wind speed of 1 m/s, module in an electrically open circuit state, wind oriented parallel to array's plane, and all sides of the array fully exposed to wind. After consultation of several different polycrystalline silicon manufacturers (such as Evergreen ES-A210 or Trina Solar TSM-PA05), a typical value of **NOCT** equal to 45 ◦**C** and a typical value of **β** approximated to 0.0045 per ◦**C** has been considered.

For sizing optimization procedure, effective area of photovoltaic generator ($\mathbf{A_{pv}}$) is defined as decision variable if $\mathbf{A_{pv}}$ is measured in m^2, $\mathbf{P_{pv}}$ is numerically equal to peak power rating of the array. Hourly solar irradiation is shown in figure 2.

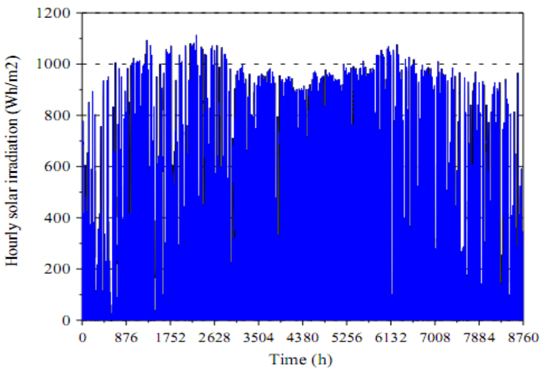

Fig. 2: Hourly values of meteorological parameters-solar irradiation on titled plane.

2. *Problem formulation:*

The benefit of RES over its life time is calculated when the PVs are allocated based on the load growth. The benefit of RES 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, CO2 emissions sold, and loss reduction. To better techno-economic analysis of renewable energy resources implementation in distribution system, the costs and benefits of RES allocation in the network can be expressed as follows [9], with the cash flows presented below in Figure 3.

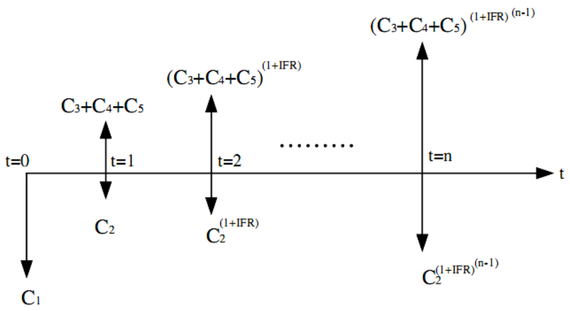

Fig. 3: Cash flows of the renewable energy resources project.

3.1. Investment cost:

The investment cost of RES units can be formulated as the following equation:

(4)

$$C_1 = \sum_{i=1}^{m} \mathrm{Fix}_i$$

Where, Fix is the investment cost of RES technologies includes PVs installed

3.2. Maintenance cost:

The maintenance cost can be evaluated by:

(5)

$$C_2 = \sum_{i=1}^{m} \mathrm{CM}_i$$

CM is the maintenance cost of RES ($NT\$\ 1.35 \times 10^7\ /year$) [10].

Present value of this annual cost considering inflation rate and interest rate in the life time is calculated by:

(6)

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

Where, T is the life time of RES (20 years), *IFR* the annual inflation rate, *INR* the annual interest rate.

***3.3.** The Profit of CO_2 Sold:*

The main profit of RES installation is the profit of CO2 sold which encourages engineering planers to employ the wind turbines in distribution systems.

The profit of CO2 sold,

(7)

$$C_3 = 8760 \times \mathrm{CF} \times \sum_{i=1}^{m} \mathrm{P}_i \times \phi \times \mathrm{Cost}_c$$

Where, m is the number of RES installed, Pi is the rated real power output of each RES technology (kW), ¢ is the Carbon exhaust coefficient (0.612 kg CO2 e/kWh) [11], Costc is the carbon trading price (NT$/ton) and CF is the capacity factor of RES.

Off course the other annual profit of RES installed includes the profit of line loss reduction, C4, the profit of power generation, C5.The formulation is calculated as follows:

The profit of line loss reduction:

(8)

$$C_4 = 8760 \times \mathrm{CF} \times \mathrm{P}_{\mathrm{loss}}^{\mathrm{r}} \times \mathrm{Cost}_e$$

The profit of power generation:

(9)

$$C_5 = 8760 \times \mathrm{CF} \times \sum_{i=1}^{m} \mathrm{P}_i \times \mathrm{Cost}_e$$

Where, $Cost_e$ the electricity price (NT$), $\mathrm{P}_{\mathrm{loss}}^{\mathrm{r}}$ the loss reduction after RES are installed (kW).

Present value of this annual profit is calculated by [12-13]:

(10)

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

The benefits of RES can be calculated as:

$$benefit = BPW(B) - C_1 - PW(C_2) \tag{11}$$

3. Technical analysis and discussion:

In this paper, to investigate the profits of utilization of renewable energy resources in electrical distribution system with aim of greenhouse gas emission, a 34-bus test system as shown in Fig.4 is considered. At first in first case, in order to investigate the effects of implantation of photovoltaic cells, 8 PVs at buses 4, 16, 9, 20, 12, 34, 23 and 27 according to decision of planner is employed. In this case the profit evaluation of photovoltaic employment in distribution system three parameters including (1) the variation of carbon price, and (2) the variation of generation output of PVs as presented further are analyzed. The line data of test system in listed in Table 1. At second case, the WTs are employed in proposed system and the discussion presented before are analyzed again.

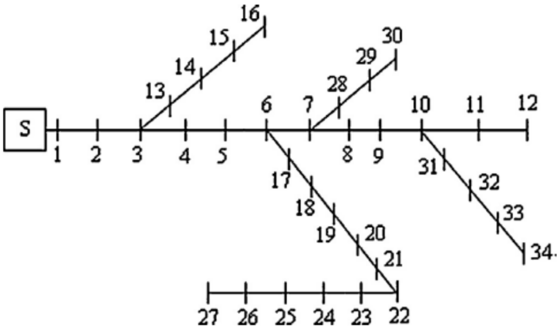

Fig. 4: The 34-bus test system.

Table 1: Line data in 34-bus test system.

From Bus	To Bus	R (p.u)	X (p.u)	From Bus	To Bus	R (p.u)	X (p.u)
1	2	0.03076	0.01567	18	19	0.09385	0.08457
2	3	0.02284	0.01163	19	20	0.02555	0.02985
3	4	0.02378	0.01211	20	21	0.04423	0.05848
4	5	0.05114	0.04411	21	22	0.02815	0.01924
5	6	0.01168	0.03861	22	23	0.05603	0.04424
6	7	0.04439	0.01467	23	24	0.05591	0.04374
7	8	0.06514	0.04617	24	25	0.01267	0.00645
8	9	0.01227	0.00406	25	26	0.01773	0.00903
9	10	0.02336	0.00772	26	27	0.06607	0.05826
10	11	0.09159	0.07206	7	28	0.05018	0.04371
11	12	0.03379	0.04448	28	29	0.03166	0.01613
3	13	0.03687	0.03282	29	30	0.06083	0.06008
13	14	0.04656	0.03410	10	31	0.01937	0.02258
14	15	0.08042	0.10738	31	32	0.02128	0.03319
15	16	0.04567	0.03581	32	33	0.00575	0.00293
6	17	0.01023	0.00976	33	34	0.02336	0.00772
17	18	0.08042	0.10738				

3.1 Profit evaluation based carbon price:

The power factor for each PV and WT 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.

In order to investigate the profit of renewable energy employment, the carbon price varied from 1000NT$/ton to 2000NT$/ton and the electricity price and power generation of WTs were maintained at 5 NT$/kWh and 140kW/unit, respectively.

The simulation results for PV and WT implantation in candidate buses, to find out the relation between the profit of system and carbon price variation are presented in Fig.5 and Fig.6 respectively.

1.1 Profit evaluation based power generation:

In third study, to investigate the profit of renewable energy employment, the electricity price and carbon price were maintained constant and the effect of power generation variation of system profit has been analyzed. The simulation result of this study when photovoltaic are located in system is presented in Fig.7.

The power output for each PV ranged from 2500kW to 300kW, while all network bus voltage magnitudes remained within 0.95-1.05/unit.

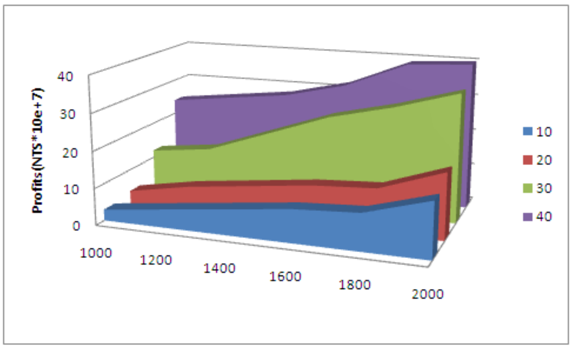

Fig. 5: System profits of PV utilization in terms of carbon price variation.

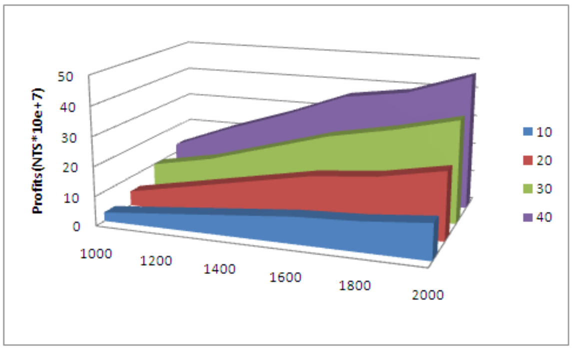

Fig. 6: System profits of WT utilization in terms of carbon price variation.

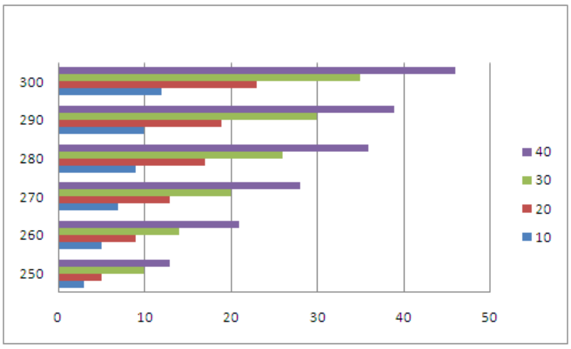

Fig.7: System profits of PV utilization in terms of generation output variation.

2. Conclusion:

This paper deals with environmental protection by avoiding CO_2 emission through renewable energy resources (RES) utilization in power generation sectors to reduce the green house gas emission of electric power sectors.

Renewable energy resources which have been employed in this research are solar and wind energies. The characteristics of solar and wind power include high capacity cost, and low CO_2 emissions as compared to fossil-fuel plants. If CO_2 emissions could be charged in the future electricity market, the environmental benefits of solar and wind power can be increased significantly.

In this research the profit evaluation of photovoltaic and wind turbine employment in distribution system under three parameters including, the variation of electricity price, the variation of carbon price, and the variation of generation output are analyzed.

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