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Environmental benefits of DGs and comparing their generation costs with thermal power plants considering production pollution on human health

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Abstract

The increase of DG presence in distribution network is the immediate result of technology development and power crisis in the world. Nowadays, renewable energy sources and high efficiency electrical systems (combined heat and power generation) are of great demand all over the world. However, exploitation systems and traditional managing of industry have led to a misunderstanding of DG benefits. In this paper, some indexes for evaluating environmental benefits of DG are considered. Then, a new mathematical method is introduced to have better calculations of the costs of power generation from renewable sources based on the environmental indexes. In this method there are negative points for each environmental pollutant and the additional costs of their distribution is also added to the generation costs of the systems producing these pollutants. This approach may help to tackle the environmental menace of these pollutants and subsequently on human health.

Keywords: Air pollution, Distributed Generation (DG), Distribution network, Environment, Generation costs.

Introduction

A reason for using DG is the need to increase the efficiency of electric power generation systems and decrease the pollutants they produce. This is due to the over production of pollutants by fossil fuel based power generation and many countries are now signatories to the Kyoto treaty to decrease the green house gases.

In 2000, the EU capacity of generating power from DG had been about 75GW which is expected to reach to 195 GW which is 22% of the whole capacity of power generation in Europe (ESD, 2001). Based on the EPRI researches in 1999, it was predicted to have about 25-30% of Americans generated power by DG (OSEC, 1999; Hatziargyriou *et al.,* 2000).

Usually, power plants generation costs include construction, installation and operation costs and no one encounters the costs of environmental effects. That’s the reason for the difference of costs between fossil fuel plants and DG sources. Two mathematical models for calculating the environmental costs of power generation have been reported (Sun, 2004; Ding *et al.,* 2007), but these models are too simple to reflected the environmental benefits of DG (Qian *et al.,* 2008).

In this paper, asset of indexes for evaluating the environmental benefits of DG is introduced and based on that a new method for calculating the power generation is presented. This method accommodates the destructive effects of pollutants by assigning negative points for each environmental pollutant and the side costs of their distribution is also added to the production costs.

Distributed Generation (DG)

DGs are electric power generating resources that are connected to the distribution substation. These sources have less generation capacity and construction costs in comparison with huge generators and power stations (Tamizkar *et al.,* 2009). Connecting these kinds of energy resources to the distribution networks has lot of benefits. What makes DGs noticeable are economical issues in developing power stations, environmental pollution reduction, high efficiency in generating electricity, high power quality for the users, less losses in distribution networks, improving voltage profile, substation capacity releasing and a lot more (Javadian *et al.,* 2008; N. Khalesi & S.A.M. Javadian, 2011).

There are different kinds of DG: the most common ones are micro turbines, wind turbines, biomass energy, internal combustion engine and fuel cell. These technologies can be categorized into three groups (Javadian *et al.,* 2008): 1) Fossil fuel based technologies including fuel motors, micro turbines, 2) Renewable energy based technologies including wind turbines, solar cells, and biomass, and 3) Energy saving based technologies including batteries, super conductor and hydro pumps.

Evaluating indexes for DG environmental benefits

About 80% of world pollutant results from burning of fossil fuel. In china, yearly costs of air pollutant are about 1.6 billion dollars. Hence, it seems necessary to present some indexes for evaluating the environmental benefits of energy generation and using those indexes for the efficiency of lessening air pollution. These indexes can be categorized (Qian *et al.,* 2008) as: The yearly amount of main pollutant production including SO_2, NO_2, CO, PM_{10}, $NMVOC_5$ caused by using energy; The yearly amount of greenhouse gas production including CO_2, CH_4, N_2O, HFC, PFC and SF_6 caused by using energy; The main pollutants *viz*. SO_2, NO_2, PM_{10} and O_3 yearly/ daily and hourly average concentration in a specific geographical area. The first and second indexes can be calculated using the distribution spreading density of the pollutant, or

Table 1. Emission characteristics of power generation technologies /kwh

Generation Type		NOx	CO_2	CO	SO_2
Traditional Power plant	Coal	0.1547~3.0938	86.473	-	0.1083~3.9446
	Natural Gas	0.0077~1.5469	49.037	-	0.4641
	Oil	0.0077~1.5469	72.396	-	-
DG	Micro turbine	0.6188	184.08	0.1702	0.000928
	Internal Combustion Engine (gas)	4.7954	170.16	1.2221	0.0232
	Internal Combustion Engine (diesel)	4.3314	232.04	2.3204	0.4641
	Fuel Cell	0.0046	ND	ND	0.0371
	Photovoltaic	0	0	0	0
	Wind Power	0	0	0	0

in other words the pollution of generation on kWh electric energy. The distribution density can be calculated by (1):

$$C_i = \frac{m_i}{W_n} \quad (1)$$

Where, m_i is the distribution amount of the i^{th}, pollution based on gr/hour and W_n is the amount of power delivered by generator in kW.

The output pollutant amount of fossil fuel power plants and distributed generation resources is presented Table 1. It shows that the wind energy and photovoltaic production considered as zero pollution. Fuel cell also can be counted as an environmental compatible energy generation system.

To do complete environment studies for evaluating DG's effect, apart from the mentioned pollution indexes, some more environmental indexes are presented as follows:

Energy changing average efficiency: This index shows the output active power to input energy ratio, and can be calculated by (2).

$$\eta = \frac{W}{H} \quad (2)$$

Table 2. Efficiencies of some DG technologies (%)

Internal combustion engine	Wind turbine	Fuel Cell	Biomass	CHP
35-41	22-30	80-95	30-41	75-90

In Table 2, the average efficiency of some distributed generation technologies is presented. It is clear that the average efficiency of DG is much higher than old energy generation technologies and thermal power plants. The fossil fuel thermal power plants efficiency is about 15 to 45 percent, where this amount is about 25 percent in Iran.

Reliability of energy changing: It can be defined as (3):

$$R = \frac{E_t}{E} \quad (3)$$

Where E is the amount of changing energy and E_t is the amount of reserved energy. For non-renewable energies, the amount of E_t decrease as E increases, where as for renewable energies Et is constant and this constant amount is a lot more than E. Therefore, it can be concluded that the reliability of energy changing for renewable energy sources is higher than non-renewable energies

Environmental evaluation index for CHP: Considering the fact that CHP generates heat and power simultaneously, to count its environmental index, its generated heat must be change to its equivalent electric energy. Assuming that the amount of power generation is W_n and the amount of generated heat is Q_h, the distribution density of CHP to generate electric energy can be formulated as below:

$$C_i = \frac{m_i}{W_n + S_{EERC}} \quad (4)$$

Where m_i is amount of the i^{th} pollutant distribution and S_{EERC} is the electrical equivalent for the generated heat.

On the other hand, CHP distribution density for generating heating energy is defined as (5):

$$C'_i = m_i \frac{S_{EERC}}{W_{EERC}} / Q_h = \frac{m_i}{W_n + S_{EERC}} \cdot \frac{S_{EERC}}{Q_h} = \frac{C_i}{\rho} \quad (5)$$

Where, ρ is the heat to electric equivalent change coefficient. So, the amount of the i^{th} pollutant distribution would be:

$$m_i = C_i W_n + C'_i Q_h \quad (6)$$

The above equation, make a relationship between generation electrical power, W_n and the generated heating energy Q_h and their environmental costs, and give an acceptable numerical analysis of the environmental benefits of the combination systems for energy generation.

1- The generation cost of DGs considering their environmental benefits

According to Ramakumar *et al.* (1993), DGs are known as sources with high installing costs, low operation and maintenance costs and no fuel costs. The generation cost without encountering the environmental costs is calculated as follows:

$$C_d = \left(\frac{r(1+r)^n}{(1+r)^n - 1}\right)\left(\frac{C_{az}}{87.6k}\right) + C_{OM} + C_f \quad (7)$$

In (7), k is the average capacity coefficient and is calculated as follows:

$$K = \frac{Annual\ power\ supply}{8760 \times rated\ power\ of\ the\ system} \quad (8)$$

In (7), C_d is generation cost based on (0.01\$/KWh), n is the investment return time which is usually equal to average equipment life, COM is the operation and maintenance costs based on (0.01$/KWh), r is the percentage of yearly average ratio and Cf is the fuel cost of generating one kWh electric energy which is zero for renewable sources. Considering (7), the cost of one kWh power energy with DG is as follows:

$$C_h = \sum_{i=1}^{m} \alpha_i [(\frac{r(1+r)^{n_i}}{(1+r)^{n_i}-1})(\frac{C_{az,i}}{87.6k_i}) + C_{OM,i} + C_f] \quad (9)$$

This equation is for a combination system of m kind of distributed generation technologies and αi is the i^{th} technology share in generating the whole output power of the system.

(9) Shows the DG generation without considering its environmental benefits. Considering environment economic theory, environmental benefits can be presented regarding its cost which usually includes pollution and pollution control costs. There are two kinds of environmental costs, one is the economical value of environmental resources which includes the pollution caused by pollutants and overusing natural resource and the other one is pollution harms. Now, in regards with environmental costs, the new mathematical model for generating costs is as follows:

$$C_h = \sum_{i=1}^{m} \alpha_i [(\frac{r(1+r)^{n_i}}{(1+r)^{n_i}-1})(\frac{C_{az,i}}{87.6k_i}) + C_{OM,i} + C_f + C_e] \quad (10)$$

Where C_e is the environmental costs and is as (11):

$$C_e = \sum_{i=1}^{m} (V_{ei} \times Q_i + V_i) \quad (11)$$

Where V_{ei} is the environmental value of the i^{th} pollutant based on $/kg and n is the number of pollutants, Q_i is the amount of pollution caused by the i^{th} pollutant and V_i is the penalty price of the i^{th} pollutant. In order to calculate the C_e caused by the power station pollutant, the effect of this pollutant on human health is considered. Air pollution can damage the cardiovascular and the breathing systems. These effects are summarized in Fig.1. In this figure more common and milder effects of air pollution are placed in lower parts of the pyramid and more dangerous and rare effects are in upper parts.

Fig. 1. Effect of air pollution on human body

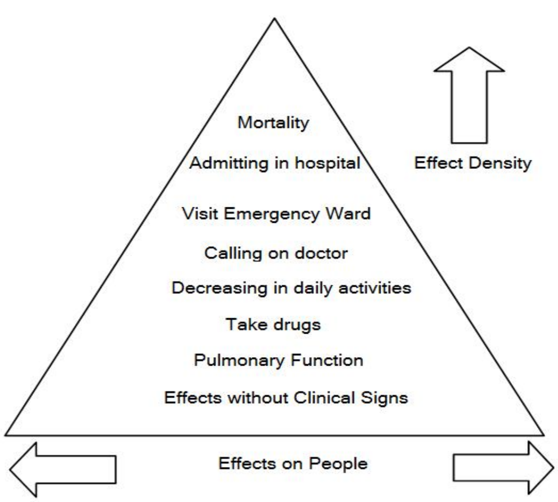


Table 3. Effect of CO on human body with considering density and time

Effect	Density (ppm)	Time (hour)
Reaction of neural center	5	20min
Damage on acuity	30	8
Headache	100	2 to 4
Tension headache	200	2 to 4
Nausea	500	2 to 4
Syncope/ convulsion	1000	2 to 3
Mortality	2000	1 to 2

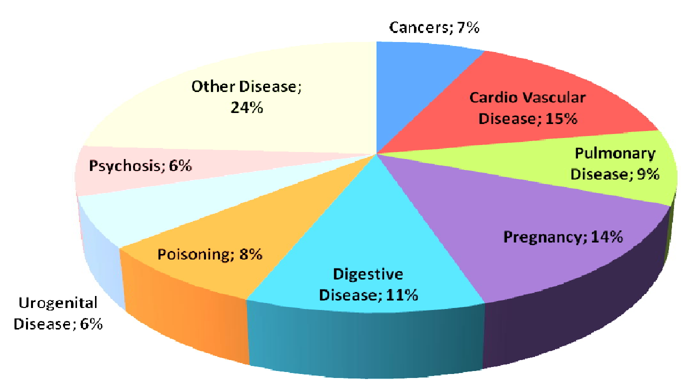
Total effects of air pollution on human health

In order to price the environmental effects of air pollutants considering their effects on human body, it is necessary to totalize and evaluate all the effects. The effects of air pollutants on human body can be categorized as: a) Acute respiratory symptoms, b) Decreasing in daily activities or loss of man hours, c) Asthma attacks, d) Calling on ER, e) Admitting in hospital and f) Early death.

Table 4. Effect of SO_x and NO_x on human body with considering density and time

NO_x	SO_x Dispose in short time	SO_x Dispose in long time
Irritation on eyes & nose	Spasm and contraction of bronchus	Acute of cardio vascular
Lung injury	Irritation on ear, pharynx, nose	Pulmonary disease
Pulmonary Infection	Exudation of mucus	
Acute of cardio vascular		

Fig. 2. Different reasons of the sickness in the world



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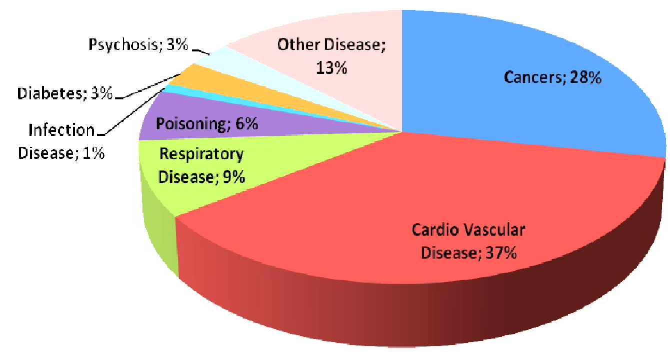
The effects of different gases on the health of human body are summarized in Table 3 & 4. For evaluating these issues all their cost must be considered. In this article, in order to minimize the number of tabulation, the costs of first to fourth cases are not considered due to their less importance; for evaluating the fifth and sixth cases, the results of more recent studies are used.
The Center of Statistics in Canada (in 1999) published a report of patient in which the reasons of the sickness were categorized in Fig.2. Accordingly, 15% of the patients suffer from vascular disease and about 9% from pulmonary disease thus 24% of patients are infected by air pollution and the medical costs of these people can be considered as a proper standard to price and evaluate the fifth case.

Fig. 3. Different death reasons in the world



Study the effect of air pollution and death is hard and expensive and only 2 studies have gained desired results until now. The results of these studies show that the air pollution plays an important role in decreasing the man life. According to Viscusi (1993) and Cropper & Simon (1996) the air pollution decreases the longevity to death 26.8% in people over 65; 49.7% in people between15 to 65 and 23.5% in people fewer than age group of 15. According to Viscusi (1993), in New Delhi most of deaths caused by pneumonia (lung infection), COPD (chronic obstructive pulmonary disease) and cardio vascular diseases can be linked with air pollution. Thus, considering yearly costs of people as 1991 dollars and that pollution results in 34,702 deaths each year, we come to the conclusion that 74,467,111 dollars are wasted each year. The diagrams in Fig.3 show that different death reasons in the world. This picture shows that 46% of deaths caused by breathing and cardio vascular diseases which are directly with air pollution.

Table 5. Standard value of environmental pollutant gases ($/kg)

SO_2	NO_X	CO_2	CO
0.75	1	0.002875	0.125

Presenting the research results

Regarding what was presented in the previous sections environmental costs of the four main exhaust gases of power plants are CO, CO_2, NO_X, and SO_2. Their effects on human health is calculated and added to producing these gases costs (regarding the produced gas volume) and at the end the cost of different power generation technologies are compared.

Table 6. Damage cost of environmental pollutant gases ($/kg)

SO_2	NO_X	CO_2	CO
0.131	0.28	0.0013	0.022

Table 7. Damage cost of environmental pollutant gases ($/kg)

Generation Technology	Investment and Installation Cost	Generation Cost	Generation Cost Considering Environmental Effect($/kWh)
($/kWh)	($/kWh)	($/kWh)	
Thermal power plant	-	0.045	0.173
Internal Combustion	200 - 800	0.055-0.1	0.0731-0.1132
Wind Turbine	1000-1500	0.055-0.15	0.055-0.15
Micro Turbine	1000-1500	0.075-0.1	0.079-0.104
Fuel Cell	3000-4000	0.1-0.15	0.172-0.221
Photovoltaic	1500-6500	0.15-0.2	0.15-0.2

Based on the researches in (Xuehao & Hao, 2003) the environmental standard value of the gases produced by industrial plants is presented in Table 5.

In Table 6, the damage costs of spreading these gases are listed. In Table 7, production costs of different power generating technologies is compared. Table 7 is prepared considering to information in Table 1 and 6 and the equations (10) and (11). It is understood from the table that respecting environmental effects of power plants and adding up the damage costs caused by pollutants spreading to the generating costs, conventional thermal power plants won't have a good chance for investment. Whereas, distributed generation sources using renewable energies for electricity generating has less generating costs.

Conclusions

Some indexes for calculating the environmental benefits of distribution generation have been introduced. Also, based on suggested indexes, a mathematical method for calculation of generation costs of distribution generation technologies considering their environmental effects has been presented. In this method, based on the destructive effects of pollutants, there are negative points for each environmental pollutant and the side costs of their distribution is also added to the generation costs of the systems producing these pollutants. To encounter the distractive effects of the pollutants, their effects on human body as well as the medicinal and death costs caused by these pollutant illnesses are also considered. It can be concluded that respecting environmental effects of power stations and adding up the damage costs caused by pollutants spreading to the generating costs, conventional thermal power plants won't have a good chance for investment. Whereas, distributed generation sources using renewable energies for electricity generating has less generating costs. It also should be noted that in this research, in order to decrease calculations and because of lack of information, only the environmental effects of CO, CO_2, NO_X, and SO_2 have been considered. So, considering the effects of other pollutants as well as other environmental effects such as their effects on plants and animals, the environmental benefits of distributed generation can be improved.

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