QUANTIFYING THE BENEFITS OF DG UNITS IN DISTRIBUTION NETWORK SYSTEMS

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ABSTRACT

Today, with the rise in global energy consumption and thus increase its production CO2 emission has increased sharply. Research shows that one third of the total CO2 emissions are from power plants. Based on the analysis of Energy Technology Perspectives (ETP2008) unless we find an effective way of decreasing CO2 level there will be a 130% increase in CO2 emission by 2050. There are many solutions suggested for preventing the excessive production of environmental contaminants such as increasing energy efficiency, utilizing distributed generators and renewable energy sources. The present study in addition to further introducing distributed generation systems as an effective method for energy production, aims to identify useful indexes for the assessment of these systems in the network, in terms of voltage, losses and environmental impacts. Then a model will be introduced for the assessment the impacts these systems have and also evaluation of the resulted financial benefits for consumers, energy companies and the general community. In the end results of the placement of photovoltaic generators as a type of distributed generation will be evaluated.

INTRODUCTION

In the early days of the electricity industry, the electrical energy was supplied by small sources in the vicinity of the load centers but gradually with the increase of energy consumption and the establishment of high capacity generation units and the increase of the voltage level of transmission lines, production and consumption centers became more and more separated. Today the main consumption energy flow is generated in big power plants, hundreds of kilometers away from the load centers. In the recent decades we are become aware of the many benefits of smaller sources and along with breaking the monopoly of power generation in restructured system and the freedom of the small users and producers in utilizing these generators, we are witnessing more tendencies for using these sources form consumers [1].

Distributed generators can cut unnecessary costs of transmission and distribution and supply energy in an area close to the consumer. Furthermore using these generators in the distribution network can be beneficial for the producers, consumers and the community. Among others, distributed generators can reduce line losses, improve voltage profile, decrease pollutants, relieve T&D congestion and increase the security of critical loads [2].

The organization of the rest of the article is as follows: an introduction to distributed generation as an effective method of supplying energy and its various technologies along with the benefits of utilizing renewable resources. Then benefit index is defined for the evaluation of these systems from in terms of voltage, losses and environmental impacts. In the next step Distributed Generation Impact Simulation Model (DGISM) Suite is introduced and finally the benefits of Photovoltaic systems as a type of distributed generation is elaborated based on the benefit index.

DISTRIBUTED GENERATION

Currently for every one KWh of electricity approximately 600 grams CO2 is produced. This figure is expected to be reduced to one third in 2050 (200g CO2). The CO2 emitted during the lifetime of oil, diesel and coal plants is much higher than other technologies. With the ever increasing use of renewable sources we hope to see a dramatic decrease in CO2 emissions.

It is estimated that with the advance of technology the electricity generation cost of wind power plants will be cheaper than today's cheap resources (coal, gas) by 2030 (fig.1). This highlights the increasing role of wind in power generation in the world. According to the figures published by the Europe Wind Energy Association indicate that for the first time in 2008 the capacity of wind plant exceeded other resources in Europe.

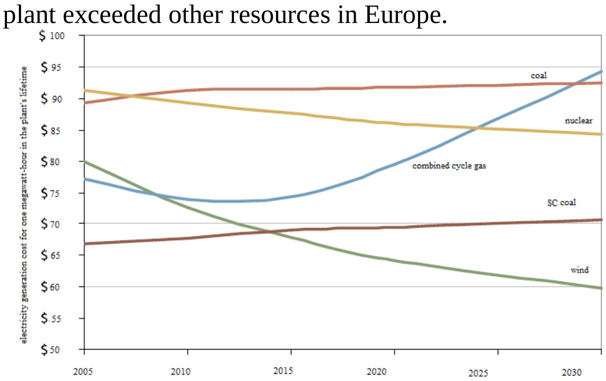

Fig.1. Cost of electricity generation through various methods in the plant's lifetime

Various methods vary in the amounts of pollutants they produce. The highest amount is produced in coal plants. By 2050 reduction of more than one third of the amount of greenhouse gases is caused by enhancement of coal plants. New plants are based on methods that do not emit CO2, therefore nuclear and renewable plants which do not produce greenhouse gases gain priority. Although nuclear plants dot not create greenhouse gases but due to other environmental issues and problems concerning atomic wastes their use is likely to be stopped by 2050.

Consequently renewable plants which will account for the 40% reduction in greenhouse gases will be more important (Fig.2).

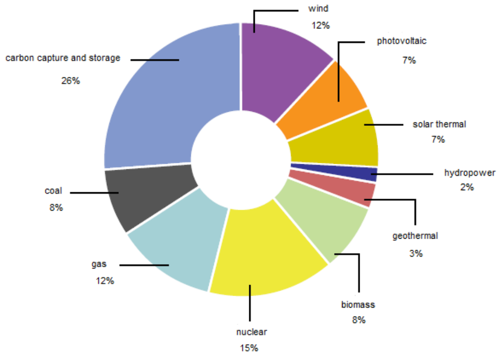

Fig.2. Contribution to reducing greenhouse gas emissions by 2050

Considering all this, planning for the development of renewable energies will accelerate by 2050. By 2030 more than one third of the electricity is generated by renewable energies and this will continue to 2050. In spite of the sharp increase in consumption, the contribution of renewable energies will increase to more than 42% of the consumed energy.

So far hydroelectric power plants have been the most important renewable energy source for generating electricity. Due to the water shortage of the future decades these plants do not have much chance for development. But wind power plants can develop faster and by 2050 the electricity generated by these plants will be 20 times more than today (fig.3).

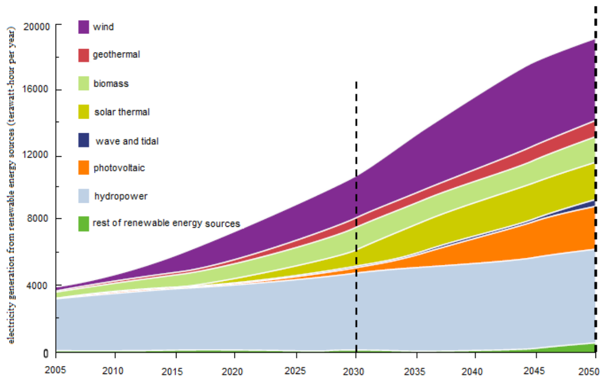

Fig.3. Electricity generation from renewable energy sources by 2050

Wind generated electricity has had a significant growth in the recent years. This became possible by the technology of creating turbines with the capacity of 4 megawatt which will make them economically justifiable compared to other sources of energy.

The running capacity of wind power plants in 2008 is estimated around 120 GW which has increased by 30% in the recent decade. This exponential growth will continue to 250 and will account for 12% of the consumed energy of the world (fig.4).

Fig.4. Installation of wind power plants over the last two decades

Definition of Distributed Generation

Various standards and the International Energy Agency (IEA) define the following characteristics for distributed generation: 1- the planning is not centralized 2- energy distribution is decentralized 3- it is usually connected to distribution networks 4- its capacity is less than 100MW-300MW. EPRI describe describes distributed generation less than 50MW.

Distributed generation (DG) can be categorized into Micro, Small, Medium and Large (fig.5).

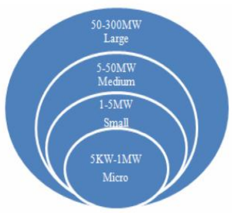

Fig.5. Categorization of DGs based on their capacity

EFFICIENCY OF DISTRIBUTED GENERATION SYSTEMS IN DISTRIBUTION NETWORK

Less line and transformer losses, reduced environmental impacts, Relieved T&D congestion, increased network security, enhanced power efficiency, peak shaving and enhanced general system efficiency are among the benefits of using DG for suppliers and network operators.

Consumers are also benefited from DG technology by receiving high quality power with more security and less cost and environmental impacts. Environmental health promotion, enhanced productivity of the system and proper use of energy sources are among the ways the community can benefit from DG.

DG GENERATION PERFORMANCE ASSESSMENT IN THE NETWORK

The DG systems connected to the network are directly connected to the distribution network and inject their output power into the network therefore similar to other generation units and electrical network elements influence the parameters and variables of the network such as voltage, losses, security and etc. Not only utilizing these systems shouldn't cause any damage or weaken the network but also the placement of DG units should aim to enhance the productivity of the network. In order to assess the effects of DGs on the network several indexes can be considered for the effects of generators on voltage, line loss and the environment.

Benefit indexes of DG systems in the distribution network

Some sources such as [3], [4] define the three indices of voltage profile, reduction of line loss and environmental effects for the assessment of DGs. First we attempt to elaborate on these indexes and then DGISM model suite will be dealt with.

Voltage profile improvement index

One of the secondary goals of utilization of DG system in the distribution system is of voltage profile improvement and safer preservation of consumer terminal voltage in the standard range. Flow of electricity in the line causes voltage drop and by injecting power into the network and supplying parts of the consumer's active and reactive power, DG system can correct the network voltage and improve the power supplied. Voltage profile improvement index (VPII) indicates the impact of DG on the voltage and can be define by the following equation:

$$VPII = \frac{VP_{w/DG}}{VP_{wo/DG}} \quad (1)$$

$VP_{w/DG}$ and $VP_{wo/DG}$ are respectively voltage profile with and without DG. Voltage profile is defined as:

$$\sum_{i=1}^{N} V_i L_i K_i \quad (2)$$

V_i is voltage magnitude at bus i in per unit, L_i load represented as complex bus power at bus i in per unit and K_i is weighting factor for bus i and N is total number of buses in the distribution system. Therefore the above equations have specific meanings in the three formats below:

VPII < 1: DG has not beneficial
VPII = 1: DG has no impact on the system voltage profile
VPII > 1: DG has improved the voltage of the system

In fact DG units can be installed and utilized at almost any point of the distribution network and VPII index can spot the best place. The highest amount of VPII indicates the best installation place – for the purpose of the improvement of voltage profile.

Line loss reduction index

One of the other hidden characteristics of DGs is reducing power loss in the line [5]. The amount of line power line depends on the flow and resistance of the transmission line. Therefore reduction of resistance or flow leads to the reduction of losses. DG units reduce the flow of the line by injecting power into the line and supplying parts of the consumer's needs. Line loss reduction index (LLRI) is defined by ratio of the total line loss of the system with DG to the ratio of the total loss without DG.

$$LLRI = \frac{LL_{w/DG}}{LL_{wo/DG}} \quad (3)$$

$LL_{w/DG}$ and $LL_{wo/DG}$ are respectively line loss with and without using DG in the network and are define by the equations 4 and 5:

$$LL_{w/DG} = 3\sum_{i=1}^{M} I_{A,i}^2 R D_i \quad (4)$$

$$LL_{wo/DG} = 3\sum_{i=1}^{M} I_{L,i}^2 R D_i \quad (5)$$

In this equation R is line resistance (p.u./km), D_i is distribution line length (km) and M is number of lines in the system. $I_{A,i}$ is the pu flow of the lines in the systems that parts of their power is generated by DG units and $I_{L,i}$ is the pu flow of the systems that do not use these systems. Loss reduction index can give meaningful concepts in three different formats:

LLRI < 1: DG has reduced electrical line losses
LLRI = 1: DG has no impact on system line losses
LLRI > 1: DG has caused more electrical line losses

Obviously the arrangement that gives out the smallest amount of the index is the best place for DG units.

Environment impact reduction index

DG can employ technologies for generating power that cause far less greenhouse emissions and pollutions compared to usual power plans. For example coal power plants emit 830-920 tons CO2, 630-1370 kilograms sulfur dioxide and 630-1560 kilograms various types of nitrogen oxides for every 1 GWH power, whereas wind farms or photovoltaic systems produce almost no output contaminants. Generating energy from renewable sources can be a significant step on the way to reducing pollution on earth and enhance the health of its inhabitants. The main idea in the definition of Environment Impact Reduction Index (EIRI) is to compare the emission of pollutants such as NO_x ‹SO_2 ‹CO_2 and etc while utilizing DG.

$$EIRI_i = \frac{PE_{iw/DG}}{PE_{iwo/DG}} \quad (6)$$

$PE_{iw/DG}$ and $PE_{iwo/DG}$ are respectively the volume of i the contaminant with and without DG (for the i the). The three following forms indicate the positive and negative impact of DG on air.

$EIRI_i$ < 1: DG has reduced the negative impact of i th pollutant
$EIRI_i$ = 1: DG has no impact on the environment
$EIRI_i$ < 1: DG has caused more the negative impact of i th pollutant

DGISM MODEL SUITE

The DGISM Suite includes a model for estimating distributed generation impacts and a model for estimating financial benefits to customers and utilities.

DGISM Suite impact Model

As shown in Fig. 6, the first step in the DGISM Suite is the Impacts Model, which is used to estimate the "unit impact" or change in each of the benefit indexes of DG systems (in the network) resulting from distributed generation.

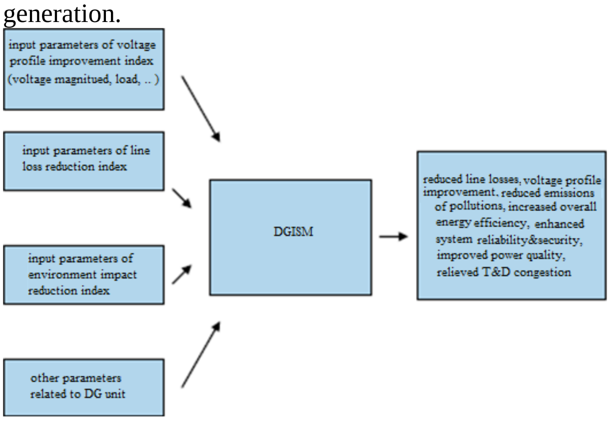

Fig.6. DGISM Suite impacts Model: Inputs and Outputs

DGISM Suite Benefits Model

The second step in DGISM is to quantify the primary and secondary benefits associated with distributed generation. As shown in Figure 7, the DGISM Suite Benefits Model provides estimates of the following benefits: Postponement of investment for the development of the network and massive power plant units, low cost of repair and maintenance of DG units, productivity enhancement, healthcare cost reduction and health improvement due to the reduction of pollutant emissions, network energy saving cost reduction, lower operation cost due to peak shaving by DG, enhanced security for sensitive and important loads.

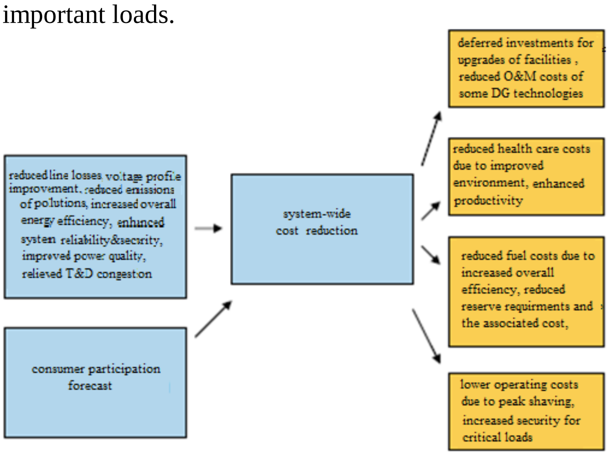

Fig.7. DGISM Suite Benefits Model: Inputs and Outputs

SIMULATION AND RESULTS ANALYSIS

The location of the photovoltaic systems can be specified as a form of distributed generation using the graph algorithm combined with sensitivity analysis in DG network. In this way optimal points for PV installation in the radial networks can be specified and the capacity of photovoltaic system can be identified. Placement of the PV generator using the mentioned method can result in reduced voltage drop and losses as much as 50%. Based on this model, photovoltaic generation benefits (PV) for distribution networks, for example the network studied in [6], will be examined.

Voltage profile improvement index is calculated by equation 1 and the ratio of the two voltage profile values is calculated by equation 2. This is how voltage profiles are obtained before and after installation of the systems:

$VP_{wo/DG} = 112.2995$

$VP_{w/DG} = 113.2842$

Therefore voltage profile improvement ratio is:

$Vp = 1.0088$

Cost reduction index is acquired with equation 1 and the ratio of the two loss figures with equations 4 and 5:

$LL_{wo/DG} = 691.961$

$LL_{w/DG} = 198.415$

Therefore the cost reduction index is:

$LLRI = 0.4312$

Obviously the installation of PV systems has reduced the losses in addition to enhancing the voltage profile and based on the benefits index of other sources the system are beneficial and effective for distribution systems.

CONCLUSION

Restructuring of the electricity industry, market competitiveness, growing demand, shortage of energy resources and environmental issues serve to highlight the role DG can play. This article elaborated on the benefit index in order to evaluate the function of these systems in the network in terms of voltage, losses and environmental impacts and introduce a model for the assessment of the resulting benefits for the consumers, energy companies and the general community. Results from positioning PV generators as a form of distributed generation on voltage and network losses Suggests the positive impact and efficiency of these systems in the network.

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