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Economic, environmental and technical effects of photovoltaic modules in distribution networks in comparison with the conventional units

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A B S T R A C T

One of the most important obstacles in the deployment of the clean technologies such as photovoltaic modules in the distribution system is their indefinite future in the coming years after the installation due to their intermittent nature in power generation because of the dependency to solar radiance profile. The authors in this study aim to analyze the economic, technical and environmental effects of the photovoltaic modules in distribution networks in the coming years after the installation date in comparison with the conventional distributed generation units such as gas turbines. So, a planning period of some years was considered and a distribution planning problem was defined during the study period in a non-private environment assuming uncertainties in order to maximize the total profit of the distribution system. A dynamic way instead of the last static or pseudo-dynamic point of views was proposed to solve the distributed generation planning problem. Since the presented problem was analyzed within a few years, a sensitivity analysis on the electricity price and global fuel price of each year carried out through two proposed methods. The effect of environmental factor was scrutinized in the planning process with and without considering the emission tax. The planning problem was applied on the 9-bus test distribution system and solved using Imperialist Competitive Algorithm. Thereby, the study proved that the use of photovoltaic modules in the distribution system in spite of their uncertain nature will lead to a good improvement in all of the technical, environmental and economic parameters during the planning period. Also, it has been turned out that the total profit of the distribution system at the end of the planning study with the photovoltaic modules accompanying the conventional units is more than the use of conventional units alone. It is concluded that the photovoltaic modules can be used in both the industry and government in terms of improving social and economic acceptance in future developments.

1. Introduction

The positive economic (Mohammad Rozali et al., 2014; Narodoslawsky et al., 2008; Santibañez-Aguilar et al., 2014) and technical (Battaglini et al., 2009; Görbe et al., 2012; Sadeghi and Kalantar, 2015) effects of the Distributed Generation (DG) units cause to develop their increasing trend in power networks but an important constraint in the future generation expansion planning is the emission limitation. Burning carbon has deeply negative effects on the well-being of humans and eco-systems. The greenhouse gas emissions trap heat in the atmosphere and prevent it to escape into the space; thereby causing the global warming which could result in world climate change. Thus, the governments and regulatory agencies at various levels have adopted specific policies to support clean renewable resources as alternative energy sources. Proper planning of clean technologies such as photovoltaic (PV) modules into existing distribution system plays a significant role to the improvement of the system performance. However, the intermittency in solar radiance and uncertainty of power availability of the PV modules make it impossible to anticipate the effect of these units on the technical, economic and environmental parameters of the distribution systems during the years after their installation. Consequently, all of the distribution system costs cannot be calculated exactly during a period of years. Therefore, it is

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Nomenclature

Indices

cy	Counter for year
g	state numbers of scenario matrix
$gtot$	Total no. of states of scenario matrix
i,j	Bus number
N_{bus}	Total number of buses
p	Pollutant no. (CO_2, CO, NO_x,..)
pn	Total pollutants (in this paper = 5)
Scen	Scenario counter
Tot. scen	Total scenarios
Ty	Total number of years of the planning period
yr	Year number

Constants

CET^{yr}	Emission tax in year yr without considering the inflation and discount rates
CF	Capacity factor of the DG units
d	Discount rate
Em_p^{conv}	The amount of produced pollutant of type p for the conventional generation in substation bus (kg/MWh)
Em_p^{GT}	The amount of produced pollutant of type p for the GT (kg/MWh)
$ENS^{g,yr}$	Energy not supplied in state g in year yr
$fuelprice_{GT}^{scen}$	Fuel price of the GT in scenario number $scen$
$gr(cy)$	Growth rate of the load in year yr
inf	Inflation rate
L_{ij}	Length of line between buses i,j (km)
$P_d(i)$	The active load in bus i
$P_{rated}^{GT}(i,yr)$	Rated power of GT in bus i in year yr
$P_{rated}^{PV}(i,yr)$	Rated power of PV module in bus i in year yr
$price_{ENS}$	Price of ENS ($/MWh)
$price_{loss}^{scen}$	Energy loss price of each scenario ($/MWh)
$price_{tr}^{scen}$	Transmission system energy price of each scenario ($/MWh)
$pricetax_p$	Tax price of pollutant of type p ($/kg)
$price_{uc}$	Upgrading cost ($/km)
$Pricegr$	Grant subsidy price
$pricemaintenance_{GT}$	Maintenance price of the GT
$pricesel_{scen}$	Price of selling energy of each scenario ($/MWh)
$Q_d(i)$	The reactive load in bus i
SL_{ij}	Thermal limit of the line between buses i,j
T_{rep}	Repair time of the faulted line
T_{res}	Restoration time of the loads
$Y(i,j)$	ijth element of admittance matrix (magnitude)
λ_{ij}	Failure rate of line between buses i,j (fail/yr km)
$\theta(i,j)$	ijth element of admittance matrix (angle)

Variables

$LF_{ij}^{g,yr}$	The line flow between buses i,j in state g in year yr
$P_{lzone}^{g,yr}$	The power loss of the islanded zone in state g year yr. It is considered to be 5% of the total load of the islanded zone
$P_{G1}^{g,yr}$	slack bus power generation in state g, year yr
$P_{loss}^{g,yr}$	The power loss of state g, in year yr
pr^{scen}	Probability of each scenario of the prices
$P_D^{int,g,yr}(ij)$	The total load of the islanded zone in state g in year yr after failing the line between buses i,j
$P_{DG}^{g,yr}(ij)$	The total installed capacity of DG units in state g in year yr in islanded zone after failing the line between buses i,j
$Q_{G1}^{g,yr}$	slack bus reactive generation in state g, year yr
$SM^{g,yr}$	gth state (row) in year yr of scenario matrix
$V_g^{yr}(i)$	Bus voltage in state g, year yr
$\delta_g^{yr}(i)$	Voltage angle in state g, year yr for bus i (V)

important to model the PV modules in an appropriate manner including the related uncertainties. In this study, a Monte-Carlo based approach to model the uncertain nature of the PV modules for each year is proposed. The authors in this paper aim to model the uncertain nature of the PV modules in the distribution system and to investigate the influence of these clean units on the years after their installation. Therefore, a distributed generation (DG) planning problem during a period of some years is defined and the technical, economic and environmental parameters of the distribution system are analyzed in presence of the PV modules and conventional DG units solely or together. Also, it will be discussed whether the clean and uncertain nature DG units have a positive effect on the total profit of the distribution system or not.

The last studies which focused on DG planning problem were analyzed within a yearlong (Atwa et al., 2010) or studied during a period of time from static or pseudo-dynamic point of views. The static planning of the DG units (Zangeneh et al., 2009) selected by most of the researchers working on a period of time cannot lead to correct and exact results. Because in these studies the planning problem was analyzed based on the load of the latest year. In this state, the investment time of installing the DG units is not obtained and all of the costs are computed based on the DG size of the latest year. Thus, the calculated costs turn not to be correct. In the pseudo-dynamic planning problems, a two-staged approach is selected for the planning process. At the first stage, the size and the place of the DG units are determined as the same as the static planning problems based on the load of the latest year. At the second stage, only the DG size for each year is calculated considering that the places and the maximum size of the DG units are determined in the last step. The solving process, due to having a two-staged approach, needs more time in comparison with the static and dynamic planning problems. The dynamic planning problem which is the most complete method in DG planning problems and is proposed in this study as well, all years of the planning period are analyzed at the same time to find simultaneously the optimum size of the DG units for each year and their best place. All of the calculated costs and incomes of each year are based on the load and DG size of the related year. The investment time of each DG type is determined in the dynamic way. Therefore, the results of the dynamic planning of the DG units can be more reliable than the other planning methods. Fig. 1 shows a brief classification of the DG sitting, sizing and planning studies.

The objective function in these planning problems consists of the technical and economic functions. The researchers have focused to improve the power quality issues such as harmonic levels, voltage stability and voltage profile of the distribution system (Biswas et al., 2012; Urbanetz et al., 2012). Reducing the power loss and improving the reliability of the distribution system are presented in Görbe et al. (2012) and Hemmati et al. (2013). In some of the planning studies (Aman et al., 2014; Boljevic and Conlon, 2008), the short circuit level and loadability of the feeders were considered as the final objective function. In all of the mentioned