ELSEVIER

Energy Policy 35 (2007) 3395–3409

ENERGY POLICY

www.elsevier.com/locate/enpol

Environmental benefits of distributed generation with and without emissions trading

A.G. Tsikalakis*, N.D. Hatziargyriou

School of Electrical and Computers Engineering, National Technical University of Athens, 9 Heroon Polytechniou Street, GR 15773 Athens, Greece

Received 17 April 2006; accepted 27 November 2006
Available online 31 January 2007

Abstract

The need for improving energy efficiency and reducing CO_2 emissions and other pollutants, as well as the restructuring of energy markets has favoured the increase of distributed energy resources (DER). The co-ordinated control of these sources comprising renewable energy sources (RES) and distributed generators (DG) characterised by higher efficiencies and lower emissions compared to central thermal generation, when based on coal or oil provide several environmental benefits. These benefits can be quantified based on DER participation in the CO_2 emission trading market. This paper provides a method to calculate emissions savings achieved by the marginal operation of DER in liberalised market conditions using available emissions data. The participation of DER in emissions trading markets is also studied, with respect to profits, pollutants decrease and change in operating schedules. It is shown that the operation of DER can significantly reduce pollutants, provided sufficient remuneration from CO_2 emission trading market participation is provided. Moreover, it is shown that using average emissions values to calculate the environmental benefits of DER might provide misleading results.

Keywords: Distributed energy resources; Renewable energy sources; Emissions trading

1. Introduction

Development of environmental friendly (renewable energy sources (RES)) and highly efficient power generation (combined heat and power (CHP) production) has attracted significant attention around the world. This is due to the increased awareness of the detrimental effects of the emissions from hydrocarbon based power stations on the environment, which has led to the commitment of many countries to comply with the Kyoto protocol (Kyoto, 1997) and reduce their green house gas (GHG) emissions. In line with the Kyoto protocol, emission trading has become a reality in several EU countries (EEX, 2006). Moreover, recent studies have been presented in literature about clean development mechanism (CDM), related either to the sustainable development of developing countries (Winkler et al., 2002), or to the emissions reduction for developed countries like Japan (Kosugi, 2005) and Canada (Potvin, 2006).

At the same time, the deregulated energy environment, among other effects, has favoured a gradual increase in distributed energy resources (DER) connected at the medium voltage (MV) or low voltage (LV) side of the distribution network (Lasseter, 2002). DER like micro turbines (MT) and fuel cells (FC), either in CHP mode or purely for electricity production, are installed in the distribution network, even within consumer dwellings (Bauen, 2004). RES, like photovoltaics (PV), small wind turbines (WT) and small hydro units, are also expected to increase their share in the coming years (EREC, 2006).

Co-ordinated operation and control of DER is essential to obtain full benefits from their operation. The technical challenges of controlling a multitude of small units with perhaps conflicting interests are huge, and thus considerable research is devoted in the USA (Lasseter, 2002), EU (MICROGRIDS, 2002), (MORE MICROGRIDS, 2005),

*Corresponding author. Tel: +30 210 772 3696; fax: +30 210 7723968.
E-mail addresses: atsikal@power.ece.ntua.gr (A.G. Tsikalakis), nh@power.ece.ntua.gr (N.D. Hatziargyriou).

0301-4215/$ - see front matter
doi:10.1016/j.enpol.2006.11.022

Japan(Tanaka,2004) and Australia(Jones, 2005) to develop centralised and decentralised control (Dimeas, 2005), (Hatziargyriou, 2005) approaches of DER-dominated MV and LV distribution networks. A microgrid, is defined as a DER-dominated LV network that operates mostly interconnected to the MV distribution network, but can be also operated in island mode, in case of faults in the upstream network (MICROGRIDS, 2002).

The installation of DER close to loads reduces flows in transmission and distribution circuits and thus losses. Moreover, the increased efficiency of DER, especially CHP, and the operation of RES reduces emissions. Preliminary studies (Microgrids, 2005a) report that reduction of losses by 1% in the UK system reduces emissions by 2 million tonnes of CO_2 per year. Moreover, in the UK, reduction by 1 GWh from hydrocarbon can reduce emissions up to 400 000 tonnes per year. In selected Portuguese networks of various types, ranging from rural LV networks to HV ones, 20% penetration of DER reduces CO_2 emissions by 2.07–4.85% (Microgrids 2005b).

A significant impact of increased efficiency in the domestic utilisation of gas and electricity on the reduction of CO_2 emissions is claimed in (Pudjianto, 2006). It is demonstrated that on European scale, 65 million tones of CO_2 per annum can be saved by 50 million installations of domestic CHP units. Next to the potential environmental benefits of DER, their economic evaluation is critically influenced by the developing CO_2 emissions trading markets (Laurikaa, 2006), which also affect production costs of electricity generated by thermal (hydrocarbon) units (Microgrids 2005a).

This paper investigates the environmental benefits of the co-ordinated operation of DER under two different optimisation objectives, namely minimising operating costs and minimising emissions, when DER are marginally deployed. Moreover, the potential benefits from the participation of DER in the CO_2 emission trading markets are calculated. Emissions estimations from average emissions of the upstream network and from analysis based on marginal units data are compared.

The structure of the paper is as follows: The method adopted for the estimation of the environmental impact from the co-ordinated operation of DG sources is presented in Section 2. In Section 3, data for a typical LV microgrid interconnected at an actual MV network, used as a case study, are provided. Section 4 presents the change in pollutants, CO_2, SO_2, NO_X and particulate matter (PM-10), under two optimisation objectives and the potential benefits obtained by DER participation in the emissions trading markets. Conclusions are drawn in Section 5.

2. Methodology for calculation of DER environmental effects

Production from DER reduces injection from the upstream grid and thus the corresponding emissions from central units. DER may have their own emissions, which should be taken into account in order to evaluate their environmental impact. Data about emissions of DER and central units for different fuels can be found in Greek Ministry of Development (2006) and emission level in kg/GJ produced in EGEC (2006). The USA Environmental Protection Agency (EPA) has created a database with emissions from existing production units (EPA, 2006a) and information on the DER in EPA (2006b).

High penetration of DER in grid operation could affect central unit commitment, i.e., it is possible that central units might need to switch off to accommodate increased DER production. In this case, the operation of the system with DER penetration should be compared with the modified operation of central generation, assuming optimal economic operation. This method was used to evaluate the economic and environmental benefits of both existing (Tsikalakis, 2003) and additional (Hatziargyriou, 2004) wind power penetration on the island of Crete. If time-series data are not available, probabilistic methods can be used instead (Karaki, 1999), to calculate the operating hours and production of both the central units and DER and the corresponding expected emissions with and without DER operation.

In this paper, DER penetration is assumed relatively low, i.e., it does not affect scheduling of the units, but changes their hourly production. The most expensive units of the system are mainly affected, the so-called marginal units. Regarding emissions data, three possibilities exist in practise, which also determine the method used when detailed time-series of the system under study are not available.

- Emissions data Type 1 (ED1): annual emissions available in gr/kWh.
- Emissions data Type 2 (ED2): monthly emissions available.
- Emissions data Type 3 (ED3): monthly 24 h emission curve different from month to month according to the type of marginal units.

The simplest type is ED1, frequently directly available by utilities (EdF, 2006) or obtained from the annual energy production by type of unit available by transmission system operators (TSOs) (HTSO, 2006). In the latter case, annual emissions for the power system can be estimated by the emission level of each unit using (1)

$$sys\_em\_lev = \frac{\sum_{i=1}^{N} emmision\_level_i \, energy_i}{energy_i}, \qquad (1)$$

where *sys_em_lev* is the emissions of the upstream network of the microgrid, i the type of unit, $energy_i$ the energy produced by unit type i for the studied period, $emission\_level_i$ is the emission unit type i, N the different types of units.