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Evaluating the impact of FIT financial burden on social welfare in renewable expansion planning

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ABSTRACT

Generation expansion planning (GEP) is the problem of determining the optimal strategy to plan the construction of new generation plants while satisfying technical and economic constraints. Over the past few years, the environmental issues have become a society concern and the Clean Air Act Amendments passage the laws indicating the need for renewable resources promotion. Multifarious incentive-based support schemes have been designed to increase the penetration rate of the renewables in power generation. In this context, open questions remain regarding the financial resources of the support schemes. This paper addresses the impacts of Feed-In-Tariff (FIT) mechanism on the social welfare in an integrated renewable-conventional GEP framework, while consumers are considered for patronizing the financial burden of FIT ($Б^{FIT}$). Hence, after applying the gravitational search algorithm to a multistage GEP model, the benefit of generation company (GENCO) and consumer surplus are both determined as the social welfare terms. The virtual price criterion is also introduced to evaluate the effect of FIT expenditure on consumers' surplus. The numerical studies emphasize that implementation of FIT regime in the GEP results in social welfare improvement even if the $Б^{FIT}$ is imposed on the demand-side consumers.

1. Introduction

Generation expansion planning (GEP) has historically addressed the problem of identifying the most adequate technology, expansion size, sitting, and timing for the construction of new plants considering economic criteria, while ensuring that the installed capacity adequately meet the expected demand growth [1].

In line with restructuring in the power industry, environmental protection has been changed as an important issue in the worldwide. Carbon dioxide (CO_2) derived from burning fossil fuels, is one of the main greenhouse gases (GHG) that are responsible for global warming and climate change, posing a huge threat to human welfare [2]. In this context, investing in renewable energy sources (RES) is a surefire way to shift from oil-fueled dependence to more eco-friendly and sustainable resources [3]. Hence, during the past few decades, promotion of RES has been central to overall energy policy in many countries. According to the whole purposes pursued in RES deployment, the most important derived effects can be regarded from different perspectives, such as environmental/society [4], economic/market [5,6], and network [7].

From environmental point of view, renewable energy investors can look forward to a world with cleaner air and far less pollution as well as fewer GHG emissions. The investors, therefore, should not only expect a financial harvest, but they can also ensure the continued vitality of Mother Earth for years to come. Nevertheless, high investment costs, intermittency, uncertainty and long period of investment return are comprised the major features related to the lack of sufficient maturity of the renewables in the power industry [8]. Hence, multifarious energy policies have been enacted in different jurisdictions around the world to persuade generation companies (GENCOs) to invest in the green generation technologies [9]. Feed-in-tariff (FIT) and quota obligations with tradable green certificate can be taken into account as the most popular incentive policies [10] among a variety of support schemes currently in existence in different countries [11,12].

In recent years, several researches have been presented addressing the integration of energy policies as well as environmental regulations into the GEP problem. The literature suggests a wide range of objectives, such as reducing the power sector emission by considering emission constraints during the generation expansion planning horizon [13–15], evaluating the effects of the policies on fostering the utilization of RES in the renewable expansion planning framework [16–18], and representing other solutions for emission mitigation, such as demand-side management programs in the GEP problem [19]. The effectiveness of

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Nomenclature

Indices

i INDEX corresponding to years of the planning horizon
t index corresponding to a generation technology available for planning
j Index corresponding to individuals of utilities in the society

Constant

$C^F_{i,t}$ fuel costs for technology t in the i-th year (€/MWh)
$C^A_{i,t}$ amortization costs for technology t in the i-th year (€/MWh)
$C^M_{i,t}$ operation and maintenance costs for technology t in the i-th year (€/MWh)
CP_t capacity of a generation unit based on technology t (MW)
$\mathrm{GC}_{i,t}$ generation cost for technology t in the i-th year (€/MWh)
D_i^{peak} peak load in the i-th year (MW)
$D_i^{\mathrm{off\ peak}}$ medium load in the i-th year (MW)
D_i^{valley} base load in the i-th year (MW)
$\mathrm{EL}^{\max}$ upper allowed limit on the emission of units (ton/h)
r discount rate
$I_{i,t}$ investment cost for the installation of a generation unit of technology t in the i-th year (€/MW)
$\mathrm{In}^{\mathrm{bud}}_{\mathrm{tot}}$ total present day budget available for planning (€/MW)
L^D_t lifetime related to technology t (year)
N^y number of years of the planning horizon
$N^{u^{\max}}_{i,t}$ upper bound related to number of units based on technology t in the i-th year
$W^{\max}_t$ maximum number of units that can be installed for technology t
τ_j commodity of individual j in the society
$\Pi^{\mathrm{FIT}}_{i,t}$ sum of market price and FIT related to technology t in the i-th year (€/MWh)
Π_i average market price in the i-th year (€/MWh)
ξ fuel mix ratio

Variables

$\mathrm{CP}^{\Sigma}_{i,t}$ total existing capacity belonging to technology t in the i-th year (MW)
C^{Spls} consumer surplus (€/MW)
E^T_i total energy sold in the i-th year (MWh)
$E^{\mathrm{ex}}_{i,t}$ energy produced by existing units of technology t in the i-th year (MWh)
$E^{\mathrm{new}}_{i,t}$ energy produced by new units of technology t in the i-th year (MWh)
$X_{i,t}$ number of units belonging to technology t in operation in the i-th year
$Б^{\mathrm{FIT}}$ financial burden of FIT
Ψ virtual price (€/MWh)
$\hbar_1, \hbar_2, \hbar_3$ load participation coefficients corresponding to peak, medium and base load respectively

Sets

Z^{ex}_i set of existing units in the i-th year
Z^{new}_i set of new units in the i-th year
$Z^{\mathrm{ex,base}}_i$ set of base type existing units in the i-th year
$Z^{\mathrm{ex,peak}}_i$ set of peak type existing units in the i-th year

Functions

$P_v(D)$ demand curve function for base load type (M€)
$P_p(D)$ demand curve function for peak load type (M€)
$P_o(D)$ demand curve function for off peak load type (M€)
S W social welfare (M€)
κ_j utility function for individual j in society

various incentive policies by their capabilities to achieve a renewable portfolio standard and deal with climate change issues in the GEP framework are also assessed in recent studies [20–22]; whereas, the possibilities and problems of the policies such as risk and compatibility in liberalized environment, are being described in Refs. [23–25].

Despite numerous investigations on the impacts of the incentive policies on different issues, such as generation expansion strategies, RES deployment, electricity market, and environmental issues, how the policies can affect the social welfare (SW) has still remained as an open question in the context of renewable expansion planning. In other words, considering the entity that is responsible for the financial burden of incentive-based support schemes is the point that has been less noticed till now in assessing the policies; this can be very significant from SW point of view. In this paper, the impact of feed-in-tariff mechanism on the social welfare is investigated in the GEP problem faced by a GENCO, while the electricity consumers are considered to be responsible for derived additional cost from the FIT system implementation. In this circumstance, the FIT can pose a huge threat to consumer surplus, while its expenditures are financed on consumers by the system operator. To clarify how the FIT can affect consumer surplus, first, an appropriate price index, the so-called "virtual price", is introduced to reflect FIT expenditures in the electricity price and then, linear demand curves with different elasticity are considered to assess consumer surplus react to the FIT mechanism. Regarding different logical constraints, here, the generation expansion planning problem is modeled as a mixed integer non-linear programming (MINLP) problem solved by one of the recently improved heuristic algorithms namely, gravitational search algorithm (GSA). Detailed explanation of the GSA is provided in Section 4.

The rest of this paper is organized as follows. How FIT regime influences the social welfare in the GEP framework is discussed in Section 2. Section 3 describes the proposed hierarchy to assess the social welfare. Section 4 explains the GSA principles in detail and the numerical analysis is conducted in Section 5. Finally, concluding remarks are drawn in Section 6.

2. FIT mechanism and its interaction with the social welfare

FIT, quota, auction and fiscal incentive or tax credit are encompassed some widespread public supports, justified according to environmental and socioeconomic aspects for developing the renewable energy resources. These supports are categorized as either price-based or quantity-based. From the application and implementation view point, FIT incentive, known as a price-based measure, is the most applied mechanism in which a specific price guaranteed for a period of several years (up to 20 years) must be paid by the government or regulatory authorities to the renewable energy generators. The level of tariff is set for a long time period in order to ensure investment security for producers. A variant of feed-in-tariff scheme is the fixed premium used in Denmark and