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GENERATION EXPANSION PLANNING IN INTEGRATED RENEWABLE CONVENTIONAL STATUS CONSIDERING SUPPORT SCHEMES

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Abstract- Generation Expansion Planning (GEP) is one of the most important decision-making activities to determine the optimal strategy to plan the construction of new generation plants. Originally, GEP was faced by vertically integrated utilities with the aim of minimizing production and capital costs. After deregulation, generation companies were forced to consider GEP from the viewpoint of market shares and financial risk. In recent years, increasing concern for environmental protection has driven many countries all over the world to promote energy generation from renewable sources. Multifarious incentive-based support schemes have been designed to promote the investment in power generation exploiting renewable resources. In this paper, regarding the environmental issues, the impact of one of the most popular incentive systems, namely feed-in-tariff, on generation planning is considered, thus obtaining a comprehensive GEP model with a suitably modified objective function and additional constraints. The resulting problem is solved by gravitational search algorithm based on the Newton's law of gravity and mass interactions. Analysis reveals that the implementation of incentive policies has remarkable impacts on investment decisions of generation companies in renewable resources and environmental issues.

Keywords: Generation Expansion Planning, Renewable Resources, Feed-In-Tariff, Environmental Protections, Gravitational Search Algorithm.

I. 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 plant capacity, while ensuring that the installed capacity adequately meet the expected demand growth [1]. In the past, vertically integrated utilities were in the position of operating under a regional monopoly regime, these utilities could set the energy sale prices to remunerate their investment in generation expansion in any case. In such framework, the aim of the GEP was simply that of minimizing the cost of energy generation since profits were guaranteed because of the monopolistic position of the utility.

After traditional regulated markets demise and the advent of competitive markets for electricity service, many issues such as the way that electricity is priced, power trading schemes or the aims considering in expansion planning problems, have seriously been changed. Such transformation is making increasingly difficult for market participants to appraise the prospects for the future electricity markets [2]. Under competition, multiple agents individually prepare their investment plans in order to maximize their profits. In such circumstance, the objective function of a new GEP problem is to maximize the profits of individual generation companies (GENCOs), which are composed of the revenues based on market prices and of the costs covering the capital and operating costs.

In addition, the objectives of individual GENCOs are correlated, interlinked, and may be conflicted each other so that they were forced to consider GEP from the viewpoint of market shares and financial risk. In parallel with the changes created in the organization of the industry, environmental issues have been also changed as an important issue in the worldwide. Carbon dioxide (CO_2) is one of the main greenhouse gases that are responsible for global warming and climate changes. The combustion of fossil fuels has played an important role in the generation of CO_2 in the atmosphere. Many countries are committed to the Kyoto Protocol and aimed for significant reduction in greenhouse gas emissions within the next decade [3]. Subsequently, problems concerning production of atmospheric emissions by fossil fuel resources and scarcity of them in the near future lead to increased interests in 'energy saving' and 'environmental protection' issues as well as promoting 'renewable energy resources (RES)' [4].

One strategy to reduce dependence to the fossil fuel resources is based on reducing 'energy consumption' by applying energy savings programs focused on energy demand reduction and energy efficiency in industrial [5] and domestic loads [6]. Another strategy to achieve this goal is implementation of RES, not only for large-scale energy production, but also for stand-alone systems [7]. Considering power industry share on global CO_2 emission, these strategies have to be adequately attended by power sector decision makers due to their impacts on investment profitability, economic and power industry performance. Appling rigid environmental regulations by regulating authorities impel GENCOs to consider the emission constraint in the GEP problem [8]. Under this circumstance, renewable energy resources can be pointed out as an appropriate alternative to fossil fuel-fired units for environmental protection issues. Hence, during the past few decades, the development of renewable energy has been central to overall energy policy in many countries. According to the whole purposes of the renewable energy implementation, the most important impacts derived from renewable resources can be categorized as follows:

- Environmental-driven: achieves environmental and social goals by greenhouse gas mitigation, contributes to national competitiveness and growth agenda, leading to accessibility of energy as well as a secure energy supply, and reducing the negative impacts on the environment and health [9].
- Economic/market-driven: results in a requirement for the establishment of new market rules, affects market stakeholder revenues and profits as well as investment decisions through receiving the government support schemes, decreases the trade of energy from fossil sources as generation from RES increases [10, 11].
- Network-driven: provides a negative impact on the reliability level if not properly planned, increases the risk cost of meeting the expected load by increasing spread between predicted and supplied energy, while RES actual production does not match forecasted demand and grid operator tries to balance difference [12].

In this paper, the economic and environmental aspects of incentivized renewable energy resources are investigated in an emission constrained generation expansion planning structure. Investing in renewable energy is a surefire way to shift from oil-fuelled dependence to more eco-friendly and sustainable resources. Renewable energy investors can look forward to a world with cleaner air, far less pollution, fewer greenhouse emissions, and increased energy security. 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.

However, high investment costs, intermittency, uncertainty, and overlong return-on-investment periods are comprised the major features related to the lack of sufficient maturity of the renewables in the power industry [13]. Hence, to support large exploitation of renewable units, governments have to ratify support schemes so that persuade GENCOs to invest in the green generation technologies [14, 15]. Feed-In-Tariff (FIT), quota obligations, tradable green certificate, and auction are taken into account as various mechanisms considered for fostering the utilization of renewable resources [16].

In recent years, several researches have been conducted on the effects of the aforementioned policies on the generation expansion planning containing environmental and investment issues. Prevention of more atmospheric pollution by power sector is introduced as an imperative task in the age of low carbon economy, and GEP is treated as a one of the key links to achieve emission reduction [17]. In reference [18], the most economical investment planning for various technology types of units is investigated regarding to the incorporated environmental and reliability criteria. A comprehensive GEP model in a partially deregulated/restructured environment is exposed to discussion with respect to the social welfare, fuel-mix ratio, and reliability simultaneously in [19]. Reference [20] presents an integrated GEP model based on a decarbonizaition structure in order to analyze the impacts of the various low-carbon factors on optimal strategy. Investment decisions affected by incentive systems for exploitation of non-conventional units are evaluated in generation planning concerning emission constraint in [21, 22]. References [23-26] evaluate the effectiveness of various incentive policies by their capabilities to achieve a renewable portfolio standard in context of GEP problem.

In this paper, the impact of feed-in-tariff support scheme is investigated on renewable expansion planning and GENCO investment portfolio using a comprehensive GEP model incorporated with different constraints. Due to non-linearity, non-differentiability and high-dimensionality nature of the expansion planning, an efficient, and reliable heuristic technique inspired inherent by swarm behaviors namely, gravitational search algorithm (GSA) is also used to solve the GEP optimization problem. GSA, which is based on the Newton's law of gravity and mass interactions, has been verified high quality performance in solving different optimization problems in the literature [27-29].

The rest of this paper is organized as follows. How FIT incentive policies influence the investment decisions in the GEP framework is discussed in section 2. Section 3 describes the proposed hierarchy to find an optimal generation expansion planning strategy. Section 4 explains the GSA principles in detail and the numerical analysis is presented in section 5. Finally, concluding remarks are drawn in Section 6.

II. INCENTIVE POLICIES INTERVENTIONS

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. FIT is defined by the government as the price per unit (e.g. kWh), which is paid to the renewable power generators. Three key provisions can be assigned to the FIT as a price-based scheme, predefined purchase price or premium, guaranteed grid access and power generation for long-term contracts [30, 31].

In quotas, which is a quantity-based measure, a specified fraction of power producers should be supplied from renewable resources versus tradable green certificates reception for each unit of electricity produced. The other quantity-based measure is the auction that is based upon the competitive bidding process organized to buy a given quantity of renewable energy in which the lowest offered price is chosen as the winner. In fiscal incentive and tax credit, subsidies such as exemptions or rebates on taxes, tax refunds, charges or special financing, or depreciation conditions are suggested [13].

From the application and implementation viewpoint, FIT incentive is the most applied mechanism in which electricity produced by renewable resources is purchased at a predefined price or premium on energy spot prices [15]. This kind of incentive is legally guaranteed payments for produced energy by renewable resources, hence provides higher security for investors resulting in more allocation of renewable investment budget in expansion planning. Therefore, in the GEP framework, it is expected that the power-generated percentage of renewable resources be risen, whereas the percentage of power generated by fossil fuel is fallen during planning horizon while the FIT regime is applied. It should be noted that contracted premium price for each renewable technology type is different as well as the contract period, depends on generation cost and life cycle duration, respectively. The effects of different feed-in-tariff participants discussed above on RES development as well as environmental issues are illustrated in Figure 1.

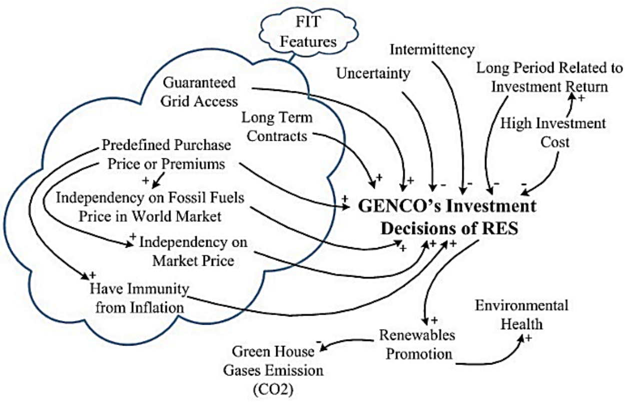

Figure 1. Causal diagram for RES investment decisions and FIT regime

III. PROBLEM STRUCTURE

The proposed hierarchy is generally illustrated in Figure 2. The multistage generation expansion planning is considered as the first step with respect to the required data including estimated load, market price, premiums related to the FIT incentive and available candidate technology types. In step #2, the optimum capacity, and arrangement of new plants from GENCO point of view, the whole FIT payments relative to each interval and GENCO profit are obtained after applying GSA to the previous step.

The amount of allocated investment budget to the renewable energy resources by GENCO, during the planning horizon, and the amount of released gas contaminations are both determined in step#3. Description of how GENCO investment portfolio and emission levels change, regarding the results yield for steps 2 and 3 is achieved in step#4. More detailed explanations about Figure (2) are elaborated in the following sections.

In the proposed framework, the decision-making of each GENCO with objective of profit maximization during a N^y year optimization horizon depends on capacity investment based on the projected demand, market price, premiums, allowed pollutant emission level and candidate technologies. Here, the objective function of a comprehensive GEP model based on aforementioned terms is presented as following.

$$\max: \left\{ \sum_{\pounds=1}^{N^y} (1+i)^{1-\pounds} \left(\pi_{\pounds} E_{\pounds}^{T} - \sum_{\Upsilon \in Z_{\pounds}^{ex}} GC_{\Upsilon,\pounds} E_{\Upsilon,\pounds}^{ex} + \sum_{\Upsilon \in Z_{\pounds}^{new}} (\pi_{\Upsilon,\pounds}^{FIT} - GC_{\Upsilon,\pounds}) E_{\Upsilon,\pounds}^{new} - I_{\Upsilon,\pounds} CP_{\Upsilon} N_{\Upsilon,\pounds}^{u} \right) \right\} \quad (1)$$

$$N_{\Upsilon,\pounds}^{u} = \begin{cases} 0 & \forall \quad (X_{\pounds,\Upsilon} - X_{\pounds-1,\Upsilon}) \le 0 \\ X_{\pounds,\Upsilon} - X_{\pounds-1,\Upsilon} & \forall \quad (X_{\pounds,\Upsilon} - X_{\pounds-1,\Upsilon}) > 0 \end{cases} \quad (2)$$

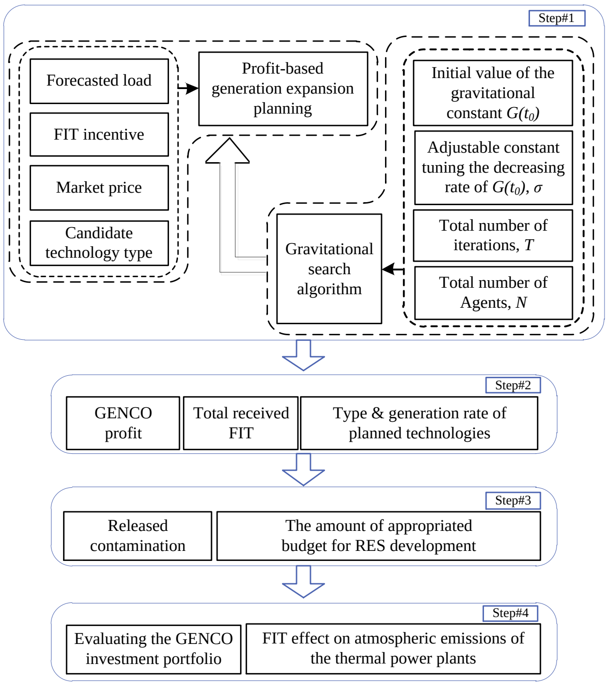

Figure 2. The proposed framework for evaluating GENCO investment decisions and atmospheric emission considering FIT regime

Equation (1) comprises the net present worth (NPW) of the gain, obtained from the difference between incomes and costs. Rate i is used to discount all future cash flows including both incoming and outgoing. Energy sold at the market price and feed-in tariff related to the incentivized renewable technologies result in revenue for GENCO. Considering the difficulty of determining a sensible price forecast for a finer time scale, an average yearly price, which is varying linearly during expansion horizon, is adopted. The number of generation units based on technology Υ, starting operation during the year $\pounds$ is determined as Equation (2). The regional and national constraints of the model associated with GENCO and system operator task are provided as follows.

A. Energy Balance Constraint

Equality constraints (3), one for each year, represent the balance between energy sold at the market and produced by all units, both existing and new.

In other words, type and number of added unit in each stage should be selected so that in addition seeking maximum profit, the meeting of the forecasted load is also guaranteed.

$$E_{£}^{T} = \sum_{\Upsilon \in Z_{£}^{ex}} E_{\Upsilon,£}^{ex} + \sum_{\Upsilon \in Z_{£}^{new}} E_{\Upsilon,£}^{new} \quad (3)$$

B. Budget Constraint

This constraint specifies the upper limit on total spending by the GENCO over the planning stages. Through this constraint, in fact, the maximum investment amount that the GENCO is able to make during the planning interval is considered. In this constraint the investments made at different planning stages in the future is comparable with respect to present day budget available using discounted values.

$$\sum_{£}^{N^{y}} \sum_{\Upsilon \in Z_{£}^{new}} (1+i)^{1-£} \, (\mathrm{I}_{\Upsilon,£} \, CP_{\Upsilon} \, N_{\Upsilon,£}^{u}) \le In_{tot}^{bud} \quad (4)$$

C. Dynamic Capacity Update

The dynamic capacity update constraint relates the total investments made by the GENCO in a given year for technology Υ, to existing investments in the same technology:

$$C_{\Upsilon,£}^{tot} = N_{\Upsilon,£}^{u} \, C_{\Upsilon} + C_{\Upsilon,£-1}^{tot} \quad (5)$$

The investment decision variable, i.e. $N^{u}{}_{\Upsilon,£}$, depends on available budget in year £. The $N^{u}{}_{\Upsilon,£}$ is merely selected when the value of the project exceeds the value of deferring the decision to invest in the future [32].

D. Limitation of Constructions

The construction time of the generating units, proportional to their types, practically restricts the number of units selected to build during a planning interval. This regional constraint is expressed as the limitation of constructions:

$$0 \le N_{\Upsilon,£}^{u} \le N_{\Upsilon,£}^{u^{\max}} \quad (6)$$

$$0 \le \sum_{£}^{N^{y}} N_{\Upsilon,£}^{u} \le W_{\Upsilon}^{\max} \quad (7)$$

where, $N_{\Upsilon,£}^{u^{\max}}$ is the maximum number of units relevant to type Υ and year £, that can be selected to build. Upper bounds related to the maximum number of units to be installed for each technology type are also established in Equation (7).

E. Fuel Mix Constraint

In the GEP problem, an optimal planning strategy must have an appropriate mix of coal, hydro, gas, wind and other technologies, as supply of any one kind of fuel is unreliable. In other words, considering to the diversity of power plant types and for maintaining the system security at an acceptable level, it is required that the total capacity of peak type generating unit be more than a certain percent of the total capacity of base type units. The aforementioned explanations can be presented as fuel mix constraint.

$$\sum_{\Upsilon \in Z_{£}^{ex,base}} \xi \, N_{\Upsilon,£}^{u} C_{\Upsilon} \le \sum_{\Upsilon \in Z_{£}^{ex,peak}} N_{\Upsilon,£}^{u} C_{\Upsilon} \quad (8)$$

where, ξ is the fuel mix ratio, $Z_{£}^{ex,base}$ and $Z_{£}^{ex,peak}$ are the sets of base and peak type technologies available for year £ respectively. This constraint ensures that the proposed plan guarantees a stable supply to the required reliability levels.

F. Emission Constraint

As mentioned, in the past decades, the environmental issues have become a society concern and since 1990, the Clean Air Act Amendments passage a law to force the utilities to modify their design or operational strategies for reducing pollution and atmospheric emissions of the thermal power plants [33]. Generation of electricity from fossil fuel in power plants releases several contaminants, such as SO_2, NO_x, and CO_2 into the atmosphere corresponding with variety of technology types. Therefore, for an efficient GEP from the social and environmental viewpoints, emission effects should be taken into account in the electricity planning process.

As a result, GENCOs are required to hold an equivalent amount of allowances to offset their pollutant emissions. Typically, emission is expressed as a polynomial or a combination of polynomial and exponential functions, depends on desired accuracy. In this paper, the emission curve is considered as a combination of polynomial and exponential functions [34] as:

$$\sum_{\Upsilon}^{Z_{£}^{ex}} (\alpha_{\Upsilon} + \beta_{\Upsilon} E_{\Upsilon,£} + \gamma_{\Upsilon} . E_{\Upsilon,£}^{2} + \eta_{\Upsilon} \exp(\mu_{\Upsilon} E_{\Upsilon,£})) \le EL^{\max} \quad (9)$$

where, $EL^{\max}$ is the total limit of pollutant emission during the planning horizon. The coefficients α, β, γ, η and μ are also emission constant related to each technology type.

IV. SOLUTION BY GSA

The model described in the preceding section consists in a large-scale mixed integer nonlinear programming (MINLP) problem. It is amenable to be solved by the gravitational search algorithm [35]. In this section, GSA mechanism is scrutinized first, and then the applying steps of the algorithm to the explained model are expressed.

A. Algorithm Outline

In the GSA, agents are considered as objects and their performances are measured by their masses. All these objects attract each other by the gravity force, and this force causes a global movement of all objects towards the objects with heavier masses. Hence, masses cooperate using a direct form of communication through gravitational force. The heavy masses (which correspond to good solutions) move more slowly than lighter ones. This guarantees the exploitation step of the algorithm. In this algorithm, each mass (agent) has four specifications viz. position, inertial mass, active gravitational mass, and passive gravitational mass.

The position of the mass corresponds to the solution of the problem, and its gravitational and inertial masses are determined using a fitness function. The algorithm is navigated by properly adjusting the gravitational and inertial masses. By lapse of time, it is expected that masses be attracted by the heaviest mass. This mass will present an optimum solution in the search space. Masses obey the following two laws.

1. Law of Gravity: Each particle attracts every other particle and the gravitational force between two particles is directly proportional to the product of their masses and inversely proportional to the square of the distance (R) between them. In reference [35], R was used instead of R^2 because R offered better results than R^2 in all the experimental cases with benchmark test functions.

2. Law of Motion: The current velocity of any mass is equal to the sum of the fractions of its previous velocities and the variations in the velocity. Variation in the velocity or acceleration of any mass is equal to the force acted on the system divided by the mass of inertia.

Now, let us consider a system with n agents (masses). At the beginning of the algorithm, the position of any agent i, consisting off N number of masses may be defined as:

$$X_i = (x_i^1, ..., x_i^d, ..., x_i^n) \qquad \forall\, i = 1, 2, ..., N \tag{10}$$

where, n is the space dimension of the problem and x_i^d defines the position of the ith agent in the dth dimension. Initially, the agents of the solution are defined randomly and according to Newton gravitation theory, a gravitational force from mass j acts mass i at the time t is specified as follows:

$$F_{ij}^d(t) = G(t)\frac{M_{pas\,i}(t).M_{act\,j}(t)}{R_{ij}(t)+\varepsilon}\left(x_j^d(t) - x_i^d(t)\right) \tag{11}$$

where, $M_{act\,j}(t)$ is the active gravitational mass related to the jth agent at time t, $M_{pas\,i}(t)$ is the passive gravitational mass related to the ith agent at time t, $G(t)$ is gravitational constant at time t, ε is a small constant, and $R_{ij}(t)$ is the Euclidian distance between the two agents i and j given by the following equation:

$$R_{ij}(t) = \left\| x_i^t, x_j^t \right\|_2 \tag{12}$$

To give a stochastic characteristic to the algorithm, it is expected that the total force that acts on the ith agent in the dth dimension be a randomly weighted sum of dth components of the forces exerted from other agents given by following equation:

$$F_i^d(t) = \sum_{j=1,\, j\neq i}^{N} \text{rand}_j \times F_{ij}^d(t) \tag{13}$$

where, rand_j is a random number in the interval [0, 1]. Hence, by the law of motion, acceleration of the ith agent at time t in the dth dimension is given as:

$$acc_i^d(t) = \frac{F_i^d(t)}{M_{int\,i}(t)} \tag{14}$$

where, $M_{int\,i}(t)$ is the inertial mass of the ith agent. Position and velocity of an agent could be calculated by employing Equations (15) and (16), respectively.

$$v_i^d(t+1) = \text{rand}_i \times v_i^d(t) + acc_i^d(t) \tag{15}$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \tag{16}$$

In Equation (15), rand_i is a uniform random variable in [0, 1]. This random number is utilized to give a randomized characteristic to the search. The gravitational constant G is initialized at the beginning and will be reduced with time to control the search accuracy. This constant, as a function of the initial value G_0 and time t, is expressed as in the following equation:

$$G(t) = G(G_0, t) = G(t_0)\, e^{-\sigma \frac{t}{T}} \tag{17}$$

In Equation (17), $G(t)$ is the value of the gravitational constant at time t, $G(t_0)$ is the value of the gravitational constant at the first cosmic quantum. σ is an adjustable constant tuning the decreasing rate of $G(t_0)$, T the total number of iterations and t is the current iteration.

The masses of the agents are computed using fitness evaluation. The heavier mass of an agent, the more influential is that agent, concerning the solution it represents. It is notable that as the Newton's law of gravity and law of motion refer, a heavy mass has a higher pull on power and moves slower. The masses are updated as follows:

$$M_{pas\,i} = M_{act\,i} = M_{ii} = M_i \quad i = 1, 2, ..., N$$

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \tag{18}$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j} \tag{19}$$

where, $fit_i(t)$ represents the fitness value of the agent i at time t, and the $best(t)$ and $worst(t)$ specify the strongest and the weakest agent of the population, respectively, with respect to their fitness route. For a minimization problem:

$$best(t) = \min_{j\in\{1,...,m\}} fit_j(t) \tag{20}$$

$$worst(t) = \max_{j\in\{1,...,m\}} fit_j(t) \tag{21}$$

For a maximization problem:

$$best(t) = \max_{j\in\{1,...,m\}} fit_j(t) \tag{22}$$

$$worst(t) = \min_{j\in\{1,...,m\}} fit_j(t) \tag{23}$$

In order to solve the optimization problem with GSA, as mentioned above, at the beginning of the algorithm, every agent is placed at a certain point of the search space which specifies a solution to the problem at every unit of time. Then according to Equations (15) and (16), the agents are recovered and their next positions are computed. Other parameters of the algorithm like the gravitational constant G, masses M and acceleration acc, are computed via Equations (17), (18), (19), and (14) respectively, and are updated every cycle of time. Accordingly, based upon aforementioned terms in gravitational search algorithm, flow diagram of this algorithm is shown Figure 3.

B. Application of GSA to the GEP

In this section, a new heuristic optimization algorithm based on Newton's law of gravity and mass interactions for solving the GEP problem is described as follows:
Step 1. Search space identification,
Step 2. Randomized initialization,
Step 3. Evaluate agent's fitness,
Step 4. Update $G(t, min(t), max(t))$, $M_i(t)$ for i=1,2,…, n,
Step 5. Calculation of total force in different directions,
Step 6. Calculation of acceleration and velocity,
Step 7. Updating agents' position,
Step 8. Repeat steps 3 to 7 until the convergence criterion is reached,
Step 9. End.

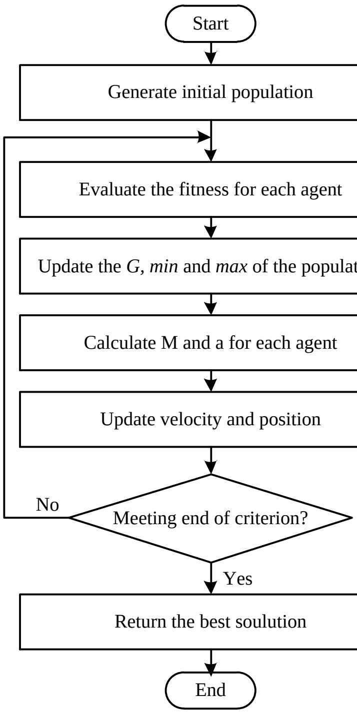

Figure 3. The flowchart of the GSA

V. TESTS AND RESULTS

In this section, a 6-year optimization horizon is considered to expansion planning. In order to accomplishment of computations based on net present worth method, for Equations (1) and (4), a 5% discount rate is adopted [31]. The incentive and new plants data is also employed from [15] and [31]. The total system capacity is 2500 MW related to base year comprising coal-fired, combined-cycle gas turbines (CCGT), heavy oil-fired units and nuclear plants. The technical and economic data pertaining to the GENCO's generation mix corresponding to the beginning of the optimization interval is presented in Table 1. The forecasted peak demand in each interval and respective market price are also shown in Table 2.

Here, a total of eight energy sources including both renewable and nonrenewable technologies are considered for possible investment. Table 3 illustrates the main techno-economic data for candidate technologies.

In order to acquire better performance of GSA, the optimum settings of different parameters are required to be determined. In this paper, because of the stochastic nature of the GSA, different trials have been performed to detect the best-input parameters.

Based on the trials, following input parameters are considered: G_0 = 0.15, σ = 16, T = 300, N = 70. The last parameter required to be considered in GEP model is FIT schemes relative to each renewable technology type. According to dependency or independency on market price, FIT mechanism can be different in designing. In the market-independent FIT policies, which are generally known as fixed-price policies, a fix or minimum premium price of electricity generated by renewable energy resources is offered by regulator entities.

In this type of FIT scheme, the premiums have immunity from some effective economic variables such as inflation, the price of fossil fuels in world market and etc., which is caused risk aversion in investment decisions of the GENCO.

Table 1. Existing plant data

Technology type	Coal	CCGT	Nuclear	Oil
Generation cost (€/MWh)	33.96	72.46	13.95	61.14
Capacity (MW)	400	200	750	250
Number of units	1	1	2	2
Utilization hours (in year)	6000	5000	7800	4100
Generation rate (MW)	383	186	1451	431

Table 2. Forecasted peak demand and market price

Year	Load (MW)	Market price (€/MWh)
Base	2500	88.5
1	3700	88.75
2	4800	90.25
3	6100	91.63
4	7400	93
5	8300	94.38
6	9100	95.75

Table 3. New plants data [31]

Technology type	Generation Cost (€/MWh)	Investment Cost (M€/MWh)	Capacity (MW)	Utilization hours (in year)
Coal	33.96	1	600	6000
CCGT	72.46	0.47	400	5000
Nuclear	13.95	2.5	1200	7800
Hydro	19.67	3	10	3400
Wind	44.79	1.2	100	1700
Biomass	146.74	2.35	20	6100
Waste	58.31	4	50	5000
Solar	83.53	4	1	1400

In this paper, the average premium for renewable energies received per MWh in Spain market [15], summarized in Table 4, is considered as the FIT mechanism. As shown in Table 4, in this incentive scheme, the most prices belong to the solar plants in comparison with other renewables resulting from high investment cost.

Table 4. Premiums for renewable energy resources [15]

	Technology type				
Year	Hydro	Wind	Biomass	Waste	Solar
1	31.72	28.08	30.54	22.65	332.52
2	29.31	28.92	27.87	20.29	340.4
3	36.06	37.37	35.17	33.18	374.06
4	35.61	36.35	46.71	37.14	392.14
5	31.69	35.97	52.06	35.84	388.74
6	42.71	42.75	73.1	61.1	429.33

A. Expansion Planning Results

The GSA has been implemented to solve the GEP problem. To better appreciate the impact that FIT measure may have on a GENCO generation planning as well as emission level, two scenarios (S1 and S2) are considered. The base case scenario, e.g. S1, is defined regarding the proposed GEP model. Hence, having assumed an upper bound on the emission EL^{max} = 11000 ton/hour and an upper bound on investment $In_{tot}^{bud} = 8500$ M€ during the whole optimization horizon. Tables 5 and 6 summarize the results of GENCO's investment decisions, scheduled by solution, on both RES-based and conventional technology types as well as generation rate of new plants regarding the startup years of new generation units. The amount of conventional and RES-based power plants participation in power production is also illustrated in Figure 4.

Results show that implementation of feed-in-tariff system, for deployment of renewable energy resources, and emission constraint could affect the generation planning of GENCO operating in a liberalized environment, so that both FIT, as an incentive-based support scheme, and emission constraint cause more renewable penetration directly and indirectly, respectively.

Considering the amount of demand growth and acceptability of emission level during the early years of planning horizon, the obtained results corroborates the fact that whit less incentive payments, the tendency of generation company to investment in renewable resources is decreased due to high investment cost of renewable resources as well as their low generation amount.

In other words, by increasing the FIT premiums (according to Table 4), during the planning horizon, more percentage of available budget has been assigned to the renewable technologies. The emission model of the generation units according to Equation (9) is shown in Figure 5. As Figure 5 demonstrates, of the three fossil fuels units, coal-fired units generally emit more air pollution than units burning natural gas or oil and hence, it is taken into account as the largest source of various air pollution, such as mercury, in power industry.

Table 5. GEP results for renewable technology types-S1

	Number of selected units by GENCO for investment				
Year	Hydro	Wind	Biomass	Waste	Solar
1	1	3	1	0	0
2	0	1	2	1	1
3	2	3	2	1	2
4	0	2	0	0	0
5	2	4	4	4	4
6	1	4	3	4	0
	Generation rate (MW)				
1	10	300	20	0	0
2	0	100	40	50	1
3	20	300	40	50	2
4	0	200	0	0	0
5	20	400	80	200	4
6	10	400	60	200	0

B. Fit Impacts on GENCO's Investment Decision and Emission

For comparison purposes, the second scenario (S2) is simulated in which none of emission constraint and FIT incentive is assumed, regarding Equation (1), eliminating the effects of FIT mechanism from the GEP model is accomplished by setting the FIT premium prices to zero. The behavior of GENCO's investment decisions on renewable energy resources is provided in Table 7, while Table 8 summarizes total amount of FIT incentives paid to GENCO in S1, during each interval. GENCO profits yield from both S1 and S2 are also shown in Table 8. The behavior of emission from conventional units relative both scenarios S1 and S2 are shown in Figure 6.

Table 6. GEP results for conventional technology types-S1

	Number of selected units by GENCO for investment		
Year	Coal	CCGT	Nuclear
1	0	3	0
2	1	1	0
3	1	0	1
4	0	0	0
5	0	1	0
6	0	0	0
	Generation rate (MW)		
1	0	916	0
2	422	109	0
3	222	0	281
4	0	0	0
5	0	81	0
6	0	0	0

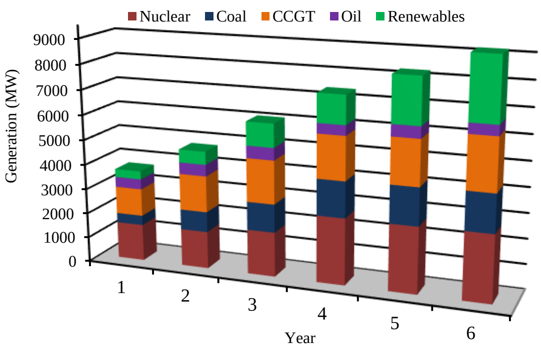

Figure 4. The amount of generation related each technology type-S1

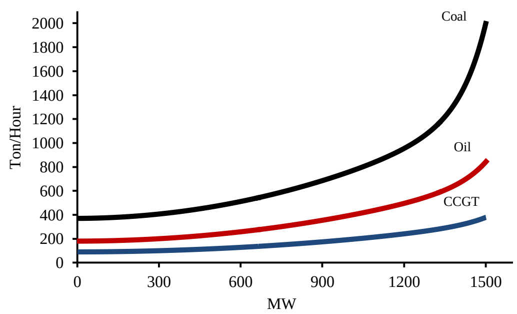

Figure 5. The emission model of nonrenewable power plants

Table 7. Number of selected units by GENCO for investment-S2

	Renewable technology types				
Year	Hydro	Wind	Biomass	Waste	Solar
1	0	1	0	0	0
2	0	1	1	0	0
3	0	1	1	0	0
4	0	0	0	0	0
5	1	2	0	0	0
6	1	2	1	0	0

Table 8. Total FIT payments and GENCO profit (M€)

Year	Total FIT received by GENCO	GENCO profit-S1	GENCO profit-S2
1	81.86	1743.7	1459.12
2	130.53	1955.2	1525.21
3	169.89	-2304.1	-2508.31
4	238.63	2303.36	1286.89
5	481.28	1046.4	1498.56
6	661.35	1767.93	1049.13

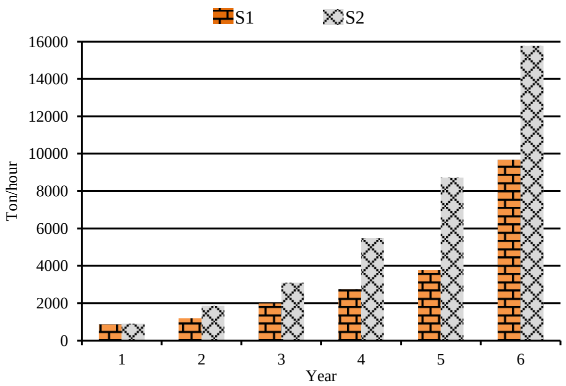

Figure 6. Maximum amount of released gas contamination, S1 and S2

Analyses of the findings reveal that without suitable incentives, few renewable technologies may be economically satisfied. Therefore, the investment in renewable generation is decreased resulting in more utilization of nonrenewable sources. Consequently the amount of atmospheric emissions of the thermal units is increased which has a remarkable impact on environmental health a global warming. From Table 8, it is apparent that GENCO profit obtained from incentivized renewable units by regulator entities is more than total FIT expenditures. Hence, apart from environmental benefits, which are not considered here in financial analyses of FIT effects, it can be concluded that intervention of incentive schemes in renewable expansion planning results in both environmental and economic benefits.

VI. CONCLUSION REMARKS

In this paper, a comprehensive GEP model is proposed for the evaluation of different generation technologies. The model described is relative to the expansion-planning problem faced by a GENCO whose choices are wholly driven by energy prices and current regulatory policies. To encourage the GENCO in investment on the renewables, feed-in-tariff mechanism is incorporated into the model, as one of the most applied support scheme. The idea of the proposed framework is that of evaluating the FIT impacts on GENCO investment decisions and environmental issues. Hence, two scenarios are defined to simulate the effects that FIT policies may have onto planning results.

The resulting model gives rise to a large-scale nonlinear programming problem with mixed (real and integer) variables. The solution of this problem is made difficult by the large number of logical constraints that need to be accounted for to properly model the incentive systems now adopted in many countries all over the world.

The gravitational search algorithm properly tailored on the characteristics of the GEP model, is found suitable to obtain satisfactory solutions within reasonable times. Results show that the implementation of FIT regime has desirable impacts on promotion of renewable resources due to some RES features such as high investment costs, intermittency, and uncertainty. Therefore, it can be seen that the FIT regime results in mitigation of gas contaminate derived from conventional units, circuitously.

NOMENCLATURES

A. Indices

$\pounds$: Index corresponding to years of the planning horizon

Υ: Index corresponding to a generation technology available for planning

B. Constants

CP_{Υ}: Capacity of a generation unit based on technology Υ (MW)

$GC_{\Upsilon,\pounds}$: Generation cost for technology Υ in the £th year (€/MWh)

EL^{max}: Upper allowed limit on the emission of units (Tones/h)

i: Discount rate

$I_{\Upsilon,\pounds}$: Investment cost for the installation of a generation unit of technology Υ in the £th year (€/MW)

In_{tot}^{bud} : Total present day budget available for planning (€/MW)

N^y: Number of years of the planning horizon

$N_{\Upsilon,\pounds}^{u\max}$: Upper bound related to number of units belonging to technology Υ in the £th year

$W_{\Upsilon}^{\max}$: Maximum number of units that can be installed for technology Υ

$\pi_{\Upsilon,\pounds}^{FIT}$: Sum of market price and FIT related to technology Υ in the £th year (€/MWh)

$\pi_{\pounds}$: Average market price in the £th year (€/MWh)

ξ: Fuel mix ratio

C. Variables

$C_{\Upsilon,\pounds}^{tot}$: Total existing capacity belonging to technology Υ in the £th year (MW)

$E_{\pounds}^{T}$: Total energy sold in the £th year (MWh)

$E^{ex}_{\Upsilon,\pounds}$: Energy produced by existing units of technology Υ in the £th year (MWh)

$E^{new}_{\Upsilon,\pounds}$: Energy produced by new units of technology Υ in the £th year (MWh)

$X_{\pounds,\Upsilon}$: Number of units belonging to technology Υ in operation in the £th year

D. Sets

$Z^{ex}_{\pounds}$: Set of existing units in the £th year

$Z^{new}_{\pounds}$: Set of new units in the £th year

$Z^{ex,base}_{\pounds}$: Set of base type existing units in the £th year

$Z^{ex,peak}_{\pounds}$: Set of peak type existing units in the £th year

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