Modelling Multi-Resource Regulatory Incentives in Expansion Planning Problem

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***Abstract*— In this paper, a new approach for distributed energy resources (DERs) expansion planning considering multi-resource regulatory incentives is presented. The intermittent nature as well as different uncertainties which are associated with the DERs would cause investors to encounter risk in their investment decisions. Therefore, considering the supporting policies for increasing the penetration rate of DERs are known as an inevitable issue. The supporting policies for each of DER technologies have remarkable impacts on investment strategy of other rivals. Consequently, the system dynamics approach is employed in this paper for modelling of this multi-dimensional complex problem. Here, the supporting policies are contemplated in combined heat and power, wind turbine and demand response resources. By using this method, the impacts of regulatory policies on market dynamics are modelled, which affect on market dynamics and investment policies of resource owners.**

***Index Terms*-- Distributed energy resources, expansion planning, multi-resource, incentive, system dynamics.**

I. INTRODUCTION

Emission reduction, depletion of fossil fuel energy resources, deregulated market environment and loss reduction have been caused to increase the special interests in distributed energy resources (DERs).

DERs as small-scale generating units are usually located nearby the load points and consist of a wide range of technologies such as renewable energy resources, fossil-based technologies, storage energy devices and demand side management (i.e., demand response (DR)) programs [1].

One of the crucial issues in competitive electricity market is increasing and inclusion of several stochastic and uncertain parameters which is due to the dynamic nature of system inputs and elements. Capacity investment for satisfying the future demand is also an uncertain issue because of system uncertainties such as long-term expectation of profitability. In competitive market environment with a large number of capitals associated with its undertaken risks, the investors tend to minimize the aforementioned risks. In this case, more investment will be employed by investors with the aim of increasing the expected profitability whilst decreasing the expected risk.

On the other hand, high investment costs as well as intermittency and uncertainty of some resources cause to prevent development of these resources. Some regulatory incentives can promote resources like renewable, DR programs and combined heat and power (CHP) with the purpose of leading this technology to compete with some distributed generation (DG) such as gas engines.

Many studies about DER expansion planning in deregulated environment have been conducted. A heuristic method beside economic analysis is addressed for optimal allocation of DGs in [2]. Refs. [3]-[6] discuss DG expansion in the presence of uncertainties in which several single-resource incentives have been considered.

Previous researches have utilized optimization methods based on equilibrium point for distributed resource expansion. The dynamic behaviour of investors and important market feedbacks are not taken into account in the above studies. Also, the aforementioned methods did not consider the deviation from long-term economic stability. Similar to many real economic systems, due to dynamic nature, generation resources do not encounter the required hypothesis that the system remains on long-run optimal trajectory at all the times [7]. In order to overcome the aforesaid challenges, applying some effective and descriptive methodologies seems to be necessary. System dynamics method as a strategic decision making tool can be useful due to its inherent characteristics. As a result, more actual perspective for strategic designing of power system can be achievable.

The system dynamics approach is considered in bulk generation expansion planning [7]-[11], while it has not been addressed in DER expansion planning so far.

It is important for DERs investors to properly identify the behaviour of the market in long term in order to evaluate their expansion strategies and obtain a suitable strategy. System dynamics theory doesn’t only simulate the actual behaviour of the market, but it can also represent the relationships between the main variables of the system in detail. Due to the existence of resources portfolio in the expansion planning with their own incentives, the impact of each incentive on penetration level of different resources should be investigated, which properly can be modelled through the system dynamics concept.

In this paper, the impacts of regulatory policies on market dynamics are modelled, which affect on dynamic behaviours and investment policies of resource owners. The proposed model simulates investments in a set of DER technologies, where each owner is represented in the model as a separate decision maker to maximize its profit. Long-term price elasticity of demand is also included in the model. Also, existence of DR as a virtual demand side resource has not been investigated in previous researches. Therefore, this resource along with other DERs has to be considered. The main contribution of this paper is presenting a model that comprehensively fulfils how to simulate the mutual effects of resources and their incentives on each other. Therefore, it can be mentioned that the system dynamic approach is employed here for modelling the DER expansion planning problem considering multi-resource incentives.

Rest of the paper is organized as follows. Section II describes DERs investment planning. Section III presents model requirements. Section IV presents modelling DERs expansion planning. Numerical results is illustrated and also analyzed in section V. Finally, section VI concludes the paper.

II. DERS INVESTMENT PLANNING DESCRIPTION

Long term behaviour of electricity market should be modelled for perfect investment decisions. In system dynamics approach, in each state of solving differential equation, investment decisions are taken based upon beneficial index. In fact, it describes relations between components which can evaluate the effects of policies and decisions on long-term behaviour of the system.

State variables of the investment system include capacity of each resource, forecasted load, production of rival investors and the incentives. The behaviour of investments can be investigated through appropriate determination of variables in several time states. In this study, fuel cost, demand growth, investment costs, interest rate, incentive, emission consideration and market type are external variables. Causal loop diagrams, which are sketches of the causal relations between different components of a system, are very useful tools for modelling the interactions between system variables. Fig. 1 represents the causal loop diagram of the problem.

Major loops in DER expansion decision model are demand loop, capacity loop (self and rival) and incentive loop.

The demand loop is the most important loop. The electricity demand reacts in response to changes in electricity prices. As a balancing loop for the "demand loop", a "capacity acquisition loop" is integrated in the model in the supply side. This loop describes investments and construction of the new generation capacities.

Moreover, the supply side is determined by the "Operation scheduling loop". Using this loop, utilization of different capacities for each class of technology is coordinated as a function of electricity price. One of the important interactions of variable is the loop which determines the "incentive loop". It expresses the amount of needed incentive that penetration level of each specified resource reach to its target.

III. MODELLING REQUIREMENTS

A. DER uncertainties

When power system takes on complexity with growing levels of DERs, there are more uncertainties and variability to be considered. As wind resources is one of the considered DERs in this paper, the stochastic nature of its power generation and seasonal intermittency are modelled with a probabilistic approach. An ARMA function is used [9] to capture the wind power generation and demand uncertainties. In this paper, the uncertainty of fuel is not considered and the gas engine resources are considered as deterministic resources.

To model the main uncertainties of demand side reactions to the proposed DR program (DRP), here, the class of customers and their behaviours regarding DRP are considered. The customers are classified according to the regional climate of their living area. For each customer class, those important factors such as their participation in the program and drop out/enrolment rates are taken into account. The DRP has a magnitude of potential market. The potential market for each class of the customers ($N_{b,t,h}$) should be estimated statistically [12]. Here, b shows the regional climate. The participation of customers in DRP contract is considered based on historical data. The uncertainty at fairly high levels can have a dramatic impact on the capacity value [13]. Participation in DRPs may be changed year by year as some customers drop out and others enrol. Most demand response programs require a one-year commitment, and customers must re-enrol on an annual basis. Ref. [14] illustrates how participation can change over time. A factor must be obtained from historical data and be multiplied to utility benefit function. Hence, it is assumed that the participation factor is 30% [15] and the dropout rate is taken 10% [14]. As a result, the actual number of participants $\tilde{N}_{b,t,h}$ can be calculated as is shown in (1) [16]:

$$\tilde{N}_{b,t,h} = N_{b,t,h} \times PF_{b,t,h} \times (1 - \text{drop}_{b,t,h}) \tag{1}$$

where, $PF_{b,t,h}$ is the customer participation factor and $drop_{b,t,h}$ is the dropout rate in each customer class, season and load level time step. The uncertainties of other resources are not considered here.

B. DER incentives

As it was described earlier, the characteristics of DERs such as the capital investment, primary resources, emission and uncertainty are different from each other; therefore, their regulatory may be different. DERs expansion planning program enormously depends to incentives. Different

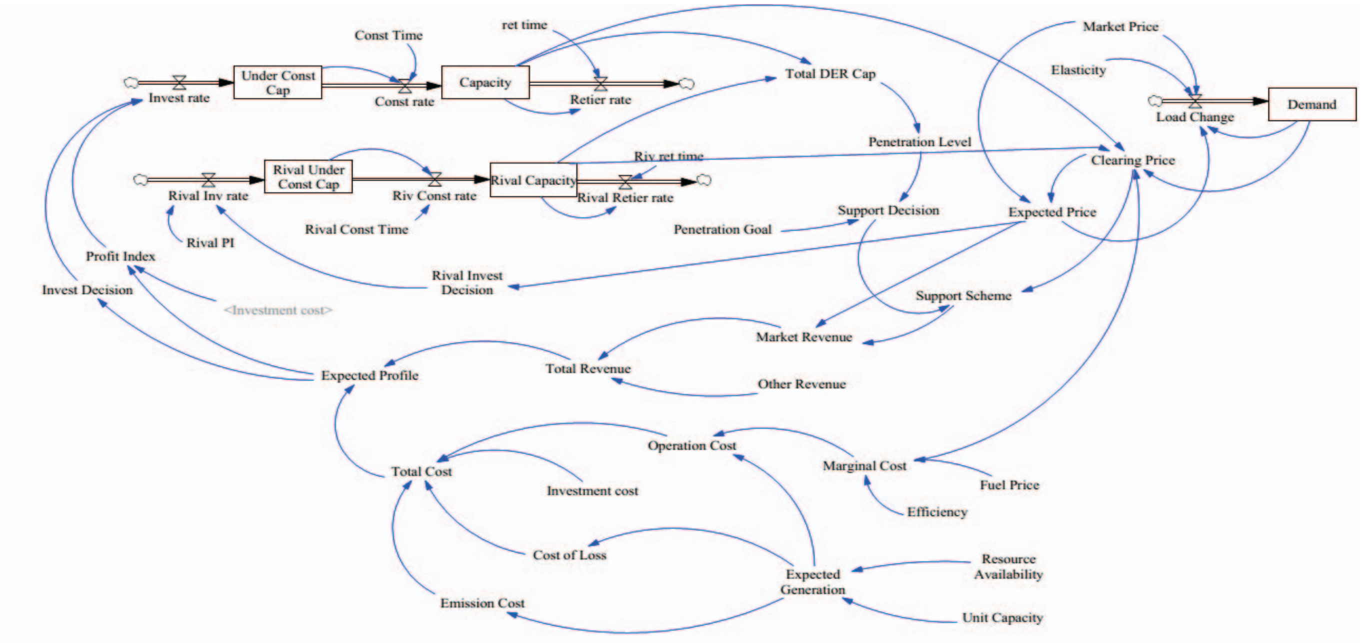

Figure 1. Casual loop diagram of DER expansion decision

mechanisms have been used to promote these resources worldwide [17]. In this paper, among various incentives, the most applied one, feed in tariff (FIT), is used for wind and CHP generations and market based incentive mechanism for promoting DRPs.

C. Modelling of the demand

The differential equation of load is used in the system dynamics model. Therefore, two main terms are considered, the first term is annual load growth which, can be represented by normal distribution and in case of system dynamics model is shown as (2).

$$d(t+\Delta t) = d(t) + \int_{t}^{t+\Delta t} DGR(\tau)\cdot d\tau \qquad (2)$$

where, *DGR* is the demand growth rate. The second term of the demand model illustrates its relation with the price, for taking into account the economical aspects of electric power consumption. Consumers are assumed to be able to modify their electrical energy consumption with price signal which depends to the price elasticity. Long-term price elasticity indicates the willingness to reduce electricity consumption (demand and/or time of use) over long period through investment on enabling technologies. Equation (3) states the responsiveness of electricity consumption to long-term price variations:

$$d(t) = d_0(t) + \varepsilon \frac{d_0(t)}{\pi_0(t)}(\pi(t) - \pi_0(t)) \qquad (3)$$

where, d and d_0 are actual and primary load in t, respectively and ε is the load elasticity. π and π_0 are actual and primary electricity price.

IV. MODELING OF DERS EXPANSION PLANNING

In the case of DER expansion planning, the impact of uncertainties and the regulatory policies on the market and investor's behaviour are modelled by the system dynamics approach. For this reason, differential equations are utilized. The following assumptions are considered for the modelling of the problem:

- The DERs include fossil-based DG, wind generator, CHP and DR program (market-based).
- Uncertainties of DERs, the electricity price and demand are considered.
- The electricity market is completely competitive.

The investors should properly forecast the electricity price to make an optimum investment decision. In this regard, the profit of each investor can be calculated according to (4). The net present value method is applied in profit evaluation in lead time of the project.

$$Profit_j = \sum_{t=1}^{T_j} \left(\frac{1}{1+IntR}\right)^t (B_j - Cvar_j) - Cfix_j \qquad (4)$$

where, B_j, $Cvar_j$ and $Cfix_j$ are benefit, variable cost and fixed cost of j-th technology, respectively and T_j is the life time of j-th technology. For economic viability of an investment in a specific time interval, the expected profit should be positive. Solving the equation $Profit_j = 0$ for interest rate, gives a value which designate the internal rate of return (*IRR*), and then the dimensionless profitability index (*PI*) can be calculated as (5).

$$PI_j(t) = \frac{IRR_j(t)}{IntR} \qquad (5)$$

The greater profitability index, encourage investors more. An S-shaped function has been proposed by [7] to describe the aggregated capacity investment in each technology. A logistic function has been used to describe the investment factor m_j for each generation technology and is shown in (6):

$$m_j = \frac{m_j^{\max}}{1+\exp(-\alpha_j \times PI_j - \beta_j)} \tag{6}$$

where, α_j, β_j and m_j^{max} are the S-shaped function coefficients. The investment rate at time t for the j-th technology can be computed as follow:

$$\dot{I}_j(t) = m_j \times \dot{I}_{ref} \tag{7}$$

$$\dot{I}_{ref} = \dot{D}_j(t) \times \dot{P}_j^{re}(t) \tag{8}$$

where, $\dot{D}_j(t)$ is the capacity addition rate of j-th technology and $\dot{P}_j^{re}(t)$ is retired capacity rate of j-th technology.

The capacity under construction for each technology is an accumulation depending to the construction accomplishment rate which is represented in (9).

$$P_j^c(t+\Delta t) = P_j^c(t) + \int_t^{t+\Delta t} \dot{P}_j^a(\tau)\cdot d\tau \tag{9}$$

In other words, the accomplishment rate depends on the capacity under construction and the construction time as illustrated in (10):

$$\dot{P}_j^a(t) = \frac{P_j^c(t)}{T_j^c} \tag{10}$$

Equations (11)-(13) represent the benefit of DGs (gas engines, CHPs and wind generators respectively) from selling electricity.

$$B_G(t) = \sum_{i=1}^{nlb} P_{G,i}(t) \times \pi(t) \tag{11}$$

$$B_{CHP}(t) = \sum_{i=1}^{nlb} \begin{aligned} &(P_{CHP,i}(t) \times [\pi(i) + f_{CHP}(\pi)] \times Eff_{CHP} + \\ &P_{CHP,i}(t) \times \pi_{heat} \times HTER) \end{aligned} \tag{12}$$

$$B_W(t) = \sum_{i=1}^{nlb} Prob(i,t) \times P_{W,i}(t) \times [\pi(t) + f_W(\pi)] \tag{13}$$

where, $P_{G,i}(t)$, $P_{CHP,i}(t)$, $P_{W,i}(t)$ are capacity of gas engine resources, wind resources and CHPs respectively. π_{heat} is the heat price and *HTER* is the heat to electricity ratio and Eff_{CHP} is efficiency of CHPs. $f_{CHP}(\pi)$ is the incentive function related to CHP, $f_W(\pi)$ is the incentive function related to the wind generators. The aim of using CHPs is obtaining electric power; then, the income from sales of heat is converted to electricity. Therefore, its benefit function will be as (12). In this paper, the DR investor is assumed to be DISCO. Its benefit function is illustrated in (14). The infrastructure capacity deferral is important goal for utilization of DERs. The income from this deferral is considered as a DISCO reward and is shown by ΔPV in (14) [18]. The other income is from the penalty of consumer because of not responding to DRP and its cost is due to the incentives given to customers for participating in DRP. Therefore, the benefit function of DISCO can be formulated as follows:

$$\begin{aligned} &BDis(t) = (-Inc \times \pi(t) \times (d_0(t) - d(t)) + Pen \times \pi(t) \times (d(t) - \\ &Pcont(t))) \times \tilde{N}_{b,h,t} - Ptrade(t) - DRInv + \Delta PV \end{aligned} \tag{14}$$

where, *Inc* is the incentive coefficient for participation of consumers in DRP and *Pen* is the penalty coefficient for the consumers who do not contribute in their commitment in DRP. *Pcont* is the contracted amount of power which consumers would reduce through DRP. *Ptrade* is amount of purchase/sale from/to upper network. Enabling technologies, infrastructures of DR programs and their related hardware, are DR capital investment cost represented by *DRInv* in (14).

The costs of each DG unit contains investment cost (fixed cost) and operation cost, environmental cost and the penalty cost for loss proportion in feeders (variable cost) and are represented by (15)-(19):

$$Cfix_j = \sum_{i=1}^{nlb} IC_j \times P_{j,i} \tag{15}$$

$$Cvar_j = C2_j + C3_j + C4_j \tag{16}$$

$$C2_j(t) = \sum_{i=1}^{nlb} C_{MWh,j} \times P_{j,i}(t) \tag{17}$$

$$C3_G(t) = \sum_{i=1}^{nlb} P_{G,i}(t) \times \sum_{k=1}^{3} \omega_k \times ER_k \tag{18}$$

$$C4_j(t) = \pi_{Loss}(t) \times P_{Loss,j}(t) \tag{19}$$

where, ω_k and ER_k are weighting factor and pollution rate of k-th pollutant. $C_{MWh,j}$ is operation and maintenance cost, $P_{Loss,j}$ is the loss caused by j-th technology and π_{Loss} is price of loss in feeders. The active power line losses are obtained using generalized generation shift distribution factors (GGSDF) [19]. To evaluate the proposed model, numerical studies have been conducted using a test network that has been presented in detail in the next section.

V. NUMERICAL RESULTS

A. *Distribution System under Study*

The distribution system under study is the same as reported in [12]. It comprises a 132 kV/33 kV, 40-MVA substation serving loads at eight buses during normal operation. Each period of time is a season and the planning horizon is considered to be 10 years, thus 40 time sequences are studied. The profit of the investor will be affected by the fluctuation of electricity spot price resulting from elastic demand curve. The uncertainty function of wind power generation is evaluated in each season. Technical characteristics of the distribution system are available in [12].

The interest rate is assumed to be 12.5 %. Annual growth of demand is assumed to be 5%. The forecasted peak load of the distribution system is 57.272 MW. The presumed amounts of input parameters of the problem are according to the aforementioned references. Table I shows the simulation case studies. This table is presented with the purpose of investigating the effects of resources variations and regulatory policy changes. In each of the cases in column 2, available resources in expansion planning are mentioned and the incentive of each is also followed. Figs. 2 and 3 illustrate fixed and price based variable incentives. In these Figures, *CP* is the clearing price.

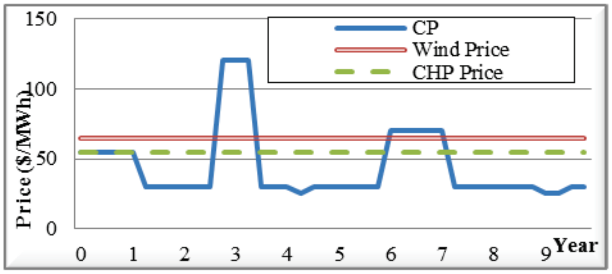

Figure 2. Fixed FIT for resources

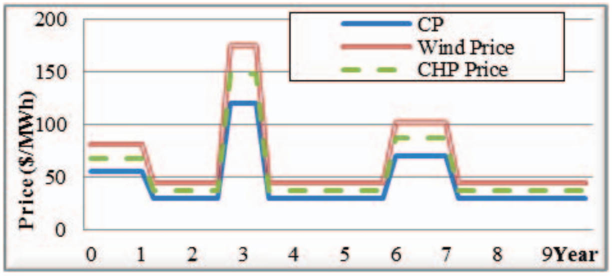

Figure 3. Variable FIT for resources

TABLE I. CASE STUDIES RELATED TO INVESTMENT DECISION PROBLEM.

Case1	Gas engine, DR and wind generator with fixed incentive
Case2	Gas engine, DR and wind generator with variable incentive
Case3	Gas engine, DR , wind generator and CHP with fixed incentive
Case4	Gas engine, DR , wind generator and CHP with variable incentive

B. *Simulation results*

The retail market is modelled with a supply and demand curve, and the electricity price is derived from the intersection of two curves. The time step is considered to be one season in the model. The results of energy resource expansion planning problem using the test model are illustrated in the following.

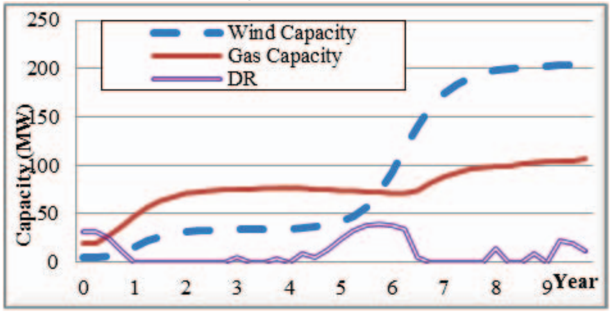

Figure 4. Investment capacity of case study #1

1) Case study 1: In this case, Gas engine, DR and wind generator are considered as resources and fixed FIT support is considered for the promotion of wind generation. Fig. 4 depicts the capacity of gas, wind and DR resources. As it is shown in this figure, growing rate of wind resources is much more comparing to gas resources in expansion years that by the incentive given to wind resources after 4 years (12 periods), the penetration rate of wind resources have become more than gas resources. DR resources growth shows that in periods with undesirable market prices that may not encourage wind and gas investors, DR resources will grow.

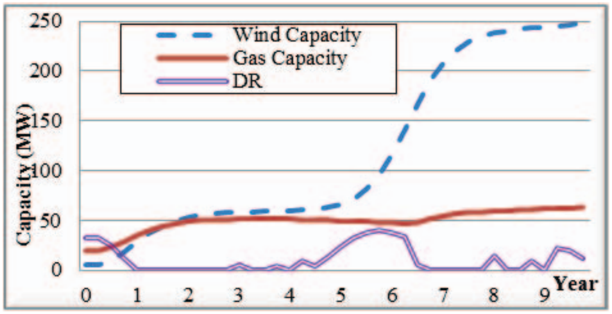

Figure 5. Investment capacity of case study #2

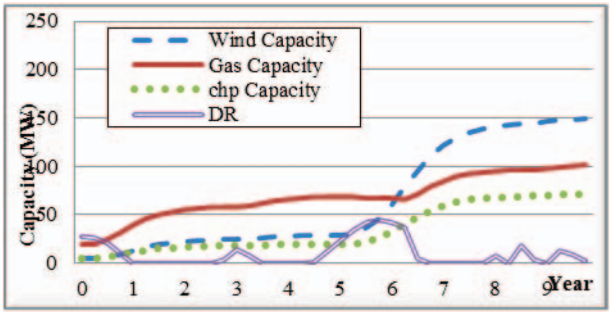

Figure 6. Investment capacity of case study #3

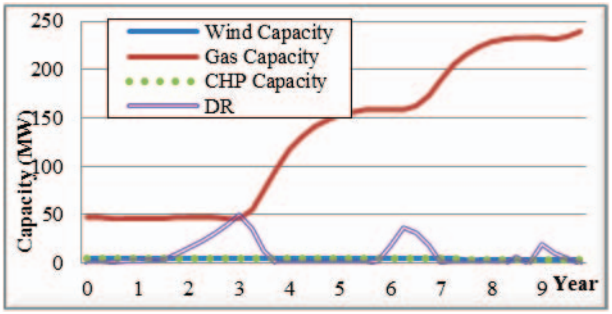

Figure 7. Investment capacity of case study #4

2) *Case study 2:* In this case, Gas engine, DR and wind generator are considered as resources and variable FIT support based on retail electricity price is considered for the promotion of wind generation. Fig. 5 shows the capacity of DERs expansion. In compare with previous results, it is denoted that, the variable incentive is more affordable than fixed incentive.

In this case, electricity price varying FIT is allocated to wind resources. Comparison of Figs. 5 and 4 proves that the investment rate in wind resources will increase in this case resulting to less investment rate on gas resources.

3) *Case study 3*: In this case, gas engine, DR, wind generator and CHP are considered as resources. Fixed incentives are considered for wind generators and CHPs. As capital cost (initial investment cost) of CHP is more

than wind resources, the amount of FIT allocated to this resource is more than wind in this case. But, their growth rate will be less than wind resources. Because of mutual effects of incentives, by comparing Figs. 5 and 4 it can be deduced that the growth rate of wind resources with the same amount of incentive will decrease. As in this case, DR resources are market-based, the growing amount of this resource during planning years will be constant comparing to case 1.

4) *Case study 4:* In this case, gas engine, DR, wind generator and CHP are considered as resources. Variable incentives based on retail electricity price are considered for wind generators and CHPs. The result of this case study is shown in Fig. 6. Comparing to case 3, it is shown that with the same average incentive, the amount of expansion growth of wind and CHP resources will decrease (in this case, they are not willing to investment).

Comparison of results of single-resource incentive cases with the multi-resource incentive ones show that, in order to achieve similar penetration rates of single-resource incentive, the amount of the incentive should be higher in case of multi-resources. Also, in the case of multi-resource incentive, the fixed incentive is more effective than the variable one. It means that, the results of several single-resource incentives could not be superposed to conclude multi-resource incentive results. Therefore, in order to achieve sustainable development, policies should be defined according the amounts necessary to increase the penetration rate of energy resources. In this case, single and multi-resource regulatory incentives have different reacts. Surely, the policies that support more growth and further diversification of energy resources, is more appropriate to achieve sustainable development.

VI. CONCLUSION

A comprehensive model for distributed energy resource expansion decision has been addressed using the system dynamics (SD) theory. The results illustrated that different structures of incentives have different impacts on investment strategies. By means of SD, the mutual effects of resources as a consequence of admitting the incentive on other resources growth are illustrated. In order to achieve the similar penetration rates of single resource incentive, the amount of the incentive may be higher in the case of multi resources. Price-based variable incentive could lead to lower investment risks in comparison with the fixed one in the case of single-resource incentive. But, in the case of multi-resource incentive it is vice versa. Furthermore, the amount of DR resources needed to be called is determined to avoid price spike. Mutual effects of incentives in multi-resource incentives confirm that, regulators cannot count on superposition of results of several single-resource incentives as same as the results of multi-resource incentives. The aforementioned incentives have different influence on sustainable development. Given the diversity and multiplicity of resources, a policy would be chosen that will make possible to achieve sustainable development.

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