SCIREA Journal of Science and Technology of Energy Sources

http://www.scirea.org/journal/Energy

October 30, 2016

Volume 1, Issue1, October 2016

A Two-Stage Optimization Model for Distribution System Planning Integrated Distributed Generator

V. V. Thang[1,*], B. Q. Khanh[2], H. T. Tung[1]

[1]Department of Electric Power Systems, Thainguyen University of Technology (TNUT), Vietnam

[2]Faculty of Electrical Engineering, Hanoi University of Science and Technology (HUST), Vietnam

Email: thangvvhtd@tnut.edu.vn

Abstract

A two-stage model for optimizing planning of distribution system with the presence of DG is presented in this paper. The proposed model can determine optimal upgrading sizing and timeframe of equipments (feeders and transformer substations) in distribution system. Hence, optimal displacement, sizing, technology and installation period of DG are also determined. The model's the objective function is life cycle cost to seek minimum costs for the planning scheme. The technical constraints are used to guarantee operability of the distribution system including AC power flow, feeder and substation upgrading section, limited of nodal voltage and DG capacity. Binary variables are also used in the model to represent the cost characteristic of equipments as well as investment and upgrade decisions. The calculation program is made in GAMS environment. The feasibility and effectiveness of the proposed model are examined by a 7-bus test system.

Key word: Distribution Systems, Distributed Generator, Life Cycle Costs, GAMS, MINLP

1. Introduction

In the past decade, distribution system planning had major changed due to the impact of competitive electricity market, DG technological development and environmental pollutions. In particular, DG connecting directly to DS or directly supplying to customers is used as a popular planning approach. These sources normally use electric generating technologies such as gas turbines, combined heat and power, Fuel Cells, solar energy and wind energies. Therefore, the benefits of DG including reduction of transmission and distribution cost, power loss and enhancement of flexibility and reliability of DS, improvement of differential voltage at nodes as well as reduction of environmental pollution [1][2]. However, DG requires high investment, makes increasing the complexity in measurement and relay protection as well as operation of DS [3]. Besides, DG using renewable energy resources has the naturally variable power according to primary energy.

Many planning models of the DG integrated distribution system are already been researched and proposed. The authors in [4] presented a long-term DS planning model in order to determine capacity, location and a new building investment process or to upgrade current equipments by using popular mathematical programming. The objectives of model are the minimum total of investment and operation costs of DG, the investing cost for feeder and substation transformers during planning period. The details of DG technology is not mentioned because of the assumption that the costing functions and effects of DG in DS planning are the same, but these are impossible in reality. Another model in [4] was proposed with the objective function including the total investing and operating costs of DG, feeders and substation transformers upgrading costs, energy expenses and minimum interruptible load costs. In this research, effects of DG technology are also not mentioned in selecting variables. The objective function of the two-stage DS planning model in [5] includes the minimum of total costs for upgrading feeders, substation transformers and DG construction, energy expenses purchased from market and environmental pollution costs. Similarly, [7] introduced a DS planning model determining optimized equipment sizing and timeframe required for DS upgrading. The selection issues optimal displacement, sizing, installation period and technologies of DG to meet the demand growth are presented in [6]. Besides, the model uses the objective function that is minimum life cycle cost for the distribution system planning introduced in [8]. The model finds best distribution system planning scheme to maximize the overall benefits and costs in the life cycle of the system. In previous studies, the output power of DG is always assumed to be constant without regarding to the natural variability which depends on the primary energy, this is not practical. The power flow constraint usually uses DC model so the impacts of reactive power to the planning problem is ignored.

Therefore, this paper proposes a DS optimized planning model that integrates output power characteristics of DG, characteristics of load demand and electricity price. The AC power flow model is used to consider influences of reactive power in DS planning..

The next parts of this paper are organized as follows. Section 2 introduces a mathematical model with objective function and constraints. Section 3 shows calculated results from the 7-bus test DS. Conclusion is presented in Section 4.

2. The Mathematical Model

In competitive electricity market, DS are usually managed by distribution companies. These companies can buy electrical energy completely from electricity market or combine with investing DG in order to meet load demands in future. So, economic and technical indicators of planning project are changed which affects considerably to time, upgrading capacity of feeders and substations when DG are chosen in DS.

The proposed DS planning model is also executed in two stages. A MINLP model in first stage is calculated and its results are fed into second stages to arrive at a comprehensive plan. The second stage receives information transferred from the first stage includes a set of decisions on location and period for equipments investment. Therefore, this model needs not use for binary variables and it is a NLP model. It should be noted that the energy production schedule obtained from the first stage is temporary and is revised in the next stage. The accuracy of model is added in the second stage plan to more closely reflect the required investments and production schedules.

2.1 The Mathematical Model of First Stage

2.1.1 Objective Function

The objective function of proposed model is to minimize total life cycle cost of the investment project during calculation period as shown in [9] and is added the part that reduced costs due to lower emissions. The total cost of objective function is calculated at base year by equation $1/(1+r)^t$ with discount rate r as equation(1).

$$J = Min\sum_{t=1}^{T}\frac{1}{(1+r)^t}.\left(CF_t + CS_t + CDG_t + EDG_t + ES_t - TCO_t + RN_t\right)\ \forall t \in T \qquad (1)$$

Where, component CF_t is upgrading costs of feeders for year t with fixed capital cost (C^{FF}) and variable capital cost (C^{FC}) as shown in equation(2). The $\alpha_{ij.t}$ is binary variable to represent the cost characteristic and decision variable for feeder upgrading is $F_{ij.t}$.

$$CF_t = \sum_{i=1}^{N}\sum_{j=i+1}^{N} L_{ij}(C^{FF}.\alpha_{ij.t} + C^{FC}.F_{ij,t})\ \ \forall ij \in N, i \neq j, t \in T \qquad (2)$$

Similar to the above, substation transformers upgrading costs in year t (CS_t) including fixed capital cost (C^{SF}) and variable capital cost (C^{SC}) is presented in equation(3). The $\gamma_{i.t}$ is binary variable to represent the cost characteristic and decision variable for transformer upgrading is $\Delta S_{i,t}^{S}$.

$$CS_t = \sum_{i=1}^{NS}(C^{SF}.\gamma_{i,t} + C^{SC}.\Delta S_{i,t}^{S})\ \forall i \in N_S, t \in T \qquad (3)$$

Electrical energy purchased cost from electricity market (ES_t) is presented in equation(4).

$$\mathrm{ES}_t = \sum_{i=1}^{NS}\sum_{s=1}^{SS}\sum_{h=1}^{H} D_s.k_P.(\rho_{P.h}^{S}.P_{i,t,s,h}^{S} + \rho_{Q.h}^{S}.Q_{i,t,s,h}^{S})\forall i \in N_S, t \in T, s \in SS,\ h \in H \qquad \mathbf{(4)}$$

The equation (5) is new investment costs in year t with technologies k of DG. Beside, electrical energy purchased cost from electricity market and costs for fuel, operation and maintenance of DG depending on per technology k, operation season s and time h are shown in equation(6).

$$CDG_t = \sum_{i=1}^{N_{DG}}\sum_{k}^{K_{DG}} C_{i,k}^{DG}.P_{i,k,t}^{DG} \qquad \forall i \in N_{DG}, k \in K_{DG}, t \in T \qquad \mathbf{(5)}$$

$$EDG_t = \sum_{i=1}^{N_{DG}} \sum_{k=1}^{K_{DG}} \sum_{s=1}^{SS} \sum_{h=1}^{H} D_s(\rho^{DG}_{P.k}.P^{DG}_{i,k,t,s,h} + \rho^{DG}_{Q.k}.Q^{DG}_{i,k,t,s,h})$$
$$\forall i \in N_{DG}, k \in K_{DG}, t \in T, s \in SS,\ h \in H \tag{6}$$

The costs arising from emission tax can be reduced due to lower emissions when DGs using renewable energy resources are substituted for traditional energies in DS (TCO_t). This part is negative and shown in equation(7) with ξ is emission coefficient of traditional energies and β is emission tax that may be enforced by the government.

$$TCO_t = \sum_{i=1}^{N_{DG}} \sum_{k=1}^{K_{DG}} \sum_{S=1}^{S_S} \sum_{h=1}^{H} \beta.\xi.D_s.P^{DG}_{i,k,t,s,h} \qquad \forall i \in N_{DG}, k \in K_{DG}, t \in T, s \in S_S, h \in H \tag{7}$$

The residual value of equipments at the end of the planning period is presented in equation(8) and it is usually evaluated basic on the current market conditions. Hence, the residual value is the present value and it is calculated at base year in objective function.

$$RN_t = \frac{(t^F_{kh} - T_F)}{T_F}.CF_t + \frac{(t^S_{kh} - T_S)}{T_S}.CS_t + \sum_{k=1}^{K_{DG}} \sum_{i=1}^{N_{DG}} \frac{(t^{DG}_{kh,k} - T_{DG,k})}{T_{DG,k}} C^{DG}_{i,k}.P^{DG}_{i,k,t}$$
$$\forall i \in N_{DG}, k \in K_{DG}, t \in T \tag{8}$$

2.1.2 The constraints

a) Constraints for power flow

The output power characteristics of each DG technology using renewable energy resources fluctuate by time of day and season in year so the power of DG is also determined by each hour, season and specially, each technology k of DG. Hence, a AC nonlinear power flow model is used in this stage represented in(9). With this constraint, influences of reactive power to calculation power and voltage loss in DS are considered so results of proposed model are more exacter.

$$\sum_{k=1}^{K_{DG}} P^{DG}_{i,k,s,t,h} + P^S_{i,s,t,h} - PD_{i,s,t,h} = \sum_{j=1}^{N} \left|Y_{ij,t}\right|.\left|U_{i,s,t,h}\right|.\left|U_{j,s,t,h}\right|.\cos(\theta_{ij,t} - \delta_{j,s,t,h} - \delta_{i,s,t,h})$$
$$\sum_{k=1}^{K_{DG}} Q^{DG}_{i,k,s,t,h} + Q^S_{i,s,t,h} - QD_{i,s,t,h} = -\sum_{j=1}^{N} \left|Y_{ij,t}\right|.\left|U_{i,s,t,h}\right|.\left|U_{j,s,t,h}\right|.\sin(\theta_{ij,t} - \delta_{j,s,t,h} - \delta_{i,s,t,h})$$
$$\forall i, j \in N, k \in K_{DG}, s \in SS, h \in H, t \in T$$

(9)

Where, $P^{DG}_{i,k,s,t,h}$ and $Q^{DG}_{i,k,s,t,h}$ are output power of DG that changes depending on the primary energy introduction in(10).

$$P^{DG}_{i,k,s,t,h} = P^{DG}_{i,k,t}.k^{DG}_{k,s,h}; \quad Q^{DG}_{i,k,s,t,h} = \cos\varphi_k.P^{DG}_{i,k,s,t,h} \tag{10}$$

b) Capacity limited constraints of DG

These constraints allow select DG capacity in limit of DG technology at nodes, and it ensures annually upgrading power corresponding to equipment parameters as shown in(11).

$$\begin{array}{ll} 0 \le P^{DG}_{i,k,t} \le P^{DG}_{i,k,\max} & 0 \le Q^{DG}_{i,k,t} \le \tan\varphi_k.P^{DG}_{i,k,t} \\ P^{DG}_{i,k,t} = P^{DG}_{i,k,t-1} + \Delta P^{DG} & Q^{DG}_{i,k,t} = Q^{DG}_{i,k,t-1} + \Delta Q^{DG} \\ \forall t \ge 1, i \in N_{DG}, k \in K_{DG}, t \in T & \end{array} \tag{11}$$

c) Upgrading section constraints of feeder

Thermal limits are imposed to limit the loading of feeders and these limits take into consideration the new feeder investments. So, the feeder upgrading constraints and upgrading power satisfying equipment parameters are shown in(12). A step increase of feeder capacity at year t $(\Delta S^F_{\mathrm{ij},t})$ is set when capacity value is equal or greater than limit capacity used at year t-1.

$$\begin{array}{l} S^{\max}_{ij,t} \le (S^{*F}_{ij,t-1} + \Delta S^F_{\mathrm{ij},t}); \Delta S^F_{\mathrm{ij},t} \ge \Delta S^F_{\min}.\alpha_{\mathrm{ij,t}}; \quad \Delta S^F_{\mathrm{ij},t} \le M.\alpha_{\mathrm{ij,t}} \\ \forall t \ge 1, ij \in N, t \in T \end{array} \tag{12}$$

Then, feeder capacity needs to meet in order to supply power to the loads present in (13) and upgrading section is selected by equation(14) with current density J.

$$S^{*F}_{ij,t} = S^{*F}_{ij,t-1} + \Delta S^F_{\mathrm{ij},t} \qquad \forall t \ge 1, ij \in N, t \in T \tag{13}$$

$$F_{\mathrm{ij},t} \ge \frac{S^{*F}_{ij,t}}{\sqrt{3}U_{dm}.J}.\alpha_{ij,t} \quad \forall t \ge 1, ij \in N, t \in T \tag{14}$$

d) Addition capacity constraints for substation

These constraints allow maximize use of existing substations capacity and to satisfy upgrading power corresponding to equipment parameters. A substation capacity addition step size $(\Delta S^S_{\mathrm{i},t})$ is used to set substation sizes as in equation(15) with the maximum and minimum allowable capacity which a substation can be upgraded.

$$\begin{aligned}&S_{i,t}^{max} \le (S_{i,t-1}^{*S} + \Delta S_{\mathrm{i},t}^{S});\; \Delta S_{\mathrm{i},t}^{S} \ge \Delta S_{\min}^{S}.\gamma_{\mathrm{i,t}}; \qquad \Delta S_{\mathrm{i},t}^{S} \le M.\gamma_{\mathrm{i,t}} \\ &\forall t \ge 1, i \in NS, t \in T\end{aligned} \tag{15}$$

e) Constraints of nodal voltage limited

Technical requirement constraints of limited nodal voltage are given in equation(16). Voltages at substation nodes are assumed constantly.

$$\begin{aligned}&U_{\min} \le \left|U_{i,s,t,h}\right| \le U_{\max} \quad \forall i \in N_L, s \in SS, t \in T, h \in H \\ &\left|U_{i,s,t,h}\right| = cons\tan t \quad \forall i \in N_S, s \in SS, t \in T, h \in H\end{aligned} \tag{16}$$

The decision variables of model include real and binary variables so calculation results must be corrected by standard equipment in fact and used as parameters in second stage.

2.2 The Mathematical Model of Second Stage

This stage takes the input parameters obtained from the first stage as addition capacity of substations, upgrading section of feeders, installation location and period of DG. Then, it determines the DG capacity within pre-defined bounds.

2.2.1 Objective Function

The model has objective function similar first stage with upgrading variables of feeders $(F_{\mathrm{ij},t})$ and substations $(\Delta S_{\mathrm{ij},t}^{S})$ are replaced by equipment parameters obtained from the first stage. Hence, equations of objective function are presented as (17) and decision variable DG power is $P_{i,k,t}^{DG}$.

$$\begin{aligned}J_2 = Min\sum_{t=1}^{T}\frac{1}{(1+r)^t}.\Bigg(&\sum_{i=1}^{N}\sum_{j=i+1}^{N} L_{ij}(C^{FF}.\alpha_{\mathrm{ij}.t} + C^{FC}.F_{ij,t}^{*}) + \sum_{i=1}^{NS}(C^{SF}.\gamma_{i,t} + C^{SC}.S_{i,t}^{*S}) + \sum_{i=1}^{N_{DG}}\sum_{k=1}^{K_{DG}} C_{i,k}^{DG}.P_{i,k,t}^{DG} \\ &+ \sum_{i=1}^{NS}\sum_{s=1}^{SS}\sum_{h=1}^{H} k_s(\rho_{P.h}^{S}.P_{i,t,s,h}^{S} + \rho_{Q.h}^{S}.Q_{i,t,s,h}^{S}) + \sum_{i=1}^{N_{DG}}\sum_{k=1}^{K_{DG}}\sum_{s=1}^{SS}\sum_{h=1}^{H} k_s(\rho_{P.k}^{DG}.P_{i,k,t,s,h}^{DG} + \rho_{Q.k}^{DG}.Q_{i,k,t,s,h}^{DG}) \\ &+ \sum_{i=1}^{N_{DG}}\sum_{k=1}^{K_{DG}}\sum_{S=1}^{S_S}\sum_{h=1}^{H} \beta.\xi.D_s.P_{i,k,t,s,h}^{DG} + \frac{(t_{kh}^{F} - T_F)}{T_F}.\sum_{i=1}^{N}\sum_{j=i+1}^{N} L_{ij}(C^{FF}.\alpha_{\mathrm{ij}.t} + C^{FC}.F_{ij,t}^{*}) \\ &+ \frac{(t_{kh}^{S} - T_S)}{T_S}.\sum_{i=1}^{NS}(C^{SF}.\gamma_{i,t} + C^{SC}.S_{i,t}^{*S}) + \sum_{i=1}^{N_{DG}}\sum_{k=1}^{K_{DG}} \frac{(t_{kh,k}^{DG} - T_{DG,k})}{T_{DG,k}} C_{i,k}^{DG}.P_{i,k,t}^{DG}\Bigg)\end{aligned}$$

$$\forall ij \in N, k \in K_{DG}, t \in T, s \in SS, h \in H$$

(17)

2.2.2 The constraints

a) Constraints for power flow and nodal voltage limited

These constraints are similar in first stage and presented on equations(9)(16).

b) Capacity limited constraints of feeder and substation

To ensure the after upgrading feeders are not overloaded by thermal limit, load flow on feeder need observe as equation(18) and substation capacity must observe as equation(19).

$$S^F_{ij,t,s,h} \le S^F_{\max.ij,t} \forall t \ge 1, ij \in N, t \in T, s \in SS,\ h \in H \tag{18}$$

$$S^S_{i,t,s,h} \le S^S_{\max.i,t}\ \ \forall t \ge 1, i \in NS, t \in T, s \in SS,\ h \in H \tag{19}$$

c) Capacity limited constraints of DG

The investment location and period of DG was determined from first stage so these constraints allow selected DG capacity according to new limits as(20).

$$\begin{array}{ll} 0 \le P^{DG}_{i,k,t} \le P^{*DG}_{\max.i,k} & 0 \le Q^{DG}_{i,k,t} \le \tan\varphi_k . P^{DG}_{i,k,t} \\ P^{DG}_{i,k,t} = P^{DG}_{i,k,t-1} + \Delta P^{DG} & Q^{DG}_{i,k,t} = Q^{DG}_{i,k,t-1} + \Delta Q^{DG} \\ \forall t \ge 1, i \in N_{DG}, k \in K_{DG}, t \in T & \end{array} \tag{20}$$

The proposed comprehensive plan includes a MINLP model in first stage and NLP model in second stage. The calculation program is made in GAMS environment used MINOS solver [10] to find out an optimal solution. The parameters, sets and indices, and variables of model are presented in table 1, table 2 and table 3.

Table 1. Parameters

No	Symbol	Definition
1	r	Discount rate (%)
2	C^{FF}	Fixed capital cost of Feeder ($/km)
3	C^{FC}	Variable capital cost of Feeder ($/km.mm^2)
4	$L_{i,j}$	Length of Feeder (km)
5	$Y_{i,j,t}$, $\theta_{i,j,t}$	Magnitude and Angles of admittance matrix element (pu)
6	C^{SF}	Fixed capital cost of Substation ($/Substation)
7	C^{SC}	Variable capital cost of Substation ($/MVA)
8	$C^{DG}_{i,k}$	New investment cost for DG i, technology k ($/M)

No	Symbol	Definition
9	ρ_h^{PS}	Active power purchased cost from market (\$/kWh)
10	ρ_h^{QS}	Reactive power purchased cost from market (\$/kVAh)
11	$\rho_{P.h}^{DG}$	O&M cost and Fuel cost of DG for active energy (\$/kWh)
12	$\rho_{Q.h}^{DG}$	O&M and Fuel cost of DG for reactive energy (\$/kVAh)
13	$PD_{i,s,t,h}$	Active power demand at bus (kW)
14	$QD_{i,s,t,h}$	Reactive power demand at bus (kVAr)
15	$P_{max.i,k}^{DG}$	Maximum power limit of DG i, technology k (MW)
16	$Cos\varphi_k$	Power factor of DG with technology k
17	$P_{max.i,k}^{*DG}$	New maximum power limit of DG in second stage (MW)
18	$F_{ij,t}^{*}$	Standard section of Feeder in planning year t (mm^2)
19	$S_{ij,t}^{*F}$	Maximum capacity need upgrading of Feeder (MVA)
20	ΔS_{min}^{F}	Capacity ramp-up limit for Feeder (MVA)
21	$S_{max.ij,t}^{F}$	Maximum capacity limit of standard Feeder (MVA)
22	$S_{i,t}^{*S}$	Maximum capacity need upgrading of Substation (MVA)
23	ΔS_{min}^{S}	Capacity ramp-up limit for Substation (MVA)
24	$S_{max.i,t}^{S}$	Maximum capacity limit of standard Substation in planning year t (MVA)
25	J	Current density at thermal limit (A/mm^2)
26	M	Big number used maximum limit of variables in MIP and MINLP models
27	U_{max}	Maximum voltage limit at bus (pu)
28	U_{min}	Minimum voltage limit at bus (pu)
29	ΔP^{DG}	Active power ramp-up limit for DG (MW)
30	ΔQ^{DG}	Reactive power ramp-up limit for DG (MVAr)
31	$k_{k,s,h}^{DG}$	Output power factor of DG with technology k
32	k_P	Variation factor of the price of electricity
33	D_S	Total day per season
34	ξ	Emission coefficient of traditional energies
35	β	Emission tax

Table 2. Sets And Indices

No	Symbol	Definition
1	N	Set of buses in distribution system
2	i, j	Bus (i, j $\in$ N)
3	N_L	Set of load buses in distribution system
4	N_S	Set of substation buses in distribution system
5	N_{DG}	Set of DG buses in distribution system
6	t, T	Planning year and overall planning period (t $\in$ T)
7	h, H	Hour and hours per day (h $\in$ H)
8	k,K_{DG}	Technology and total technology of DG (k $\in$ K_{DG})
9	s,SS	Season and total seasons in year (s $\in$ SS)

Table 3. Variables

No	Symbol	Definition
1	$F_{\mathrm{ij},t}$	Upgrading section of Feeder (mm^2)
2	$\Delta S^{S}_{\mathrm{i},t}$	Addition capacity for Substation (MVA)
3	$P^{DG}_{\mathrm{i},k,t}$	New investment capacity of DG (MW)
4	$P^{S}_{\mathrm{i},s,t,h}$	Active power purchased from electricity market (kW)
5	$Q^{S}_{\mathrm{i},s,t,h}$	Reactive power purchased from electricity market (kVAr)
6	$\Delta S^{F}_{\mathrm{ij},t}$	Addition capacity of Feeder (MVA)
7	$P^{DG}_{\mathrm{i},k,s,t,h}$	Active output power of DG (kW)
8	$Q^{DG}_{\mathrm{i},k,s,t,h}$	Reactive output power of DG (kVAr)
9	$U_{i,s,t,h}$	Voltage for bus (pu)
10	$\delta_{i,s,t,h}$	Voltage angle at bus (pu)
11	$\alpha_{\mathrm{ij},t}$	Binary variable on feeder upgrade decision (1/0)
12	$\gamma_{i,t}$	Binary variable on feeder upgrade decision (1/0)

3. Results And Discussions

3.1 Diagram and Parameters of distribution system

The 7-bus and 22kV voltage radial diagram is investigated in this research as figure 1 and is connected to 110kV transformer substation. The total active power and reactive power at the base year are 8838.0kW and 7309.2kVAR, respectively.

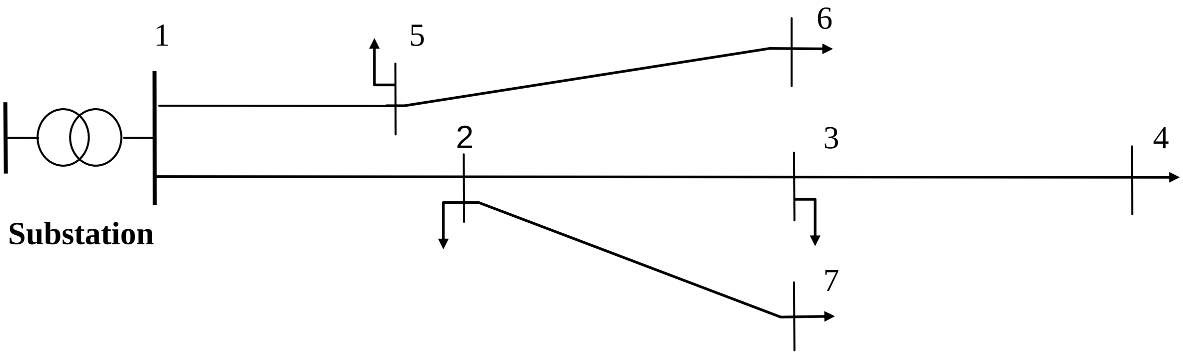

Figure 1. Diagram of test distribution system

3.2 Assumptions in analyis

This research utilizes some economic and technical assumptions for the ease of computation:

- Planning period is 5 years and annual developing rate of load demand is constant, 10% per year. At all of load locations the typical characteristics of load demand for four seasons are assumed as figure 2.

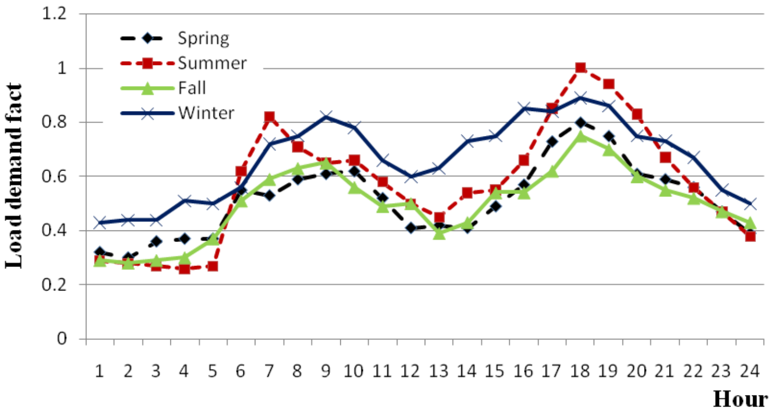

Figure 2. The typical characteristics of load demand for four seasons

- The constructing cost of 110kV substation including fixed costs and variable costs is 0.2M$ and 0.05M$/MVA, respectively (S. Wong, K. Bhattacharya1and J.D. Fuller 2009).

Similarly, the upgrading costs of 22kV feeders consist of 0.15M$/km and 0.001M$/MVA.km. The assumption life of feeder is 20 year.

- The effects of each DG technology are represented by investment, operation and fuel costs. Two DG technologies, photovoltaic (PV) and gas turbine sources, are used in this research with the corresponding capital costs to be 3.0M$/MW and 0.8M$/MW.
- Average operation and management (O&M) costs depend on used technology and the life of DG such as table 4.
- Energy prices purchasing from electricity market through substations are shown in figure 3.

Table 4. Average O&M Costs And Lifespan of DG

No	**Technology**	**Average O&M costs**		**Lifespan (years)**
		Active power ($/kWh)	**Reactive power ($/kVArh)**	
1	PV	5	0	30
2	Gas turbine	50	2.5	20

- PV and gas turbine are manufactured in compact modules occupying small spaces and time to install is short. Hence, installing areas are not limited and DG can be selected to install at all of load locations. Similarly, areas for upgrading of substation transformers and feeders are not limited.
- Constraints of load nodes voltage limited allow change from 0.9pu to 1.1pu, and it should be 1.05pu at substation node.
- Decided variables in the model are continuous in order to reduce the complexity of the model. Hence, they should be rounded to match real equipments.

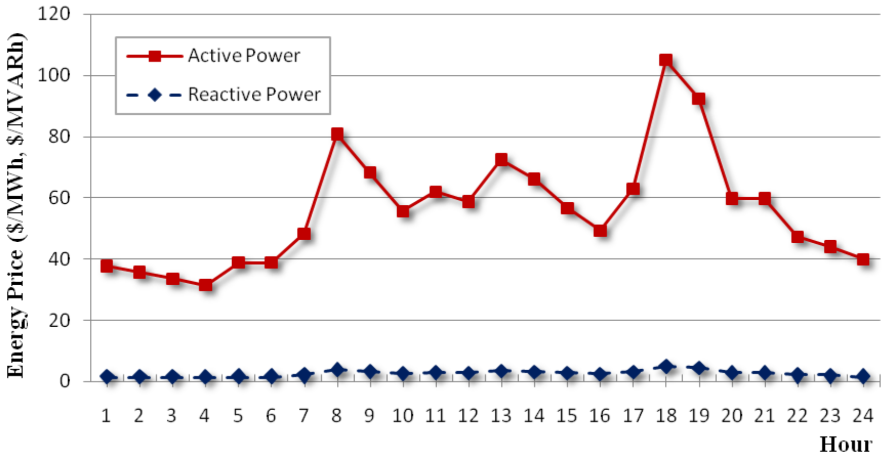

Figure 3. Energy prices purchasing from electricity market

3.3 The output power characteristics of DG

The output power of PV depends on the intensity of solar radiation and its performance. The power factor of PV calculated basing on the given solar radiation intensity is presented as figure 4. In contrast, gas turbine does not depend on the nature of the primary energy source so its output power can be constant.

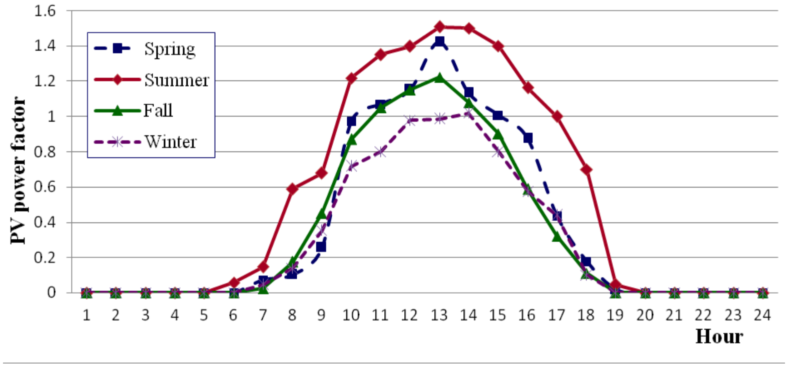

Figure 4. The output power characteristics of PV

3.4 Analysis results and disscussions

The feasibility of the proposed model and efficiency of DG are investigated in two cases. Case A is calculated when DG is not considered. Conversely, case B integrates DG in the researching model to plan the DS.

The calculation results showed that both of two cases are upgraded the substation with 10MVA capacity. However, case A is just upgraded at first year and investment to upgrade substation in case B is deferred to 3rd year because of the load demand increasing in the future is provided by DG. Similarly, in the case A, 3 feeders need be upgraded in the time from 2nd year to 5th year as represented in table 5. The feeders 2-3 and 1-5 in case B are not upgraded during the planning period while only feeder 1-5 is invested to upgrade at 5th year with 70mm^2 section.

Table 5. Feeders Upgrading Decisions

Feeder	**Feeder section upgrading in eyear t (mm2)**									
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
	Case A					**Case B**				
1-2		70								70
2-3					70					
3-4										
1-5				50						
5-6										
2-7										

Table 6 presents optimal investment decisions of proposed planning model for DG. The total of investment capacity during planning time is 3.0MW equivalent to 33.9 percent of load demands at base year. The both two technologies of DG are invested and selected that location of these sources are far from substation. Therefore, high economic and technical efficiencies are gained.

Table 6. DG Investment Decided

Bus	DG capacity invested in year t (MW)									
	1	2	3	4	5	1	2	3	4	5
	PV					Gas turbine				
2										
3						0.5				
4				1.0						
5						0.5				
6				1.0						
7						0.5				

Economic indicators are compared between case B and case A as shown in table 7. The case B holds a better economic indicator. Cost for investment of DG and feeders, substations upgrading are more expensive than those in case A about 3.51M$ due to a very high cost of DG investment. However, O&M and electrical energy expenses that calculated at base year have been decreased about 0.43M$ because of very low O&M expenses of DG. Therefore, total life cycle cost of case B is lower than these of case A by 0.33M$, equal to 2.22%.

Table 7. Economic Indicators Comparison

No	Cost	Case A	Case B	Comparison B and A	Note
1	Total life cycle cost (M$)	14.84	14.51	-0.33	**Total life cycle cots is reduced -2.22%**
2	Feeder and Substation upgrading cost (M$)	3.52	1.32	-2.2	
3	O&M and Electrical energy cost (M$)	14.32	13.89	-0.43	
4	Investment DG cost (M$)	0	5.71	5.71	

The technical indicators of DS are also improved when DG is integrated on DS planning. The electrical energy loss always reduces during planning period as represented in figure 5. At just 1st planning years the electrical energy loss is reduced 0.74%, the corresponding 322.92MWh. This value decreases in 4th planning years and it only is 0.25% because feeders upgraded of case A decrease the resistors of DS. Total of electric energy purchased from market is also decreased 70,700.0MWh corresponding to 18,382.0tons are CO_2 emission of traditional sources (S. Wong, K. Bhattacharya1and J.D. Fuller 2009), which contributes to the decrease of environmental pollution.

The transmission capacity on the feeders in case B is lower than in case A due to supported by DG that installed at load nodes. Therefore, the voltage loss of system reduces and voltage profiles at the all bus are improved during calculation time. In particular, load node having the biggest support is 4-bus as shown on figure 6. This bus voltage profile increased 1.3% at 18th hour in 1st planning year. The 2nd year selected to upgrade feeder 1-2 so the difference of voltage profiles in 2 cases are dropped and then they increase at next year depending on the rise of load demand.

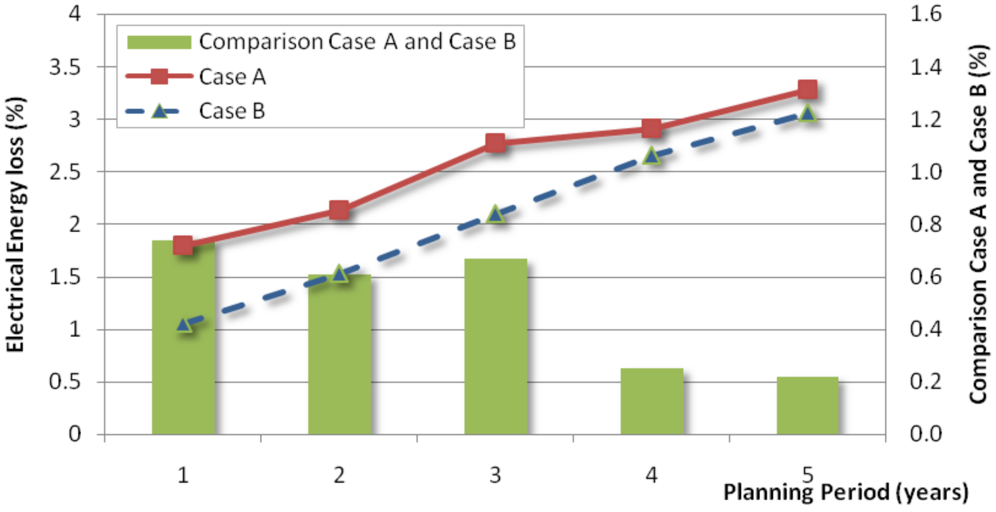

Figure 5. Comparison electrical energy loss between Case B and Case A

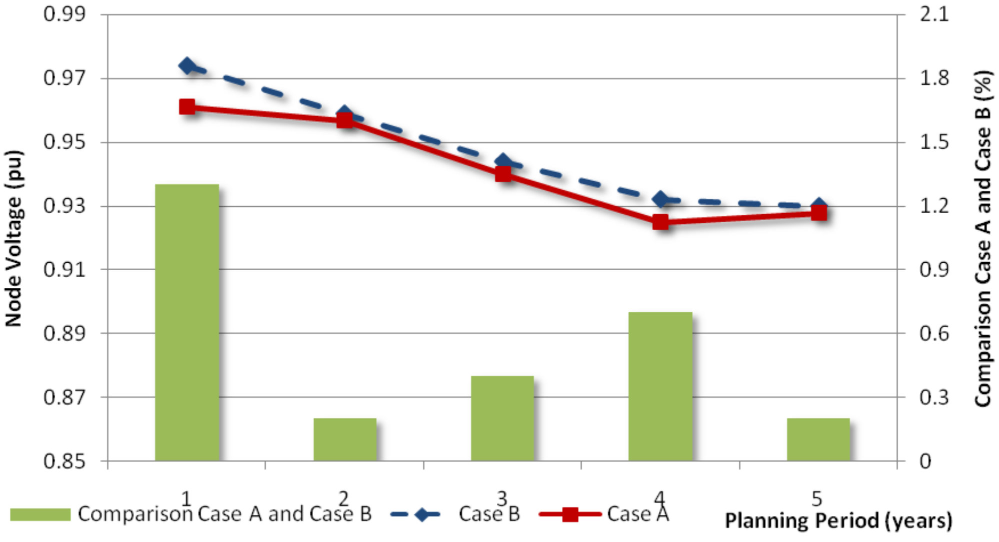

Figure 6. Comparison voltage of 4-bus between Case B and Case A

4. Conclusions

Recently, the DS planning has been changed significantly by the impacts of DG and environmental policies. The effects of DS is improved by DG as enhancement of flexibility and reliability, bus voltage improvement, reduction of transmission cost and power loss as well as reduction of environmental pollution. However, the investment cost of DG is usually expensive and power of these sources that used renewable energy is natural variability according to primary energy so the planning and operation calculation of DS will be more difficult. Therefore, this study proposed a new two-stage optimized model that is integrated DG in DS planning problem. In this model, equipment sizing and timeframe required for upgrading equipment of DS well as selection technologies and power variable constraints of DG can be determined. The objective function is minimizing total life cycle cost of the investment project. Calculated results showed that the proposed model is suitable in DS planning calculation and the planning together with using DG provided better economic and technical indicators. The total life cycle cost of planning project that integrated DG always reduces. The effects of DG on DS are either on loss reduction or feeders and substations capacity deferment. The power and electrical energy loss also decrease furthermore voltage profile of nodes are always improved.

Appendix A. Data of Feeder Parameters

No	Bus i - Bus j	F_{ij} (mm^2)	$S_{max.ij}$ (MVA)	L_{ij} (km)	Rf_{ij} (Ω)	Xf_{ij} (Ω)
1	1-2	50	8	2.3	1.362	0.961
2	2-3	50	8	2.2	1.302	0.920
3	3-4	35	6.67	3.3	2.551	1.416
4	1-5	35	6.67	3.5	2.706	1.502
5	5-6	35	6.67	1.7	1.314	0.729
6	2-7	35	6.67	1.2	0.928	0.515

* Where: S_{max} - Thermal limit capacity for Feeder

Appendix B. Data of Loads

No	**Bus**	**PD_0 (kW)**	**QD_0 (kVAr)**	**No**	**Bus**	**PD_0 (kW)**	**QD_0 (kVAr)**
1	**1**	-	-	5	**5**	1284.0	1047.6
2	**2**	651.6	429.6	6	**6**	2196.0	1929.6
3	**3**	1950.0	1580.4	7	**7**	776.4	513.6
4	**4**	1980.0	1808.4		***Total***	***6465***	***5091***

* Where: PD_0, QD_0 - active and reactive power demand at bus in base year of planning period

REFERENCES

[1] M. H. Albadi and E. F El-Saadany, "*The Role of Distributed Generation in Restructured Power Systems",* Proc. 40th North American Power Symposium, 2008 (NAPS '08), Calgary, AB, Canada

[2] Thomas Ackermann, Göran Andersson, Lennart Söder, *"Distributed generation: a definition",* Electric Power Systems Research 57, 2001

[3] S. Wong, K. Bhattacharya and J.D.Fuller, "*Comprehensive framework for long-term distribution system planning"*, Proc. IEEE PES Annual General Meeting, Tampa, USA, 2007

[4] Algarni, A.A.S.; Bhattacharya, K., "*A Novel Approach to Disco Planning in Electricity Markets: Mathematical Model"*, Power Systems Conference and Exposition, 2009. PSCE '09. IEEE/PES

[5] El-Khattam, W.; Hegazy, Y.; Salama, M., *"An integrated distributed generation optimization model for distribution system planning"*, Power Engineering Society General Meeting, IEEE, 2005

[6] S. Wong, K. Bhattacharya1and J.D. Fuller, *"Electric power distribution system design and planning in a deregulated environment"*, IET Generation, Transmission & Distribution, 2009

[7] V.V.Thang, D.Q.Thong, B.Q.Khanh, "*A New Model Applied to the Planning of Distribution Systems for Competitive Electricity Markets",* The Fourth International

Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT) 2011, Shandong, China, 2011

[8] Su. H, Zhang. J, Liang. Z, Niu. S, *“Power Distribution Network Planning Optimization Based on Life Cycle Cost”*, 2010 China International Conference on Electricity Distribution, 13-16 Sept. 2010

[9] V. V. Thang, D. Q. Thong, B. Q. Khanh, L. T. Phong, *A Two-Stage Model Calculated Distribution System Planning Intergrated Distribution Generator,* 2013 International Workshop on Renewable Energy (IWRE 2013), 2 - 3 October 2013, Hanoi, Vietnam

[10] Richard E. Rosenthal, “*GAMS - A User's Guide*”, GAMS Development Corporation, Washington, USA, 2010.