DISTRIBUTION NETWORK EXPANSION PLANNING CONSIDERING DISTRIBUTION AUTOMATION SYSTEM

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ABSTRACT

Planning of distribution networks is usually accomplished using a cost-based conventional model that minimizes the total cost of construction and reinforcement of substations and feeders. The resulted expansion plan designed by this cost-based model is not necessarily the best choice for an electrical distribution company (DISCO) in the nowadays deregulated structure. This happening is mainly due to the fact that the utility seeks to maximize its profit in this competitive environment. On the other hand, this model does not consider the upcoming new challenges ahead of distribution systems, such as smart grid and distribution automation technologies.

This paper presents a novel profit-based model for multi-stage distribution network expansion planning considering distribution automation. The objective function to be maximized is the net present value of the company's profit. The problem is solved employing the genetic algorithm approach as a promising technique in solving such optimization problems. The proposed method effectiveness is finally evaluated on an illustrative 24-node test network and the obtained results and discussions are then presented.

INTRODUCTION

Expansion planning study of distribution networks is accomplished in practice by planning engineers [1]. In this study, the system planner considers the existing network and load forecasting, together with the technical and economical considerations. He/she aims to optimize the followings:

- Routing (layout), construction timing, and sizing of the distribution feeders,
- Location, construction timing, and sizing of the substations,
- Reconductring of the feeders and reinforcement of the existing substations.

Most of the planning models associated with the distribution network expansion proposed in the literature employ a cost-based objective function to be minimized [2]. With electricity industry restructuring trend and privatization process of distribution companies, the main goal of these companies, however, is to maximize their profits of business. On the other hand, one of the challenges facing the distribution companies in this new environment is the reliability of electricity service delivered to the customers. Although there are a variety of approaches to improve the electric service reliability, the distribution companies are willing to achieve this goal by implementing the distribution automation technologies due to many technical and economical reasons [3].

Distribution automation can be implemented at different levels of the network and has a variety of capabilities and applications. One of these important applications is the improvement of the reliability of the electric service delivered to customers. This capability that is called automatic fault management (AFM) can be achieved by the considerate management and coordination of the processes involved in the fault detection, location, and isolation, as well as service restoration of the customers [4]. Implementing the distribution automation system with such features significantly reduces the outage time and the consequence costs.

The proposed expansion planning model assumes that the distribution network is equipped with the automation system with such capabilities. With this assumption, among various alternatives for network expansion, a plan that satisfies the problem constraints and also maximizes the company's profits will be chosen as the network expansion final plan.

So, in this paper a model for expansion planning of distribution networks is proposed that is useful in the new competitive environment and it is also capable of modelling the impacts of distribution automation.

PROPOSED METHOD

Formulation

The objective function of the distribution expansion planning model is the net present value of the DISCO's profit that can be calculated as follows:

$$\text{Profit} = R - (C_{\text{Investment}} + C_{\text{Operation}} + C_{\text{Maintenance}} + C_{\text{Interruption}}) \quad (1)$$

where

$$R=\sum_{t=1}^{T}\frac{1}{(1+0.5r)^{2t+1}}.P_{Demand}(t).C_{MWh} \tag{2}$$

$$C_{Investment}=\sum_{t=1}^{T}\frac{1}{(1+r)^{t-1}}.\left\{\sum_{j=1}^{N_{sb}}\left(IC_{sb_j}\right)+\sum_{j=1}^{N_f}\left(L_j.IC_f+IC_{sw_j}\right)\right\} \tag{3}$$

$$C_{\text{Operation}}=\sum_{t=1}^{T}\sum_{j=1}^{N_f}\frac{1}{(1+0.5r)^{2t+1}}.\left(8760Lf_f.P_{loss_j}.C_{loss}\right) \tag{4}$$

$$\begin{aligned}C_{\text{Maintenance}}=\sum_{t=1}^{T}\frac{1}{(1+0.5r)^{2t+1}}.&\left\{\sum_{j=1}^{N_{sb}}MC_{sb_j}\right.\\&\left.+\sum_{j=1}^{N_f}\left(L_j.MC_f+MC_{sw_j}\right)\right\}\end{aligned} \tag{5}$$

$$C_{\text{Interruption}}=\sum_{t=1}^{T}\sum_{j=1}^{N_{lb}}\frac{1}{(1+0.5r)^{2t+1}}.(VOLL_j.EENS_{j,t}) \tag{6}$$

where

R	Revenue
C	Cost
T	Time horizon
r	Interest rate
IC	Investment cost
MC	Maintenance cost
P	Active power
Lf	Loss factor
L	Length
$VOLL$	Value of lost load
$EENS$	Expected energy not served
sb	Substation
lb	Load bus
f	Feeder
sw	Switch

For the calculation of the interruption cost in (6), it is assumed that the regulation enforces the DISCO to pay off the cost imposed to customers due to the outages.

The problem constraints include the technical constraints (Line and transformer capacities, load point voltages, etc.) and the non-technical constraints that are related to the optimization technique and the decision variables. The technical constraints are as follows:

$$P_{sb_j}^2+Q_{sb_j}^2\le S_{sb,max_j}^2 \qquad \forall\, j\in\Omega_{sb} \tag{7}$$

$$P_{f_j}^2+Q_{f_j}^2\le S_{f,max_j}^2 \qquad \forall\, j\in\Omega_{f} \tag{8}$$

$$V_{\min}\le V_j\le V_{\max} \qquad \forall\, j\in\Omega_{lb} \tag{9}$$

where

Q	Reactive power
S	Apparent power
V	Voltage
Ω	Set

The decision variables are all binary (presence or absence of each line or transformer in the plan); so the optimization problem can be considered as a mixed integer non linear programming (MINLP) one, and the genetic algorithm is used to solve this problem.

Automation modelling

Distribution automation system improves the reliability indices and reduces the outage time; as a result, considering this system improves the proposed objective function by decreasing the imposed penalties and increasing the electricity sales.

As mentioned above, it is assumed that the network under study has some automation functions including AFM. These functions can be implemented by means of devices such as remote controlled switches in appropriate locations in the network. So, for considering automation in this model, it is assumed that the switches of the network have the capability to be controlled remotely by a dedicated distribution automation system.

Therefore, for modelling the AFM function, during a fault, the outage time of the customers that can be restored without repairing the fault is assumed to be negligible, and the outage time of other affected customers is equal to fault repair time.

CASE STUDY

The developed model is tested to solve the multi-stage expansion planning problem on a 24-node test network shown in Figure 1. This test network is a 20-kV distribution system that is supplied by two 20-MVA, 63/20 kV substations. The proposed feasible routes and locations for constructing future feeders and substations are displayed in Figure 1. Table 1 represents the data related to the load points, including the forecasted peak power demand over five years and the data required for reliability evaluation. Table 2 gives the location of the switches and fuses in the network. In addition to these switches, there is a circuit breaker at the beginning of each feeder. Figure 2 represents the structure of the load buses with and without switch. The conductors that is used in the existing network and for expansion is of overhead type, with resistance of 0.342 ohms per kilometer and reactance of 0.387 ohms per kilometer, and with maximum current 150 A at 20 kV. Other required data is shown in Table 3.

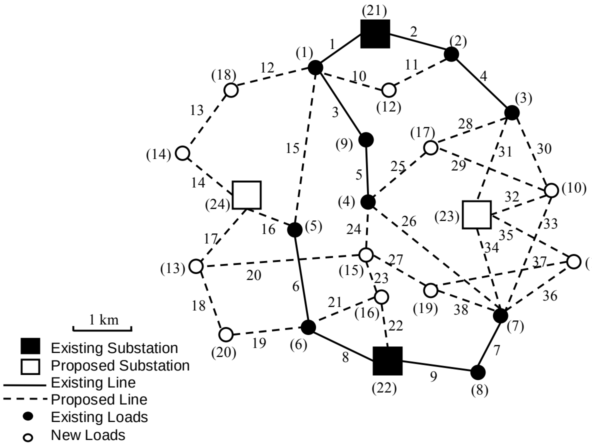

Figure 1: 24-node test network under study

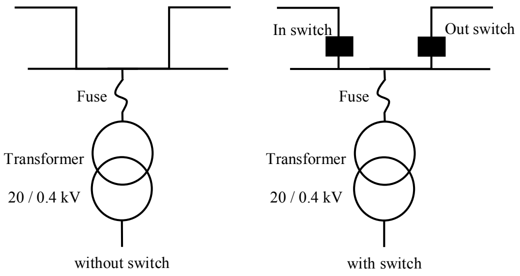

Figure 2: Structure of the load buses

Table 1: Data related to the load points

Bus	Forecasted demand (MW) at planning years						No. of cust.	VOLL ($/kWh)
	0	1	2	3	4	5		
1	3.63	3.70	3.75	3.86	3.90	3.92	17	38
2	0.72	0.86	0.88	0.90	0.95	1.01	25	24.5
3	2.37	2.50	2.61	2.69	2.80	2.91	20	24.1
4	0.41	0.43	0.46	0.34	0.41	0.41	40	27.8
5	0.26	0.31	0.34	0.37	0.33	0.39	10	24.5
6	1.07	1.28	1.31	1.31	1.35	1.40	23	29.9
7	4.10	3.09	3.38	3.40	4.05	4.07	33	24.5
8	0.65	0.67	0.73	0.80	0.80	0.84	20	24.5
9	1.14	1.25	1.33	1.35	1.37	1.47	3	30
10	0	1.70	1.86	2.04	2.33	2.35	21	24.5
11	0	1.67	1.78	1.91	2.05	2.38	9	17.5
12	0	0	0.88	0.93	0.99	1.13	19	17.5
13	0	0	1.12	1.15	1.18	1.26	24	17.5
14	0	0	0	3.05	3.07	3.07	12	24.8
15	0	0	0	1.62	1.62	1.62	4	20.1
16	0	0	0	2.16	2.20	2.29	14	29.9
17	0	0	0	0	0.94	1.05	16	20.1
18	0	0	0	0	1.89	1.99	34	21.6
19	0	0	0	0	0	1.55	26	29.9
20	0	0	0	0	0	3.79	22	24.5

Table 2: Location of the switches and fuses

Lines with fuse	3, 5, 11, 19, 24, 27, 29, 37
Load buses with switch	1, 4, 10, 14, 17

Table 3: Other required data

IC_f($/km)	15000	IC_{sb}($)	700000
$IC_{sw,remote}$($)	12000	$IC_{sw,manual}$($)	9000
MC_f($/km)	600	MC_{sb}($)	1000
$MC_{sw,remote}$($)	500	$MC_{sw,manual}$($)	500
C_{MWh}($/MWh)	60	C_{loss}($/MWh)	60
Lf	0.35	r	0.1
Line failure rate			10
Substation failure rate			0.015
Line repair time (hours)			10
Substation repair time (hours)			150
Fault detecting time (minutes)			5
Fault locating time (minutes)			45
Manual switching time (minutes)			30

For comparison, two case studies are performed:

- Case I: Planning with the common minimum-cost model without considering automation,
- Case II: Planning with the proposed method.

Case I

In the minimum-cost model, the objective function is the net present value of the total cost that is the sum of the cost of investment, operation, maintenance and interruption [5]. The achieved plan for expansion of the network is shown in Figure 3. Table 4 represents the detail of the multistage plan, in other words shows the elements that must be added to the network at each stage (year) to expand the network according to the proposed plan. Table 5 shows the present value of the costs must be paid for the expansion and operation of the network over the planning horizon.

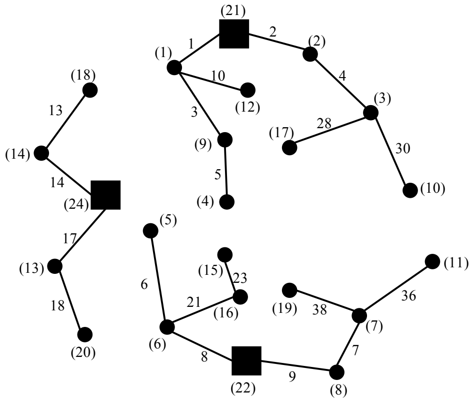

Figure 3: Achieved expansion plan in case I

Table 4: Detail of the multistage plan in case I

Element	*t*=1	*t*=2	*t*=3	*t*=4	*t*=5
Added substation	-	24	-	-	-
Added line	30, 36	10, 17	14, 21, 23	13, 28	18, 38

Table 5: Costs calculated in case I

$C_{investment}$ ($)	1944152
$C_{operation}$ ($)	182541
$C_{maintenance}$ ($)	98172
$C_{interruption}$ ($)	145350
C_{total} ($)	2370215

Case II

Figure 4, Table 6 and 7 present the expansion plan that is achieved by the proposed model. The comparison of the results associated with the conventional minimum-cost and the proposed maximum-profit model shows that there are considerable differences between the plans designed by these two models.

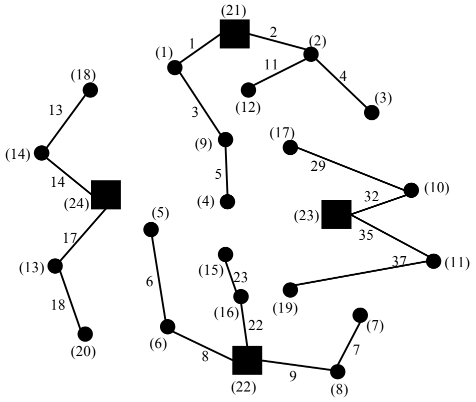

Figure 4: Achieved expansion plan in case II

Table 6: Detail of the multistage plan in case II

Element	t=1	t=2	t=3	t=4	t=5
Added substation	23	24	-	-	-
Added line	32, 35	11, 17	14, 22, 23	13, 19	18, 37

Table 7: Costs, revenue and profit calculated in case II

$C_{investment}$ ($)	2225309
$C_{operation}$ ($)	210562
$C_{maintenance}$ ($)	127035
$C_{interruption}$ ($)	42695
C_{total} ($)	2605601
R ($)	3173086
Profit ($)	567485

The results show that in case I, only one transformer is added to the network in the first year, but in case II, two transformers are added to the network in the first and second year of the planning horizon, and the layout of the feeders is different from the scheme that is proposed by the cost-based model.

By comparing Tables 5 and 7, it can be seen that the proposed model leads to a more expensive plan. This inconsistency can be explained by the fact that a profit-maximizing firm should often invest more than a cost-minimizing one. Therefore, a DISCO that develops its network according to the plan achieved from the presented model, can expect better performance in the competitive environment.

Furthermore, the comparison of the interruption cost in the two cases shows that considering distribution automation in the proposed model, leads to a plan that improves the reliability of the system.

CONCLUSIONS

Benefiting from smart grid is a strategic goal for most of the electrical distribution companies. This objective should be hence considered in the network expansion studies.

This paper has presented a multi-stage profit-based model for expansion planning of primary distribution network. This model performs the expansion planning from a DISCO’s perspective that must compete to survive in the deregulated structure.

The results of the case studies have shown that the plan obtained from the proposed method may be more expensive than the plan designed based on the minimum-cost models. However the cheaper plan may not result in the best performance in a competitive environment.

Additionally, one of the main advantages of the proposed model is that an expansion plan that is developed by considering smart grid technologies such as distribution automation is better consistent with the strategic plan towards the smart distribution grid.

REFERENCES

[1] T. Gonen and I. J. Ramirez-Rosado, 1986, “Review of Distribution System Planning Models: A Model for Optimal Multistage Planning,” *Proc. Inst. Elect. Eng.*, vol. 133, no. 7, 397-408.

[2] M. Lavorato, M. J. Rider, A. V. Garcia and R. Romero, 2010, “A Constructive Heuristic Algorithm for Distribution System Planning,” *IEEE Trans. Power Syst.*, vol. 25, no. 3, 1734-1742.

[3] S. Kazemi, 2011, “Reliability Evaluation of Smart Distribution Grids,” *Doctoral Dissertation*, Dept. Elec. Eng., Sharif University of Technology and Aalto University.

[4] D. M. Staszesky, D. Craig and C. Befus, 2005, “Advance Feeder Automation is Here,” *IEEE Power & Energy Mag.*, 56-63.

[5] R. C. Lotero and J. Contreras, 2011, “Distribution System Planning with Reliability,” *IEEE Trans. Power. Del.*, vol. 26, no. 4, 2552-2562.