Distribution Feeder Reconfiguration in the New Environment Distribution Networks

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Abstract**-- Due to the deregulation and restructuring in many countries, it is expected that amount of small-scale generations connected to the distribution networks increase. So it is necessary that impact of these kinds of generators on distribution feeder reconfiguration would be investigated. This paper presents an approach for distribution reconfiguration considering Distributed Generators (DGs). The objective function is summation cost of electrical energy generated by DGs and substation bus (main bus). A Tabu search optimization is used to solve the optimal operation problem. The approach is tested on a real distribution feeder.**

Index Terms**—Distributed Generator, Distribution Reconfiguration, Distribution system, Tabu Search Optiization**

I. INTRODUCTION

Distributed generation, the small-scale production of electricity at or near customers' homes and businesses, has the potential to improve the reliability of the power supply, reduce the cost of electricity, and lower emissions of air pollutants. Distributed generation can come from conventional technologies, such as motors powered by natural gas or diesel fuel, or from renewable technologies, such as solar photovoltaic cells. A study done by the Electric Power Research Institute (EPRI) indicates that by 2010, 25% of the new generation will be distributed, and also, a study by Natural Gas Foundation concluded that this figure could be as high as 30%. Therefore, it is necessary that the impact of these generators on distribution systems would be studied [1]-[3].

Distribution feeder reconfiguration is one of the important control schemes at distribution substations, which defined as altering the topological structure of distribution feeders by changing the open/closed states of sectionalizing and tie switches.

Many researchers have investigated distribution feeder reconfiguration [4]-[16]. In most of them, the impacts of DGs on distribution system performance have not been studied in detail yet.

Since the distribution feeder reconfiguration is a nonlinear optimization problem, one of the optimization algorithms should be used. Evolutionary methods can be used to solve these sorts of problems owing to independence on the type of objective function and constraints. In this paper an evolutionary method based on tabu search, is used to solve the optimization problem. The tabu search optimization has been used to solve several combinatorial optimization problems [17] - [20].

This paper presents a method for distribution feeder reconfiguration regarding DGs. The proposed method includes the economic effect of different energy prices using different feeder configuration during the operation of distribution networks.

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II. DISTRIBUTION FEEDER RECONFIGURATION REGARDING DISTRIBUTED GENERATION

From a mathematical standpoint the distribution feeder reconfiguration with regard to distributed generation is an optimization problem with equality and inequality constraints.

A. Objective function

The objective function is the summation of electrical energy generated by DGs and substation bus as follows:

$$Min\ \ f(\overline{X}) = \sum_{t=1}^{N_d} \left\{ \sum_{i=1}^{N_{Sub}} P_{subs,i}\,\Delta t_t * MCP^t + \sum_{i=1}^{N_g} C_{Pgi}(P_{gi}{}^t) * \Delta t_t \right\} \quad (1)$$

$$\overline{X} = [\overline{Tap}, \overline{U_C}, \overline{Sw}, \overline{\mathrm{P}_{\mathrm{Sub}}}, \overline{P_G}]$$

$$\overline{Tap} = [\overline{Tap_1}, \overline{Tap_2}, ..., \overline{Tap_{Nt}}]$$

$$\overline{Tap_i} = [Tap_i{}^1, Tap_i{}^2, ..., Tap_i{}^{Nd}];$$

$$\overline{Sw} = [\overline{Sw_1}, \overline{Sw_2}, ..., \overline{Sw_{Nsw}}]$$

$$\overline{Sw_i} = [\overline{Sw^1{}_i}, \overline{Sw^2{}_i}, ..., \overline{Sw^{Nd}{}_i}]$$

$$\overline{\mathrm{P}_{\mathrm{Sub}}} = [\overline{\mathrm{P}_{\mathrm{Sub1}}}, \overline{\mathrm{P}_{\mathrm{Sub2}}}, ..., \overline{\mathrm{P}_{\mathrm{Sub},Nsub}}]$$

$$\overline{\mathrm{P}_{\mathrm{Sub},i}} = [\mathrm{P}^1{}_{\mathrm{Sub,i}}, \mathrm{P}^2{}_{\mathrm{Sub,i}}, ..., \mathrm{P}^{\mathrm{Nd}}{}_{\mathrm{Sub,i}}]$$

$$\overline{U_C} = [\overline{U_{c1}}, \overline{U_{c2}}, ..., \overline{U_{cNc}}]$$

$$\overline{U_{ci}} = [U_{ci}{}^1, U_{ci}{}^2, ..., U_{ci}{}^{Nd}];$$

$$\overline{P_G} = [\overline{P_{g1}}, \overline{P_{g2}}, ..., \overline{P_{gNg}}]$$

$$\overline{P_{gi}} = [P_{gi}{}^1, P_{gi}{}^2, ..., P_{gi}{}^{Nd}];$$

In above-mentioned equation:

N_{sub}: number of substations.

N_c: number of capacitors.

N_g: number of DGs.
N_{Sw}: number of switches.
N_{bus}: number of buses.
N_d : number of load variation steps.
N_t : number of transformers.
t: index which represents time steps of load level.
$\overline{X}$: state variables vector.
$Psubs_i^t$: active power of ith substation.
$\overline{Tap}$: tap vector representing tap position of all transformers for the next day.
$\overline{Tap_i}$: tap vector including tap position of the i[th] transformer for the next day.
$Tap_i^{\ t}$:tap position of the i[th] transformer for the t[th] load level step.
$\overline{P_{sub}}$: Substation active power vector including active power of all substations for the next day.
$\overline{P_{sub,i}}$: substation active power vector including active power of i[th] substation for the next day.
$P_{sub,i}^{\ t}$: active power of the i[th] substation for the t[th] load level step.
$U_{ci}^{\ t}$: state of the i[th] capacitor in the light of turning on and off during time "t" ,which equals 0 or 1.
$\overline{U_{ci}}$: capacitors switching vector including state of i[th] capacitor for the next day.
$\overline{U_C}$: capacitors switching state vector including state of all capacitors for the next day.
$Sw_i^{\ t}$: state of the i[th] switch in the light of turning on and off during time "t" ,which equals 0 or 1.
$\overline{Sw_i}$: switching vector including state of i[th] switch for the next day.
$\overline{Sw}$: switching state vector including state of all switches for the next day.

Δt_t: time interval.
$MCP^{\ t}$: Market Clearing Price for the t[th] load level step.
$C_{Pgi}\left(P^t{}_{gi}\right)$: cost of active power generated by the i[th] DG during time "t".
In this problem, it is assumed that tap position of transformers changes stepwise.

B. *Constraints*

1. active power constraints of DGs:

$$(P_{gi}^{\ t})^2 + (Q_{gi}^{\ t})^2 \le S^2_{gi,\max} \quad (2)$$

$P_{gi}^{\ t}$ *and* $S_{gi,max}$ are active power for tth load level step and apparent power of ith DGs respectively.
In this paper, it is assumed that active power of DGs has been previously specified and fixed by distribution operator.

2. Distribution line limits:

$$\left|P_{ij}^{Line}\right|^t < P_{ij,\max}^{Line} \quad (3)$$

$\left|P_{ij}^{Line}\right|^t$ and $P_{ij,\max}^{Line}$ are absolute power flowing over distribution lines and maximum transmission power between nodes i and j respectively.

3. Tap of transformers:

$$Tap_i^{\min} < Tap_i^{\ t} < Tap_i^{\max} \quad (4)$$

$Tap_i^{\min}$, $Tap_i^{\max}$ and $Tap_i^{\ t}$ are the minimum, maximum and current tap positions of the ith transformer respectively.

4. Unbalanced three-phase power flow equations.

Maximum allowable daily operating times of transformers:

$$DOT_i^{Trans} \le MADOT_i^{Trans} \quad (5)$$

DOT_i^{Trans} and $MADOT_i^{Trans}$ are the daily operating times and maximum allowable daily operating times of the ith transformer respectively.

5. Maximum allowable daily operating times of capacitors:

$$\sum_{t=1}^{Nd} U_{ci}^{\ t} \le MADOT_i^{Cap} \qquad i=1,2,3,\ldots,Nc \quad (6)$$

$MADOT_i^{Cap}$ is the maximum allowable daily operating times of the ith capacitor.

6. Substation power factor:

$$Pf_{\min} \le Pf^{\ t} \le Pf_{\max} \quad (7)$$

$Pf_{\min}$, $Pf_{\max}$ and $Pf^{\ t}$ are the minimum, maximum and current power factor at substation bus during time t.

III. TABU SEARCH ALGORITHM

Tabu search is a heuristic algorithm for guiding the search to find a good solution to a combinatorial problem. It is derived from the works of Fred Glover with seminal ideas and contributions from various other sources. Tabu search has successfully been applied to obtain optimal or sub optimal solutions to problems such as timetable, a traveling salesman and so on.
To apply Tabu Search algorithm to solve the proposed distribution feeder reconfiguration, the following steps should be repeated.

Step 1: Generation of initial population

An initial population, Xi that must meet constraints, is selected randomly.

$$Initial\_Population = [X_1, X_2, \ldots, X_{Nintial}]$$

$$X_{i\min} \le X_i \le X_{i\max} \quad (8)$$

The value of taps and capacitor reactive power is considered as discrete. Ninitial is the number of initial population.

Step 2: Selection of good population and generation of Tabu List

For each member of initial population, unbalanced three-phase power flow is solved. After that, the objective function for each member is calculated and sorted, then a number of good members (N) that have the minimum objective function, are selected.

Tabu List is created by selection of a number of Nτ members from initial population that have minimum objective.

Step 3: Creation of New Population

New population (N) is created based on mutation and recombination rules.

Step4: Evaluation and Selection

A combined population is formed with the new population and current population.

Firstly, each individual of combined population is ranked based on the objective function value. A best solution would gain the first number place, i.e., the highest rank (RC=1). Then to prevent from being trapped in a local minimum, each individual of combined population is ranked based on distance to Tabu list, which is defined as:

$$D_i = \sum_{k=1}^{N_\tau} \left| X_i - X_{tabu,k} \right| \tag{9}$$

The best solution that is at the greatest distance has the highest rank (RD=1).

The fitness function of the ith individual is expressed as:

$$F_i = RC_i + \alpha * RD_i \qquad i = 1,2,..., 2*N \tag{10}$$

where α is an adaptive decay scale.

Individuals will be ranked in descending according to their fitness function. A number of N individuals that have the best fitness function are selected to the next population. If the next population does not include the current best solution, the best solution must replace the last individual in the next population.

Step 5: Update Tabu List

Tabu list, which records the solutions just visited and all local optimal solutions visited so far, should be updated. The best solution in the new population, which has minimum objective function, is replaced with the last individual of Tabu list if the following condition (as Tabu Restriction) is not met:

$$\left| X_{best} - X_{tabu,i} \right| < d_{tabu} \quad i = 1,2,.., N_t \tag{11}$$

where dtabu is the tabu distance.

Tabu restriction can reactive when this condition (aspiration criteria) is met:

$$f(X_{best}) < f(X_{tabu,i}) \tag{12}$$

Step6: Check of convergence

If the maximum iteration is reached stop, otherwise go to step4.

IV. Distributed Generator Modeling

Generally, DGs in distribution networks can be modeled as PV or PQ models.

Since distribution networks are unbalanced three phase systems, DGs can be controlled and operated in two forms:

Simultaneous three-phase control

- Independent three-phase control or single phase control

Therefore, regarding the control methods and DGs models, four models can be defined for simulation of these generators (Fig.1):

- PQ model with simultaneous three-phase control
- PV model with simultaneous three-phase control
- PQ model with independent three -phase control
- PV model with independent three -phase control

It must be taken into account that when DGs are considered as PV models, they have to be able to generate reactive power to maintain their voltage magnitudes. In order to model DGs as PV buses many researchers have presented several procedures [21] and [22]. In this paper, DGs are modeled as the PQ buses with simultaneous three-phase control.

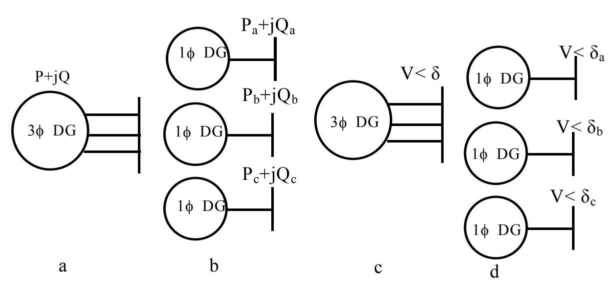

Fig.1. Models of DGs
(a). PQ Model with simultaneous three-phase control
(b). PQ Model with separately three- phase control
(c). PV Model with simultaneous three- phase control
(d). PV Model with independent three- phase control

V. Simulation

In this section the proposed method is applied to distribution feeder reconfiguration on a realistic radial distribution test feeders (Fig (2)).

It is assumed that there are 3 generators whose specifications are given in Table I.

Daily energy price variations and daily load variations are shown in Figs.3 and 4.

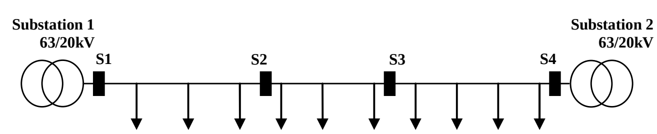

Fig.2 Single Line Diagram

TABLE I
Characteristic Of Generators

	Capacity (kW)	Max Reactive Power (kVar)	Min Reactive Power (kVar)	Capital cost ($/kW)	Life time (Year)	Fuel cost ($/kWh)	O & M cost ($/kWh)
G1	300	240	-180	3674	12.5	0.029	0.01
G2	500	400	-300	1500	20	0	0.005
G3	1000	800	-600	715	20	0.067	0.006

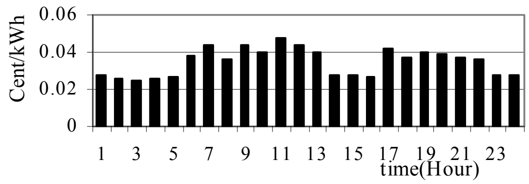

Fig.3. Daily energy price variations

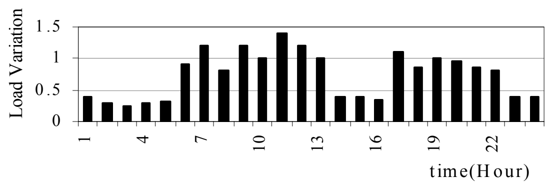

Fig.4. Daily load variations

In this paper, it is assumed that cost of each kilowatt-hour of electric energy generated by each DG is composed of the following components:

- Investment (equipment purchasing, establishment)
- Operation & maintenance cost
- Fuel cost.

The hourly cost function of DGs can be defined as follows:

$$C_{Pg}(P) = a + b * P \tag{13}$$

Coefficients "a" and "b" are calculated as follows:

$$a = \frac{Capital\ \ Cost(\$/kW)\ \ *Capacity(\ kW)*Gr}{LifeTime(Y\ \ ear)*\ 365*24*LF} \tag{14}$$

$$b = FuelCost(\$/kWh) + O\&MCost(\$/kWh) \tag{15}$$

where *Gr* and *LF* are the annual rate of benefit and DG loading factor respectively.

Table II presents a comparison among the results of Tabu search and Genetic Algorithm for 300 random tails.

Table II
Comparison of Average and Standard Deviation of the objective function values for 300 Trails

Method	Average	Standard Deviation	Best solution	Worst solution
Tabu Search	950.6	25	926.3	990.8
GA	992.3	25	961.42	1013.47

Fig.5 shows the convergence characteristic of the Tabu search for the best solution.

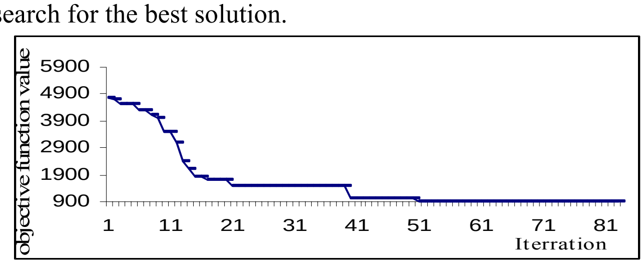

Fig5. Convergence Characteristics of the TABU SEARCH for the best solution

Table III give the comparison of results between the Tabu search and Genetic Algorithm for the best solution.

TABLE III
COMPARISON RESULT FOR THE BEST SOLUTION

	Tabu search	GA
Objective function Value ($/h)	926.3	961.42
Losses (Kw)	1455.45	1523.4
Execution Time (S)	~650	~400

Table IV shows status of switches.

TABLE IV
STATUS OF SWITCHES

Hour	S1	S2	S3	S4	Min Voltage	Max Voltage
1	1	1	0	1	0.993	1.002
2	1	1	0	1	0.993	1.001
3	1	1	0	1	0.995	1.004
4	1	1	1	1	0.982	1.001
5	1	1	1	1	0.990	1.002
6	1	1	1	1	0.978	1.002
7	1	1	1	1	0.987	1.008
8	1	1	1	1	0.987	1.007
9	1	1	1	1	0.967	1.006
10	1	1	1	1	0.984	1.008
11	1	1	1	1	0.983	1.008
12	1	1	1	1	0.932	1.009
13	1	1	1	1	0.992	1.009
14	1	1	0	1	0.963	1.010
15	1	1	1	1	0.984	1.008
16	1	1	1	1	0.977	1.010
17	1	1	1	1	0.984	1.006
18	1	1	1	1	0.993	1.004
19	1	1	1	1	0.987	1.004
20	1	1	1	1	0.993	1.001
21	1	1	1	1	0.994	1.005
22	1	1	0	1	0.989	1.006
23	1	1	0	1	0.979	1.005
24	1	1	0	1	0.995	1.003

As shown in Tables II and III and Fig6, the Tabu Search can be used to apply to distribution feeder reconfiguration. The results of these Tables and Figs can be summarized as follows:

1. The method can be applied to a wide variety of similar optimization problems. On the other hand, this method can be used to non-differential and non-continuous objective function and constraints.
2. Objective function value and active power losses in the Tabu Search is less than GA.
3. Because most of dispersed generations owned and controlled by private sections, necessary mechanisms must be applied for supervision and control of optimal operation in power systems. In this paper costs pertaining to active and reactive power generation offered by owners of dispersed generations have been used as a decisive factor for optimal control of them. Results achieved in last sections show that we can apply these methods to control dispersed generations and be sure that high benefits will be gained from them.

VI. CONCLUSION

Since the number of DGs will be increasing and also DGs affect on distribution network, it is necessary, that impact of DGs on this part of power system to be studied. This paper presented an efficient algorithm for distribution feeder reconfiguration in distribution with DGs. Tabu search optimization is used to obtain the solution of the optimization problem The simulation result showed that the Tabu search could be implemented in practical distribution networks.

Since the most of DGs owned by private section, active and reactive power generation costs of DGs considered as optimal parameter control of them.

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VIII. BIOGRAPHIES

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