Minimize the Customer Outage for Improved Reliability in Distribution System with Photovoltaic Distributed Generation

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***Abstract*— This paper presents minimize the customer outage for improved reliability in distribution system with photovoltaic distributed generation. The objective functions to be minimize the customer outage cost. The problem is to reliability improvement of distribution system with distributed generations. The technique employed to solve the outage cost by Tabu search algorithm. An application of the Tabu search algorithm to test system for the case study is a radial distribution system with Roy Billinton Test System (RBTS) bus 2. Numerical results from the tests demonstrate that the optimal placement of distributed generators can be used to promote the reliability of the distribution system.**

***Keywords*— Customer Outage, Distributed Generation, Reliability, Photovoltaic**

I. Introduction

An ideal alternative on electric distributions to electric users is the installation of a small sized generator or commonly known as distributed generator (DG). This type of disturbance is typically by a short circuit, or fault, on the power distribution grid. A distributed generation system with DGs installation as show in Fig. 1. The grid, in this case, includes the mains wiring inside the building. Most experts agree that more than 50% of voltage sags are caused by something inside the building.

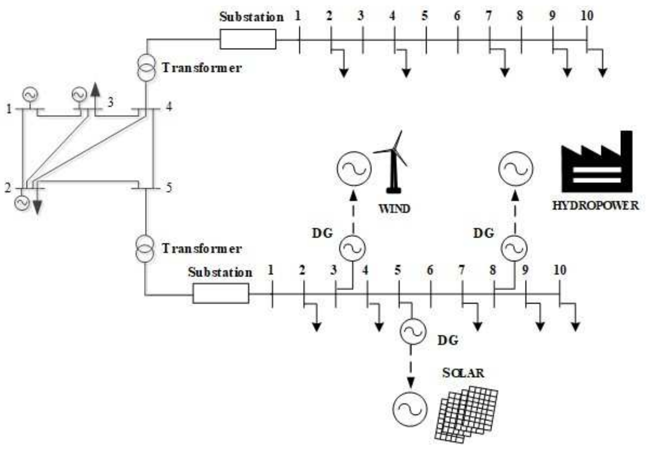

Fig. 1. Distributed generation system with DGs installation.

DG is a small-scale active generating unit located on or near the site where it is to be used (i.e., in distribution systems). The primary energy resources of DG could be wind, solar, biomass, fuel cells and hydrogen as show in Fig. 2.

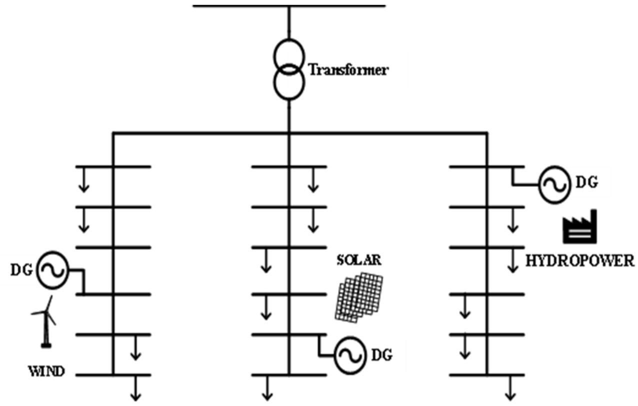

Fig. 2. Distributed system with DGs installation

Although DGs have gained many positive effects, they still have some economic and technical issues to be addressed before their applications in the distribution system can be realized. The main objective of this paper is to investigate the impact of distributed generation on distribution system reliability. It is expected that reliability on the installation of DGs can be improved because they can be served as backup generation when a utility supply interruption occurs. In other words, some of the load points can still be electrically supplied by the DGs and therefore economic loss as a result of the power outage can be reduced. However, amount of reliability improvement depends on location and size of the DGs to be installed. It is therefore proposed in this paper a method to determine the optimal placement and sizing of DGs in a distribution system to minimize the customer interruption cost subject to system operational constraints [1-2]. DG units can have a positive impact on distribution system reliability if they are correctly coordinated with the rest of the network. A common example of DG use is as generation backup, in which the unit operates in the case of main supply interruption. A DG application that is gaining popularity is the injection of power into the network when the DG capacity is higher than its local loads. A typical example is a cogeneration plant, where the DG owner is charged only for the difference between the energy drained from the distribution utility and the amount injected into the network [3-5]. In 2009 [6] a feeder reconfiguration problem to the distribution system with dispatchable distributed generators by Tabu search. Tested in a distribution system 69 bus with MATLAB, the results of the study were able to reduce the power loss and manufacturing costs of the system. In 2009 [7], an optimal feeder reconfiguration with distributed generators in distribution system by fuzzy multiobjective and Tabu search tested in a distribution system 69 bus. The test results can reduce the power loss of the system. In 2011 [8] a method of coordination between distributed generators and voltage regulators was studied to improve system voltage using Tabu search Tested in IEEE 34-bus systems, test results can improve system voltage.

The technique employed to solve the minimization problem is based on a developed Tabu search algorithm and reliability worth analysis. The Tabu algorithm systematically searches solutions expressed in forms of the location and size of DGs. The solution obtained will then be passed to reliability worth analysis to evaluate the quality of the solution. The process is repeated until the best solution has been found. The developed methodology is tested with a distribution system of Roy Billinton Test System (RBTS) bus 2. The customer outage cost are calculated from reliability indices of the load point and customer damage function [9].

II. Distribution System Reliability

The basic distribution system reliability indices at a load point are average failure rate λ, average outage duration *r*, and annual outage duration *U*. With these three basic load point indices, the following system reliability indices can be calculated [10].

Average interruption frequency index (SAIFI)

$$SAIFI = \sum \frac{\lambda_i N_i}{N_i} \quad (1)$$

System average interruption duration index (SAIDI)

$$SAIDI = \sum \frac{U_i N_i}{N_i} \quad (2)$$

Customer average interruption duration index (CAIDI)

$$CAIDI = \sum \frac{U_i N_i}{\lambda_i N_i} \quad (3)$$

Average service availability index (ASAI)

$$ASAI = \frac{\sum N_i \times 8760 - \sum U_i N_i}{\sum N_i \times 8760} \quad (4)$$

Average service unavailability index (ASUI)

$$ASUI = 1 - ASAI = \frac{\sum U_i N_i}{\sum N_i \times 8760} \quad (5)$$

Energy not supplied index (ENS)

$$ENS = \sum L_{a(i)} U_i \quad (6)$$

Average energy not supplied index (AENS)

$$AENS = \frac{\sum L_{a(i)} U_i}{\sum N_i} \quad (7)$$

Where N_i is total number of load points *i*

U_i is annual outage duration *i*

$L_{a(i)}$ is failure rate of contingency *i*

A basic approach to quantifying the worth of electric service reliability is to estimate customer interruption costs due to electric power supply interruptions. One convenient way is an interpretation of customer interruption costs in terms of customer damage functions. The customer outage cost (*ECOST*) is calculated from reliability indices of the load point and customer damage function [11-12].

III. Photovoltaic

Photovoltaic [13-15] is a method of generating electricity directly. In recent years, all large-scale urban blackouts are due to transmission line overload which connected one or more distribution network with transmission network. Therefore, the energy control strategy which this article designed will satisfy the internal load demand of distribution network in maximal degree. And the thoughts of this strategy are reduced the long-distance power transmission, autarky and superfluous power feeding external. The photovoltaic diesel generator hybrid power supply system will be programmed as isolated island operation model which could access new energy maximum and will running at grid connected mode to send out extra solar energy [16] schematic diagram of the solar power system as shown in Fig.3.

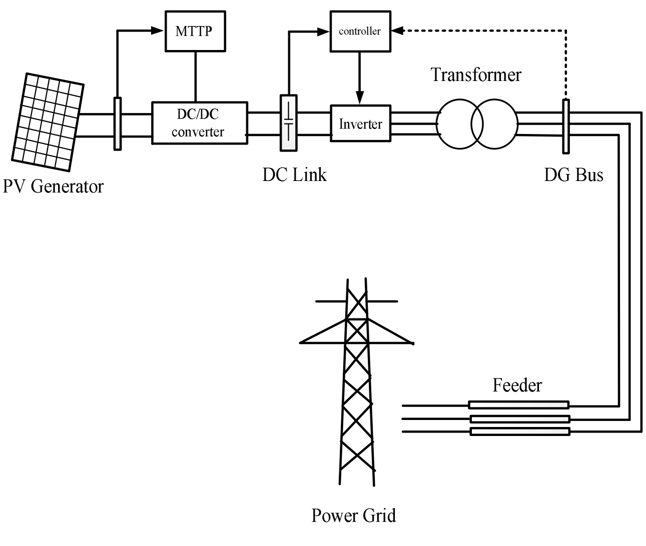

Fig. 3. Schematic diagram of the solar power system

Without photovoltaic outputting, if the battery packs output is less than the local load demands the diesel generators will fully generating. If the battery packs can satisfy load demand, the load will chose using battery backs or diesel engines to undertake the residual load and the criterion is sensitive load. When the photovoltaic fully outputting can't satisfy the load demand, the diesel generators will undertake the surplus load demand. This could avoid get or send energy to distribution network. Therefore, the access number and access positions of photovoltaic diesel generator hybrid power supply system are random. In each access position, the optimizing function can get the optimal access capacity and control model. The equivalent static model of a photovoltaic by a diode circuit as shown in Fig.4 [17].

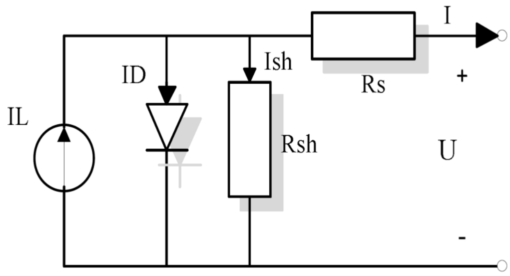

Fig. 4. Equivalent static model of a photovoltaic

The relation between the output voltage U and the load current can be formulated as follows [17].

$$I = I_L - I_D = I_L - I_O\left[exp\left(\frac{U + RI_s}{\alpha}\right) - 1\right] \qquad (8)$$

Where	I	is	load current
	I_L	is	current photo
	I_O	is	saturation current
	U	is	output voltage
	R_S	is	series resistor
	α	is	voltage temperature coefficient

IV. Tabu Search

Tabu search is a meta-heuristic that guides a local heuristic search strategy to explore the solution space beyond local optimality [18]. The basic idea behind the search is a move from a current solution to its neighborhood by effectively utilizing a memory to provide an efficient search for optimality. The memory is called "Tabu list", which stores attributes of solutions. In the search process, the solutions are in the Tabu list cannot be a candidate of the next iteration. As a result, it helps inhibit choosing the same solution many times and avoid being trapped into cycling of the solutions.

The quality of a move in solution space is assessed by aspiration criteria that provide a mechanism for overriding the Tabu list. Aspiration criteria are analogous to a fitness function of the genetic algorithm and the Bolzman function in the simulated annealing as shown in Fig. 5.

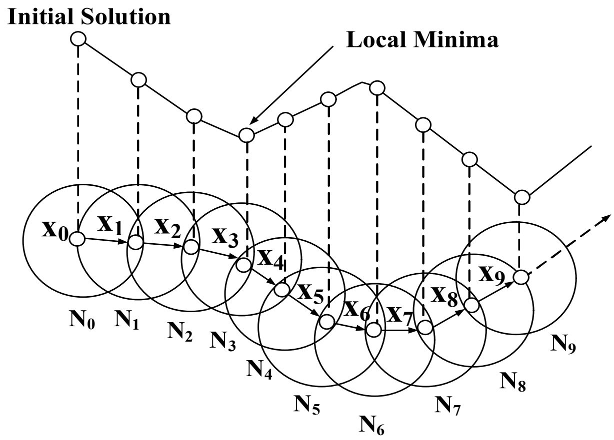

Fig. 5. Search direction of Tabu search

In the search process, a move to the best solution in the neighborhood, although its quality is worse than the current solution, is allowed. This strategy helps escape from local optimal and explore wider in the search space.

A Tabu list includes recently selected solutions that are forbidden to prevent cycling. If the move is present in the Tabu list, it is accepted only if it has a better aspiration level than the minimal level so far. The main concept of a search direction in Tabu search shows in Fig. 6 [19].

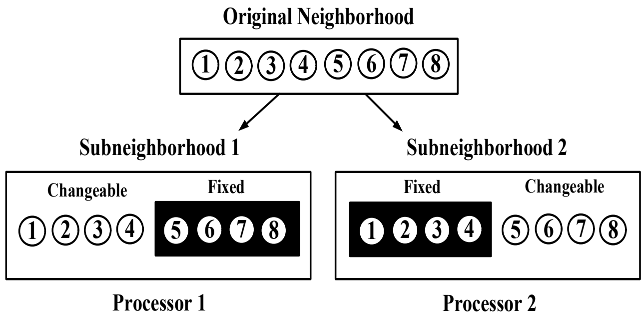

Fig. 6. Search direction of Tabu search

V. Problem Formulation

The objective is to minimize the customer outage cost that can be written as follows:

$$Minimize \quad ECOST = \sum_{h=1}^{n_h} \sum_{i=1}^{n_i} \left(L_{a(i)} C_{hi} r_h \lambda_h\right) \qquad (9)$$

where	$L_{a(i)}$	is	average load connected to load point i
	C_{hi}	is	outage cost (\$/kW) of customer due to contingency h
	l_h	is	failure rate of contingency h
	r_h	is	average outage time of contingency h
	n_h	is	number of contingencies h
	n_i	is	total number of load points i

The optimal placement and sizing of DGs is shown in Table I.

TABLE I. OPTIMAL PLACEMENT AND SIZING OF DGS

Case	Location of DG (bus)	Capacity of DG installed (kW)	Total capacity of DG (kW)
1	-	-	-
2	5, 15	600, 1100	1700
3	5, 11, 15	600, 600, 1600	2800
4	4, 5, 11, 15	1200, 500, 1900, 1200	4800

VI. CASE STUDY

The developed Tabu search algorithm is tested with a distribution system of RBTS bus 2 [20] to minimize the customer outage cost. There are 4 feeders and 22 load points. The peak loading level of bus 2 is 20 MW. The configuration of the system is shown in Fig.7.

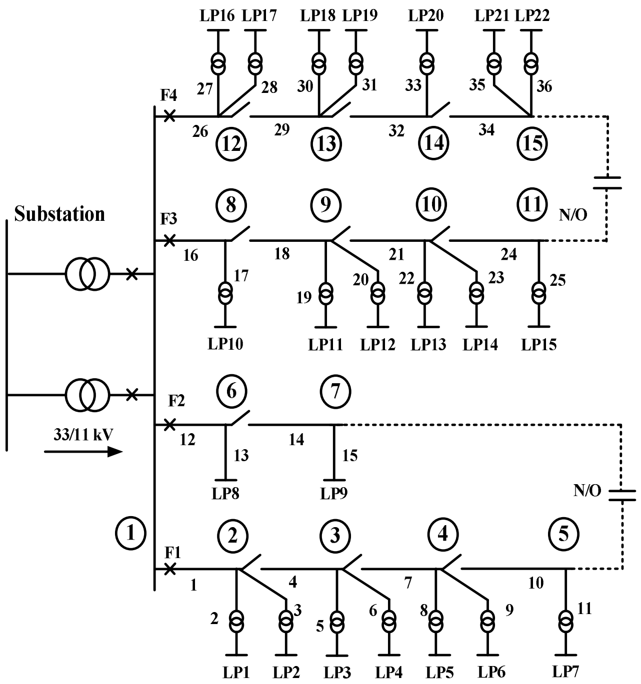

Fig. 7. Distribution system of RBTS bus 2

The maximum iteration for Tabu search is 100. The minimum and maximum voltages for each bus are 0.95 p.u. and 1.05 p.u., respectively. The sizes of DGs are 100 kW-1,500 kW. The failure of a transformer is recovered by repair. All protective devices and DGs are assumed to be fully reliable. Five cases are investigated in Table II. The DG types for testing include Photovoltaic: PV, Wind Turbine: WT and Hydro Power: HP

TABLE II. CASE STUDY FOR RELIABILITY ANALYSIS

Case	Type	Maximum number of DGs, n_{DG} (unit)	Total installed capacity, G (kW)
1	-	-	-
2	Photovoltaic	2	≤ 2000
3	Wind Turbine	3	≤ 3000
4	Hydro Power	4	≤ 4000
5	Photovoltaic Wind Turbine Hydro Power	5	≤ 5000

The results from the case study are shown in Table III. and IV. and Distribution system of RBTS bus 2 with distributed generation for case 5 as shown in Fig. 8.

TABLE III. OPTIMAL PLACEMENT AND SIZING OF DGS

Case	Location of DG (bus)	Capacity of DG installed (kW)	Total capacity of DG (kW)
1	-	-	-
2	5, 15	600, 1200	1800
3	9, 11, 15	200, 600, 1200	2000
4	5, 11, 14, 15	600, 600, 400, 1200	2800
5	5, 7, 10, 11, 15	600, 1200, 600, 1000, 1200	4600

TABLE IV. RESULT OF STUDY FOR RELIABILITY INDICES

Reliability indices	**Cases**				
	1	**2**	**3**	**4**	**5**
SAIFI (interruptions/customer)	0.2482	0.248211	0.248211	0.248211	0.248211
SAIDI (hours/customer)	3.7321	3.72557	3.72571	3.72243	3.72212
CAIDI (hours/customer interruption)	15.036	15.0097	15.0103	14.9971	14.9958
ASAI	0.9996	0.999575	0.999575	0.999575	0.999575
ASUI	0.0004	0.000425	0.000425	0.000425	0.000425
ENS (kWh/year)	40,775.30	39,899.8	39,911.6	39,417.9	38,965.5
AENS (kWh/customer/year)	21.37	20.9118	20.918	20.6593	20.4222
ECOST ($/year)	49,922.30	44,290.3	44,395.6	41,459.8	40,735.8

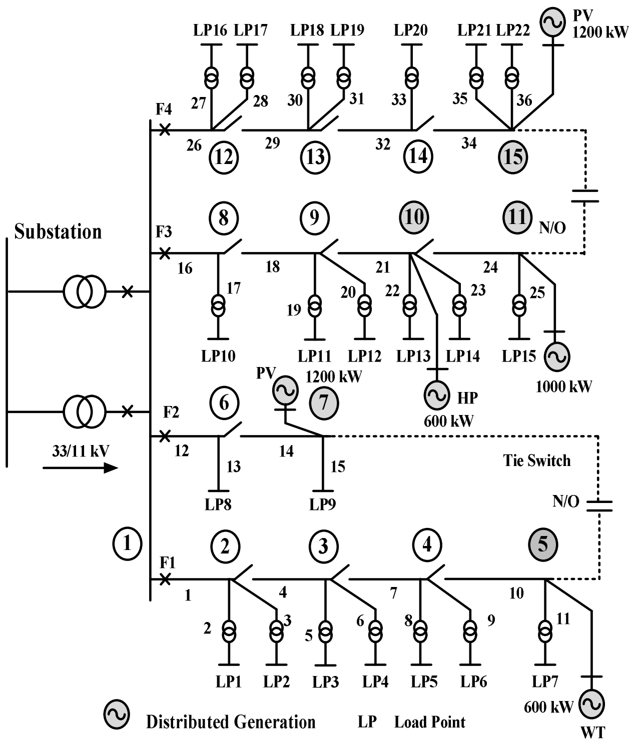

Fig. 8. Distribution system of RBTS bus 2 with distributed generation for case 5

VII. CONCLUSION

This paper has presented a Tabu search-based method for optimal placement of distributed generation in distribution systems with the main objective to maximize reliability benefits described in forms of the customer interruption cost.

From a reliability point of view, distributed generation is served as a back up generation for load points that would otherwise have been left disconnected until the repair of a faulted component had been completed. The effectiveness of the proposed method was demonstrated by a case study of a distribution network of RBTS bus 2. It can be seen from the case study that distributed generation can reduce the customer interruption cost and therefore improve the reliability of the system.

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