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Using Particle Swarm Optimization Algorithm in the Distribution System Planning

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Abstract: Technology advancement, the drive to reduce environmental pollution and energy security concern, have led toan increase in the use of Distributed Generations (DGs). One of the important aspects of the power system is the optimal operation of distribution networks. Therefore, the objective of this paper is to determine the possiblesolution for optimal operation of distribution networks which takes into account the impact of DG. Since the optimal operation of distribution networks is an optimization problem with discrete and continuous variables, it can be introduced as an integer problem that can be formulated using themetaheuristic approach. This paper utilizes the Particle Swarm Optimization (PSO) algorithm to solve the distribution planning problem with DG. In addition, a case study on IEEE 34 bus system has been carried out to demonstrate the effectiveness of the PSO algorithm with regards to Genetic Algorithm (GA). Results indicate that PSO havebetter peformanceover the GA in terms of cost of lossesminimizationand convergence time.Future work should consider to minimize the overall network cost simultaneously that takes into account the DG investment cost, cost of losses and maintenance cost.

Key words: Distributed Generation, Distribution System Planning, Particle Swarm Optimization, Genetic Algorithm

INTRODUCTION

The electricity industry has faced major changes during the past decades. The desire to create a competitive environment has caused the separation of various entity such as generation, transmission and distribution. These developments and the other issues such as the climate change challenge, energy supply security and technology advancement havecaused the increase in the utilization of DG. Most of DGs can be directly connected to the distribution network which located close to the load centre. This issue offers a significant benefit to the system such as avoiding or deferring the need to install new transmission lines and reduce network power losses. Past research (Massoud Amin, S. and B.F. Wollenberg, 2005; Hobbs, B.F., 2001; Wilson, R.B., 1997) conducted under the Electric Power Research Institute (EPRI) have shown that more than 25% capacity of new installed DGs were installed until 2010.

With regards to the matterson DGs, thus there is a strong urge that the past system studies related to the system planning should be revisited.

One of the essentialareas that need to be further explore is the optimal management of distribution networks (Chiradeja, P., 2005; Wang, Z. and Q. Xu., 2011). Generally, the optimal operation of distribution networks has leadto an optimum use of resources within the prescribed network constraints (Danny Pudjianto, 2013; Chin Kim Gan, 2011). The optimization problem can be tacklein two conditions: firstly, the objective function has a minimum value;and secondly, the technical constraint of the problem should be met. The distribution networkprior to DG connection wasnot involved with the distributed energy resources, thus the problem formulation of optimal management will only include the active power resources control that aims at reducingnetwork losses (Ghadimi, A.A. and H. Rastegar, 2009; Wille-Haussmann, B., 2009).

The swarm intelligent algorithm is one of the evolutionary computation methods created to solve the optimization problems and since then, their ability to be used in optimization problems has been demonstrated (Kennedy, J. and R.C. Eberhart, 1997; Holland, J.H., 1992). In this method, the movement towards the optimal positionisobtained from the best information of each particle which isincluded in the initial population (Best Personal Position) and the optimal position that is found by the neighbour'spositions(Best Global Position).

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Initialy, at the PSO algorithm, some particlespositionare assumed in the intended search space as initial population. All points are based on Euclidean distance in a various categories.The instance, as illustrated inFigure 1,$X_i$consists of three factors tracer, namely based on Previous Position, Personal Best Position and Global Best Position. The function of each particle in the search space is calculated and each category determines the value of particle depending on the target function which is minimized or maximized. Thus, the best member of each category is determined. On the other hand, with regard to previous information of each particle, the best point can be identified,which is already discovered. Therefore, the optimal point of each category and particle is determined. The first recognition in each category corresponds to the global optimum and the second recognition corresponds to the personal or local optimum point. According toFigure 1, supported with the precedent paragraph, the particle can be moved in the direction of the following vector equation (Del Valle, Y., 2008):

$$V_i^{t+1} = (w * V_i^t) + \alpha\left(X^{Pbest} - X_i^t\right) + \beta\left(X^{Gbest} - X_i^t\right) \quad (1)$$

$$X_i^{t+1} = X_i^t + V_i^{t+1} \quad (2)$$

Where,
X_i^t Current position of Particle
X^{Pbest} Best personal position of Particle
X^{Gbest} Best global position of Particle
V_i^t Velocity of particle *i* towards previous vector
V_i^{t+1} Velocity of particle *i* towards next position
w Inertia weight factor
α&β Acceleration coefficient
OF Objective Function

$$X^{Pbest} = \begin{cases} X^{Pbest(j)} if OF^{j+1} \geq OF^j \\ X_i^t if OF^{j+1} \leq OF^j \end{cases} \quad (3)$$

$$X^{Gbest} = \begin{cases} X^{Gbest(j)} if OF^{j+1} \geq OF^j \\ X^{Pbest(j+1)} if OF^{j+1} \leq OF^j \end{cases} \quad (4)$$

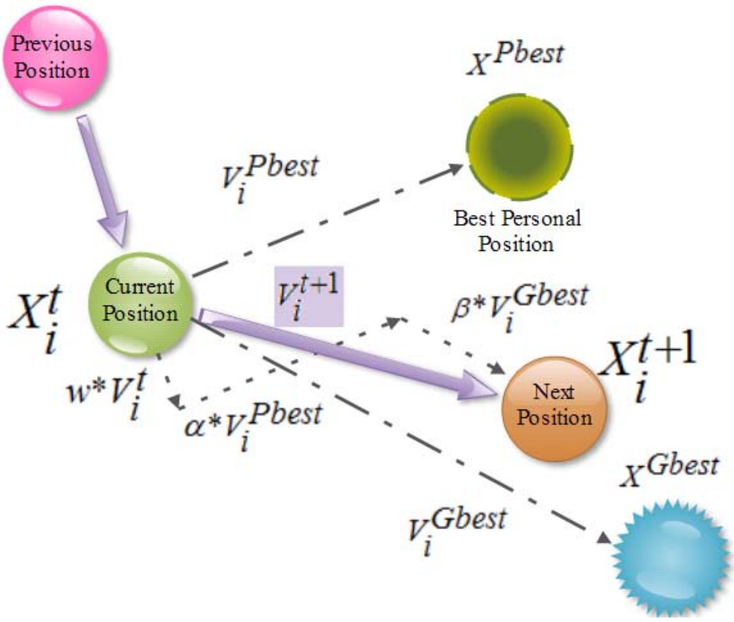

Fig. 1: Principle of the PSO particle movement.

The impacts of DGs on distribution network voltage dropneed to befurther investigated as it is one of the major constraints in objective function. Due to the small ratio of X to R in the distribution networks and the radial structure of these grids, the impact of DGs on distribution network voltage is much higher than the other power reactive resources. For this purpose, the following two-bus networksand voltage drop equation for the network are calculated (Moradi, M.H. and M. Abedini, 2010) (Figure 2).

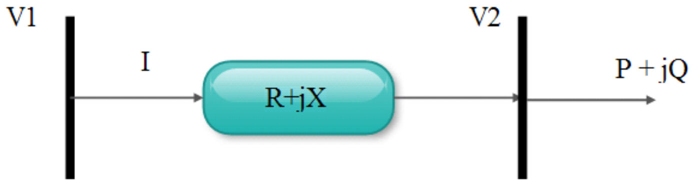

Fig. 2: Two-bus networks.

$$\boldsymbol{\Delta V = V_1 - V_2 = (R + jX)I} \quad (5)$$

$$\boldsymbol{I = \frac{P - jQ}{V_2^*}} \quad (6)$$

$$|\boldsymbol{\Delta V}|^2 = \frac{(\boldsymbol{RP+XQ})^2 + (\boldsymbol{RP-XQ})^2}{\boldsymbol{V_2^2}} \approx \frac{(\boldsymbol{RP+XQ})^2}{\boldsymbol{V_2^2}} \quad (7)$$

Where,

ΔV Line voltage drop

$R + jX$ Line impedance

Q Reactive power

P Active power

I Current flow through the line

$V_1 \& V_2$ Bus 1 and 2 voltage amplitude, respectively

As observed from the above equations, the voltage change affiliation to active power is not negligible because of the greater resistance value of distribution networks towards their reactance. Therefore, the optimization problem constraints are deemed necessary as these constraints are one of the penalty factors in the objective function.

The main target of distribution network planning is to minimize the objective function equation whereby the variables of this particular equation have a non-linear relation.Therefore, the objective function of the optimal operation problem is non-linear and discrete. In other words, the PSO algorithm is able to achieve the possible optimal global point with a sequence iteration and find the near optimal solution based on the related objective function.Pls re-write your objective in only 1 statement!!

Methods:

PSO Operation Procedure:

The PSO is a heuristic method based on creating an initial random solution as illustrated in Figure 3. There are six stages involved in the PSO flowchart, namely(a) Initialize Input data: The configuration of the distribution network and candidate DG sizing and locating are provided in this stage. The function model is produced by setting the random initial population and iteration number, random initial selection of position and velocity into the search space, (b) Calculate the objective function: The network solution program will be set up with the initial data whereby the objective function will calculate the summation of each particle, (c) Determine Pbest: The parameters of objective function values related to the positioning of each particle are compared with the corresponding value in previous positions. The lower objective function is then listed as Pbest for the current iteration as shown in the equation (3) (Ziari, I., 2009), (d) Determine Gbest: In this stage, the lowest objective function among the Pbests is related to all particles in the current iteration. It is then compared with the previous iteration and the lower one is recorded as the Gbest as shown in the equation (4) (Ziari, I., 2009), (e) Update velocity and position: The position and velocity of particles can be calculated for next iteration using both equations (1) and (2). It should be noted that α&β are acceleration coefficients that can be calculated as follows:

$$\boldsymbol{\alpha = C_1 r_1} \quad (8)$$

$$\beta = C_2 r_2 \quad (9)$$

Where, C_1 is the personal learning coefficient, C_2 is global learning coefficient and $r_1 \& r_2 \sim U(0,1)$ are uniformly distributed random numbers and (f) Check stop condition: There are three different modes for finalization of the algorithm depending on the objective function for stopping the iteration loop as shown in Figure 4. The algorithm can be finalized 1) after achieving the satisfying cost and desired value of the objective function, or 2) after achieving the some stall iteration, which means after the specified time has elapsed or the number of iterations without any improvement in outcome, or 3) after the specified time has elapsed or number of state iterations. Hence, after calling each of the above cases, the algorithm will be finalized and the results will be printed in the output.

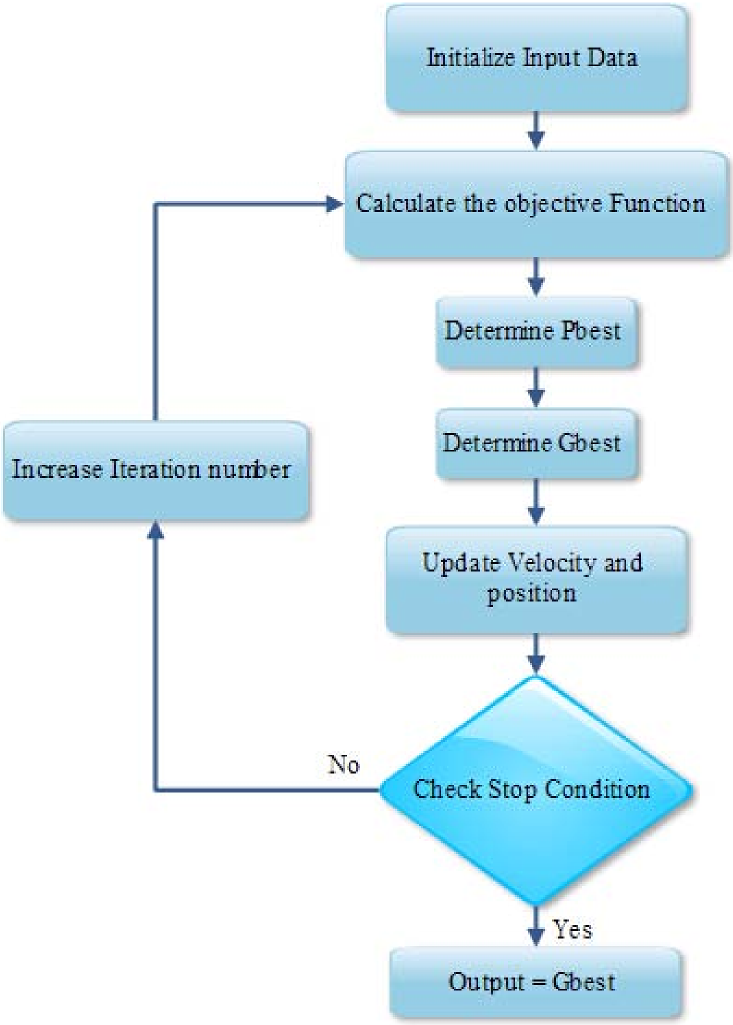

Fig. 3: The PSO algorithm flowchart.

Objective Function Formulation:

The allocating and sizing of the DG resources haveseriously impacted on the system losses in the distribution networks. Therefore, the following objective function in the equation (12) will minimize the power losses and improve voltage profiling in the radial distribution network (Najafi, S., 2009; Niknam, T., 2005). The objective function and problem formulationas well as constraints are formulated as follows:

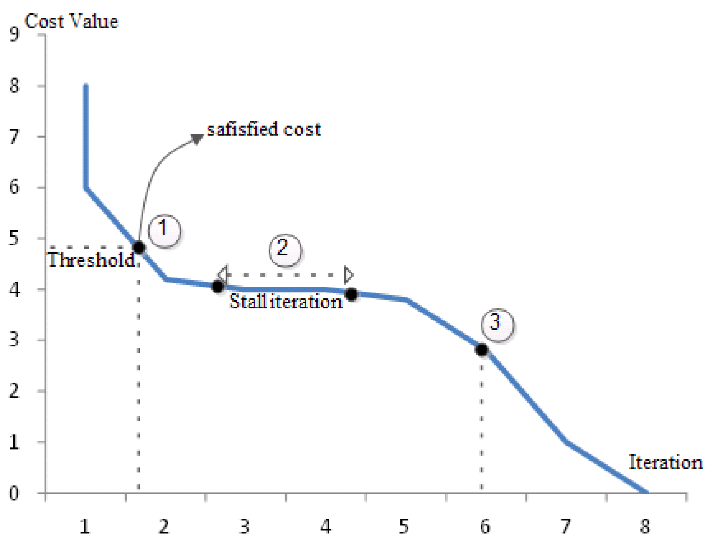

Fig. 4: Stop Conditions.

The following equation is represented power losses:

$$L_{realpower} = \sum_{i=2}^{n}(APO_i - APD_i - (Vs_i * Vr_i * Ysr_i * \cos(\delta r_i - \delta s_i + \theta y_i))) \quad (10)$$

Where,

$L_{realpower}$	*Real Power Losses*
APO_i	*Active power from output bus i*
APD_i	*Active power on demand bus i*
Vs_i	*Voltage from sending bus i*
Vr_i	*Volatge on receiving bus i*
Ysr_i	Admittance between sending and receiving at bus i
δs_i	Phase angle of sending bus i
δr_i	Phase angle of receiving bus i
θy_i	Phase angle of $Y_i \angle \theta_i$

The following equation is represented to improve the voltage profile:

$$V_P = \sum_{i=1}^{n}(Vr_i - V_{rate})^2 \quad (11)$$

Where,V_P is voltage profile of objective function and V_{rate} is rated voltage.Thus, from equations (10) and (11),they representthe objective function in Equation(12) which must be minimized.

$$Z = Min\left[\left(L_{realpower} + \gamma * V_P\right) + DP\right] \quad (12)$$

Where, γ is violation coefficient, DP is the penalty factor that derived from problem constraints and Z is thecost function that should be minimized with PSO algorithm.

The problem constraints and limitation of optimal management distribution system planning are as follows:

Bus voltage	$V_i^{min} \le V_i^t \le V_i^{max}$
Current feeders	$I_{fi} \le I_{fi}^{rated}$
Reactive power of capacitors	$Q_{ci}^{min} \le Q_{gi}^t \le Q_{ci}^{max}$
Maximum power line transaction	$\left\|P_{ij}^{line}\right\|^t \le P_{ij\,max}^{line}$

RESULTS AND DISCUSSION

The distribution system planning is solved based on the results of the PSO algorithm and the GA application. The IEEE 34 busesthat has been used in this study isas shown in Figure 5 with three different types of DG installed at the respective buses. The number of buses connected with DG and the DG characteristicsare as listed in Table 1. The comparison between the results of PSO and GA after solving the objective function is shown in Table 2.

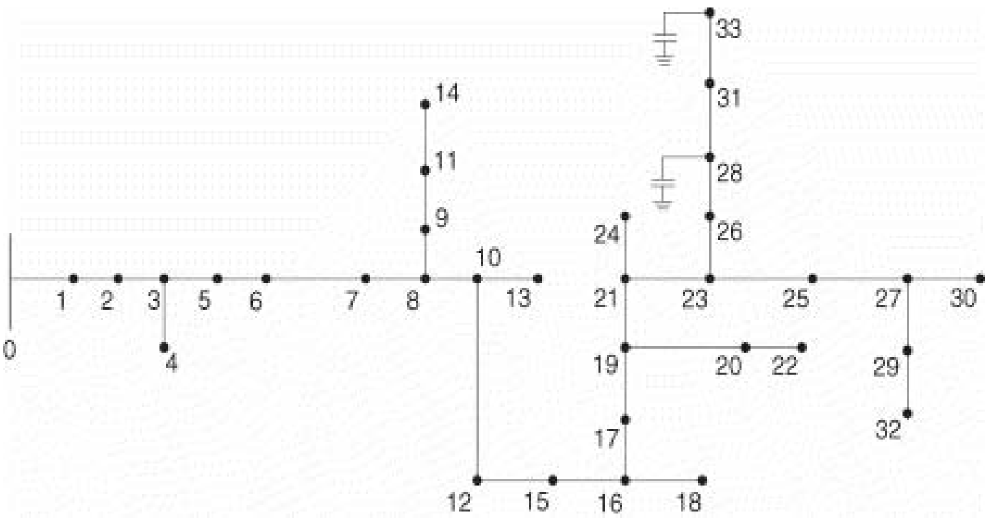

Fig. 5: IEEE 34 buses diagram.

Table 1: Distributed Generation features.

	G1	G2	G3
Active power (kW)	100	400	600
Max reactive power (kVar)	80	320	480
Min reactive power (kVar)	-60	-240	-360
Position in buses	5	15	33
Type of DG	Micro-turbine with CHP	Wind Turbine	Gas Turbine with CHP

Table 2: Comparison between GA and PSO.

Solution	Convergence time(Sec)		Objective function	
	Best	Worst	Best	Worst
GA	1200	1300	1026.46	1268.24
PSO	450	600	1020.43	1270.56

Figures 6 and 7 show the GA and PSO respectively from the Matlab program output after solving the optimization problems.Both figures indicate the convergence time after the number of iterations to reach to the satisfied cost function.

Fig.shows the GA algorithm is obtained to the best result after passing around 639 iterations but

Fig. shows the best result is achieved after 373 iterations. The convergence time for each method is shown in Table 1: Distributed Generation features.

	G1	G2	G3
Active power (kW)	100	400	600
Max reactive power (kVar)	80	320	480
Min reactive power (kVar)	-60	-240	-360
Position in buses	5	15	33
Type of DG	Micro-turbine with CHP	Wind Turbine	Gas Turbine with CHP

which pointed out the PSO algorithm could gain the better result in a superior way than GA.

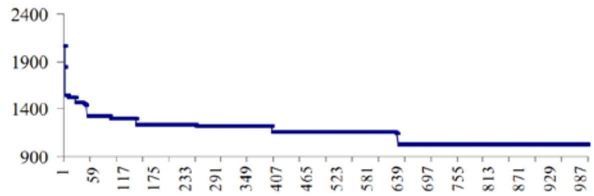

Fig. 6: Minimize the cost according to the number of iterations in GA.

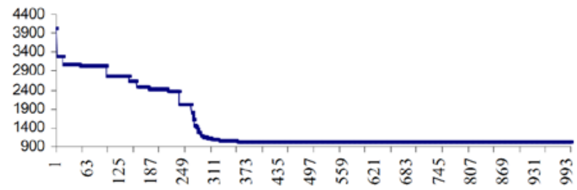

Fig. 7: Minimize the cost according to the number of iterations in PSO.

Conclusion:

Technology advancement has helped to facililate the effective integration of DGs, which is commonly connected to the distribution networks. Moreover, this paper compares the performance of PSO and GA algorithm in terms of cost of losses minimization and convergence time.The presented study suggests that PSO solutionis less time intensive if compared to GA method for cost of losses minimization problem in multi-DG system. The future work should consider to minimize the overall network cost simultaneously that takes into account the DG investment cost, cost of losses and maintenance cost.

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