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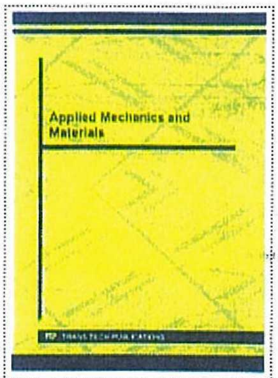

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Room: ICE-SEAM 2

2:00 **C2-1**	***The Potential Energy of Plastic Solid Waste as an Alternative Fuel for Power Plants in Indonesia*** Muhammad Anshar (Universiti Teknologi Malaysia, Malaysia); Farid Nasir Ani (Universiti Teknologi Malaysia, Malaysia); Ab Saman Kadir (Universiti Teknologi Malaysia, Malaysia)
2:15 **C2-2**	***Gasification of Empty Fruit Bunch Briquette in a fixed bed tubular reactor for hydrogen production*** Bemgba Bevan Nyakuma (Institute of Hydrogen Economy (IHE) Department of Chemical Engineering Universiti Teknologi Malaysia, Malaysia); Mojtaba Mazangi (Institute of Hydrogen Economy (IHE) Universiti Teknologi Malaysia, Malaysia); Tuan Amran Tuan Abdullah (UTM, Malaysia); Anwar Johari (Institute of Hydrogen Economy (IHE) Universiti Teknologi Malaysia, Malaysia); Arshad Ahmad (Institute of Hydrogen Economy (IHE) Universiti Teknologi Malaysia, Malaysia); Olagoke Oladokun (Institute of Hydrogen Economy (IHE), Universiti Teknologi Malaysia, Malaysia)
2:30 **C2-3**	***Optimal Capacitor Allocation in Distribution System using Particle Swarm Optimization*** Ihsan Hasan (Universiti Teknikal Malaysia Melaka, Malaysia); Meysam Shamshiri (Universiti Teknikal Malaysia Melaka, Malaysia); Chin Kim Gan (Universiti Teknikal Malaysia Melaka, Malaysia); Datuk Prof. Dr. Mohd Ruddin Ab Ghani (UTeM, Malaysia); Ismadi Bugis (Lecturer, Malaysia)
2:45 **C2-4**	***Reactive Power Imbalance Method for Islanding Detection in Micro-Grid Operation*** Meysam Shamshiri (Universiti Teknikal Malaysia Melaka, Malaysia); Revinnath Daram (Universiti Teknikal Malaysia Melaka, Malaysia); Chin Kim Gan (Universiti Teknikal Malaysia Melaka, Malaysia)
3:00 **C2-5**	***An Investigation of a Self-Pressurized Alpha V-Type Stirling Engine Converted Diesel Engine*** Mohd Yusof Idroas (Universiti Sains Malaysia, Malaysia); Farid Nasir Ani (Universiti Teknologi Malaysia, Malaysia); Zainal Alimuddin Zainal Alauddin (USM, Malaysia); Muhamad Azman Bin Miskam (Universiti Sains Malaysia, Malaysia)
3:15 **C2-6**	***Performance Evaluation of Dye Sensitized Solar Cell for Variation TiO2 Thicknesses*** Gomesh nair Shasidharan (Universiti Malaysia Perlis, Perlis, Malaysia)

Optimal Capacitor Allocation in Distribution System using Particle Swarm Optimization

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Keywords: Capacitor Allocation, Distribution Networks, PSO, OpenDSS.

Abstract. In distribution networks, capacitor installation is one of the commonly used methods for reactive power compensation. Capacitor placement and sizing in power system can be applied in multiple objectives and reasons. In this paper, the optimum capacitor placement and sizing has been applied in the distribution network in terms of power losses minimization and voltage profile improvement. The maximum and minimum bus voltage and maximum possible capacitor size are the constraints of optimum capacitor placement and sizing problem which considered as a penalty factor in the objective function. In order to solve the obtained objective function, the Particle Swarm Optimization (PSO) is utilized to find the best possible capacitor placement and size. The OpenDSS software has been utilized to solve the power flow through Matlab coding interface. To validate the functionality of the proposed method, the IEEE 13-bus test system is implemented and the obtained results have been compared with IEEE standard case and without capacitor case. The result shows that the proposed algorithm is more cost effective and has lower power losses compare to the IEEE standard case. In addition, the voltage profile has been improved, accordingly.

Introduction

The optimum capacitor placement and sizing problem consists of various reasons such as reactive power compensation, the contribution to increase the network capacity, power losses and voltage profile improvement in both Medium Voltage (MV) and Low Voltage (LV) networks. Since the capacitor size has discrete values and electrical elements have nonlinear equation, the obtained objective function is nonlinear and discrete in nature. In recent years, the intelligence methods and evolutionary computation algorithms such as Genetic Algorithm (GA), Fuzzy Logics, Ant Colony and Particle Swarm Optimization (PSO), has been developed in order to solve the capacitor placement and sizing problem [1–4]. The researchers suggested variety of objective function in terms of different targets for capacitors installation. This work aims to find the optimum capacitor placement and sizing with subject to achieve the minimum power losses and best possible bus voltage profile. The voltage range constraints for each buses and maximum capacitor size are considered as a penalty factor in the objective function.

OpenDSS. To find the optimum placement and sizing of capacitors in distribution system, the power flow solution requires finding the results of optimization problem. Open Distribution System Simulator (OpenDSS) is a comprehensive electrical system simulation tool for electric utility distribution systems. The OpenDSS is an open source developed by the Electric Power Research Institute [5]. The OpenDSS engine includes the COM interface which can be used in other simulation programs such as MATLAB, VBA, C# and etc. The OpenDSS engine can help the researchers to obtain the variety of significant information about the simulated power system. In this paper, OpenDSS engine is utilized as a power flow solution in order to find the power system parameters such voltage profile, power factor, real and reactive power flowing in each line, power losses and etc. which can be used in optimum capacitor placement and sizing problem in distribution system.

Particle Swarm Optimization (PSO).

Researcher applied PSO algorithm successfully in complex non-linear engineering problem, principally in planning of distribution system, control systems, multi-objective optimization problems with multiple constraints, shape optimization and etc. [3]. Since the capacitor installation in distribution system has the non-linear and discrete equation, therefore, this paper utilized PSO algorithm as one of the accurate methods to solve the capacitor allocating problem. The procedures of this algorithm have been described in [6]. Fig. 1 shows the optimal movement of each particle during particle movement based on vectors of previous position, best personal position and best global position. The equation of the next position's vector and the next position are shown in Eq. 1 and Eq. 2, respectively.

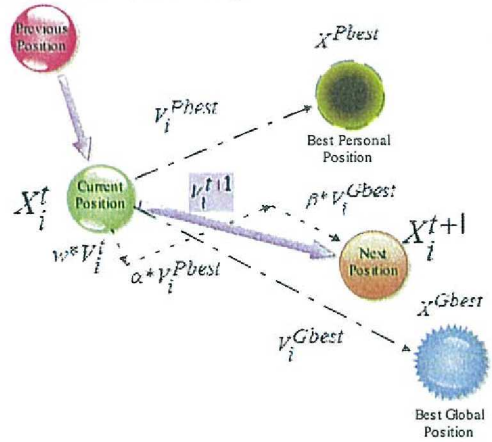

Fig. 1: Principle of the PSO particle movement [6]

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

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

Where, X_i^t is the current position of particle, X^{Pbest} is the best personal position of particle, X^{Gbest} is the best global position of particle, V_i^t is the velocity of particle i towards previous vector, V_i^{t+1} is the velocity of particle i towards next position, w is the inertia weight factor, α & β is the acceleration coefficient and OF is the objective function. It should be noted that α & β are acceleration coefficients that can be calculated as $\alpha = C_1 r_1$ and $\beta = C_2 r_2$.

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

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

Where, C_1 is the personal learning coefficient, C_2 is the global learning coefficient and $r_1 \& r_2 \sim U(0,1)$ are the uniformly distributed random numbers.

Proposed Methodology

The proposed algorithm that utilized in this paper is subject to find the optimum capacitor allocation as shown in Fig. 2. The problem formulation includes two objectives. The first is the optimum placement of capacitor which is an integer optimization problem that results will either the selected bus to install the capacitor or non-selected bus. The second is the optimum sizing of capacitor which is a discrete optimization problem and the results will define the optimum capacitor size that should be installed in related buses. As shown in Fig. 2 algorithm, initially the capacitor cost, available capacitor, number of buses, load data, bus data, line data and other variables will be defined. Then, power flow solver is implemented by OpenDSS engine and the results of power flow are imported to Matlab program for analysis. The maximum reactive power that can be injected to each bus is calculated and minimum bus voltages have been detected. Based on the power factor correction calculation and minimum bus voltages, the numbers of the buses are selected as the sensitive buses for optimum placement algorithm.

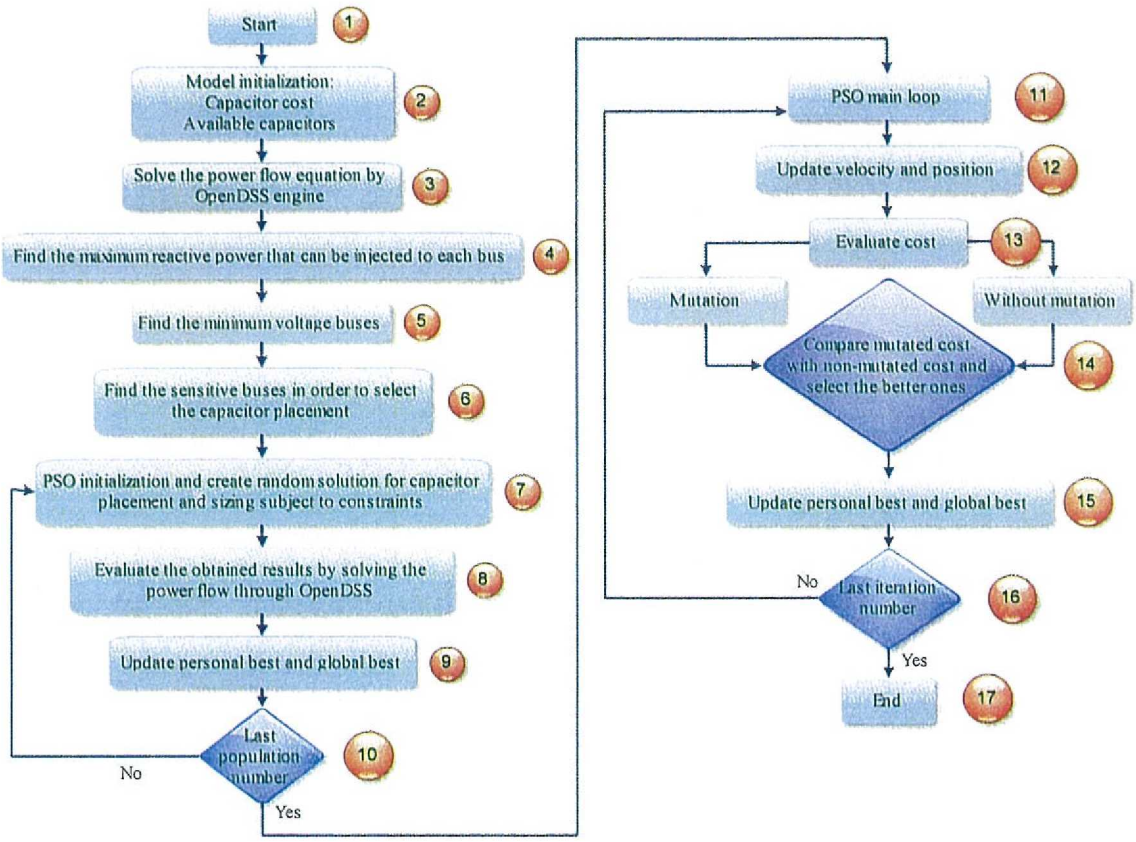

Fig. 2: The proposed algorithm for optimum capacitor placement and sizing problem

In sequence the PSO will be initialized by the number of population and maximum iteration number. The other parameters of PSO algorithm have been obtained from previous steps such as minimum and maximum variables, number of decision variables and etc. The first random solution will be created in terms of capacitor placement and sizing by considering the problem constraints. In addition, each particle include two data which are the capacitor size and bus number, and export them to OpenDSS engine for solving power flow. Furthermore, the obtained results of power flow will be evaluated based on the discovered files by OpenDSS and determining the Personal best and global best and updating will be executed. In the PSO main loop, initially updating the position and velocity of particles are executed. The cost function will be evaluated based on the best global position of the particle which represents the minimum cost function. The mutation has been applied on the number of population to avoid the local minima optimization and to obtain the best possible results. Therefore, the mutated results have been compared with non-mutated population. The minimum cost from the comparison block will be selected as the best cost. The personal best and global best particles will be evaluated in order to update the best obtained possible results. This procedure will be performed subsequently until the end of the iteration number. Finally the minimum cost will be extracted from the output of the algorithm.

Problem Formulation

In most of related papers, the capacitor placement and sizing problem solved by a combination of the objective functions and convert it as an objective function [6, 7]. This paper uses the PSO algorithm to solve an objective function of the optimum capacitor placement and sizing in power system. In this algorithm the objectives of the problem are considered independently and they converge to the minimum simultaneously by acceleration coefficient that obtained from PSO. Finally the aggregate answers will be selected as the best possible result.

Cost Minimization. In capacitor placement and sizing, costs are included the power losses cost and the capacitors cost which objective function can be written as follows [1]:

$$Z=\sum_{i=1}^{nb} C_L.P_{Loss}^i+\sum_{j=1}^{nc} C_{Cost}^j.C_C^j \quad (5)$$

$$P_{Loss}^i=\sum[V_i^2+V_j^2-2V_i^2.V_j^2\cos(\delta_i+\delta_j)].Y_{ij}\cos\varphi_{ij} \quad (6)$$

Where, nb is the number of buses, $C_L[\$/kW]$ is the cost losses per kW, $P_{Loss}^i[kW]$ is the active power losses on bus i, nc is the number of selected capacitor, $C_{Cost}^j[\$/kVAR]$ is the cost of capacitor j which will be defined based on capacitor price table in [8, 9], and $C_C^j[kVAR]$ is the capacitor capacity on bus i. $V_i,\delta_i,V_j,\delta_j$ are voltage magnitude and angles of bus i and j, respectively. Y_{ij} and φ_{ij} are the line admittance magnitude and angle between buses i and j, respectively.

Constraints. In voltage profile improvement is tried to keep the voltage buses difference in certain desired range. The first constraint in capacitor placement and sizing problem is the bus voltage range $V_{\min}\le V_i\le V_{\max}$ that must not below or exceeds than minimum or maximum defined voltages, respectively. The voltage constraint based on standard can be written as a voltage constraint as follows:

$$0.95\le V_i\le 1.05 \quad (7)$$

Where, V_n and V_i are the nominal and bus i voltages, respectively. In addition, the capacitor sizing in optimization problem has constraint due to economic and technical consideration in power system planning. The summation of the all installed capacitors must not be exceeding than total demand reactive power which is $Q_{\max}$, and Q_C^j is the capacitor size in bus number i.

$$\sum_{j=1}^{nc} Q_C^j\le Q_{\max} \quad (8)$$

Test System

To demonstrate the PSO algorithm performance on capacitor allocation, the IEEE 13–bus [10] test system is studied as unbalance case study. The loads data, Bus data, Line data and all information about this case study have been noticed in [10]. This case initially includes capacitors on buses 675 and 611 with 600 and 100 kVAR capacities, respectively. To find the optimum capacitor placement and sizing in this case, initially removed those capacitors from the buses in order to convert the system into collapse point and destroy the voltage profile and increase the power losses. The obtained network is solved by above explained PSO algorithms in order to find the optimum placement of capacitors in the system. The obtained results are compared with the normal IEEE case (with capacitor) to illustrate the optimum results advantages in terms of cost minimization. Table 1 shows the voltage profiles before capacitor installation and after optimum capacitor placement and sizing by proposed method. As clear from the Table 1, the optimum allocating capacitor has the better voltage profiles compares to without capacitors case. Similarly, Fig. 3 shows the active power losses in three different operation modes which optimum capacitor allocating has the minimum losses compare to without capacitor case. Fig. 3 (b) indicates the losses for each bus which is reduced after optimum capacitor installation.

Table 1: The voltage profile before and after optimum capacitor allocating

Bus number	Before Capacitor			After Capacitor			Bus Number	Before Capacitor			After Capacitor		
	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C		Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
650	1.000	1.000	1.000	1.000	1.000	1.000	645	-	1.025	1.001	-	1.024	1.023
RG60	1.062	1.05	1.069	1.062	1.050	1.069	646	-	1.024	0.999	-	1.022	1.021
633	1.011	1.033	1.000	1.019	1.031	1.023	692	0.976	1.039	0.949	0.991	1.036	0.995
634	0.987	1.014	0.981	0.995	1.013	1.004	675	0.969	1.04	0.945	0.984	1.038	0.992
632	1.014	1.035	1.003	1.022	1.033	1.025	684	0.975	-	0.946	0.990	-	0.995
671	0.976	1.039	0.949	0.991	1.036	0.995	611	-	-	0.942	-	-	0.993
680	0.976	1.039	0.949	0.991	1.036	0.995	652	0.969	-	-	0.985	-	-

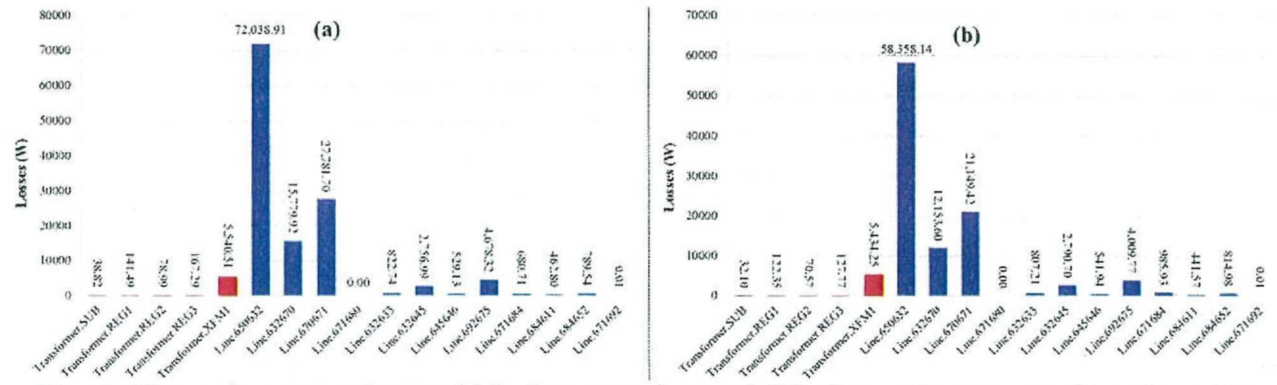

Fig. 3: The active power losses (a) before capacitor and (b) after optimum capacitor allocating

The cost minimization is the main objective function of optimum capacitor placement and sizing problem which Fig. 4 shows the cost minimization based on Number of Function Evaluation (NFE). NFE is an index to evaluate the functionality of algorithm based on the number of function calls. It shows the manner of cost reduction during the NFE and number of iterations. Table 2 shows the results of IEEE 13-bus test system in terms of voltage improvement, losses reduction and cost minimization by using the optimum capacitor placement and sizing.

Table 2: The results of IEEE 13-Bus test system in terms of voltages, losses and cost

	Without capacitor installation	Standard case capacitor installation	With optimum capacitor allocating
Capacitor location and size	-----	Bus: 675 size: 600 Bus: 611 size: 100 Total: 700 kVAR	Bus: 675 size: 350 Bus: 684 size: 200 Bus: 611 size: 150 Total: 700 kVAR
Active power losses (kW)	132.3	110.9	107.8
Minimum voltage (pu)	0.9424	0.9748	0.9843
Maximum voltage (pu)	1.0685	1.0685	1.0686
Total cost ($)	22226.4	18813.2	18392.9

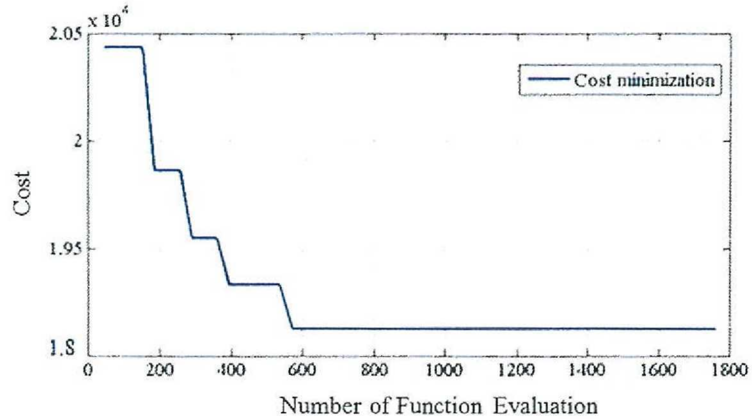

Fig. 4: The cost minimization curve after obtaining the desire amount.

The results show three operation mode of system which are without capacitor installation, IEEE standard normal case and after optimum capacitor allocating which is clear from the results that optimum capacitor allocating has the better possible cost compare to the IEEE standard case.

Summary

In this paper, the optimum capacitor placement and sizing has been applied in the distribution network in terms of power losses reduction, voltage profile improvement and cost minimization. The PSO algorithm and OpenDSS engine in Matlab coding program are used to solve the optimization problem and power flow. To validate the functionality of the proposed method, the IEEE 13-bus test system is implemented. The obtained results from proposed method have been compared with the IEEE standard case. The result shows, the optimum capacitor placement and sizing by utilizing the proposed algorithm was capable to minimize the cost and power losses compare to the standard case. In addition, the voltage profile has been improved, accordingly.

Acknowledgement

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