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# A new perspective in power loss reduction of ninety two buses integrated D-STATCOM

***Abstract**. The electrical energy demand continues to increase along with the rapid development of technology and population growth. Fulfilling the electricity supply is a challenge for the operation of the electric power system since the construction of distribution and transmission infrastructures require large costs and such long time process. The complexity of the power distribution system itself may affect the voltage deviation and power loss parameters. The more complex of the distribution system was configured the more critical impacts on those disturbance parameters encountered entire the power network. The main contribution in this research is exploring on 99 bus context with D-STATCOM injection to increase the voltage profile, reducing the total active power loss and optimal size of D-STATCOM using the Optimal Power Flow (OPF) method for load flow analysis and Particle Swarm Optimization (PSO) in optimizing total loss active power and size of D-STATCOM on a radial distribution network system. This study aims to improve the distribution network performance in terms of the voltage profile, the total active power loss through optimal D-STATCOM placement. Optimization uses the Optimal Power Flow (OPF) method based on Particle Swarm Optimization (PSO). The proposed algorithm is calculated numerically for the North Makassar distribution system with ninety two buses included a network pattern open-loop radial configuration and the total load reaches 4.914 MW. The optimized computation algorithm result a minimum voltage profile of up to 0.73%, an average voltage profile up 0.8% or 4kV and a minimum total active power loss around 10.53%.*

*Streszczenie. Celem artykułu jest poprawa parametrów sieci przez optymalizację położenia układu D-STATCOM oraz zastosowanie metody OPF (optymalny przepływ mocy) z wykorzystaniem algorytmów rojowych PS. Zaproponowany algorytm jest obliczony numerycznie dla regionu North Makasar w Algerii. Uzyskano poprawę jakości napięcia I minimum mocy biernej. (**Nowe perspektywy w redukcji strat mocy w sieci zintegrowanej z D-STATCOM**))*

**Keywords:** optimal power flow, D-STATCOM, Particle Swarm Optimization Algorithm, Power Loss
**Słowa kluczowe:** optymalny przepływ mocy OPF, STATCOM, algorytmy rojowe

## Introduction

Fulfillment of electricity supply is a challenge for the operation of the electric power system and the construction of distribution channels in supporting the continuity of electric power delivery which requires huge costs and a long time process. The complexity of the power distribution system increases the voltage deviation and the power loss. To solve the problem, installing a Distribution Static Compensator (D-STATCOM) in a radial distribution network is one solution [1].

Generally, the electric power system is divided into three main components, namely the generating system, transmission system, and distribution system. A distribution system is a network that connects sources to loads or consumers. Radial network configuration is the simplest distribution network configuration and the lowest investment cost. The radial distribution system has many branches, the distance between the source of the generator with the load is far, the ratio of R/X value is high. These things can cause voltage drops and power losses in the distribution network [2].

Power loss causes inefficient power grids in distributing from source to load or consumers. Whereas the voltage drop can cause damage to consumer electrical equipment. Some researchers claim that 13% of the total power generated is wasted as a loss in the distribution system [3]. Because it is necessary to make efforts to overcome this, one solution is to inject the Distribution Static Compensator (D-STATCOM) in the radial distribution system. Through time series simulation to analyze the dynamic characteristics of the distribution network for various seasons shows that D-STATCOM increases the voltage profile and power factor on each bus [4]. D-STATCOM implementation on various types of loads using the Simpower System toolbox with MATLAB Simulink control is obtained D-STATCOM conceptually similar to STATCOM on the transmission network. D-STATCOM can compensate for reactive power, increase power factor, control the harmonic voltage, thereby improving power quality at the distribution end [5].

D-STATCOM is an inverter-based voltage source which is a special power device, connected in parallel with the power system and can supply reactive power to increase the voltage profile and reduce power loss in the line [6]. The main components of D-STATCOM include, VSC (Voltage Source Converter), energy storage equipment, transformers that are connected parallel to the distribution network through transformer couplings. The basic principle of D-STATCOM is it will produce an ac voltage source in the distribution that can be controlled by a voltage source converter (VSC). The output voltage from D-STATCOM can control the active and reactive power exchanges between D-STATCOM and the distribution network system [7]. In the D-STATCOM installation, the placement and isntallation of power capacity is essential, improper location selection and D-STATCOM size can cause even greater loss [8].

Power flow optimization which is called Optimal Power Flow (OPF) is used to optimize the power flow of the interconnected electric power system so that the active, reactive and voltage control variables are obtained [9]. To determine the size and placement of D-STATCOM on the distribution network in reducing power loss is solved using the Particle Swarm Optimization (PSO) method [10]. This method was chosen because it is easy to implement with a small number of parameters used. Algortima PSO is a stochastic optimization based on increasing individual, competition and social cooperation in the population. PSO reduces computational burden when compared to other classical optimization methods [11]. The PSO-based algorithm can be used to determine the location and size of an optimal multi-DG unit to reduce loss in the main distribution network [12].

To minimize system power loss and increase the voltage profile with DG and DSTATCOM, Cuckoo Search Algorithm (CSA) based optimization is applied to the IEEE 33 and 136 bus standards [13]. While determining the optimal location of DG and DSTATCOM on a radial distribution network system in reducing losses, increasing the profile and stability of the distribution system voltage by considering load variations using a new method namely

Lightning Search Algorithm (LSA). Its application on IEEE 33 buses and 69 buses obtained very satisfying results [14]. Furthermore, T. Yuvaraj et al conducted a study on the placement and size of D-STATCOM in a radial distribution network to minimize power loss using the new bat algorithm method. The Voltage Stability Index (VSI) is used to determine the optimal location and bat algorithm to determine the optimal size of the D-STATCOM. Applied to the IEEE 33 bus and 69 bus radial distribution systems, the simulation results show that the implementation of D-STATCOM in the radial distribution network has reduced the total power loss [15]. Unbalanced load caused by non-linear load results in a decrease in power quality. To improve power quality, D-STATCOM-based Levenberg-Marquard Back (ANN-LMBNN) propagation is proposed. Simulation results show that the D-STATCOM-based intelligent control method applied to the IEEE 13 bus system is able to overcome power quality problems [16,17].

This research applies the D-STATCOM PSO Algorithm hybrid computing technique as an alternative problem solving on Makassar Power Distribution Network which consist of 92 bus. With Operational Power Flow (OPF), power grid variables can be obtained in the form of voltage, angle, active power, reactive power and total active power loss.

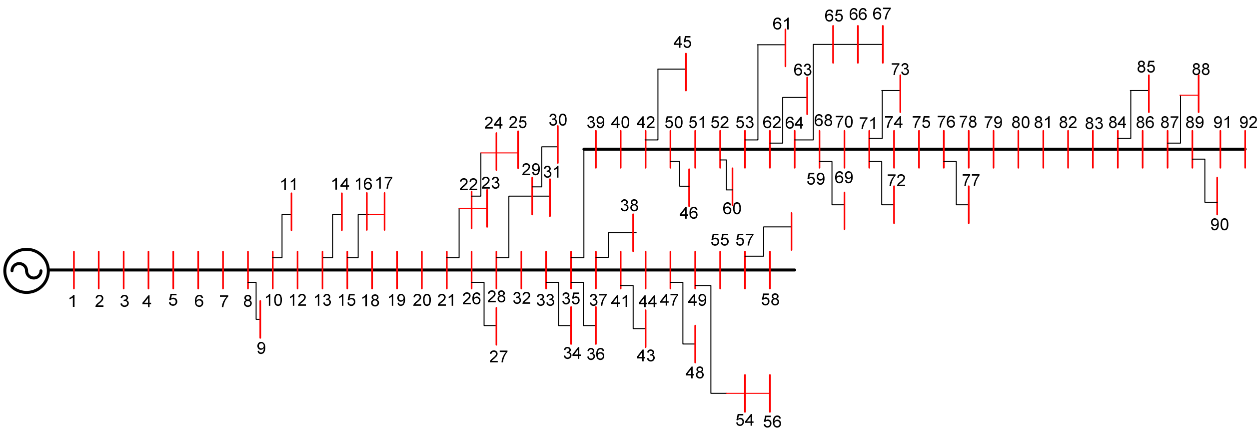


Fig.1. Distribution System of North Makassar 92 Bus

**Optimal Power Flow (OPF)**

Optimal Power Flow (OPF) was first formulated in 1962 by Carpentier. Carpentier presented the OPF as an extension of the problem*economic dispatch*(ED) in the power system. Carpentier's main contribution includes the power flow equation in the formulation of economic dispatch (ED) [18]. Optimal Power Flow (OPF) plays a very important role in the operation of the power system. OPF schedules certain variables in the power system optimally to meet the balance of power flow and power system constraints [19]. The aim of the OPF is to optimize power grid variables including active power, reactive power, voltage and angle of the bus that can affect the increase in voltage profile and reduce power loss in the distribution network [20]. The OPF method can determine the optimal operating conditions on distribution networks that experience problems in operation. As with the object of this study that uses a broad radial system depicted in the figure 1. Optimal point variables are formulated and solved using an appropriate optimization algorithm, such as the Newton-Raphson method. The objective functions to minimize power loss are as follows [21,22].

Minimizing loss on distribution network systems

(1) $min \sum_{i=1}^{n} P_{loss}$

A simple one-line diagram can be illustrated as in Fig. 2.

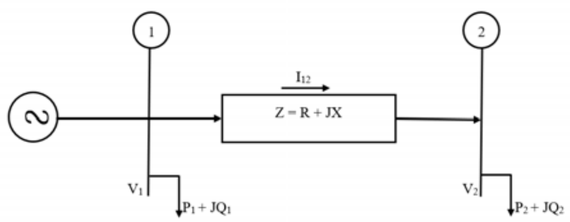


Fig.2. Simple one-line diagram

Based on Figure 2, the stresses in vertices 1 and 2 are obtained as follows:

(2) $V_1=V_2+I_{12}*(R+jX)$

(3) $V_2=V_1-I_{12}*(R+jX)$

Line Current is calculated using the equation (4) :

(4) $I_{12}=\left(\frac{P_1+jQ_1}{V_1}\right)^*$

Active and reactive power losses are calculated using equations (5) and (6)

(5) $P_{losses(1,2)}=(I_{12})^2*R=\left(\frac{P_1^2+Q_1^2}{|V_1|^2}\right)*R$

(6) $Q_{losses(1,2)}=(I_{12})^2*X=\left(\frac{P_1^2+Q_1^2}{|V_1|^2}\right)*X$

Total active and reactive power losses are calculated by adding all active and reactive power losses in each branch as in equation (7).

(7) $P_{Total\ Losses}=\sum P_{losses(1,2)}$

The minimization of active and reactive power loss as an objective function is stated as follows:

(8) $F=min(P_{loss})=\sum_{i=1}^{n} I_{12}^2*R$

(9) $F=min(Q_{loss})=\sum_{i=1}^{n} I_{12}^2*X$

**Particle Swarm Optimization (PSO)**

Particle Swarm Optimization (PSO) is an optimization algorithm based on swarm intelligence. The PSO algorithm is initialized with a population consisting of random solution candidates. Swarm Intelligence is formed from the coordination and competition of particles in the population, which conducts searches and produces optimization [23].

PSO algorithm is a particle in the population that follows superior particles, that is, the particle which is the best candidate for a solution, with a certain speed to find the most optimal solution in the solution space based on objective functions. The speed of these particles is regulated dynamically based on the experience of individual and community particles[24,25]

Mathematically, the PSO algorithm is written as follows [26]:

(10) $x_{id}(t+1) = x_{id}(t) + v_{id}(t+1)$

(11) $v_{id}(t+1) = w\, v_{id}(t) + c_1 r_1 (P_{id} - x_{id}(t)) + c_2 r_2 (P_{gd} - x_{id}(t))$

where : $x_{id}$ = the current search position of a particle I ; $x_{id}$ (t + 1) = updated search position of a particle I ; $v_{id}$ = current speed of a particle I ;$v_{id}$ (t + 1) = updated speed of a particle i; $c_1$, $c_2$ = constants (0 to 4); $r_1$, $r_2$ = uniformly distributed random variables (0 to 1); w = inertia constant ; $P_{id}$ = $P_{best}$ = the best position of a particle i; $P_{gd}$ = $G_{best}$ = The best solution for a particle i .

The Particle Swarm Optimization (PSO) method can help optimizing power system problems. The initial generation of PSO is started by random movements which are adjusted to the speed and position of the particles. Then find the best solutions and fitness according to the objective function used. Random moves and then selected through the best fitness values from Pbest and Gbest. The operating results of the fitness value will be evaluated according to the objective function used so that the next variable is included in the looping process. The PSO process stops when it reaches the specified maximum iteration. Optimal power flow completion steps with the PSO algorithm to minimize total active and reactive power losses, increase the voltage profile, location and size of the D-STATCOM on the North Makassar 92 bus distribution system as shown in Fig. 3.

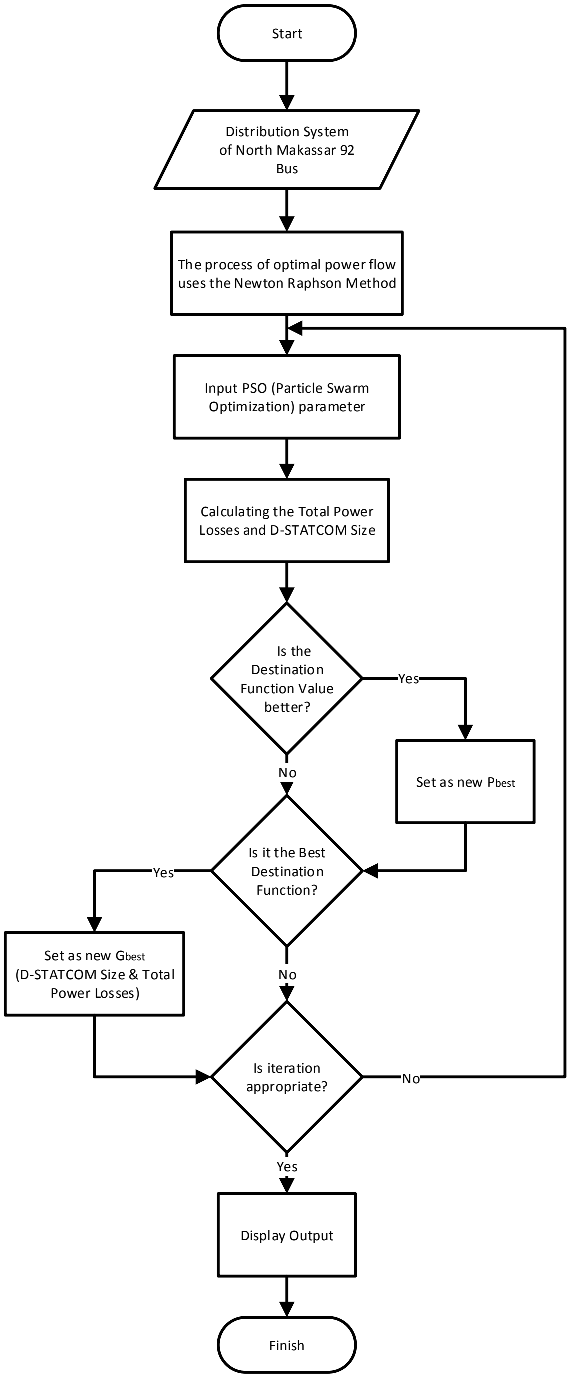


Fig.3. Flow chart of optimization using Particle Swarm Optimization Algorithm

**Simulation Results and Discussion**

To analyze how the effect of D-STATCOM injection using the OPF method and its size with the PSO algorithm is applied to the North Makassar Distribution system, 92 buses with a total active power load of 4.91378 MW are calculated by adding all active loads to each bus and the total reactive power load of 2.86481 MVar calculated by adding all reactive loads to each bus. The voltage profile for each bus before the D-STATCOM injection is shown in Fig. 4, where the total value of active power loss is 195.940 kW, the total reactive power loss is 68.36 kVar, the minimum voltage is 0.95190 pu on bus 80 and bus 92 and the average voltage for all the bus is 0.96364 pu.

To find out the effect of D-STATCOM injection on the voltage profile on each bus and the total active power loss in the North Makassar distribution system, 92 Buses, 7 case trials were conducted (A, B, C, D, E, F, and G). Case A is the initial condition as a base (without D-STATCOM injection), and cases B, C, D, E, F and G are D-STATCOM injection cases on bus 20, bus 35, bus 48, bus 51, bus 80, and bus 81, respectively. The selection of D-STATCOM injection is based on a single line diagram which is the location of the bus in the front branch, middle branch, and final branch.

The results obtained from the North Makassar distribution system, 92 buses using Optimal Power Flow (OPF) are shown in Table 1. and the optimal size of D-STATCOM using the Particle Swarm Optimization (PSO) algorithm can be seen in Table 2.

Table 1. Voltage on the bus

| Scenario | Voltage (PU) | | | | | | $V_{average}$ (PU) |
|---|---|---|---|---|---|---|---|
| | Bus 20 | Bus 35 | Bus 48 | Bus 51 | Bus 80 | Bus 81 | |
| Case A | 0.97000 | 0.96616 | 0.96507 | 0.96132 | 0.95262 | 0.95249 | 0.96364 |
| Case B | 0.97312 | 0.96953 | 0.96864 | 0.96469 | 0.95600 | 0.95587 | 0.96680 |
| Case C | 0.97146 | 0.96798 | 0.96709 | 0.96314 | 0.95444 | 0.95432 | 0.96530 |
| Case D | 0.97220 | 0.96890 | 0.96843 | 0.96406 | 0.95536 | 0.95524 | 0.96616 |
| Case E | 0.97335 | 0.970333 | 0.96944 | 0.96650 | 0.95781 | 0.95768 | 0.96785 |
| Case F | 0.97310 | 0.97003 | 0.96913 | 0.96608 | 0.95992 | 0.95580 | **0.96817** |
| Case G | 0.97167 | 0.96825 | 0.96735 | 0.96369 | 0.95580 | 0.95573 | 0.96588 |

Table 2. Total active power loss, total reactive power loss and the percentage of loss reduction

| Scenario | Injection D-STATCOM (kVar) | Ploss (kW) | Qloss (kVar) | Loss Reduction (%) | |
|---|---|---|---|---|---|
| | | | | Ploss | Qloss |
| Case A | - | 195.94 | 68.36 | - | - |
| Case B | 375 | 182.25 | 22.24 | 6.99 | 67.46 |
| Case C | 113 | 188.84 | 44.01 | 3.62 | 35.62 |
| Case D | 221 | 184.54 | 32.16 | 5.82 | 52.95 |
| Case E | 526 | 176.62 | 10.31 | 9.86 | 84.93 |
| Case F | 481 | **175.31** | 6.66 | 10.53 | 90.26 |
| Case G | 129 | 186.66 | 36.34 | 4.74 | 46.84 |

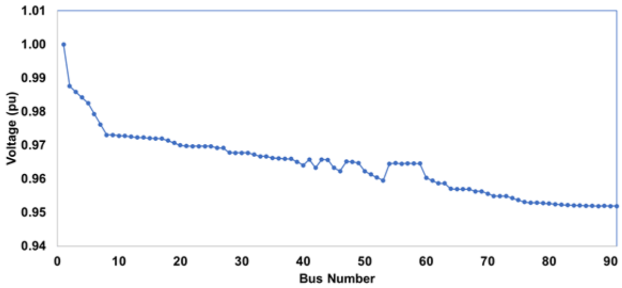


Fig.4. Profile of North Makassar distribution system voltage before D-STATCOM injection

Based on Table 1 that, with D-STATCOM injection can increase the voltage profile, when D-STATCOM is injected on the bus 20 the minimum voltage increases to 0.95528 pu on buses 88 and 92, if D-STATCOM is injected on the bus 35 the minimum voltage rises to 0.95373 pu on buses 88 and 92, while for D-STATCOM injection respectively on bus 48, bus 51, bus 80 and bus 81 the minimum voltage rises: 0.95464 pu; 0.95709 pu; 0.95512 pu and 0.95514 pu for buses 88 and 92. The highest increase in minimum voltage on buses 88 and 92 occurred when D-STATCOM was injected on Bus 80 by 0.73%, and the average voltage value for all buses was 0.96817 pu in Case F (Bus 80) with a percentage increase of 0.4% equivalent to 8kV.

Comparison of the voltage profile before D-STATCOM injection (Case A) and after D-STATCOM injection for Cases B, C, D, E and F are shown in Fig. 5.

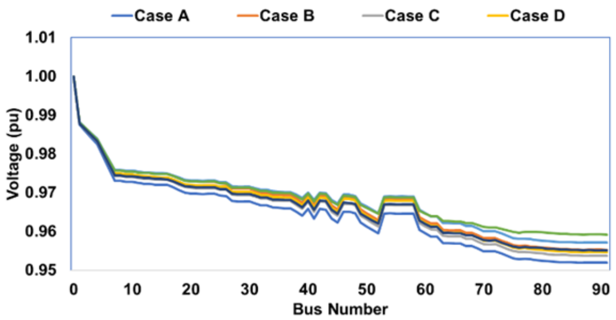


Fig.5. Comparison of Voltage Profiles based on

Based on the results in Table 2, when D-STATCOM was injected on bus 20 by 375 kVar the total active and reactive power loss were reduced to 182.25 kW and 22.24 kVar. Similarly, when 113 kVar D-STATCOM were injected on bus 35 the total active and reactive power loss were reduced to 188.84 kW and 44.01 kVar while D-STATCOM injection in case D, case E, case F and case G respectively total active and reactive power loss were reduced by 221 kVar D-STATCOM, Ploss = 184.54 kW, Qloss = 32.16 kVar; 526 kVar D-STATCOM, Ploss = 176.62 kW, Qloss = 10.31 kVar; 481 kVar D-STATCOM, Ploss = 175.31 kW, Qloss = 6.66 kVar and 129 kVar D-STATCOM, Ploss = 186.66 kW, Qloss = 36.34 kVar. The smallest total active and reactive power loss occur when D-STATCOM is injected on bus 80 (case F), i.e. the total active power loss is 175, 31 kW and reactive power 6.66 kVar, the reduction percentage reached 10.53% for active power and 90.26% for reactive power.

Comparison of total active power loss and reactive power loss before and after D-STATCOM injection is shown in Fig. 6. While the variation of total active power loss versus iteration is shown in Fig. 7, it appears in the picture that for case B (injection on bus 20) convergence is achieved at 29th iteration, case C (injection on bus 35) convergence is reached at 22 iteration, case D (injection on bus 48) convergence achieved at 29th iteration, Case E (injection on bus 51) convergent reached at 31st iteration, case F (injection on bus 80) convergence is achieved at 31st iteration and case F (injection on bus 81) convergence reached at 27th iteration.

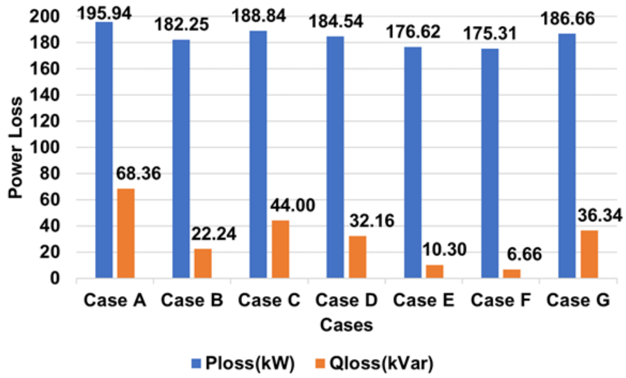


Fig.6. Comparison of total active power loss and reactive power loss

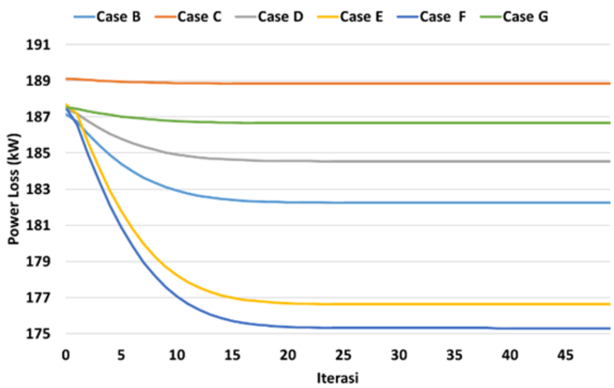


Fig. 7. Variations in total active power loss based on the scenario

## Conclusion

The optimization method of North Makassar power distribution system applied using PSO algorithm in this study exhibited the excellent increasing of the voltage profile and reducing the total active power loss. There are seven scenarios that have been tested, where one scenario is the base case while the other six scenarios are the placement of D-Statcom based on the bus position. The most optimal D-STATCOM injection is placement on bus 80 (case of F) amount 481 kVar. Bus 80 placed on single line diagram of North Makassar distribution system. It's result the increasing of the minimum voltage profile on Bus 88 and Bus 92 by 0.73% (14.6 kV) and the average voltage for all buses is 0.4% (4kV) and is able to minimize the total active power loss of 10.53% . Compared to other scenarios, D-Statcom placement using PSO on bus 80 is superior 94.63% for decrease power loss.

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