The Optimization of SVC Placement in Sulselbar Transmission System Using Inertia Weight Particle Swarm Optimization

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***Abstract*— Sulselbar power flow condition indicates the existing of buses voltage under specified standards which is determined. The operation of the Sulselbar electrical system consists of 44 buses and the power loss is 80.104 MW due to the non-optimal location of the reactive power. One of the solution to overcome the problems is the installation of Static Var Compensator (SVC) in Sulselbar transmission system. Several methods were conducted and improved to optimize the location of SVC. In this paper, the installation of SVC is using Inertia Weight Particle Swarm Optimization (IWPSO) which is the improvement of PSO. The optimization result shows that the Sulselbar transmission system require 4 location of SVC which are at bus 5 with 45.7 MVAr, bus 17 with 34.06 MVAr, bus 31 with 50.8 MVAr, and bus 40 with 120 MVAr. The result of the SVC installation is that the bus average raised 3.3% from 0.961 pu to 0.994 pu which also leads to power losses reduction on average of 9.14% from 80.104 MW to 72.777 MW.**

Keywords—Inertia Weight PSO; Optimization; Power Flow; Static Var Compensator

I. Introduction

The operation of power system consists of several generating units which is interconnected one to another. One of the problems in power system operation is the location of load which is far away from the generation, hence leads to voltage drop level significantly. This caused by the resistance and reactance in transmission line. Drop voltage will have an impact on power quality resulting in system power losses. Drop voltage and power loss reduce the performance of the system [1].

There are some solution to increase the voltage level and reduce the power loss. The compensation of reactive power require to solve the problem conducted with installation of Flexible Alternating Current Transmission System (FACTS). This is one of the solution to locate the type of FACTS equipment such as SVC by using the optimization method [2,3].

Before installation, some analysis about the existing system in Sulselbar power flow is required. The power flow studies on the benefit and importance were done to know the existing operation, planning and designing of the expansion power system. The transmission systems in common feature has balanced and interconnected three phase networks [4]. Capacitor and reactor were used to regulate the reactance of the transmission line, in order to increase the ability of power transfer in the transmission line [5].

The adjustment of reactive power sometimes is required to consume the reactive power of system. The static tools that is used to control the reactive power is reactor which is used commonly to control the reactive power condition of the system [6]. Static Var Compensator is a tool that produce the reactive power compensation in high voltage transmission system. SVC is a part of the transmission system tool which is flexible, and able to adjust the voltage and stabilized the system [7].

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The transmission system should have a voltage rating which is not exceeding the limits of tolerance and low power loss. SVC placement requires the optimization method to optimize the result to the system operation. Based on Artificial Intelligence (AI), random equipment placement is performed to find the best location as it has been widely used in several studies [6]. Particle Swarm Optimization (PSO) is one of the evolutionary of computation technique based on tracking the algorithm and begins with a random population called particles [7]. This method has been developed to be applied in several system condition. One of the method is the application to optimize the placement of SVC in the system.

Some of research were conducted and improved to optimize the location of SVC. Muhira, et al conducted the optimization of SVC placement in Sulselbar transmission system by using Genetic Algorithm [8]. Another research about the optimization reactive power is SVC and TCSC using Genetic Algorithm. The proposed approach is applied to the IEEE 14 and 30 bus test systems [9]. Further research on the placement and size of SVC by using PSO was applied in IEEE 14 bus test system [10] which is also determined the Location and Optimal Capacity of SVC (Static VAR Compensator) to improve security using Voltage Performance Index and Quantum Swarm Evolutionary Algorithm (QSEA) [11].

This paper presents of the power flow conditions from the South and West Sulawesi (Sulselbar) and the placement of SVC to determine the optimal location in order to make the increasing the system reliability. The optimal location was determined by method using Inertia Weight Particle Swarm Optimization (IWPSO) which is the improvement of conventional PSO method.

II. METHOD

A. Existing System

Before applying the PSO inertia weight to placement of optimal SVC location in Sulselbar transmission system, it is crucial to know the existing condition using Newton-Raphson power flow method of analysis. The existing system of Sulselbar that is used in this research is based on the peak load on March, 11, 2015 at 19.30 P.M. In this paper, drop voltage and power loss are the parameter of measurement that are used for analysis.

The existing systems of Sulselbar consist of 150 kV, 66 kV, 30 kV, and 20 kV which have 44 buses and 52 lines with 11 power stations.

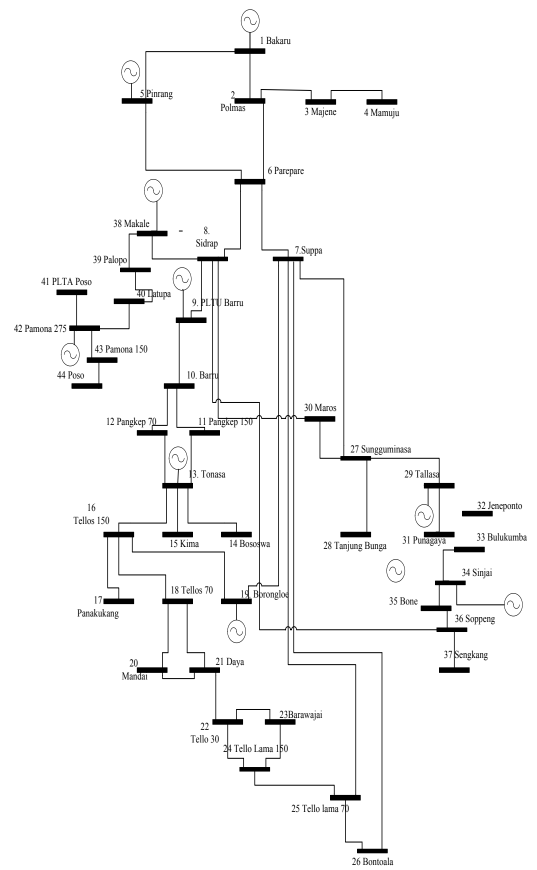

Fig.1 Single line diagram of Sulselbar transmission system

The peak load profile of Sulselbar transmission system can be seen in the figure below:

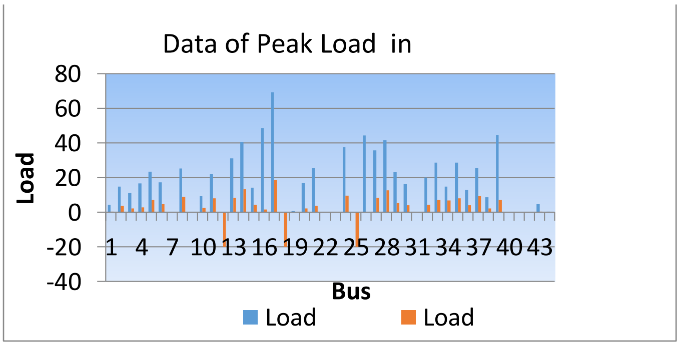

Fig. 2 Peak load condition

By using the Newton-Raphson load flow method, the voltage profile that were obtained on the existing system at peak load condition in Sulselbar system is shown in the figure below:

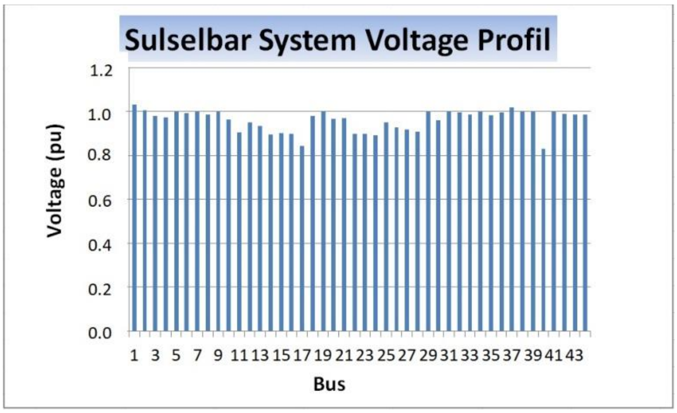

Fig. 3 Voltage profil on each bus of Sulselbar transmission system before SVC installation

There are 13 bus that show the voltage below the expected tolerance limit Bus 11 (Pangkep 150) 0.904 pu, Bus 13 (Tonasa) 0.934 pu, Bus 14 (bosowa) 0.895 pu, Bus 16 (Tello 150) 0.899 pu, Bus 17 (Panakukang) 0.844 pu, Bus 22 (Tello 30) 0.899 pu, Bus 23 (Barawaja) 0.899 pu, Bus 24 (Tello lama 150) 0.891 pu, Bus 25 (Tello Lama 70) 0.949 pu, Bus 26 (Bontoala) 0.929 pu, Bus 27 (Sungguminasa) 0.918 pu, Bus 28 (Tanjung Bunga) 0.909 pu, Bus 40 (Latupa) 0.829 pu

According to figure 2, there are some bus in stable condition. However, in bus 11, the voltage rating become critical with 0.904 pu, similar to bus 13 with 0.934 pu, bus 25 with 0.949 pu, bus 26 with 0.929 pu, bus 27 with 0.918 pu and bus 28 with 0.909 pu. These were caused by the unbalanced load between the active and reactive power and also due to the industrial area which is requiring more reactive power. Therefore, the voltage drop occurs below the allowable voltage value.

Bus on fall conditions occur in bus 14 with 0.895 pu, bus 16 with 0.899 pu, bus 17 with 0.844 pu, bus 22 with 0.899 pu, bus 23 with 0.899 pu, bus 24 with 0.891 pu, and bus 40 with 0.829 pu. These are caused by the bus in industrial area and citizen which require more reactive power. Power station is located in north while the load demand is required more in south area because of the lesser power reactive allocation, which then affect the voltage level below the allowable voltage value. Hence in this condition the reactive power supply is required to balance the load.

B. *Inertia Weight Particle Swarm Optimization*

The algorithm is the development of Particle Swarm Optimization. The steps for applying the Inertia Weight PSO algorithm are as follows:

1. Initialize a population of particles with random position and velocity.
2. Evaluate the optimization fitness in variable of each particle.
3. Compare the evaluation of fitness particle with Pbest.
4. Identify the particle in the environment with the best results so far.
5. Update velocity and particle position.
6. Do the step 2 again until getting the criteria. Usually stops at a good fitness value or until the maximum number of iterations.

Below are the formula of inertia weight PSO:

$$Vi^{K=1} = W * V * +C1\, rand1^{*}\,(Pbest - Si^{k}) + C2^{*}\, rand2^{*}\,(Gbest - Si^{k}) \quad (1)$$

$$Si^{K=1} = Si^{k} + Vi^{k} \quad (2)$$

$$W = Wmax - \left(\frac{Wmax - Wmin}{Iter\ max}\right) * Iter \quad (3)$$

Where W is inertia weight, C1 C2 is weighting factor (0 until 4), Si^{k} is the current position of agent i at k^{th} iteration, Si^{k+1} is the current position of agent i at k $(k+1)^{th}$ iteration, Iter max is the maximum iteration number, Iter is the current iteration number, P_{best} is the Personal best, G_{best} is the Global best, W_{max} is the invertia weight value 0.9, W_{min} is the inertia weight value 0.2.

III. Implementation of Inertia Weight PSO

This section explain the implementation of inertia weight PSO to optimum placement and capacity of SVC. Parameters of inertia weight PSO are Iter max = 100; swarm = 50; C1=2; C2=2; Rho max=1; Rho min = 0; inertia weight = 0.9.

A. *Coding*

SVC configuration is determined by the SVC location and rating. SVC is placed on a bus where each part has a different location which only allows one SVC on one bus. The number of SVCs determined is 10 pieces. Regarding the value of SVC capacity, the value is encoded between 10-150 MVar. This value is the SVC rating that will be used.

B. *Swarm initialization*

The following are the swarm size parameters:
the number of SVCs is 10 pieces
nSVC = round (rand (1) * 7 + 3)
The two information required will be carried by each particle, namely the SVC location and rating.

C. *Objective and Constraint Functions*

In order to obtain the optimal results, SVC placement optimization using the Inertia Weight PSO method will be applied:

1) Objectif function

$$f = \sum_{i=2}^{n\,Bus} Qci$$

Where f is the objective function, $nBus$ is the bus Value, i is the bus, and Qci is the location of bus.

2) Constraints

a. Related to the voltage level on each bus (violation factor). Voltage in the range of 0.95 pu to 1.05 pu has a value of 1. The voltage outside the range decreases exponentially. So the objective *function given is as follows* $(0.95 \le Vi \le 1.05)$ PU.

b. Relate to the SVC rating value injected into the SVC-installed bus, namely minimizing the SVC rating, but the voltage level on each bus remains within the allowable range. SVC_{cap} = 10 – 120 MVar.

D. Determine Pbest and Gbest

Personal best (P_{best}) is a particle that shows the position of particle prepared to obtain best solution. Global best (G_{best}) is a particle swarm or between the best P_{best} position.

E. Update Velocity and Particle Positions

Update velocity and particle position:

$$Vj(i) = \theta Vi(i-1) + c1r1\,[Pbest,j - Xj\,(i-1)] + c2r2\,[\,Gbest - Xj(i-1)] \quad (4)$$

Where: V = velocity, X = particle, I = iteration

The following is the algorithm of the process applying Inertia Weight PSO:

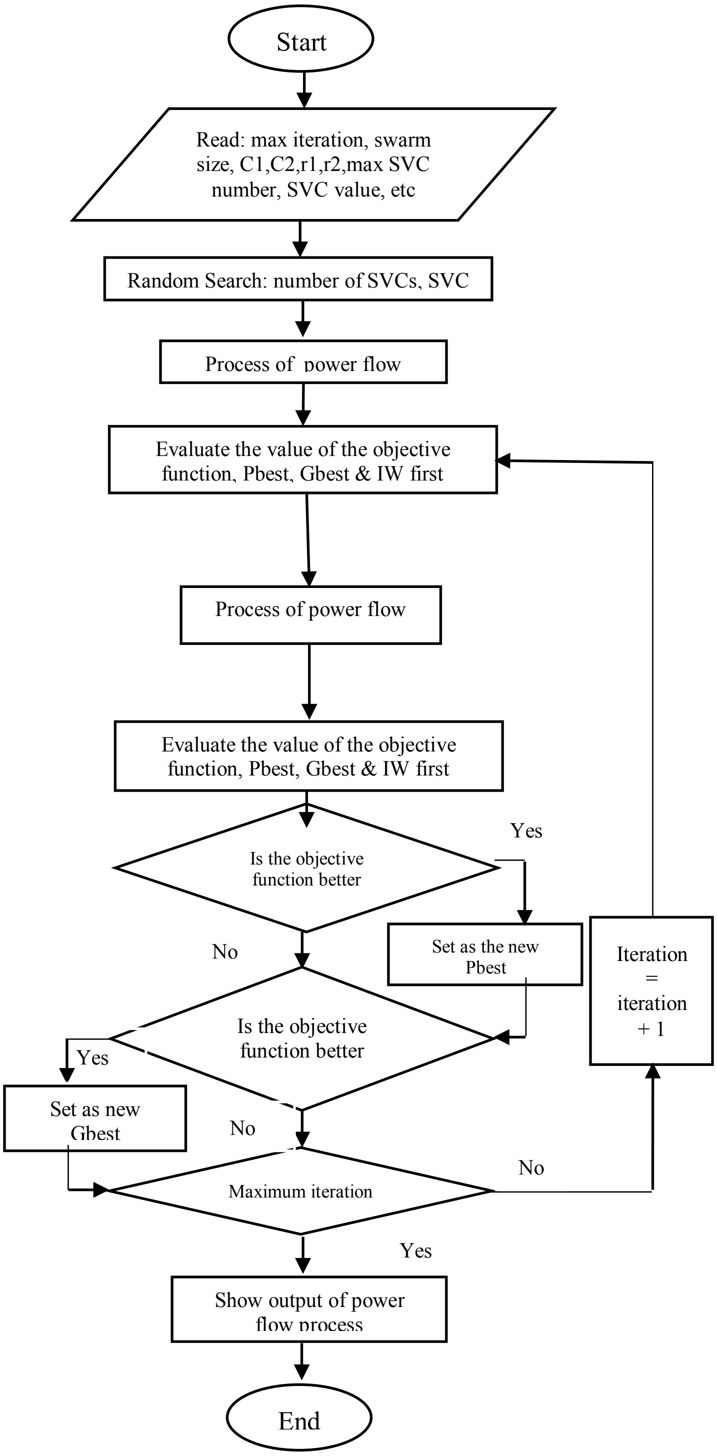

Fig. 4 Algorithm of Inertia Weight PSO

IV. RESULT AND DISCUSSION

The optimization of SVC placement on Sulselbar power flow system by using Newton-Raphson method based on the data: voltage base = 150 kV, power base = 100 MVA, mismatch = 0.001, acceleration = 1.1, iteration maximum = 100.

Based on table 1, the optimization inertia weight PSO require 4 SVC in 4 location of bus. Bus 5 with 45.7 MVar, bus 17 with 43.7 MVAr, bus 31 with 50.8 MVAr, and bus 40 with 120 MVAr.

TABLE I. PLACEMENT AND CAPACITY OF INERTIA WEIGHT PSO

No bus	Bus name	MVAr injection
5	Pinrang	45.7
17	Panakukang	43.7
31	Punugaya	50.8
40	Latupapa	120

Inertia weight PSO method is a development of conventional PSO method. This method superior based on result of voltage level and power loss. In addition, it has faster calculation and better convergence than the conventional PSO method.

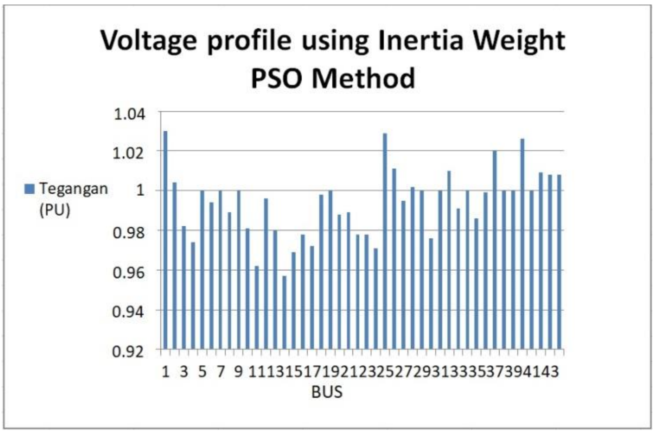

Fig. 5 Voltage profile using Inertia Weight PSO Method

Voltage profile using Inertia Weight PSO in figure 5 describes all voltage on each bus of Sulselbar system in range 0.95 pu ≤ V ≤ 1.05 pu. The result of SVC placement optimization on Sulselbar system using the Inertia Weight PSO method shows a considerable change in voltage increase compared to the PSO method. The bus voltage below the specified voltage level increases where the average value of the voltage increases by 3.3%.

Table 2 shows the comparison of power losses before and after the SVC installation in Sulselbar system.

TABLE II. COMPARISON OF POWER LOSSES

Before	After
82.104 MW	72.777

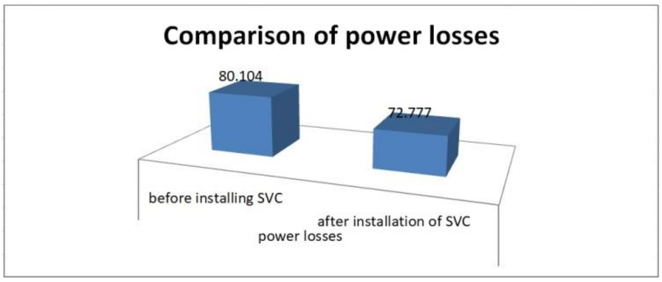

Fig. 6 Comparison of power losses

Based on figure 6, it can be seen that by placing the FACTS record in the form of SVC on the Sulselbar transmission system, the power losses are reduced due to injection of reactive power by the SVC. Voltage value below the voltage tolerance limit increase and power loss also decreases. Optimization of SVC placement using the Inertia Weight PSO method results in a drop in power losses from 80,104 MW to 72.777 MW or 9.14%.

V. CONCLUSION

The result of the power flow analysis using Newton Raphson method is that there are 12 buses that are below the tolerance voltage limit, namely buses 11, 13, 14, 16, 17, 22, 23, 24, 25, 26, 27, 28 and 40, with power loss of 80,104 MW. The condition of Sulselbar transmission system using the Inertia weight PSO method in accordance with SVC installation in bus 5 is 45.7 MVAr, bus 17 is 43.06 MVAr, bus 31 is 50.8 MVAr and bus 40 is 120 MVAr. Moreover, the power loss of Sulselbar system drop at 3.3% and the voltage increase of 9.14%.

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