IOP Conf. Series: Materials Science and Engineering **306** (2018) 012056 doi:10.1088/1757-899X/306/1/012056

Optimization Placement of Static Var Compensator (Svc) on Electrical Transmission System 150 kV Based on Smart Computation

Hasbullah*, Y Mulyadi, Y Febriana and A G Abdullah

Program Studi Pendidikan Teknik Elektro, FPTK Universitas Pendidikan Indonesia

*hasbullah-elektro@upi.edu

Abstract. To improve voltage profile, we can use FACTS equipment. One of them is SVC (Static Var Compensator). This study aims to determine the location and optimal capacity of SVC and to determine the effect after SVC installation. This research was conducted in 150 kV transmission system, West Java load regulator area of South Bandung and New Ujungberung subsystem. The research method used for power flow simulation is Newton Raphson and to determine the optimal position and capacity of SVC was using genetic algorithm in MATLAB R2014. After the SVC placement is optimized, then the system performance will increase such as the voltage of all buses is at the standard level and the decrease of power losses.

1. Introduction

Nowadays, the need for electrical energy increases along with industrial, commercial and population growth. This is evidenced by the data of PLN and BPPT energy team, that the average electricity demand in Indonesia grew by 6.5% per year [1]. The increasing of load demand will lead to heavy loading of the transmission so that there may be voltage drop [2]. An uncontrolled voltage drop can lead to voltage instability [3].

According to IEEE the allowable voltage standard is 0.95 pu to 1,05 pu [4]. A reliable electric power system must have a voltage that doesn't exceed the tolerance limit and few power losses [5]. The voltage drop affects the power losses. Power losses are unavoidable but can be reduced by improving the voltage profile. The voltage profile setting requires two things: the location and amount of reactive power provided must be precise [6]. Technological developments in the semiconductor industry led to the creation of FACTS (Flexible AC Transmission) equipment. FACTS equipment that commonly used in power grid is SVC (Static Var Compensator) because it is cheaper. SVC is a shunt associated with the generation or absorption of static reactive power to maintain or control special parameters on the electrical system, that is bus voltage. SVC placement should be optimized to have an impact on the power system [7]. Optimization method that used in this research is genetic algorithm. Genetic algorithms are the simplest method of solving optimization problems based on natural selection. Genetic algorithm is simpler, easier in explanation and its ability is fast [8].

1.1. Newton Raphson power flow

Power Flow is a study conducted to obtain information about the power flow or system voltage in steady operating conditions. In each bus, there are four values consist of voltage V |, phase angle (δ), real power (P) and reactive power (Q). On each bus only two kinds of quantities are determined while the other two are the final result of the calculation. Newton Raphson method is an iteration process to achieve the function approach. Newton Rapson uses nonlinear algebraic equations with his own variables. The value of the variable per unit and the phase angle in radians [9]. The equation is shown as follows:

$$P_i = \sum_{j=0}^{n} |V_i||Y_{ij}||V_j| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (1)$$

$$Q_i = -\sum_{j=0}^{n} |V_i||Y_{ij}||V_j| \sin(\theta_{ij} - \delta_i + \delta_j) \quad (2)$$

Where:
V_i = bus i voltage,
V_j = bus j voltage
Y_{ij} = admittance between bus i and bus j
P_i = bus i active power
Q_i = bus i reactive power
θ_{ij} = m admittance polar angle Y_{ij}
δ_j = V_j voltage angle
δi = V_i voltage angle

The power flow from bus i to bus j and the power flow from bus j to bus i will be shown in equation 3-4.

$$S_{ij} = V_i I_{ij}^* \quad (3)$$
$$S_{ji} = V_j I_{ji}^* \quad (4)$$

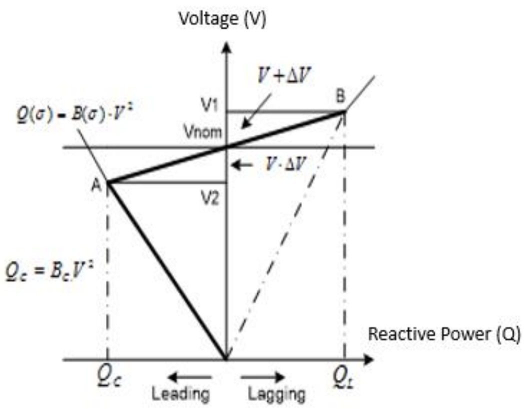
The i-j bus losses are the algebraic sum of the power flow approaches of equations 3 and 4. Power losses are shown in equation 5.

$$S_{Lij} = S_{ij} + S_{ji} \quad (5)$$

1.2. Static Var Compensator

Static Var Compensator (SVC) is a fast-acting electrical device compensating for reactive power in high voltage transmission lines [10]. In other words, Static Var Compensator is defined as a device which the output can be adjusted and transformed into capacitive or inductive currents to maintain or control special parameters on electrical power systems [11]. This tool is called static because there are no moving components in it, but consists of power electronics components such as a switch. Static switch used is thyristor [12]. SVC consists of TCR (Thyristor Controller Reactor) which is parallel with TCS (Thyristor Switch Capacitor).

Curve of reactive power to bus voltage that are generated from SVC is shown in figure 1 [5].



S

Figure 1. Reactive power and voltage curve of SVC.

There are three Static Var Compensator work areas:
1. Between V1 and V2. In this area SVC is capacitive and inductive.
2. When the bus voltage exceeds V1. In this area SVC has inductive characteristics.
3. When the voltage is less than V2. In this area SVC has capacitive characteristics.

There are 2 models of SVC as follows :

1.2.1. Suseptance model. In this model, SVC as reactance is automatically regulated through the suseptance variable to obtain the desired voltage according to the boundary. The suseptance value is obtained from the total of SVC suseptance that is sufficient to maintain the bus voltage at a certain value [13]. The SVC suseptance model is shown in figure 2.

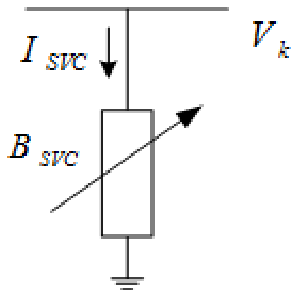


Figure 2. SVC suseptance model.

Based on figure 2, it can be explained that the SVC current can be formulated as follows [14]:

$$I_{svc} = jB_{svc}V_k \quad (6)$$

jB_{svc} is SVC suseptance value, V_k is voltage

The minimum and maximum restriction of reactive power output QSVC is written as follows [2]:

$$Q_{max} = B_{ind}.V_{ref}^2 \quad (7)$$

$$Q_{min} = B_{cap}.V_{ref}^2 \quad (8)$$

Where:
Q_{max} is maximum reactive power
Q_{min} is minimum reactive power
B_{ind} is inductive suseptance. The value is $B_{ind} = 1/X_L$
B_{cap} adalah capacitive suseptance. The value is $B_{cap} = 1/X_C$

SVC Suseptance (BSVC) is expressed as the ignition angle function of thyristor (α) as follows:

$$B_{svc} = B_{cap} - B_{ind}(\alpha) \quad (9)$$

Reactive power injected by SVC with suseptance model can be formulated as follows [14]:

$$Q_{svc} = Q_k = -V_k^2 B_{SVC} \quad (10)$$

1.2.2. Firing angle model

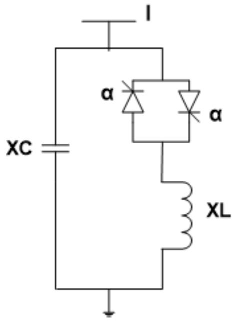


Figure 3. Firing angle model of SVC [3].

Figure 3 shows SVC firing angle model represented by fixed capacitor and thyristor controlled reactor [15]. The thyristor-based switch is used to convert to admittance. The thyristor will be controlled by ignition of the α angle and the change is equivalent to SVC reactance [3]. The reactive power values injected by SVC with the angle of ignition model are as follows [16]:

$$Q_k = -V_k^2 \left\{\frac{X_c[(\pi-\alpha)+\sin 2\alpha]-\pi X_L}{\pi X_c X_L}\right\} \quad (11)$$

$$X_{svc} = -V_k^2 \left\{\frac{\pi X_c X_L}{X_c[2(\pi-\alpha)+\sin 2\alpha]-\pi X_L}\right\} \quad (12)$$

Where:
X_c is capacitive reactance, with X_c=1/ωC
X_L is inductive reactance, with X_c=ωL
B_{svc} is SVC suseptance, with
$B_{svc} = -1/X_{svc}$

1.2.3. Genetic algorithm. In artificial intelligence, a genetic algorithm is a search that imitates the natural selection process developed by John Holland and Goldberg in 1970 at the University of Michigan [17]. It is a metaheuristic optimization method that iteratively solves problems by increasing candidate solutions based on certain criteria [18]. Genetic algorithm is a search algorithm based on genetic mechanism and natural selection [19].

The following step will explain how to implement genetic algorithm.

a. Coding Technique
Defines the code representation that used on chromosomes as solution candidates [20]. After encoding, the next step is setting the initial population randomly which is the solution candidate. In general, solution candidates are represented as code numbers according to each variable of the optimization problem, called chromosomes [21].
b. Fitness value evaluation
The fitness function aims to determine the quality of chromosomes associated with objective function [22].
c. Genetic Operator
There are 3 genetic algorithm operators that are selection, crossover and mutation. Before performing the process on the genetic operator, we have to determine the algorithm parameters.
   1) Reproduction Selection
   Reproduction is the probabilities selection of individu’s chromosomes that is chosen to produce offspring based on fitness values [23]. After evaluating an individual with its fitness value then a good individual will have a high probability to do the next iteration [24].
   2) Crossover
   Crossover process is the process of crossing or exchanging genes from two selected chromosomes of the parent [25]. Crossover’s function is to produce a child's chromosome from

IOP Conf. Series: Materials Science and Engineering **306** (2018) 012056 doi:10.1088/1757-899X/306/1/012056

a combination of parental chromosome genes. The genetic algorithm will converge faster when using a high probability (0.6 - 0.9).

3) Mutation
Mutation acts as a process of replacing the value of a previous gene with a new value that random-determined with a predetermined range [25]. The selection of mutated genes uses random numbers generated as many as genes in the population. If the result of random number is less than the mutation probability, then the mutation occurs [26].

4) Stop Condition
The optimization process performed using genetic algorithm will stop after a stop condition is met. Some of the stopping conditions used are the number of generations, the computation time limit, the fitness value limit, etc. Towards the end of the solution will converge to a certain value that will be the optimal solution approaching the problem [12].

2. Research Methods

Improved Voltage profiles on transmission systems 150 kV APB West Java subsystems of South Bandung and New Ujungberung is strongly influenced by the location and capacity of the installed static var compensator. It requires optimization to locate the optimal SVC location and capacity. Optimal means that the SVC can reduce power and voltage losses. The research flow diagram is shown in figure 4.

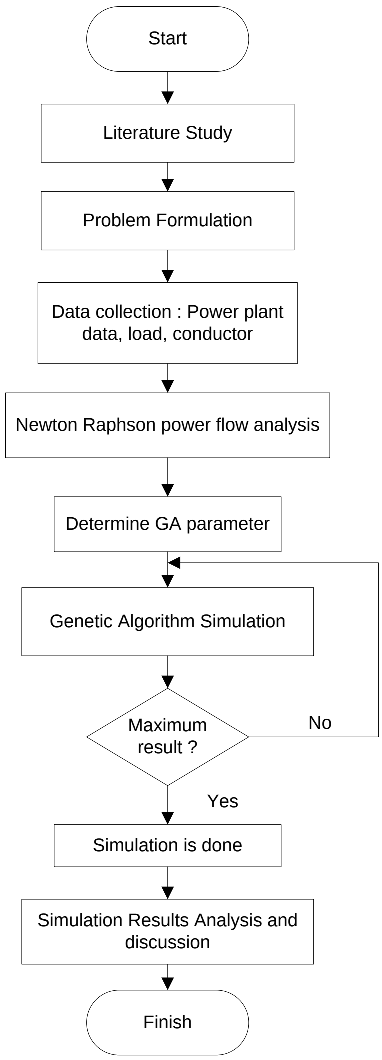


Figure 4. Research flow diagram.

Simulation of power flow and simulation of genetic algorithm using MATLAB R2014A. Simulation of power flow using peak load data, power generated data and conductor data on February 1, 2016. This power flow as input for simulation of genetic algorithm. To determine the location and capacity of the SVC using genetic algorithm with objective function of minimizing the power losses total and considering the voltage at each bus, that is Genetic algorithm parameters is shown in table 1.

Table 1. Genetic algorithm parameter.

Parameter	Value
Population size	10
$P_{crossover}$	0.6
$P_{mutation}$	0.06
Number of genes	16
Max generation	500

3. Results and Discussion

One line diagram of transmission system 150 KV APB West Java subsystem South Bandung and New Ujungberung is shown in Figure 5.

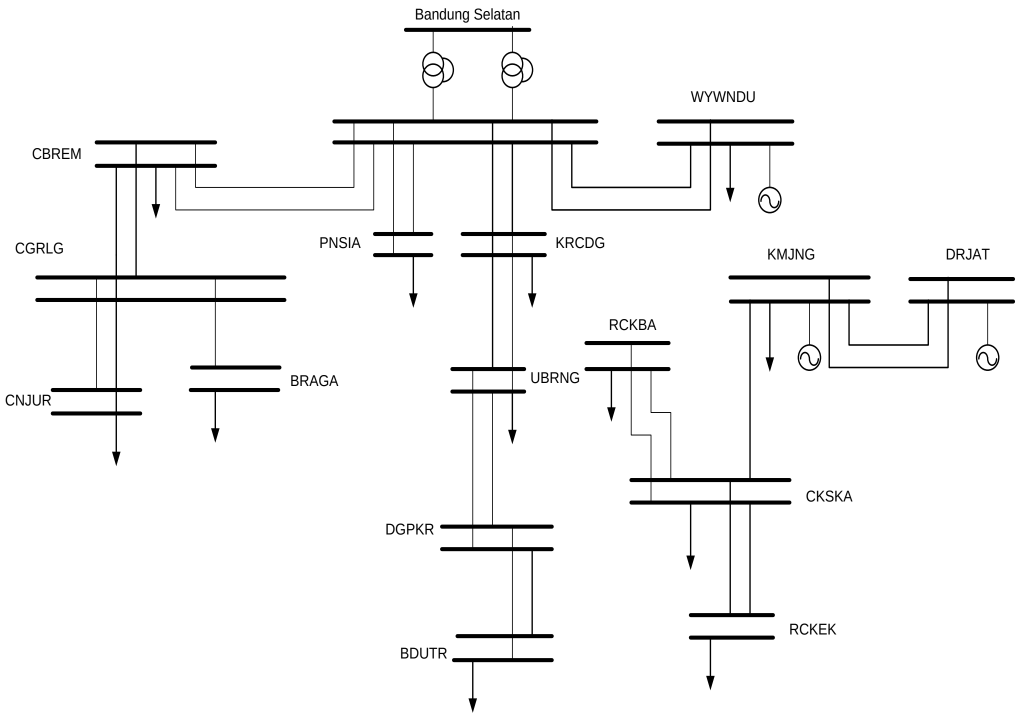


Figure 5. One line diagram of South Bandung and New Ujungberung Subsystems.

Figure 5 shows that the transmission system of 150 KV APB West Java subsystem of South Bandung and New Ujungberung has 16 buses with the following details:

1. Bus slack = South Bandung
2. Bus generator = Kamojang, Wayang Windu and Darajat
3. Load Buses = Cibeureum, Cigereleng, Panasia, Kiaracondong, Ujungberung, Dago Pakar, North Bandung, Rancaekek, Cikasungka, Cianjur, Braga and Rancakasumba

Subsystem channel of South Bandung and New Ujungberung consists of 16 channels. Newton Raphson power flow is done before and after SVC placement to find the voltage profile.

3.1. Power flow before SVC placement

Newton raphson power flow simulation uses MATLAB with 0.0001 accuracy, voltage base 150 kV, MVA base 100 and maximum iteration 500. The power flow results is shown in table 2.

Table 2. Voltage value.

No	Bus	Voltage (KV)	Angle (°)
1	Bandung Selatan	150	0
2	Wayang Windu	150	4.304
3	Kamojang	150	3.469
4	Drajat	150	7.573
5	Cigereleng	144.3	-3.619
6	Kiaracondong	140.85	-4.12
7	Bandung Utara	133.2	-8.065
8	Panasia	149.1	-0.385
9	Cianjur	135.3	-9.529
10	Cibereum	143.7	-4.168
11	Braga	144.15	-3.773
12	Cikasungka	143.55	-1.451
13	Rancaekek	140.7	-3.63
14	Rancakusumba	143.25	-1.903
15	Ujungberung	138.6	-5.191
16	Dago Pakar	135.45	-6.807

Based on IEEE the allowed voltage limits are between 0.95 pu to 1.05 pu [4]. Based on Table 4 it can be seen that the voltage on the South Bandung and New Ujungberung subsystems are outside the limit of 0.95 pu to 1.05 pu, there are 6 buses namely Kiaracondong bus, North Bandung, Cianjur, Rancaekek, Ujungberung and Dago Pakar. The Kiaracondong bus has a voltage of 0.939 pu or 140.85 kV. North Bandung Bus has a voltage of 134.1 kV or 0.888 pu Bus Cianjur has a voltage of 0.902 pu or 135.3 kV. Bus Rancaekek has a voltage of 0.938 or 140.7 kV. Ujungberung bus has a voltage of 0.924 pu or 138.6 kV. Bus Dago Pakar has a voltage of 0.903 pu or 135.45 kV. The power flow results before the placement of SVC are inputted into genetic algorithm simulation.

3.2. SVC location and capacity

In determining the location and capacity of SVC, we used two parameters namely location parameters and capacity parameters. One chromosome consists of 16 genes where 16 genes show the number of buses that exist in the subsystem of South Bandung and New Ujungberung.

Each gene contains two parameters. The first value to determine the SVC location variable encoded in binary numbers (0 and 1) where 0 indicates SVC is not installed and 1 indicates SVC is installed. The second value is to determine the capacity variable of the SVC encoded in a real number between -250 MVAR to 250 MVAR because the upper and lower limit of SVC reactive power in MATLAB genetic algorithm simulation is -250 MVAR and 250 MVAR. Optimal capacity will be obtained through the process of genetic operator with objective function of minimizing power losses total and considering the allowable voltage range, that is $0.95\ pu \leq V_{bus} \leq 1.05\ pu$. The fitness function in MATLAB is the minimized objective function. So it can be said the fitness function as same as the objective function. The location and capacity of SVC using genetic algorithm is shown in Table 3.

Table 3. Location and capacity of SVC using genetic algorithm.

Location	Rating (MVAR)
BDUTR	70.5
CNJUR	62.19
RCKEK	193.53

The iteration process and fitness values comparison is shown in Figure 6.

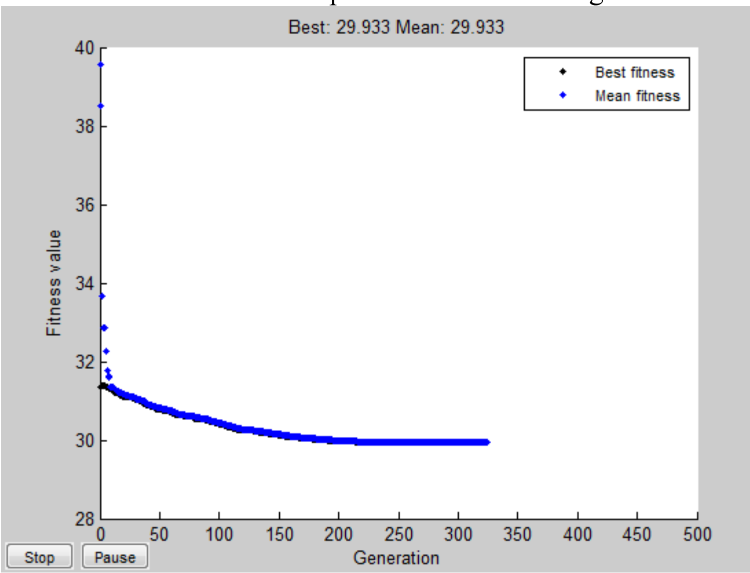


Figure 6. Graph of fitness values per generation.

Figure 6. shows that the algorithm will produce convergent solutions to the best value by increasing the generation or iteration, power losses is smaller than the previous generation.

3.3. Power flow after SVC placement

After SVC added on buses of North Bandung, Cianjur and Rancaekek then voltage profile Subsystem of South Bandung and New Ujungberung is shown in Figure 7. In Figure 7. the voltage profile after placement of SVC is compared with the voltage profile before SVC placement.

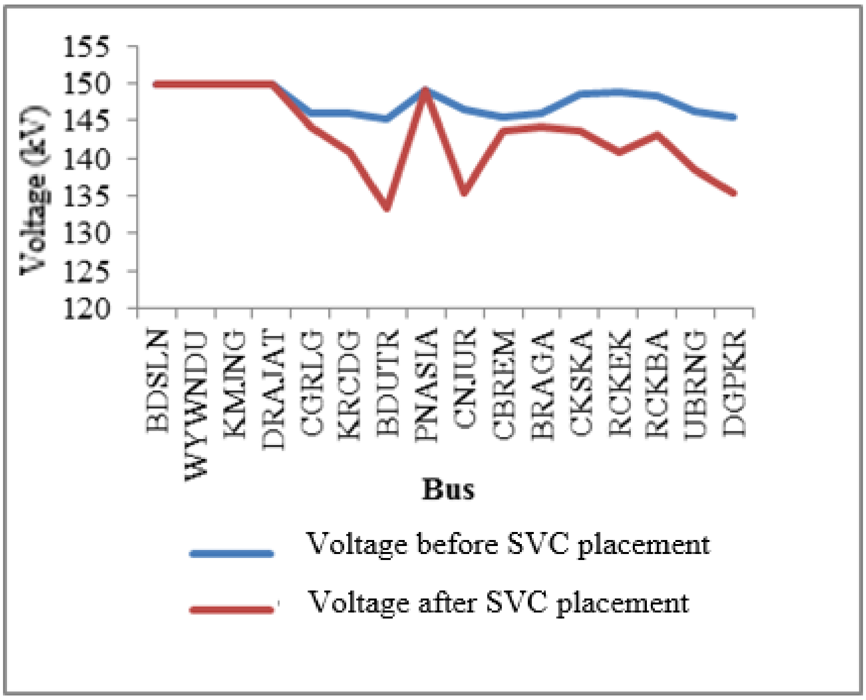


Figure 7. Graph of voltage before and after SVC placement.

In Figure 7, it can be seen that after SVC added on the North Bandung bus, Cianjur and Rancaekek, the voltage profile on the load bus increases while the voltage profile on the generating bus is unchanged. The result of active power loss after SVC placement is shown in Figure 8.

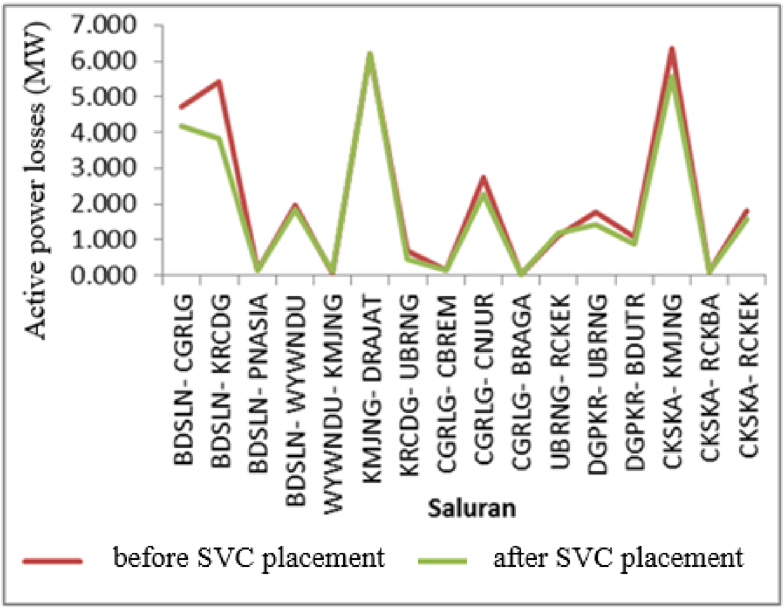


Figure 8. Graph of active power losses before and after SVC placement.

The largest decrease of active power losses occurred in the South Bandung-Kiaracondong channel 1,577 MW or 29.10%. The smallest decrease of active power losses occurred in the Cigereleng-Cibereum channel 0.03 MW or 2.36%. Total active power losses before SVC placement is 34,309 MW and after placement of SVC is 29,933 MW. The comparison of reactive power loss before and after SVC placement is shown in Figure 9.

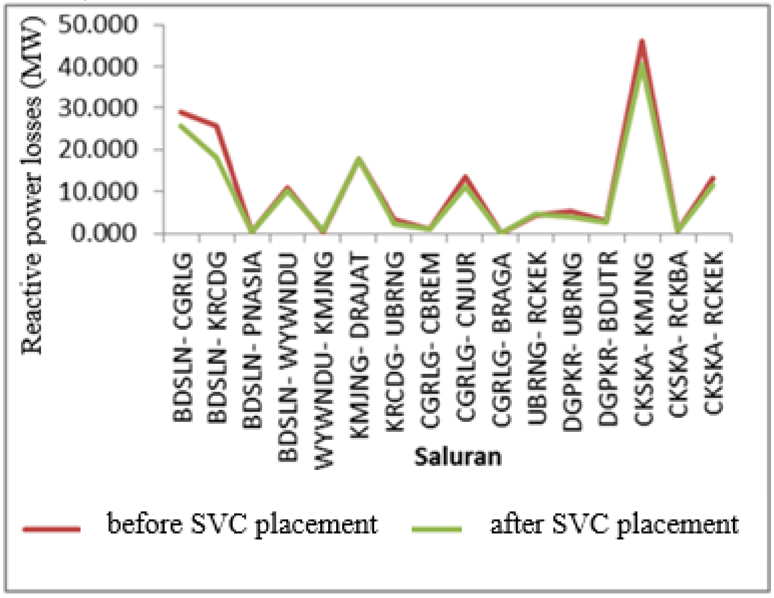


Figure 9. Graph of Reactive power losses before and after SVC placement.

The largest decrease in reactive power losses occurred in the Cikasungka-Kamojang channel 7.46 MVAR or 29.10%. The smallest decrease of reactive power losses occured in Cigereleng-Braga channel

0.02 MVAR or 2%. Total reactive power losses before SVC placement is 174,574 MVAR and after SVC placement is 151,467 MVAR.

4. Conclusion
Optimal Static Var Compensator (SVC) placement on 150 kV transmission system Subsystem of Bandung Selatan and New Ujungberung is placed on North Bandung bus with Rating -70.5 MVAR and 70.5 MVAR, Cianjur bus with Rating -62.19 MVAR and 62.19 MVAR and Rancaekek bus with rating - 193.53 MVAR and 193.53 MVAR. Optimal SVC installation can improve the voltage profile so that the voltage on all buses is within the standard of 0.95 pu to 1.05 pu. In addition, power transmission capacity increases. So, there is a decrease of power losses.

References
[1] Dhi M M dan P darma 2003 PROYEKSI KEBUTUHAN LISTRIK PLN *Pengembangan Sistem Kelistrikan Dalam Menunjang Pembangunan Nasional Jangka Panjang* 19–29
[2] Muslimin, Suyono H, and Hasanah N 2013 Perbaikan Profil Tegangan pada Feeder Harapan Baru Lima (H5) Area Samarinda untuk Pengurangan Susut Energi *EECCIS* **7** 2 131–136
[3] Karami M, Mariun N and Kadir M Z A A 2011 Determining Optimal Location of Static Var Compensator by Means of Genetic Algorithm *IEEE* 172–177
[4] Sullivan D J, Paserba J, Reed G, and Arai J 2006 Design and Application of a Static VAR Compensator for Voltage Support in the Dublin *IEEE*
[5] Liliana I S 2014 Penempatan SVC (Static Var Compensator) Pada Jaringan Distribusi Dengan ETAP 7.5.0. *Jurnal Sains, Teknologi Dan Industri* **12** 1 1–8
[6] Marsudi D 2006 *Operasi Sistem Tenaga Listrik* (Yogyakarta: Graha Ilmu)
[7] Rahman A K M R, Alam S and Hossain Z 2013 Localization of FACTS Devices for Optimal Power Flow Using Genetic Algorithm *IEEE* 0–5
[8] Anwar S, Suyono H, and Soekotjo H 2012 Optimisasi Penempatan SVC untuk Memperbaiki Profil Tegangan dengan Menggunakan Algoritma Genetika *Jurnal Elektro ELTEK **3** 1 ISSN 2086-8944* **3** 1 203–208
[9] Cekdin C 2005 *Teori dan Contoh soal Teknik Elektro menggunakan bahasa pemograman Matlab* (Yogyakarta: Penerbit Andi)
[10] Lalit and A K J 2015 Optimization Of Electrical Power Transmission System Using PSO With SVC *International Journal for Technological Research in Engineering* **2** 9 1859–1865
[11] Savic A 2014 Optimal sizing and location of SVC devices for improvement of voltage profile in distribution network with dispersed photovoltaic and wind power plants *Science Direct* **134** 114–124
[12] Skaria N A 2014 Genetic Algorithm Based Optimal Location of SVC in Power System for Voltage Stability Enhancement *IEEE*.
[13] Veramuri S D S 2015 Perfomance Comparison Of SVC and TCSC in power flow control *IEEE*
[14] Pali B S 2012 Newton-Raphson Power Flow Models of Static VAR Compensator *IEEE* 9–13
[15] Kumari M S 2006 A New Decoupled - Quadratic Load Flow Approach for Adjustment of Static *IEEE* 266–270
[16] Hassan M O, Cheng S J, and Zakaria Z A 2009 Steady-State Modeling of SVC and TCSC for Power Flow Analysis *Proceedings of Yhe Internatioanal Multi Conference of Engineers and Computer Scientist **II***
[17] Dheebika S K K 2015 Optimal Location Of SVC , TCSC And UPFC Devices For Voltage Stability Improvment And Reduction Of Power Loss Using Genetic Algorithm *IEEE* 1–6

[18] Azim I and Rahman F 2014 Genetic Algorithm Based Reactive Power Management by SVC *International Journal of Electrical and Computer Engineering (IJECE)* **4** 2
[19] Farsangi M M, Nezamabadi-pour H, and Lee K Y 2006 Multi-objective VAr Planning with SVC for a Large Power System Using PSO and GA *IEEE* **1** 274–279
[20] Pisica I, Bulac C, Toma L, and Eremia M 2009 Optimal SVC Placement in Electric Power Systems Using a Genetic Algorithms Based Method *IEEE* **2** 1–6
[21] Marouani I, Guesmi T, Abdallah H, and A O 2011 Optimal Location Of Multi Type FACTS Devices For Multiple Contigencies Using Genetic Algorithms *IEEE*
[22] Bhandari M and Gurav S S 2015 Genetic Algorithm Based Optimal Allocation Of SVC For Reactive Power Minimization In Power Systems *IEEE* 1651–1655
[23] Preethi V A 2011 Application of Genetic Algorithm to Power System Voltage Stability Enhancement Using Facts Devices *IEEEE* 333–338
[24] Dongmei Z, Pei W, and Xu Z 2014 Reactive Power Optimization by Genetic Algorithm Integrated with Reduced Gradient Method *IEEE Workshop on Advance Research Anf Technology in Industry Application* **4** 838–841
[25] Suyanto 2005 *Algoritma genetika dalam matlab* (Yogyakarta: Penerbit Andi)