

# Implementation of Particle Swarm Optimization Method for Voltage Stability Analysis in 150 kV Sub System Grati – Paiton East Java

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**Abstract.** Based on the data from State Electric Company on 15 January 2013, the undistributed power in the 150 kV sub system Grati-Paiton Region IV, that consist of 26 bus 150 kV and 2 bus generation 500 kV system, was recorded 3.286,00 MW. At the same time, the frequency of the system was down to 49 Hz. This lead to a deficit generation and unstable voltage condition in the system. Fast Voltage Stability Index (FVSI) method is used in this research to analyze the voltage stability of the buses. For buses with unstable voltage condition, reactive power will be injected through capacitor installation. The site where the capacitor will be installed is determined using the Fast Voltage Stability Index (FVSI) method while the size of the capacitor is determined using the Particle Swarm Optimization (PSO) method. The PSO method has been applied in some researches, such as to determine optimal placement and sizing in radial distribution network as well as in transmission network.. In this research, the PSO method is used to find the  $Q_{loss}$  of an interconnection transmission system, which in turn, the value of the  $Q_{loss}$  is used to determine the capacitance of the capacitor needed by the system.

## 1. Introduction

Paiton is a one of the largest generation units to supply the electrical energy needed for Java, Bali, and Madura island. Based on the data taken from State Electric Company on 15 January 2013, the undelivered power in sub system Grati Paiton Region IV 150 kV was recorded at 3.286,00 MW and the frequency system was down to 49 Hz. This leads to unstable voltage condition and cause the system to blackout. Voltage stability is one of important parameters in a system. Voltage stability is an ability of a bus or transmission line to maintain the nominal voltage in a bus after disturbance occurs [1]. There are many methods that used to analyze the voltage stability such as PV curve, QV curve, Line Stability Index, Voltage Stability Index (VSI), L Index, and Fast Voltage Stability Index (FVSI) [3,4,5]. In this research, the voltage stability is analyzed using Fast Voltage Stability Index (FVSI) method. The purpose of this method is to indicate the condition of a bus. If the bus has the stability index close to unity its reach the limit level of instability condition. If the bus has the stability index close to zero this bus is in stable condition [3].

The bus that indicates in unstable condition will be injected with reactive power through the capacitor in order to improve voltage stability in a bus.



## 2. Reactive Power Loss

There is some method that usually used to reactive power injection that is through STATCOM, SVC, Shunt capacitor series, and capacitor installation [7,8,9]. In this research using a capacitor as a reactive power injection that installs in switchgear. The method that used to determine the capacitance of the capacitor is Particle Swarm Optimization method. The purpose of this method is to calculate reactive power loss (Q loss) in the transmission line, so from the reactive power loss value can determine the capacitance of the capacitor. The equation of load flow in transmission line is

$$S_R = P_R + jQ_R = E_R I^* = E_R \left[ \frac{E_S \cos \delta + jE_S \sin \delta - ER}{jX} \right] \quad (1)$$

Where

$S_R$  = Apparent power of receiving bus

$P_R$  = Active power in receiving bus

$Q_R$  = Reactive power in receiving bus

$E_R$  = voltage in receiving bus

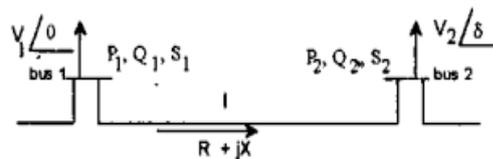
$E_S$  = voltage in sending bus

$$Q_S - Q_R = (E_S - E_R)^2 X^{-1} = X I^2 \quad (2)$$

Equation 2 is illustrated by the relation between reactive power, voltage, and impedance in transmission line system. The deviation between  $Q_s$  and  $Q_r$  is a reactive loss in line. To control the value of reactive loss in the transmission line can control the value of impedance.

## 3. Fast Voltage Stability Index

Fast Voltage Stability Index (FVSI) is a method that used to calculate the index of voltage stability. if the bus has the stability index close to unity (1) its reach the limit level of instability condition but if the bus has the stability index close to zero this bus is in stable condition [5].



**Figure 1.** Radial system of 2 bus

From this figure the equation in receiving bus is

$$V_2^2 - \left[ \frac{R}{X} \sin \delta + \cos \delta \right] V_1 V_2 + \left( X + \frac{R^2}{X} \right) Q_2 = 0 \quad (3)$$

$$\frac{4Z^2 QX}{V_1^2 (R \sin \delta + X \cos \delta)^2} < 1 \quad (4)$$

“i” symbol is for sending bus and “j” symbol is for receiving bus so the equation for Fast Voltage stability method is

$$FVSI_{ij} = \frac{4Z^2 Q_j}{V_i^2 X} \quad (5)$$

Where

$Z$  = impedance of line (ohm)

$X$  = reactance of line (ohm)

$Q_j$  = Reactive power in receiving bus (Var)

$V_i$  = voltage in sending bus (Volt)

#### 4. Particle Swarm Optimization

Particle Swarm Optimization is a one of a method that used to optimization calculated. This method firstly introduces by Kennedy and Eberhart in 1995. This method adapts from the behavior of bird in a swarm to collect the food [8,9,10]. The first step that must do in this method is the initialization of population which are created and each particle will be updated in every iteration and used to find the value of objective function. In each iteration, there are Pbest value and Gbest in a swarm. To update the velocity and new position can calculate with this equation

$$V_i(k+1) = W * V_i(k) + C_1 * rand_1 * (Pbest_i - S_{ik}) + C_2 * rand_2 * (Gbest_k - S_{ik}) \quad (6)$$

$$S_i(k+1) = S_i(k) + V_i(k+1) \quad (7)$$

Where

$V_i(k)$  = velocity of particle I in kth iteration

$V_i(k+1)$  = velocity of particle I in (k+1)th iteration

$W$  = inertia weight

$C_1, C_2$  = Weighting factor

$S_i(k)$  = particle position in kth iteration

$S_i(k+1)$  = particle position in (k+1)th iteration

$Pbest$  = personal best of particle i

$Gbest$  = global best of particle i

The value of weight factor can determine from this equation

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} * iter \quad (8)$$

Range value of weight factor is 0.9 to maximum and 0.4 to a minimum. Iter max is maximum iteration and iter is the number of iteration from this program.

#### 5. Problem Formulation

The purpose of this research, in order to know the reactive power losses in transmission line which, in turn, can determine the capacitance of a capacitor that will be used to reactive power injection to improve voltage stability and voltage profile in the system. If in transmission line illustrated with two bus that is bus I as a sending bus and bus j as a receiving bus and the impedance of transmission line is  $Z = R + jX$  per phase in line so the equation to calculate the reactive power loss is

$$Q_{ij} = \frac{1}{X^2 + R^2} [V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)] X \quad (9)$$

Total reactive power losses from system determine with add all of the losses in every branch. The range of voltage limit on a bus is

$$V_{min} < V_i < V_{max} \quad (10)$$

After knowing the value of Q loss in transmission line so that can determine the sizing of capacitance capacitor with this equation

$$Q_c < Q_{loss} \quad (11)$$

$Q_c$  is a capacitance of capacitor and  $Q_{loss}$  is a reactive power loss in the transmission line. The value of the capacitor is smallest than reactive power loss in order to in normal condition ( not in peak load) reactive power in the system not over, it can cause overvoltage. To calculated load flow analyze between two buses represented by this equation

$$P_{ij} = \frac{1}{R^2 + X^2} (R |V_i|^2 - R |V_i| |V_j| \cos \gamma - X |V_i| |V_j| \sin \gamma) \quad (12)$$

$$Q_{ij} = \frac{1}{R^2 + X^2} (X |V_i|^2 - X |V_i| |V_j| \cos \gamma - R |V_i| |V_j| \sin \gamma) \quad (13)$$

## 6. Implementation of PSO

Particle Swarm Optimization is a one of a method that used to optimization calculation. PSO of this research in order to know the reactive power losses in transmission line which, in turn, can determine the capacitance of a capacitor that will be used to reactive power injection to improve voltage stability and voltage profile in the system.

Step 1: initialized data system that is transmission line data, voltage data in each bus, range value of voltage limit, entry the data of PSO parameters such as the number of particles, number of iteration, weight factor, acceleration factor ( $C_1$ ,  $C_2$ ) etc.

Step 2: location of capacitor installation predefine with FVSI method

Step 3: after that calculate the objective function to determine  $Q_{loss}$  value with equation (9)

Step 4: Update the value of  $P_{best}$  and  $G_{best}$

$$V_i(k+1) = W * V_i(k) + C_1 * rand_1 * (P_{best_i} - S_{ik}) + C_2 * rand_2 * (G_{best} - S_{ik})$$

Step 5: Update the value of particle velocity with equation

$$V_{min} < V < V_{max} \quad (14)$$

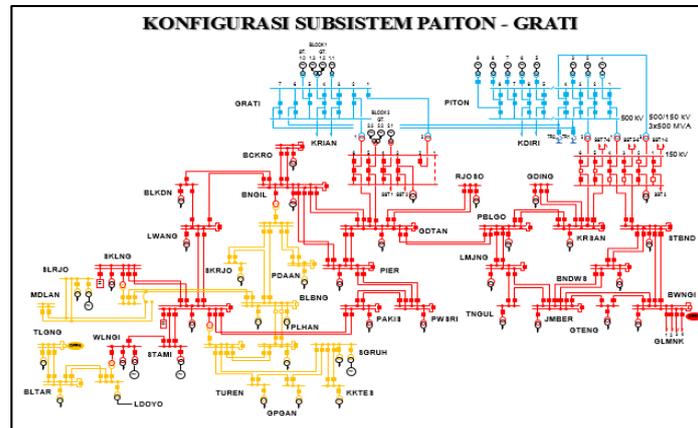
Step 6: Update the particle position

$$X_{ij}^t = X_{ij}^{t-1} + V_{ij}^t$$

$$X_{min} < X < X_{max} \quad (15)$$

Step 7: after getting the optimal result, replace the impedance line with line impedance after compensation through capacitor in objective function and repeat the iteration

## 7. Result and discussion



**Figure 2 .** Single line diagram Paiton – Grati

Electrical energy distribution system Paiton – Gratis consists of 26 bus 150 kV and 2 bus generation 500 kV. Based on the calculation of FVSI in sub system Paiton – Grati, the bus that has the highest FVSI index is in Situbondo – Banyuwangi line 0.313 Paiton – Situbondo 0.1602, Genteng – Banyuwangi line 0.15167, Probolinggo – Gondangwetan line 0.134869 (see appendix 1). The transmission line that has the highest index indicate that this bus in unstable voltage condition. In this bus will be installing the capacitor as a reactive power injection to improve voltage stability and voltage profile. After analyzing the voltage stability the value of Q loss can calculate with PSO method. This table represents the value of reactive power loss before installing the capacitor.

**Table 1.** Voltage of the bus and reactive power before compensation

Line transmission	Before installing capacitor		
	V(i) (kV)	V(j) (kV)	Qloss (kvar)
Probolinggo - Gondangwetan	143.8	143.8	38.3
Situbondo- Banyuwangi	144.4	143,5	323
Paiton – Situbondo	145,2	144,4	1281,3
Genteng - Banyuwangi	143	143,5	602,5

V(i) is a sending voltage bus and V(j) is a receiving voltage bus. Based on table 1 reactive power loss in probolinggo – the gondangwetan network is 38.3 kvar so that to decide the capacity of the capacitor as a reactive power injection used PSO method with the value from this parameter XL, Vi, and Vj.

**Table 2.** Parameter of PSO for Probolinggo – Gondangwetan network

Vi (kV)	Vj(kV)	$\delta 1$	$\delta 2$	XL(up)
143.8	148.3	-5.29	-5.58	239

This parameter will be calculated in the objective function ( equation 9) so that can obtain reactive power loss with PSO method. Reactive power loss in Probolinggo-Gondangwetan network is 193

MVAR. The value of the Q loss is used to determine of capacitor needed, so with Q loss 193 MVAR capacitor that used is 150 MVAR. After installing capacitor do the simulation again so that obtained Q loss after compensation.

**Table 3.** Voltage of the bus and reactive power after compensation

Line transmission	Before installing capacitor		
	V(i) (kV)	V(j) (kV)	Qloss (kvar)
Probolinggo - Gondangwetan	153	153	29,2
Situbondo- Banyuwangi	150,6	149,8	274,5
Paiton – Situbondo	148,9	148,3	1113,5
Genteng - Banyuwangi	147	147,6	548,2

The capacitor that used as a reactive power injection installed in three bus wick is Probolinggo bus, Gondangwetan bus, and Banyuwangi bus. This bus is a bus that has the highest FVSI value. Based on reactive power loss calculated the capacity of capacitor needed is 150 MVAR in Gondangwetan bus, 100 MVAR in Probolinggo bus and 50 MVAR in Banyuwangi bus. From table 1 and 3 show that the value of reactive power loss decrease and the voltage value at the bus increase after compensation.

**Table 4.** FVSI of the bus after compensation

Line transmission	Before installing capacitor		After installing capacitor	
	Q (j)	FVSI	Q (i)	FVSI
Probolinggo- Gondangwetan	50.96	0.135	14.73	0.034
Situbondo- Banyuwangi	56.232	0.194	27.531	0.0875
Paiton- Situbondo	57.7	0.1412	57.7	0.1298
Genteng - Banyuwangi	56.232	0.1516	27.531	0.068

From table 4 show that after installing capacitor reactive power loss in bus decrease so that the value of FVSI decrease.

## 8. Conclusion

The main purpose of this research is to determine the capacity of the capacitor by calculated the reactive power loss in a transmission line using the Particle Swarm Optimization (PSO) method. This research applied in interconnection network Paiton – Grati 150 kV east java. The result shows that the capacity capacitor installed at gondangwetan bus is 150 Mvar, at Probolinggo bus is 100 Mvar and at Banyuwangi bus is 50 Mvar. After installing the capacitor, the reactive power loss at Probolinggo – Gondangwetan line decreases from 38.3 kvar to 29.2 kvar, so that the voltage of bus increases and the FVSI index decrease close to zero. This condition indicates that the bus is in stable condition after installing the capacitor. This research proves that the PSO can be used to determine reactive power loss and the capacity of capacitor that needed so that the voltage value in bus increase and voltage system be stable.

## 9. Acknowledgment

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## 10. Appendices

**Table A1. Voltage stability Index based on FVSI**

No	Sending bus	Receiving bus	V(j)	FVSI
1	PAITON	SITUBONDO	144.4	0,160221
2	PAITON	SITUBONDO	144.4	0,141227
3	SITUBONDO	BANYUWANGI	143.5	0,194443
4	SITUBONDO	BANYUWANGI	143.5	0,313891
5	SITUBONDO	BONDOWOSO	143.5	0,021024
6	SITUBONDO	BONDOWOSO	143.5	0,017146
7	BONDOWOSO	JEMBER	142.8	0,045072
8	BONDOWOSO	JEMBER	142.8	0,015463
9	JEMBER	GENTENG	143	0,063648
10	GENTENG	BANYUWANGI	143.5	0,15167
11	PAITON	KRAKSAN	145	0,014371
12	PAITON	KRAKSAN	145	0,014371
13	KRAKSAN	GENDING	145	0,010253
14	KRAKSAN	GENDING	145	0,010253
15	KRAKSAN	PROBOLINGGO	143.8	0,023407
16	KRAKSAN	PROBOLINGGO	143.8	0,016237
17	PROBOLINGGO	GONDANGWETAN	143.8	0,134869
18	PROBOLINGGO	GONDANGWETAN	143.8	0,114758
19	PROBOLINGGO	LUMAJANG	142.7	0,032083
20	PROBOLINGGO	LUMAJANG	142.7	0,027119
21	LUMAJANG	TANGUL	142.7	0,009698
22	TANGUL	JEMBER	142.8	0,034247
23	GRATI	GONDANGWETAN	143.8	0,042718
24	GRATI	GONDANGWETAN	143.8	0,036348
25	GONDANGWETAN	REJOSO	143.4	0,019137
26	GONDANGWETAN	REJOSO	143.4	0,019137
27	GONDANGWETAN	PIER	143	0,017886
28	GONDANGWETAN	PIER	143	0,016122
29	PIER	BANGIL	143	0,00369
30	PIER	BANGIL	143	0,003208
31	GONDANGWETAN	BANGIL	143	0,017003
32	GONDANGWETAN	BANGIL	143	0,014782
33	BANGIL	BUMICOKRO	142.9	0,000301
34	BANGIL	BUMICOKRO	142.9	0,000155
35	BANGIL	LAWANG	141.8	0,024532
36	LAWANG	KEBONAGUNG	141.2	0,055076

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