Optimal Placement of STATCOM in Unbalanced Distribution Networks ConsideringVoltage Stability

Ali Sadeghizadeh, Mahmoud Zadehbagheri

Abstract— In this paper, optimal placement of STATCOM in unbalanced distribution networks to improve voltage stability has been done. Target of placement is modified profile of voltage buses network and minimizing losses. Optimal placement by forward-backward propagation has been done based on Genetic Algorithm, and simulation on an unbalanced distribution network 19-bus by MATLAB is done. Simulation results show that the optimal placement of STATCOM could injected reactive power into the network and is causing voltage stability causing the voltage stability. The simulation results prove Improve the voltage profile and the validity of the performance.

Index Terms— STATCOM, voltage stability, Genetic Algorithm, forward-backward propagation.

1 Introduction

The electric networks in terms of size, technology and price, and economic are developing and optimal utilization of these networks is very important. Topics discussed of the restructured in the power systems makes need to use more advanced equipment such as STATCOM be felt in the market more than before. Due to economic considerations compensator installation at all bus network is unnecessary and impossible. This issue is effective especially in the case expensive equipment such as static compensation. So in order to achieve greater benefits and better performance of reactive power compensators, select the correct of size and location of this equipment particular importance in the design and operation the network. In this paper, optimal placement of STATCOM in unbalanced distribution networks to improve the voltage profile and minimizing losses in unbalanced distribution network has been performed.

2 Static Compensator (STATCOM)

Performance of STATCOM is similar to the synchronous condenser. Since the construction of this device is used to power electronics devices called static compensator. Converters used in the compensator, the required reactive power locally (at the junction of STATCOM to Network) has provided and its output is adjustable continuously Therefore, in cases where the grid voltage is wide variation This compensator is used. The connection STATCOM to network is shown in Fig. 1.

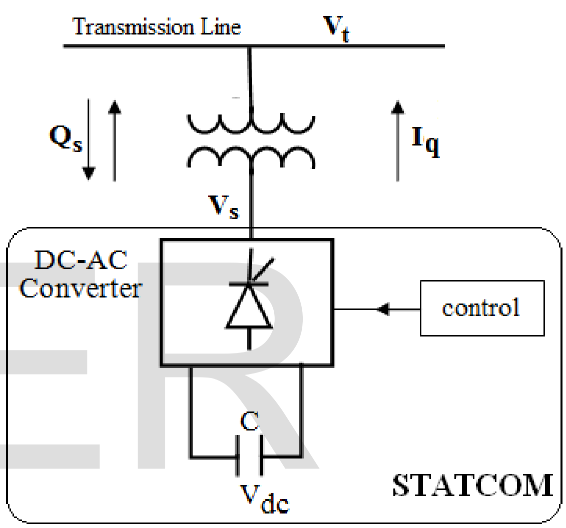

Fig. 1. The connection STATCOM to network.

STATCOM consists of a DC voltage source and a controllable switch (inverter) and a transformer that is placed in parallel with the grid. In order to study of the stability, STATCOM can be modeled by a current source. Phase angle of the STATCOM current Is different 90 degrees with bus voltage phase angle that is installed on it. Therefore, the STATCOM current as Equation 1. can be expressed:

$$I_{STATCOM} = I_{STATCOM} e^{j(\theta m \pm 90)} \quad (1)$$

3 Load Flow

Load flow is an important tool for the analysis of any power system and it is used in the operational as well as planning stages. Generally distribution networks are radial and its R/X ratio is very high. And also due to unbalance, distribution network matrices are ill conditioned and conventional load flow methods based on Gauss – Siedel and Newton – Raphson techniques are inefficient in solving such networks. Recently many researchers have paid attention to obtain the load flow solution of distribution network. The proposed method considers all aspects of three-phase modelling of branches and

• *Ali Sadeghizadeh is with the Science and Research Branch, Islamic Azad University, Kohgilouye and BoyerAhmad, Yasouj, Iran. (a_sadedgi2002@yahoo.com).*
• *Mahmoud Zadehbagheri is with the Islamic Azad University of Yasouj, Faculty of Engineering, Yasouj, Iran. (mzadehbagheri@gmail.com).*

detailed load modelling. The solution technique is based on forward and backward propagation to calculate current in each branch and voltage at each node. Further, the method can be extended to find optimal feeding point in a distribution network and reactive power compensation, network reconfiguration etc [5].

3.1 Three phase model

3.1.1 Line branch model

Most of the distribution feeders consist of three phase overhead lines or underground cable sections. It has double-phase or single phase line sections towards the end of the feeder In the three phase power flow algorithm, we number each node or line section in the network by a single index, regardless of the number of phases of this node or line or line section. The impedance and shunt admittance of a line section k, shown in Fig. 2. are represented by 3×3 matrices as given in Equations (2)–(3).

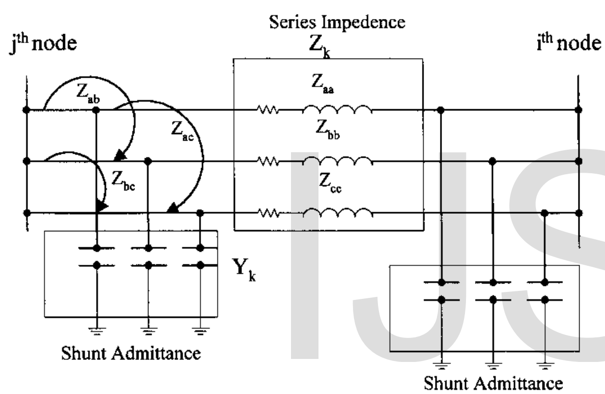

Fig. 2. Model of line section k.

$$Z_K = \begin{bmatrix} Z_{aa,k} & Z_{ab,k} & Z_{ac,k} \\ Z_{ba,k} & Z_{bb,k} & Z_{bc,k} \\ Z_{ca,k} & Z_{bc,k} & Z_{cc,k} \end{bmatrix} \quad (2)$$

$$Y_K = \begin{bmatrix} Y_{aa,k} & Y_{ab,k} & Y_{ac,k} \\ Y_{ba,k} & Y_{bb,k} & Y_{bc,k} \\ Y_{ca,k} & Y_{bc,k} & Y_{cc,k} \end{bmatrix} \quad (3)$$

Where: Z_{aa}, Z_{bb} and Z_{cc} = self impedance of phase A, phase B and phase C, respectively; Z_{ab}, Z_{bc} and Z_{ca}, etc. mutual impedance between phases [5].

3.1.2 Load model

The three phase balanced/unbalanced loads can be represented as either constant power, or constant current, or constant impedance type or a combination of these based on the proportion of the type of consumer loads. There is no limitation on the type of load to be modelled in the proposed algorithm. The three phase load model is shown in Fig. 3.

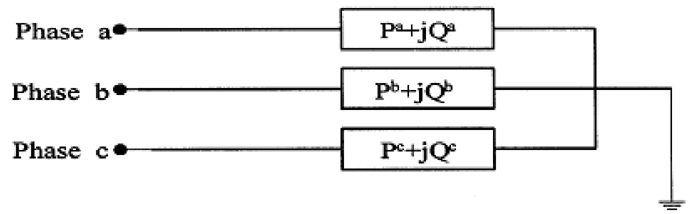

Fig. 3. Three phase load model.

The loads can be modelled separately for each phase as follows:

$$P_{load} = P^{0}_{load}\left(A_0 + A_1 V + A_2 V^2 + A_3 V^{lp}\right) \quad (4)$$

$$Q_{load} = Q^{0}_{load}\left(R_0 + R_1 V + R_2 V^2 + R_3 V^{lp}\right) \quad (5)$$

Wher: P^{0}_{load}, real power of the total load at the given phase of node; Q^{0}_{load}, reactive power of the total load at the given phase of node; V, voltage magnitude of the given phase at the node; A_0, R_0, proportion of constant power component of the active and reactive load; A_1, R_1, proportion of constant current load component; A_2, R_2, proportion of constant impedance component of the active and reactive load; A_3, R_3, proportion of active and reactive loads proportional to V^{lp}, V^{lq} ; and lp, lq, exponent of V based the actual load characteristics

$A_0 + A_1 + A_2 + A_3 = 1.0$
$R_0 + R_1 + R_2 + R_3 = 1.0$

3.2 Backward propagation

The purpose of the backward propagation is to calculate branch current in each section, by initially assuming nominal voltage at each node. That is, during backward propagation, voltage values are held constant and information about currents are transmitted backward along the feeder using backward walk. During this propagation the load current is calculated using the Equations (6) – (7), depending on the load type. The half line charging shunt currents of all the branches at the node are added to the load current.

For constant power loads the load current at i th child node is given by Equation (6).

$$\begin{bmatrix} I_{La}(i) \\ I_{Lb}(i) \\ I_{Lc}(i) \end{bmatrix} = \begin{bmatrix} S_{La}(i)/V_a(i) \\ S_{Lb}(i)/V_a(i) \\ S_{Lc}(i)/V_a(i) \end{bmatrix}^{*} \quad (6)$$

For constant impedance load, the load current at i^{th} node is given by Equation (7).

$$\begin{bmatrix} I_{La}(i) \\ I_{Lb}(i) \\ I_{Lc}(i) \end{bmatrix} = \begin{bmatrix} V_a(i)/Z_{La}(i) \\ V_b(i)/Z_{Lb}(i) \\ V_c(i)/Z_{Lc}(i) \end{bmatrix}^{*} \quad (7)$$

where: $I_{La}(i)$, $I_{Lb}(i)$, $I_{Lc}(i)$ = Load current at i th node for constant power loads; $S_{La}(i)$, $S_{Lb}(i)$, $S_{Lc}(i)$= Complex power of constant power load at i th node; and Z_{La}, Z_{Lb}, Z_{Lc} = Impedance of constant impedance load at i th node.

Once the child node current is calculated, the parent branch current is updated using Equation (8).

$$\begin{bmatrix} I_a(m) \\ I_b(m) \\ I_c(m) \end{bmatrix} = \begin{bmatrix} i_{La}(i) \\ i_{Lb}(i) \\ i_{Lc}(i) \end{bmatrix} + \sum_{p\varepsilon M} \begin{bmatrix} I_{ap} \\ I_{bp} \\ I_{cp} \end{bmatrix} + \sum_{p\varepsilon M} [Y_{sh}] \begin{bmatrix} V_a(i) \\ V_b(i) \\ V_c(i) \end{bmatrix} \quad (8)$$

Where $I_a(m)$, $I_b(m)$ and $I_c(m)$ are branch current of line section (m) and i_a, i_b, i_c are current in branch m before updating and M is the set of line sections connected to m th branch (for an example if we consider node 6, m = 5 and p = 6, 7).

3.3 forward propagation

The purpose of forward propagation is to calculate the voltage at each node starting from the child node of feeder source branch. The feeder substation voltage is set to its actual value (measured voltage). During forward propagation the current in each branch is held constant to the value obtained in backward walk. The node voltages are calculated using the Equation (9).

$$\begin{bmatrix} V_a(j) \\ V_b(j) \\ V_c(j) \end{bmatrix} = \begin{bmatrix} V_a(i) \\ V_b(i) \\ V_c(i) \end{bmatrix} - \begin{bmatrix} Z_{aa,k} & Z_{ab,k} & Z_{ac,k} \\ Z_{ba,k} & Z_{bb,k} & Z_{bc,k} \\ Z_{ca,k} & Z_{bc,k} & Z_{cc,k} \end{bmatrix} \left\{ \begin{bmatrix} I_a(m) \\ I_b(m) \\ I_c(m) \end{bmatrix} - [Y_{sh}] \begin{bmatrix} V_a(i) \\ V_b(i) \\ V_c(i) \end{bmatrix} \right\} \quad (9)$$

Where: j , i are parent and child (source and load) nodes of m th branch.

4 VOLTAGE STABILITY TESTING ON THE IEEE 19-BUS NETWORK

The network Considered in this paper is an unbalanced radial distribution system 19-bus and The total load of the network is 1.2033KW and 68.984 KVAR. This network is shown in Fig. 4. The main bus voltage is 1 pu, the nominal power of the network is 1000KVA and the reference voltage is 11KV. Other network properties such as active and reactive power at each bus, resistance and inductance of lines and distance between buss based on km is in the appendix tables 2 - 5.

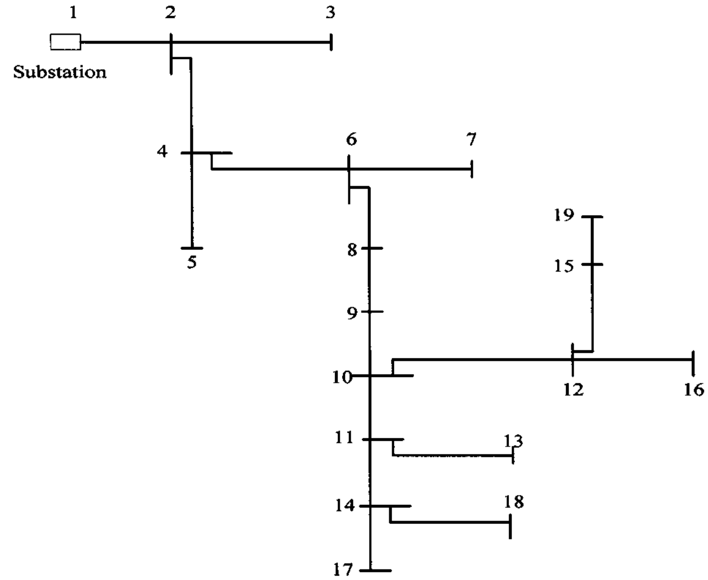

Fig. 4. A practical distribution feeder in India.

4. 1 Cost function

The main objective of optimizing is maximum exploitation of the network. In this study, increases bus voltage with optimal placement of STATCOM, that cost function is calculated as follows:

$$\cos t = W_1 \left(\sum_{n=1}^{Number\ bus} 1 - \frac{v_n}{v_{base}} \right) + W_2 \left(\sum_{n=1}^{Number\ line} R_{line_n} I_{line_n}^2 \right) \quad (10)$$

In equation (10) the cost function consists of two parts, the first part related to the voltage drop of bus network and the second effects of power loss. In this relation R_{line_n} is resistance of each network line and I_{line_n} is indicates current of each line. In this function, v_n is the nominal voltage of each network bus and v_{base} represents the bus voltage. W_1 and W_2 weighting coefficients for each of the objectives and the sum of these weighting coefficients should be equal to 1. in the simulation $W_1 = W_2 = 0.5$ is considered. This function shows whatever v_n is closer to v_{base} the Cost value will be less and the voltage stability is created.

4.2 The simulation results

Optimal placement by forward-backward propagation has been done based on Genetic Algorithm and simulation on an unbalanced distribution network 19-bus by MATLAB is done. And the optimal locations are obtained for the installation of three STATCOM at buses of 15, 16 and 19. Given that the network is unbalanced Therefore simulations has been done for each phase separately. Simulation results for with STATCOM and without STATCOM for each phase separately are given in the Fig. 5 - 7.

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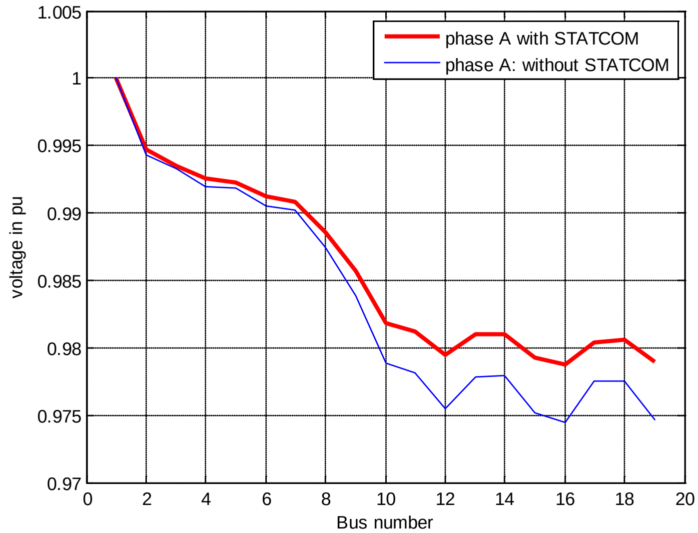

Fig. 5. voltage profile of 19-bus network in Phase A.

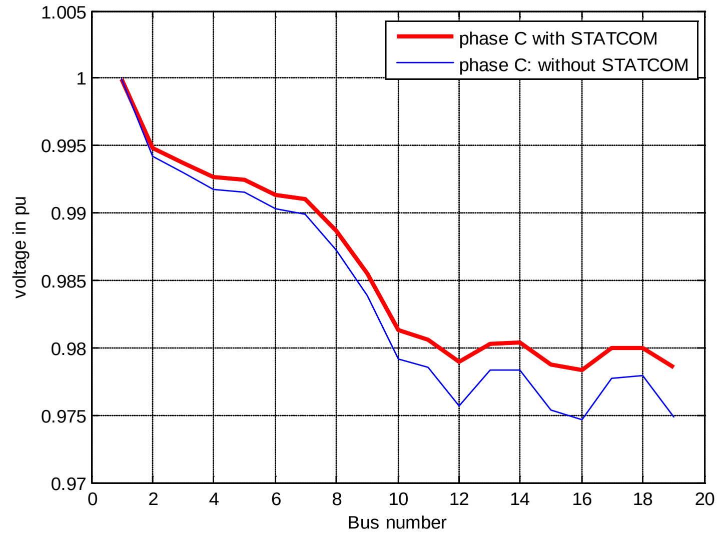

Fig. 7. voltage profile of 19-bus network in Phase C.

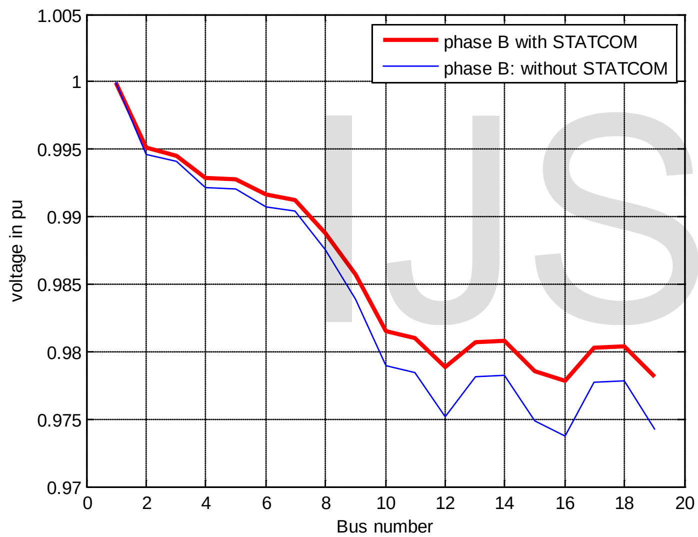

Fig. 6. voltage profile of 19-bus network in Phase B.

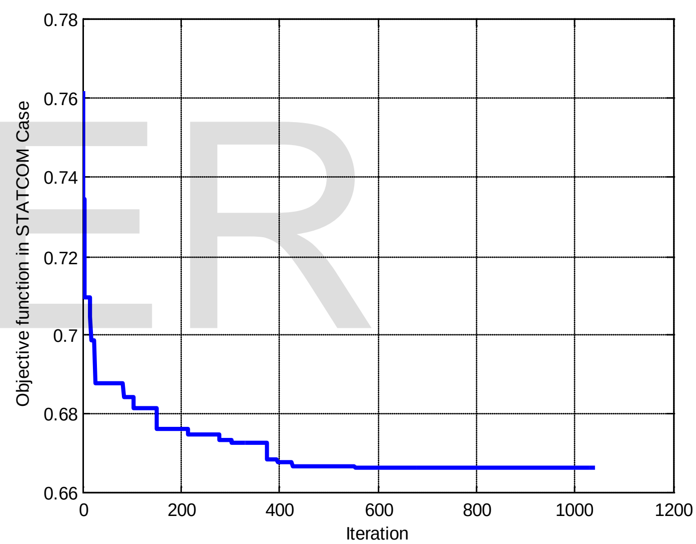

Fig. 8. Convergence graph of the cost function.

As these figures show, with installation STATCOM in locations obtained, the voltage profiles is improved in all three-phase and therefore causes is voltage stability. Fig. 5 shows the convergence function. As is clear from the figure the objective function is reached to converge at about 400 iterations. Table 1 shows the bus voltage values from 1 to 19 with STATCOM and without STATCOM

Table 1

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Bus voltage values from 1 to 19 with STATCOM and without STATCOM

Bus Number	voltage in phase A (pu)		voltage in phase B (pu)		voltage in phase C (pu)	
	with STATCOM	without STATCOM	with STATCOM	without STATCOM	with STATCOM	without STATCOM
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9947	0.9943	0.9951	0.9946	0.9948	0.9942
3	0.9935	0.9933	0.9945	0.9941	0.9937	0.9929
4	0.9925	0.9920	0.9929	0.9922	0.9926	0.9918
5	0.9923	0.9918	0.9927	0.9920	0.9925	0.9916
6	0.9912	0.9906	0.9916	0.9907	0.9914	0.9903
7	0.9908	0.9902	0.9913	0.9904	0.9910	0.9899
8	0.9886	0.9874	0.9888	0.9875	0.9887	0.9872
9	0.9857	0.9839	0.9857	0.9339	0.9855	0.9839
10	0.9818	0.9889	0.9816	0.9790	0.9813	0.9792
11	0.9812	0.9782	0.9810	0.9784	0.9806	0.9786
12	0.9794	0.9755	0.9788	0.9752	0.9790	0.9757
13	0.9810	0.9778	0.9807	0.9781	0.9803	0.9783
14	0.9810	0.9779	0.9808	0.9782	0.9804	0.9783
15	0.9793	0.9751	0.9786	0.9748	0.9788	0.9754
16	0.9788	0.9744	0.9778	0.9738	0.9783	0.9746
17	0.9804	0.9775	0.9803	0.9777	0.9800	0.9778
18	0.9806	0.9775	0.9803	0.9778	0.9800	0.9779
19	0.9790	0.9747	0.9782	0.9742	0.9786	0.9749

5 Conclusions

In this paper, optimal placement of STATCOM for voltage stability has been done on the unbalanced distribution network. In this research, load flow is done by forward-backward propagation and Cost function is designed to reduce the voltage drop on the bus. Optimal placement has been done based on Genetic Algorithm, and simulation by MATLAB is done.
With installation STATCOM, the voltage profiles is improved in all three-phase and therefore causes is voltage stability

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APPENDIX

Table 2
Summary of results for the feeder shown in Fig. 4

Load real power in phase A (KW)	702.00
Load real power in phase B (KW)	646.20
Load real power in phase C (KW)	684.90
Load reactive in phase A (KVAR)	339.99
Load reactive in phase B (KVAR)	312.97
Load reactive in phase C (KVAR)	331.71
Total load real power (KW)	2033.10
Total load reactive Power (KVAR)	984.68
Total feeder real power (KW)	2946.48
Total feeder reactive power (KVAR)	1375.79
Total feeder real power loss (KW)	913.38
Total feeder reactive power loss (KVAR)	391.11
Percentage real power loss%	31.00
Percentage reactive power loss%	28.43
Feeder power factor	0.91

Table 3
Branch data

From bus	To bus	Conype	Length (km)
1	2	1	3.00
2	3	2	5.00
2	4	1	1.50
4	5	2	1.50
4	6	1	1.00
6	7	2	2.00
6	8	1	2.50
8	9	1	3.00
9	10	1	5.00
10	11	1	1.50
11	14	1	1.00
11	13	2	5.00
14	17	1	3.50
14	18	2	4.00
10	12	1	1.50
12	16	2	6.00
12	15	1	5.00
15	19	1	4.00

Table 4
Load data under unbalanced condition

Node no.	Load in phase A (KVA)	Load in phase B (KVA)	Load in phase C (KVA	Trans capacity (KVA)
2	64.0	32.0	64.0	160
3	68.0	32.0	60.0	160
4	25.0	35.0	40.0	100
5	40.0	32.0	28.0	100
6	26.0	19.0	18.0	63
7	60.0	50.0	50.0	160
8	46.0	33.0	21.0	100
9	76.0	92.0	82.0	250
10	21.0	26.0	16.0	63
11	46.0	46.0	68.0	160
12	60.0	50.0	50.0	160
13	27.0	33.0	40.0	100
14	19.0	19.0	25.0	63
15	27.0	30.0	43.0	100
16	48.0	64.0	48.0	160
17	40.0	30.0	30.0	100
18	33.0	33.0	34.0	100
19	54.0	62.0	44.0	160

Table 5
Conductor data

Conductor type	Conductor name	Resistance (PU/km)	Reactance (PU/km)
1	ACSRWSL	0.008600	0.003700
2	WEASAL	0.012950	0.003680
Base voltage = 11 kV, Base KVA = 1000			