International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 7 (2015) pp. 18593-18605

http://www.ripublication.com

Sensitivity Based Voltage Profile Improvement in Radial Distribution System

S. Senthil Kumar[1] and Dr. C. Kamalakannan[2]

[1]Research Scholar, EEE Department, St. Peter's University, Avadi, Chennai
Email:senkmr6@yahoo. co. in
[2]Supervisior/Professor, EEE Department,
Rajalakshmi Engineering College, Thandalam, Chennai
Email:kamalakannan. c@rajalakshmi. edu. in

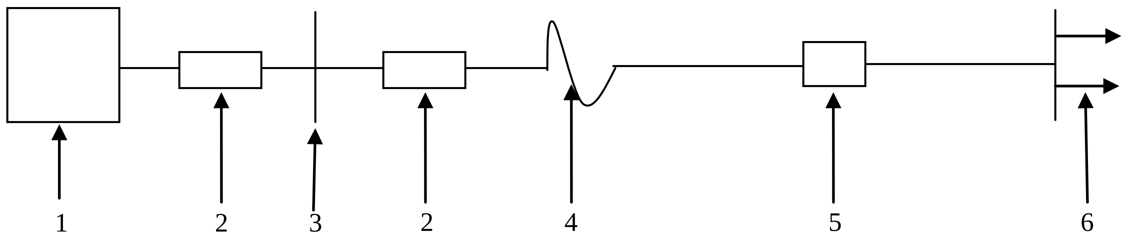
Abstract

The distribution system is the most visible part of the supply chain and also, the most exposed to the critical observation of its users. Many of the distribution systems need to work with minimum monitoring systems to include local and manual control of capacitors and sectionalizing switches, voltage regulators and with limited computation complexity for the system operators. Thus there is an increasing trend to automate distribution systems to improve their reliability, efficiency and service quality. The work focuses mainly on sensitivity computations in feeders and improving voltage profile. A voltage sensitivity analysis-based technique using fourth order radical that compute an index at each bus and identify the bus closest to the point of voltage collapse is achieved. A voltage collapse index for stressed systems is analyzed to improve the voltage stability of RDS to reduce the losses

Keywords: RDS, Sensitivity, Voltage profile, reconfiguration

Introduction

Power distribution systems typically have tie and sectionalizing switches whose states determine the topological configuration of the network figure1. The system configuration affects the efficiency with which the power supplied by the substation is transferred to the load. The sub transmission substation supplies the primary distribution system feeders radiating from the substation bus. They feed the distribution transformer of substation which step down the voltage to distribution voltage and supply various loads through distributor. This is also shown as radial distribution and is one the secondary distribution side. Feeders are conductors that are not tapped in between the sub-transmission substation and distribution substation while distributors are conductors that are tapped throughout at all points when they are laid from substation transformers to various consumers in the area to be served. Primary feeder voltage of 11kV and 33 kV are very common. The secondary distribution voltage at the consumers is 415/230 V, the system being three phase four-wire.



1. Transmission Substation, 2. Substation Bus, 3. Circuit Breaker, 4. Fuse, 5. Distribution Transformers, 6. Load

Figure1:Radial System of Distribution

Requirements of a Distribution System

Typical distribution systems expect the voltage drop and power losses to be minimum with the voltage regulation requirements at the farthest load point also satisfied. Radial Distribution System (RDS) are widely operated at higher levels of loading to maximize utilization of capital investments. From the previous works, it is inferred that voltage collapse of a line occurs due to restricted availability of reactive power which, limits the real power transfer capacity. Optimal reconfiguration can be implemented to route power through the RDS such that the loadability is maximized. Such an approximation is valid only for a specific operating point and cannot be used for varying load, especially, considering the nonlinear behavior of a RDS near the point of maximum loadability or voltage collapse. This research work focus on enhancement of voltage stability and minimize power loss in radial networks. The calculations presented in this work can be used as developments of indices to compute the loadability of RDS and accordingly reconfigure the network with an objective to enhance loadability/voltage stability. The rules for load allocation of constraints on substation and feeders are listed in Table 1.

Table 1: Rules for load allocation of Constraints on substation and feeders

Constraints on substation	Constraints on feeders	Inference
Rule 1: If the load of substation is greater than 70% of the installed capacity of its main transformer, a new substation is needed	Rule 1: The Current of each feeder is limited to be less than 300 A to avoid overloading of typical ACSR Conductor	New substation needed
Rule 2: If the load point of a main transformer exceeds 90% of its installed capacity	Rule 2: for example, the desirable load of each feeder is between 2800 KVA and 6300 KVA. If the load on a feeder exceeds 6300 KVA, load transfer should be performed in this feeder to reduce the load to a level less than 6300 KVA. For that part of load between 2800 KVA and 6300 KVA, load transfers is optional. If the load on an existing feeder is less than 2800 KVA, no load transfer will be considered.	Load reallocation to a main transformer required.
Rule 3: The number of feeders for each main transformer is limited.	Rule 3: At most two load points are allowed to connect to the same load point. Rule 4: The voltage regulation of each load point must be within ±5%	A main transformer with an installed capacity of 25 MVA is restricted to have at most five feeders.

Previous Work

In [1] the paper presents the loss minimization in distribution network by considering multiple scenarios. Minimizing the total real power loss by both size &location and the voltage stability index to find optimum placement based on BIBC(Bus-injection to branch current) & BCBV (Branch current to bus voltage) matrices is proposed. In [2] the paper presents a method which isbased on analytical approach for real power minimization of distribution network by injecting power by distributed generation at a given power factor, By this method validate the suitability and importance of appropriate DG allocation in power distribution network. In [3] the paper presents a planning and operation of active distribution network with respect to placement and sizing of distributed generators by using fuzzy logic and new Analytical method. In [4] the paper presents the loss minimization in power distribution system through feeder restructuring incorporating DG and placement of capacitor. In [5] the paper addresses the issue of improving the network voltage profile in distribution systems by installing a DG of the most suitable size at a suitable location with an analytical approach is based on algebraic equations. In [6] the paper presents determines the optimal location and sizing of DG units using (MOPI) Multi Objective Performance Index for enhancing the voltage stability of radial distribution system using chaotic Artificial Bees Colony Algorithm. In [7] the ultimate goal of the paper is to improve the voltage stability margin by considering the load and renewable DC generation. The DG units' placement and sizing is formulated using mixed-integer non-linear programming. In [8] the paper presents an Evolutionary programming based technique for placement of DG units in Radial Distribution System with the correlation between load and renewable resources with two strategies namely turning off wind turbine generator and clipping wind turbine generator output which has applied to 12. 66KV, 69-bus distribution system in order to loss reduction and voltage profile improvement. In [9] the paper presents an analyticalalgorithm for proper single distributed generation allocation regard to DG power factor effect, in order to minimize the losses by considered an analytical approach algorithm. The algorithm is based on exact loss formula with a 33 bus test feeder. From this only active power generated by Distributed Generator with power factor is calculated.

Connection Scheme of Distribution System

Three different ways exist to lay out a power distribution system used by electric utilities, each of which has variations in its own design. The comparison of different scheme is shown in Table 2.

Table 2: Connection scheme in Distribution System

Scheme	Features	Remarks	
		+Ve	-Ve
Radial feeder system	Single path between substation and each customer	Easy maintenance and Cost is less	It results in complete loss of power if interrupted
Ring main system	Two path between power source and each customer	power supply will not be interrupted a	More maintenance cost is more
Interconnected system	Generating station during peak hours can be fed from other generating stations. This reduce reserve power capacity and increase efficiency of the system		More complicated and difficult to analysis and operate

Requirement of a Distribution System

A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. The requirement of distribution system is shown in Table 3.

Table 3: Voltage, Power & Reliability requirements of Distribution Systems

Requirements	Remarks
Proper voltage	The voltage variation at consumers terminals should be as low as possible i. e. within ± 6% (IER standard)
Availability of power on demand	Power must be available to the consumers in any amount that they may require from time to time.
Reliability	Reliability can be improved by stable automatic control system, providing additional reserve facilities and inter-connected system wherever required.

Voltage drop calculation in terms of active and reactive power on feeder lines

In an RDS with several buses, any line between buses *i* and *j* of the RDS may be represented by an equivalent circuit model as in figure 3.

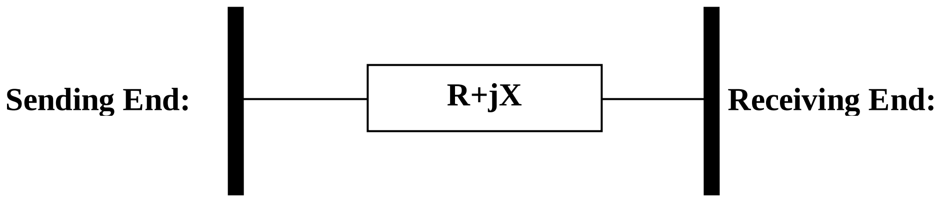


Figure3:Model of a transmission line in a RDS with any number of buses

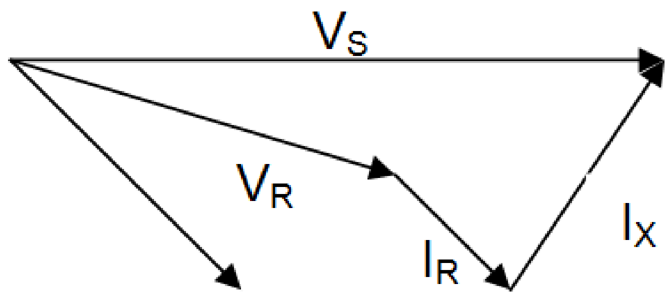


Figure4:Phasor diagram

The complex power flowing at the receiving end of the line may be expressed as ($P_R + j\,Q_R$). It is computed as follows:

$$P_R + jQ_R = V_R \times I_L^* \qquad (1)$$

I_L^* is the conjugate of the load current I_L

$I_L = (P_R - jQ_R) / V_R$

Sending end voltage $V_S = V_R + (I_L \times Z)$ (2)

where, V_R is the receiving end voltage.

$V_S = V_R + ((P_R - jQ_R) / V_R) \times (R + jX)$

$V_S = V_R + ((RP_R + XQ_R) / V_R) - j\,((XP_R - RQ_R) / V_R)$ (3)

Since ‘j’ part is negligible,

$V_S = V_R + ((RP_R + XQ_R) / V_R)$ (4)

$(VD)P.\,U. = ((V_S - V_R) / V_R) = (RP_R + XQ_R) / V_R V_B$ (5)

where, (V_B = system voltage or base voltage)

Complex power

$S = P_R + jQ_R$ and $P_R = S \times \cos\theta$ and $Q_R = S \times \sin\theta$

$(VD)\ P.\,U. = ((S \times \cos\theta / V_R) \times R + (S \times \sin\theta / V_R) \times X) / V_B$ (6)

The most important aspect of the distribution system is minimizing voltage drop and power losses. Having lowest possible line voltage drop holds great essence in scheming RDS.

Sensitivity Analysis

The placement and value of capacitor should be chosen such that the effect of reconfiguration in a particular node has less inter node effects. This effect is measured in terms of a factor called sensitivity. Reconfiguration is said to be effective if equation (7) is satisfied at all nodes. Additionally, maximum value of self-sensitivity (i. e. i=0 in equation (7)) is preferable.

$Sens[\delta_n] \geq sens\ [\delta_{n+i}]$ for i=1 to n ----------- (7)

In this research, the cross sensitivity is selected such that after reconfiguration if the value is within a threshold (0. 2 is chosen) for all the nodes, then that capacitor placements and value is preferable. If a lower value of threshold is chosen, the solution will be good, but reconfiguration time will be large and can offset its utility in real-time situation. The cross sensitivity is classified as

i. Optimal $if Sens[\delta_n] \geq sens\ [\delta_{n+i}]$

ii. Closer to Optimal $if\,|Sens[\delta_n] - sens[\delta_{n+i}]| \leq$threshold

Non Optimal $if Sens[\delta_n] < sens[\delta_{n+i}] and if Sens[\delta_n] - sens[\delta_{n+i}] >$ threshold

Sensitivity Index for N-bus RDS

For a 15-bus RDS, the sensitivity value is calculated among i[th] bus (i+1)[th] bus. These values are plotted in figure 5a. In figure 5b, the value for bus -2 alone is shown separate along with the sensitivity plot.

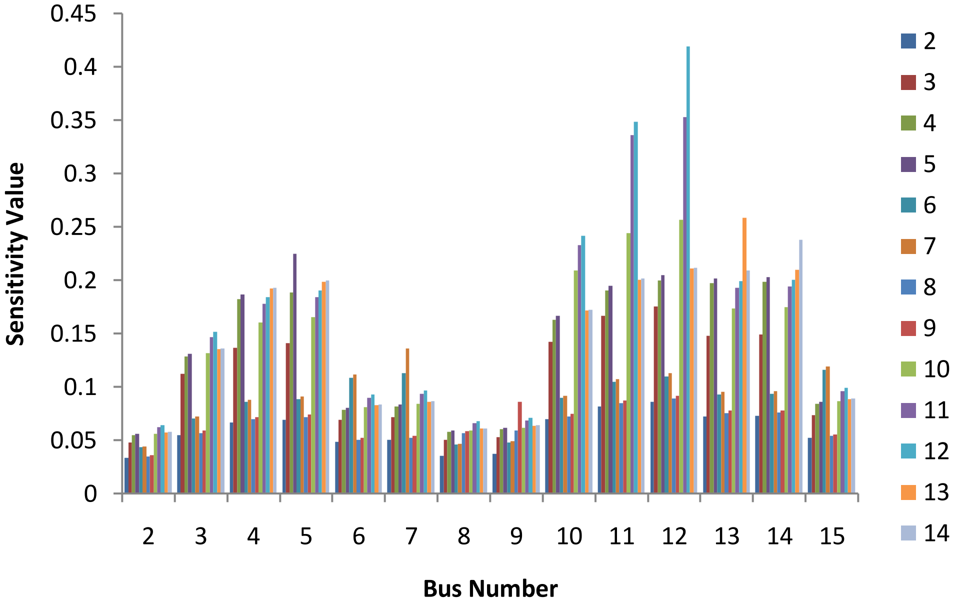


Figure 5(A): Sensitivity Value Vs Bus Number

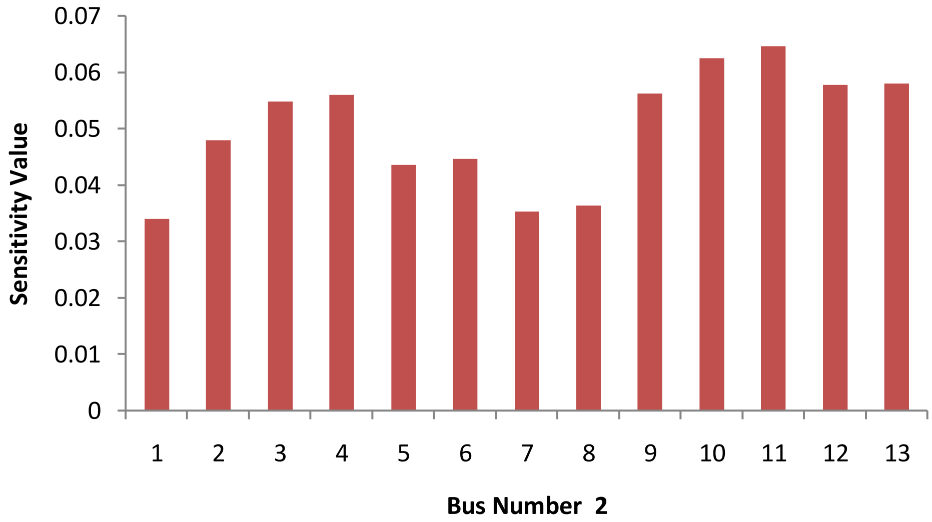
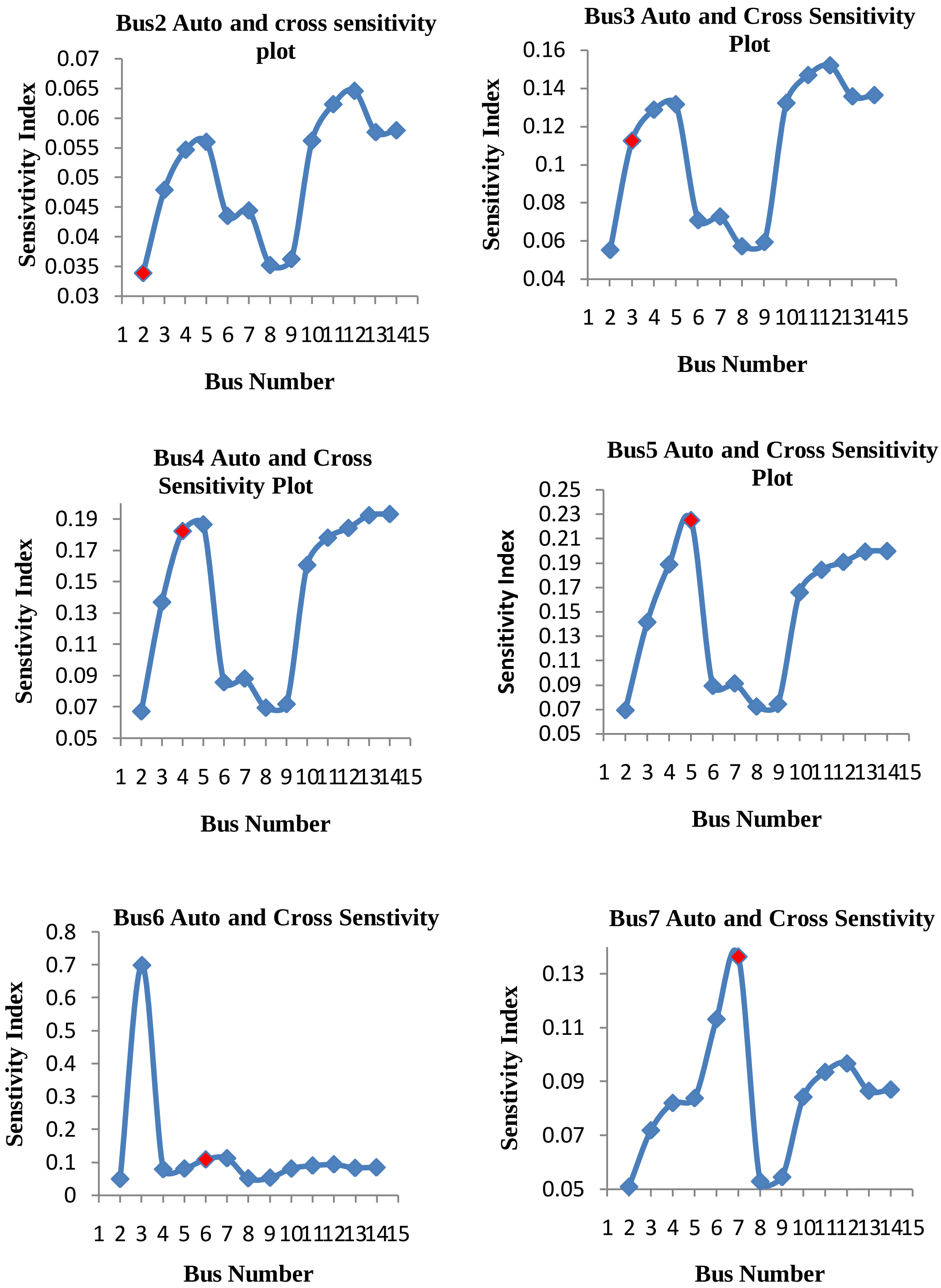


Figure 5(B): Sensitivity Value Vs Bus Number 2

Results and Discussion

The sensitivity Index variations with respect to individual Bus numbers are shown in Figure 6.



Note: Red color denotes Auto Sensitivity

Figure 6: Sensitivity Index for Bus 2 to Bus 7

Optimizing topology using sensitivity index

I. Calculate for the placed capacitor values location

a. Auto Sensitivity Index

b. Cross Sensitivity Index

II. Calculate $F = |S[\delta_n] - S[\delta_{n+1}]|$ for all 'i' $+\emptyset_c$where $\emptyset_c$ are the constraints

III. Choose min[F] as best for i^{th} topology`

Table 4: Non - optimal/Close to optimal/Optimal bus occurrence.

Bus '*i*'	**optimal buses relative to *i*thbus**	**Close to optimal bus relative to *i*thbus**	**Non- optimal buses relative to *i*thbus**
2	-	8, 9	3, 4, 5, 6, 7, 10, 11, 12, 13, 14
3	2, 6, 7, 8, 9	4, 5	10, 11, 12, 13, 14
4	2, 3, 6, 7, 8, 9, 10, 11	5, 12, 13, 14	-
5	2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14	-	-
6	2, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14	-	3
7	2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14	-	-
8	2, 3, 6, 7	4, 5, 9, 10	11, 12, 13, 14
9	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14	-	-
10	2, 3, 4, 5, 6, 7, 8, 9, 13, 14	-	11, 12
11	2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14	12	-
12	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14	-	-
13	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14	-	-
14	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	-	-

Expectancy of the three classification of the buses is obtained by summing the number of entries in each class for the ith bus and with 'i' varying from 2 to 14.

Table 5: Expectancy ofNon - optimal/Close to optimal/Optimal bus Categorization

Bus '*i*'	**Expectancy of optimal buses relative to ith bus**	**Expectancy of close to optimal buses relative to ith bus**	**Expectancy of non-optimal buses relative to ith bus**
2	0	(2/12)	(10/12)
3	(5/12)	(2/12)	(5/12)
4	(8/12)	(4/12)	0
5	1	0	0
6	(11/12)	0	(1/12)
7	1	0	0
8	(4/12)	(4/12)	(4/12)
9	1	0	0
10	(10/12)	0	(2/12)
11	(11/12)	(1/12)	0
12	1	0	0
13	1	0	0
14	1	0	0

SAMPLE CALCULATION FOR 13-BUS:
(i) Expectancy of optimal buses relative toith bus

$$(0+5/12+8/12+(1x6)+11/12+4/12+10/12+11/12) = 10.083$$

(ii) Expectancy of close to optimal buses relative to ith bus

$$(2/12+2/12+4/12+0+0+0+4/12+0+0+1/12+0+0+0) = 1.083$$

(iii) Expectancy of non-optimal buses relative toith bus

$$(10/12+5/12+0+0+1/12+0+4/12+0+2/12+0+0+0+0) = 1.833$$

The method to determine the sensitivity index and there from identify the capacitor value is illustrated in Figure 7.

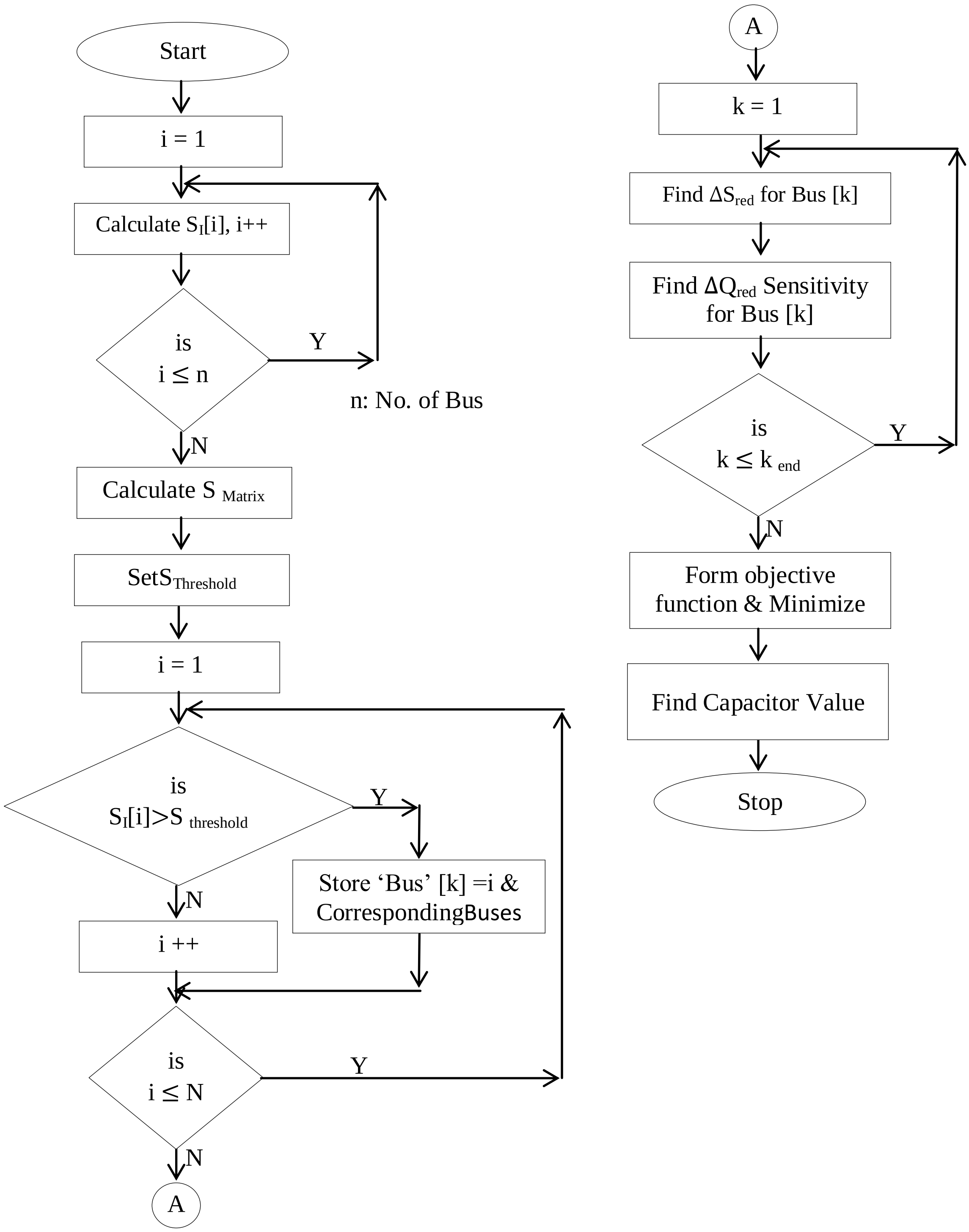


Figure 7: Determining Sensitivity index and obtaining Capacitor value

Existing optimal values of average sensitivity are unaffected after reconfiguration and the positions which were originally non-optimal/closer to Optimal is compared and given in Table 4. It can be inferred that after reconfiguration the non-optimal entries are very less.

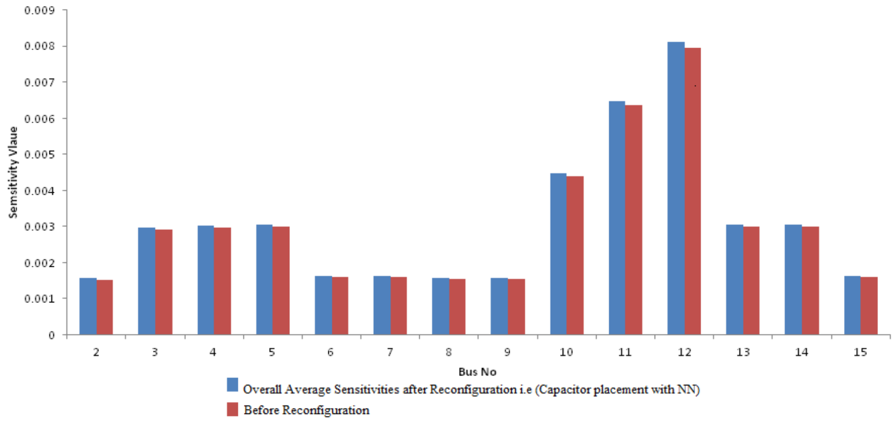


Figure 8: Sensitivity analysis based reconfiguration (overall Average Sensitivity)

Conclusion

The Complex power flowing at the receiving end of line is determined. The placement & value of capacitor was determined from the classification of buses into three categories such as optimal, suboptimal and non-optimal. Sensitivity values were studied with respect to bus number. Both auto & cross sensitivity plot were obtained and a novel strategy to optimize topology is proposed. Expectancy of optimal buses relative toi^{th}busis 10. 083, Expectancy of close to optimal buses relative toi^{th}bus is 1. 0833 and Expectancy of non-optimal buses relative toi^{th}bus is 1. 8333. The percentage improvement for optimal class bus achieved is nearly 82% compared to the reported work. Also, the percentage improvement for close to optimal bus is negligible.

References

[1]. A. Parizad, A. Khazali, M. Kalantar. "Optimal placement of distributed generation with sensitivity factors considering voltage stability and losses indices ", Proceedings of ICEE2010

[2]. Gopiya Niak. s, D. K. Khatod, M. P. Sharma "sizing and siting of distributed generation in distribution network for Real power loss Minimization using Analytical approach. " @2013 IEEE

[3]. S. Kumar Injeti, Dr. Navuri p kumar "Optimal planning of distributed generation for improved voltage stability and loss reduction" Volume 15-No. 1 February 2011.

[4]. L. Ramesh, S. P. Chowdhury"Minimization of power loss in distribution networks by different techniques", Vol:3, 2009-04-28.

[5]. K. M. Muttaqi, M. Negnevitsky, G. Ledwich. ”An algebraic approach for determination of DG parameters to support voltage profile in Radial Distribution Network”, IEEETransactions on Smart Grid, VOL. 5 NO. 3MAY 2014.

[6]. N. Mohandas, R, Balamurugan, L. Lakshminarasimman “Optimal Location and sizing of real power DG units to improve t5he voltage stability in the distribution system uusing ABC algorithm united with chaos” 0142-0615/2014

[7]. R. S. AlAbri, Ehab F. El-Saadany and Yasser M. Atwa “Optimal placement and sizing method to improve the voltage stability Margin in a distribution system using Distributed Generation. ” VOL. 28 NO. 1 February 2013.

[8]. Dheeraj K. Khatod, Vinay Pant and Jayadev Sharma “Evolutionary programming based optimal placement of Renewable Distributed Generators” VOL. 28. NO. 2 MAY 2013.

[9]. Reza KarbalaeiHoosseini, RaasoolKazemzadeh “Optimal DG Allocation by extending an Analytical Method to minimize losses in Radial Distribution Systems”.