Usage of Interlinks in an Electrical Distribution System-----A Boon in Reducing Reactive Power Requirement at the Load Bus

V. Chayapathy, G S Anitha

***Abstract*:-It is observed that one of the reasons for voltage instability is voltage collapse. Generally the concept of reactive power management is used to mitigate voltage collapse. But in this work the fallowing novel concept is used. The mathematical derivations begin from the usage of the conventional voltage collapse indicators(VCPI) Interlinks are used in the power system to distribute real powers locally (Inter bus power transfer) to mitigate voltage collapse. Optimal assignment of Distributed generation capacities are found out at different buses to mitigate voltage collapse. A mathematical model is derived and this model helps to design a valid algorithm to take care of voltage collapse problems. The Implementation of the algorithm is done through a MATLAB program which is shown in the Appendix. But minimum reactive power is to be maintained in the system.**

Quadratic Programming is applied in the fields of Control and Communications [13], Optimizing the civil structural design[14],nonlinear programming applications are presented that have arisen in different industries, namely food and insurance[15], Economics portfolio selection, monopolists' profit maximization, inequality constrained least-squares estimation, spatial equilibrium analysis, goal programming with quadratic preferences, and optimal decision rules [16] , But in this work Quadratic Programming is applied to find a way to mitigate voltage collapse in a power system.

***Keywords:* Voltage Collapse, Mitigation of Voltage Collapse, Inter Links, Inter Bus Power Transfer, Assignment of optimal value of real power , Distributed Power.**

OBJECTIVES

As the load on a distribution system increases the load voltage decreases ultimately resulting in voltage collapse. The earlier method of mitigating voltage collapse was to pump reactive power during high loads and to improve the voltage profile of the system. But in this method real powers are optimally distributed among different buses to mitigate voltage collapse in the system. This is done by using inter bus power transfer. By maintaining minimum amount of reactive power in the system mitigation of voltage collapse is be possible by using Inter links.

INTRODUCTION

Modern power systems are designed to sustain high loads and complicated interconnections for reasons of reliability and economy. To manage such complex power systems, sophisticated control mechanisms are in place. Despite these control mechanisms, the intricacy of power grids and high load demands cause power systems to behave in an unpredictable manner causing major network collapses and blackouts. The cause of such network collapses is often attributed to voltage instability. Several combinations of events and system conditions cause voltage instability.In recent times several blackouts which were reported in many countries relate to voltage collapse problems. Blackouts occurred even when generation of electrical energy was adequate. So anexhaustive study of voltage collapse is being under taken in this work.

Electric utilities have always been experiencing voltage instability problems. Several black outs in recent times in countries such as France, Germany, Belgium, United States and India have triggered an interest in voltage stability studies. The complexity of modern power systems has called for a more in depth study of power system stability and in particular study of voltage instability.

The causes of voltage instability are over voltages at the different load buses, not maintaining the required voltage levels at the buses of a power system, loss of main transmission lines in a power system, loss of generators in a power system, Serious faults occurring in a power system, Short circuits and open circuits at different parts of the power system and voltage collapse.

Voltage instability occurs due to excessive overloading, insufficient reactive power supply and sudden faults [1],[2]. There are several metrics for measuring the voltage stability [3]. In this work, the degree of voltage stability at a bus, fed by a power line is measured using the voltage collapse Proximity Indicator (VCPI)[4] at that bus.

Voltage collapse often starts in a local network and gradually extends to the whole system. The event that triggers voltage collapse may be a small gradual system change such as normal increment in system load, or a large sudden disturbance such as loss of a generating unit or loss of a heavily loaded line. Voltage collapse indices are used to determine how close the system is to the brink of voltage collapse. It is an established fact that the most important requirement for avoiding voltage collapse is to maintain the sufficient amount of reactive powers at the load buses. Keeping in view the above mentioned requirement of maintaining the reactive powers at the load buses reactive power compensating devices are used at the load buses [17-20].

Inter-buspower transfer and optimal assignment of available distributed generators are used in an existing radial distribution network to provide better voltage stability. This is achieved by equalizing the voltage collapse Proximity Indicators of the distribution buses in the network. Assignment of available distributed generators to the appropriate locations are determined so as to minimize the inter-bus power transfer cost while maintaining equal values of voltage collapse Proximity Indicators among the distribution buses. Binary integer Quadratic Programming techniques are used to achieve this.

The voltage instability and the consequent voltage collapses are posing potentially serious challenges for the electrical distribution networks with widely fluctuating and unpredictable loads. The electrical utility companies are progressively innovating new devices and techniques to overcome the voltage instability threat and to prevent major power disruptions.

I. VOLTAGE COLLAPSE PROXIMITY INDICATOR

Voltage collapse Proximity Indicator (VCPI) is defined as,

$$\mathrm{VCPI} = \frac{\mathrm{Pr}}{\mathrm{Prmax}} \quad (1)$$

Where, Prmax is the maximum real power that can be transferred to the receiving end, and Pr = Actual power received. At voltage collapse condition, VCPI = 1. Theoretically, the range of VCPI is from 0 to 1. Lower the value of VCPI, better is the voltage stability. But then, the Pr will be well below the maximum capacity of the line. From Eq. (5.1) we see that, VCPI also represents the line capacity utilization ratio. In practice, VCPI's are held in the range 0.8 – 0.9. In our proposed scheme, the ratio of the reactive power to the real power is assumed to be constant. Thus, if Pr is within the safe limit, it is assumed that the corresponding reactive power Qr is also within the safe limit. Therefore, hereafter, only the active powers are taken into considerations in the analysis and design.

There are several ways of preventing voltage collapse in a complex power system like selective load shedding [4, 5,6], use of FACTS devices [7, 8, 9] and distributed generators [10, 11, 12]. In this paper we use inter-bus power transfer and distributed generators

II. EQUALITY OF VCPI'S AND INTER-BUS POWER TRANSFER

Inter bus transfer which is a new concept is considered in this work and the inter bus carries currents to supply to a region where the load is more as explained below.Consider the situation where two nearby distribution buses are supplying power P(1) and P(2), without inter-bus power transfer as shown in Fig.1. Let the maximum power capacities of the feeder lines be Prmax(1) and Prmax(2) respectively, and let the actual power flows in the feeder lines be Pr(1) and pr(2) as shown in Fig..1. Here, distribution bus DB(1), sends out power P(1) while receiving power Pr(1) and similarly DB(2) sends out P(2) while receiving Pr(2). Therefore, when there is no inter-bus transfer, power balance at DB(1) and DB(2) gives,

$$\mathrm{Pr}(1) = \mathrm{P}(1) \quad (2a)$$

$$\mathrm{Pr}(2) = \mathrm{P}(2) \quad (2b)$$

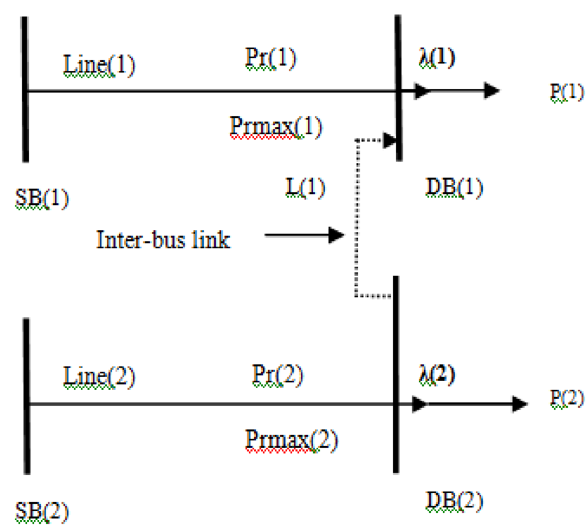

Fig.1 Lines with unequal VCPI's

VCPI's of Line(1) and Line(2) at DB(1) and DB(2)are represented by λ(1) and λ(2) as,

$$\mathrm{VCPI}(1) = \lambda(1) = \frac{\mathrm{Pr}(1)}{\mathrm{Prmax}(1)} = \frac{\mathrm{P}(1)}{\mathrm{Prmax}(1)} \quad (3a)$$

$$\mathrm{VCPI}(2) = \lambda(2) = \frac{\mathrm{Pr}(2)}{\mathrm{Prmax}(2)} = \frac{\mathrm{P}(2)}{\mathrm{Prmax}(2)} \quad (3b)$$

Let λ(1) and λ(2) be unequal as, λ(1) ≥ λ(2). Since λ(1) is higher, Line(1) is operating near the voltage instability point and its voltage stability margin is low. However, Line (2) is much safer because of its lower λ(2). The voltage stability margin of Line (2) is higher than that of Line (1). But Line (2) is carrying a relatively lower power Pr(2) with respect to Prmax(2) when compared to Line(1). Therefore some additional power can be transmitted along Line(2) and fed to DB2 via the inter-bus link as L(1). See Fig.1. Then Pr(1)_new is reduced to Pr(1) – L(1) = P(1)– L(1). Therefore, λ(1) of Line(1) is reduced to a safer value compared to its previous value. On the other hand, Line(2) is now carrying an additional power, as Pr(2)_new = P(2)+L(1). Therefore, λ(2) increases and the safety margin of line(2) decreases. The question is, to what extent Pr(2) should be increased and Pr(1) should be reduced. The principle of natural justice says that the increase in Pr(2) and the decrease in Pr(1) should be such that their VCPI's are made equal. In that case both lines will have equal voltage stability margin as well as equal line capacity utilization ratio. After the inter-bus power transfer L(1), the condition for equal VCPI's is given by,

$$\frac{P(1)-L(1)}{Prmax(1)} = \frac{P(2)+L(1)}{Prmax(2)} = \lambda \tag{4}$$

Here we assume that Prmax(1) and Prmax(2) remain same even after L(1) is fed into DB(1). Also, P(1) and P(2) are assumed to be same before and after feeding L(1) into DB(1).

Where λ is the common VCPI for both the lines.

Eq. (5.4) is solved for L(1) as,

$$L(1) = \frac{P(1) * Prmax(2) - P(2) * Prmax(1)}{Prmax(1) + Prmax(2)} \tag{5}$$

Thus, the use of inter-bus power transfer equalizes the VCPI's of the two given buses.

III. USE OF DISTRIBUTED LOCAL GENERATORS

Since there is lot of scope to use renewable energy to generate electrical power these renewable energy sources can be used to generate electrical power and in turn the generations can be used as local generators.

In many cases, the value of L(1) as given by Eq. (5) may be too high to implement in practice or the cost of the inter-bus may be very high because of physical terrain and other reasons. In such cases, local generators are used to feed the distribution buses to balance the load flow requirements and also to provide equality of VCPI's. These generators are generally renewable energy sources and they supplement the load power requirement. In this paper we discuss about the capacities and locations of these generators for minimum overall cost of the inter-bus power transfer and that of the generators. These generators are connected to the distribution buses to supply additional load as shown in Fig. 2.

3.1 Basic Model, Symbols, Assumptions and Relations

The logical layout of the power distribution network is shown in Fig.2. Basically it is a radial distribution system with the addition of inter-bus links and local generators. There are N distribution buses fed by N source buses. The distribution buses are designated as DB(1), DB(2),…,DB(j),…,DB(N) and the corresponding source buses are designated as, DS(1), DS(2),…,DS(j),…,DS(N). The equalized VCPI(j) of Line(j) is given by,

$$VCPI(j) = \lambda = \frac{Pr\ (j)}{Prmax(j)} \tag{6}$$

for j =1 to N. Here λ =λ(1)=λ(2)=…=λ(j)=…=λ(N) .

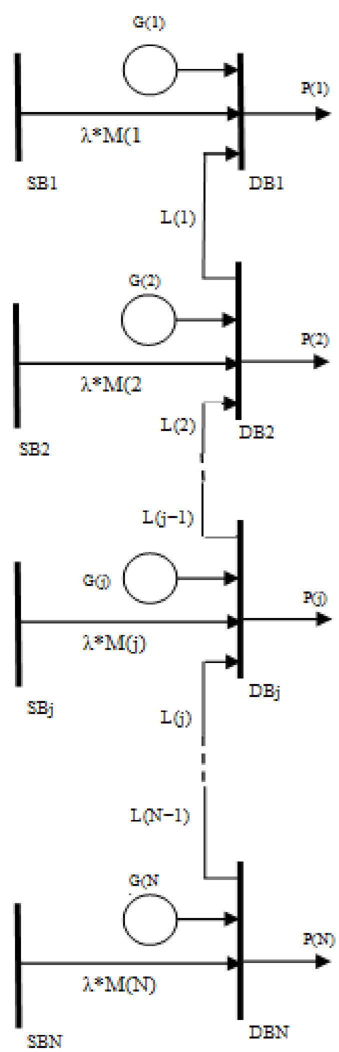

Fig 2 Logical Layout of the DistributionNetwork

In Eq. (6), Prmax(j) is the maximum power carrying capacity of Line(j) and Pr(j) is the actual power flow in Line(j).

From Eq. (6), the power flow in Line(j) is,

Pr(j) = λ*Prmax(j) (7)

for j =1 to N.

P(1), P(2),…,P(N) are the load power outflows from DB1, DB2,…,DBN respectively. L(1), L(2),…,L(N−1) are the inter-bus power transfers with directions as marked in Fig.2. In Fig.2, L(j) is the inter-bus flow from DB(j+1) to DB(j) for j =1 to (N−1). In Fig.1, the generator power input to bus DB(j) is represented by G(j), for j =1 to N. In our scheme, it is assumed that P(j)'s, Prmax(j)'s for j = 1 to N are given in proper units and the value of λ is specified. We assume that Prmax(j) is not affected by L(j) and G(j) because L(j) and G(j) are small compared to Prmax(j) and P(j).

IV. COST OF INTER-BUS POWER TRANSFER

Consider the ohmic power loss due to the inter bus power transfer L(j). The ohmic power loss due to L(j) is given as follows. In this work only ohmic losses are considered and all the other losses such as carona loss is neglected.Using the single line equivalent circuit,

Ohmic Power Loss = W(j)= $I(j)^2$*R(j) (8)

Simplifying Thus we see that the cost of inter-bus power transfer is proportional to the square of the power transfer L(j).In our scheme, there are (N−1) transfers. See Fig. 1. Therefore the total cost C of inter-bus power transfer is,

$$C = \sum_{j=1}^{N-1} c(j) = \sum_{j=1}^{N-1} k(j) * L(j)^2 \tag{9}$$

In this work other costs are not taken into account.

4.1 Determination of L(j)'s assuming equal VCPI's

For Distribution Bus DB(1), power balance Equation gives,

L(1)+Pr(1)+G(1) = L(1)+λ*Prmax(1)+G(1) = P(1)

Therefore,

L(1) = P(1) − λ*Prmax(1) – G(1) (11)

Simplifying the equation is

(L(j))2 = XT*F(j, N) *X (12)

***4**.3 Cost c(j) in terms of F(j, N)*

The cost c(j) is given by,

c(j) = k(j)*XT*F(j, N) *X = XT*(k(j)*F(j, N)) *X (13)

Simplifying the equation is

C=XT*H*X (14)

Thus C is a quadratic function of X. This means, C is a quadratic function of G(j)'s. Our objective is to minimize C subjected to the relevant constraints. Thus, minimization of C is a Quadratic Programming problem.

4.4 Constraints on X

Let the lower and upper bounds on the individual generators be as,

Gmin(j) ≤ G(j) ≤ Gmax(j) after simplifying the constraints are expressed as,

LMIN ≤ D*X ≤ LMAX (15)

4.5 Quadratic Programming to Determine G(j)'s

Initially, we determine X that minimizes C with constraints

G(j)=P(j)− λ*Prmax(j)– x(j) (16)

4.6 Quadratic Programming Problem Formulation:

Using the Quadratic Programming technique,

C=XT*H*X

subjected to the conditions,

x(1)+x(2)+…+x(N– 1)+x(N) = 0

LB≤ X≤ UB

LMIN ≤ D*X ≤ LMAX

After getting optimal values of x(j)'s, the corresponding optimal values of G(j)'s are obtained.

4.7 Use of QuadprogFunction from MATLAB

In this paper, we usequadprog(…)[53]from Mat lab to solve the quadratic programming problem. The quadprog(…) function determines X that minimizes 0.5*XT*H*X+fT*X. In our case, f = all zeros so that the objective function is just 0.5*XT*H*X. Since 0.5 is a positive constant, quadprog(…)obviously minimizes XT*H*X. The arguments for the function and the order of them are as follows.

X =quadprog(H, f, A, B, Aeq, Beq, LB, UB);

The default optimization algorithm used in quadprog(…) is 'interior-point-complex' [xx2].

The algorithm to get G(j)'s using the Quadratic Programming is given below.

Algorithm

1. Inputs: N, the number of distribution buses.

2. λ, the common voltage collapse Proximity Indicator,

3. Prmax(j)'s, the maximum power capability of the feeder,

4. Line from SB(j) to DB(j),

5. P(j)'s, power outflows from DB(j)'s,

6. Gmin(j)'s and Gmax(j)'s, lower and upper bounds on G(j)'s,

7. Lmin(j)'s and Lmax(j)'s, lower and upper bound on L(j)'s. Inter-bus power transfer cost factor k(j)'s.

All the above values are given for j=1 to N.

Output: Optimal values of G(j)'s, for j=1 to N.

// Steps 1 and 2 give H.

8. Set H=zeros(N,N) //initialize H to zeros

9. For j=1 to N-1,

    a. Get the binary row vector E(j, N) as,

    E(j, N) = [ones(1, j) zeros(1, N-j)].

    b. Get the matrix F(j, N) using Eq. (34) as,

    F(j, N) =E(j, N)T*E(j, N).

    c. Get H as,

    H = H+k(j)*F(j, N)

  Endfor.

10. GetLB and UB using Eqs.(5.46) and (5.47).

11. Get Aeq and Beq as given by Eqs. (5.60) and (5.61).

12. Get LMIN, LMAX and D using Eqs.(5.51), (5.52) and (5.53). From these values calculate matrices A and B as given by Eqs. (5.57) and (5.58).

13. Set f=[zeros(N,1)] an all zero matrix of size Nx1.

14. Get X using the Matlab function quadprog(…) as,

  X=quadprog(H, f, A, B, Aeq, Beq,LB,UB);

15. Get vector G using Eq. (54b).

    //G(j)'s are the elements of vector G for j = 1 to N.

    Results:

Example 1: The values of the inputs are given in appropriate units as follows.

N=5.

λ = 0.8.

PRMAX=[100 200 50 80 150]T

P = [130 510110 124 340]T

GMIN=[0 0 0 0 0]T

GMAX =[300 300 300 300 300]T

LMIN=[−100 −100 −100 −100 −100]T

LMAX=[100 100 100 100 100]T

K=[k(1) k(2) k(3) k(4)] = [1 1 1 1]

Take f =[0 0 0 0 0]T

Now, H is found to be,

$$H = \begin{bmatrix} 4 & 3 & 2 & 1 & 0 \\ 3 & 3 & 2 & 1 & 0 \\ 2 & 2 & 2 & 1 & 0 \\ 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

LB=XMIN is calculated using Eq. (46) and is found to be,

LB = P−λ*M−GMAX=[−250 50 −230 −240 −80]T.

From Eq. (47), UB=XMAX=P−λ*PRMAX−GMIN is found to be, UB = [50 350 70 60 220]T.

After using quadprog(…), The value of X is found to be,

X = [x(1) x(2) x(3) x(4) x(5)]T = [−25 50 −25 0 0]T

From this, G is found using Eq. (44b) as,

G=[G(1) G(2) G(3) G(4) G(5)] = [75 300 95 60 220]T

Inter-bus power flow L(j)'s, found from Eq. (17a) are,

[L(1) L(2) L(3) L(4)] = [−25 25 0 0].

The minimized cost C=(−25)2 +(25)2 = 1250 units.

Example 2: Following changes are made in the inputs of Example 1 to get example 2. Other values remain same.

K=[k(1) k(2) k(3) k(4)] = [3 2 1 1]

P = [130 510110 124 400]T

GMAX =[250 250 250 250 250]T

In this case,

$$H = \begin{bmatrix} 7 & 4 & 2 & 1 & 0 \\ 4 & 4 & 2 & 1 & 0 \\ 2 & 2 & 2 & 1 & 0 \\ 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

XT=[x(1) x(2) x(3) x(4) x(5)]=[−40 100 −60 −30 30]

GT = [90 250 130 90 250].

L =[L(1) L(2) L(3) L(4)] = [−40 60 0 −30].

C= 3*(−40)2+2*(60)2+0+1*(−30)2 = 12900 units.

In Example 1 and 2 we have taken same values for the upper bounds Gmax(j)'s. IngeneralGmax(j)'s need not be same.

Optimal Assignment of Existing Generators to loads:

The total cost C of Eq. can be expressed as,

C=FC+QC+LC (17)

QC can be written as,

QC =0.5* GT*H*G (18)

After simplification

C =FC +0.5* GT*H*G+ FT*G (19)

The Our objective is to minimize C by properly choosing G(j)'s out of available generators.

iv. Assignment of available generators

Let the number of generators (facilities) available be N. They are designated as,

AG:=[Ag(1), Ag(2),…, Ag(i),…,Ag(N)]T (20)

Here, Ag(i) represents the power output capacity of the ith generator. Also, when there is no ambiguity, Ag(i) represents the ith generator. AG is the column vector that holds Ag(i)'s. we assume that, Ag(1)+Ag(2)+…+Ag(N) = S(1)+S(2)+…+S(N)

In this scheme, G(j) is the generator input power to distribution bus DB(j). We have to select one of the Ag(i)'s for G(j) for j=1 to N, to minimize the resulting cost. Then we say the selected Ag(i) is assigned to DB(j) which means G(j)=Ag(i). Since the assignment is unique and one to one, the assignment is a permutation. Let π be a permutation of integers from 1 to N that represents a specific assignment. For example, with N=5, let π = [4 5 3 1 2]. Then G(j)'s are assigned as,

The objective now is to find that π which minimizes C.

Algorithm

Inputs: N, the number of distribution buses (DB(j)'s).

λ, the common voltage collapse Proximity Indicator.

Prmax(j)'s, the maximum power capability of the feeder

line from SB(j) to DB(j),

P(j)'s, power outflows from DB(j)'s,

Available generators, Ag(j)'s,

Inter-bus power transfer cost factor k(j)'s.

All the above values are given for j=1 to N.

Output: Optimal assignment values of G(j)'s, for j=1 to N.

1. For j =1 to N, Get S(j)

S(j) = P(j) − λ*Prmax(j)

2. For j = 1 to N get D(j)'s

D(j) = S(1)+S(2)+…+S(j)

3. For j=1 to N,

a. Get the binary row vector E(j, N) as,

E(j, N) = [ones(1, j) zeros(1, N-j)].

b. Get the matrix U(j, N) using Eq. (6.36) as,

U(j, N) =E(j, N)T*E(j, N).

Endfor

4. Get FT

5. Get R

6. Get W using

W = RT*H*R.

7. Get V

V: = RT*F.

8. Get matrix A

9. Get vector V

10. Take lb=[zeros(N2, 1)] and ub = [ones((N2, 1)].

11. Take ctype(i) ='E' for i = 1 to 2*N.

12. Take varitype(j) = 'B' for j =1 to N2.

13. Take schoptions=schoptionsset (default).

14. Get XMIN using the function quadprog(…) as,

[XMIN,fmin,status, extra]

= iquadprog(schoptions,sense,V, A, b, ctype, …

lb, ub, varitype)

15. Get vector Gopt

// The elements of vector Gopt for j = 1 to N,

are the optimal assignments.

16. Get PM opt and π(opt)

17. END

Results:

Example 1: The values of the inputs are given in appropriate units as follows.

N=5 and λ =0.8.

PRMAX =[100 120 90 110 105].

P =[100 126 112 113 94].

S=[20 30 40 25 10].

k =[3 4 5 10 0].

AG = [10 20 15 35 45].

After using iquadprog(…), The value of XMIN is found to be,

XMIN=[0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 1 0 0 0 1 0 0 0 0]T

By reshaping XMIN the corresponding optimum permutation is,

π(opt) = [1 2 3 … N]*PMopt= [3 4 5 2 1]

The generator assignments are,

[Ag(3) Ag(4) Ag(5) Ag(2) Ag(1)] to

[DB(1) DB(2) DB(3) DB(4) DB(5)]

The corresponding G values are,

Gopt=[G(1) G(2) G(3) G(4) G(5)] =

[Ag(3) Ag(4) Ag(5) Ag(2) Ag(1)] = [15 35 45 20 10].

From Eq. (6.20) D(j)'s are found to be,

[D(1)D(2) D(3) D(4) D(5)] = [20 50 90 115 125]

From Eq. (40), the fixed cost FC is found to be,

FC = 183950 units.

fmin from iquadprog(...) function is found to be −183750. This is the minimum cost of QC+LC. Therefore the total minimum cost is, Cmin =FC+fmin = 200 units …….Minimum cost.

A. Assignment cost inclusion

Infrastructural arrangements and additional operational expenditures are needed to install and connect the required generators to the selected distribution buses. Let the cost of assigning generator Ag(i) to bus DB(j) be gc(i, j) in proper units. Given gc(i, j) for i = 1 to N and j=1 to N, we can add this cost to the inter bus power transfer cost to calculate the overall cost.

1) Calculation of assignment cost: Let the assignment permutation matrix be PM. From Eq. (51) we see that, PM(i, j)=1 means Ag(i) is assigned to DB(j). Then the resulting cost is gc(i, j). Therefore the assignment cost gc(i, j) accrues only when PM(i, j)=1. If PM(i, j)=0, there will be no assignment of Ag(i) to DB(j) and hence no cost. Therefore the cost of assignment of Ag(i) to DB(j) can be represented as,

Cost(Ag(i) to DB(j) = gc(i, j)*PM(i, j) (21)

Simplifying,

Ctot= FC + 0.5*XT*W*X + (Va)T*X (22)

So, the assignment cost is absorbed in Va. The quadratic assignment problem is now solved with Va as the linear cost coefficient vector instead of V.

Example 2: Except Cost matrix GC, all other parameters are same as given in Example 1. GC is given below.

$$GC = 1000 * \begin{bmatrix} 25 & 24 & 27 & 19 & 20 \\ 25 & 10 & 24 & 19 & 19 \\ 18 & 15 & 16 & 26 & 23 \\ 23 & 40 & 29 & 26 & 24 \\ 13 & 12 & 10 & 13 & 25 \end{bmatrix}$$

Here, the optimum assignment permutation is found to be,

π(opt) = [4 2 3 5 1] …….The assignment of the generators at the buses

B. Optimization with less number of generators

Consider the case when the number of distributed generators available M is less than N, where N is the number of distribution buses. In this case we cannot cover all the buses with generators. A few buses have to manage without a generator connection. In this case we place the first M elements of AG with the M available generators and the remaining elements of AG are filled with zeros as,

AG = [Ag(1) Ag(2) ... Ag(M) 0 0 ... 0] (23).

Simplifying it is found that When Ag(1)+Ag(2)+...+Ag(M) > S(1)+S(2)+...+S(M), the available generators are under loaded .

Example 3. Same as Example 1 except the number of available generators are only 3, as AG=[35, 40, 50, 0, 0].

The optimum permutation is found to be,

π(opt) = [4 3 2 1 5] and G =[0, 50, 40, 35, 0]. Here DB(1) and DB(5) have no generators. DB(2) is fed by Ag(3), DB(3) is fed by Ag(2) and DB(4) is fed by Ag(1).

C. Optimization with more number of generators

Consider the case when the number of distributed generators available M is greater than N, where N is the number of distribution buses. In this case (M−N) generators are not assigned to any bus. In this case AG is taken as,

$$AG = [Ag(1)\ \ Ag(2) \ldots Ag(N)\ \ Ag(N+1) \ldots Ag(M)] \quad (24).$$

Simplifying we get vec(PM) by X we get,

$$([ones(1, N)] \otimes (AG)^T)*X \geq D(N) \quad (25)$$

Results on different practical test systems:

Test System-I (8 Bus System)

There is one incoming line at 66 KV from Davanagere followed by installation of two transformers of 12.5 and 8 MVA respectively. There are seven loads and a capacitor bank which is connected as shunt to the loads. Table 1 and 2 shown are load flow details and capacitor loading details conducted at site respectively.

Table 1 Load Flow Details of 66/11 KV Sub Station 8 BusSystem

Bus Nos.	Description	Load in MW	MVAR	Load in Amps
1	66 KV Incoming from Davanagere	10.6	4.95	106
2	Hiremegalgere	2.0	0.46	120
3	Kanchikere	2.5	0.575	150
4	Kyarekatte	3.10	0.713	186
5	Laxmipura	0.80	0.18	48
6	Punabgatta	2.5	0.575	150
7	Hosakote	2.8	0.644	168
8	Arasikere	1.6	0.368	96

Table 2: Analysis at 66/11KV Substation 8 Bus System (Conductedat Site)

Inter Links are connected between Bus (1 and 3) and Bus (2 and 5)

Description	Before connecting the Inter Links	After Connecting the Inter Links	Compe nsation
Inter Links connected at 110% Full Load	350 amps	280 amps	61.76 amps
	5.86MW	4.60 MW	1.27 MW
Inter Links connected at 125% Full Loadz	190 amps	170 amps	19.16 amps
	3.16 MW	2.30 MW	0.90 MW
Total compensation after adding inter Links was 0.96 MVAR			

The total reactive power compensation at all the receiving stations are evaluated at a load power factor of 0.85 lagging.

Test System-II .. 11 Bus System

There are three incoming lines at 66KV from Davanagere receiving stations and Independent wind turbine generators followed by installation of two transformers of 12.5 and 6.3 MVA respectively. There are eight loads and two capacitor banks which are connected as shunt to the loads. Table 3 and 4 shown are load flow details and capacitor loading details conducted at site respectively.

Table 3: Load Flow Details of 66/11 KV Substation 11 Bus System

Designated Bus Nos.	Description	Load in MW	MVAR	Load in Amps
1	66 KV Incoming from Davanagere	10.3	4.970	103
2	Wind 1 (IPP)	8.0	3.66	80
3	Wind 2 (IPP)	6.0	2.77	60
4	Kadur	1.7	0.34	102
5	Hirekandwadi	3.5	0.50	210
6	BevinaDurga	3.0	0.40	180
7	Kothehal	1.2	0.30	72
8	Chickjajur	6.1	1.8	366
9	Chikkandwadi	4.0	0.9	240
10	Gangiganur	0.6	0.1	36
11	Water house	0.1	0.001	06

Table 4: Analysis at 66/11KV Substation 11 Bus System (Conducted at Site)

Inter Links are connected between Bus (7 and 8) and Bus (3 and 5)

Description	Before connecting the Inter Links	After Connecting the Inter Links	Compensation
Inter Links connected at 110% Full Load	102+218=320 Amps 5.34MW	Reduced to 279 Amps 4.11 MW	1.26MW
Inter Links connected at 125% Full Load	202+38=240 Amps 4.0MW	2.9 MW	1.11MW
Total compensationafter adding inter Links was			1.10 MVAR

Test System-III ..15 Bus System

There are five incoming lines at 220 KV, in that three from Guttur (400 KV receiving station) and two from Shimoga (220 KV Mahatma Ghandi receiving station) followed by installation of three winding transformers of two 100 and 60 MVA respectively. There are ten loads at 66 KV and two capacitor banks which are connected as shunt to the loads. Table 5 and 6 shown are load flow details and capacitor loading details conducted at site respectively.

Table 5: Load Flow Details of 220/66/11 KV Receiving Substation 15 Bus System

Bus No.	Description	Load in MW	MVAR	Load in Amps
1	Incoming from 400KV Guttur-1	131	42.75	327.5
2	Incoming from 400KV Guttur-2	73	23.98	182.5
3	Incoming from 400KV Guttur-3	123	59.419	307.5
4	Incoming from Receiving Station Shimoga-1	131	42.75	327.5
5	Incoming from Receiving Station Shimoga-2	105.6	34.68	564
6	66KV Sokke Line	16.0	12.62	160
7	66KV Davanagere Line	11.0	6.0	110
8	66KV Avargere Line	13.5	7.0	135
9	66KV Chitrdurga Line	11.0	6.0	110
10	66KV Industrial Line	21.0	18.2	212
11	66KV Harihara Line	20.0	6.00	200
12	66KV Kukwada Line	4.0	4.10	130
13	66KV Yaragunta Line	11.0	6.0	110
14	66KV Shimoga Line	26.0	16.0	260
15	66KV Harappanahalli Line	10.5	2.60	105

Table 6: Analysis at 220/66/11KV ReceivingSubstation 15 Bus System (Conducted at Site)

Inter Links are connected between Bus (2 and 4) and Bus (6 and 8)

Description	Before connecting the Inter Links	After Connecting the Inter Links	Compensation
Inter Links connected at 110% Full Load	888.9amps	719.9amps	71.0 amps
Inter Links connected at 125% Full Load	88.89MW	70.11 MW	13.78MW
Total compensation after adding inter Links was 10.11 MVAR			

SUMMARY

It is seen that when experiments were conducted at the load sites of 8 Bus System, 11 Bus System and 15 Bus System receiving stations a total reactive power compensation of 0.96, 1.10 and 10.11 MVAR respectively was possible at a power factor of 0.85 lag after using the Inter Links.

CONCLUSIONS

From the analysis of the result it is clear that the objectives are met. Quadratic Programming is used to find the distributed generator capacities for optimal performance of a given radial distribution system. The solution minimizes the cost of total inter-bus power transfer. The contribution of this work is that Mitigation of voltage collapse is done by finding distributed generator capacities. So this method uses control on the generator side and not on the load side.But minimum reactive power required for the operation of the system is to be maintained. This concept is innovative in the process of mitigation of voltage collapse.Quadratic assignment problem is converted into an equivalent binary integer quadratic programming problem and then solved to assign available generators to the appropriate distribution buses. The assignment of available generators where the number of generators is less and where it is more are solved. The contribution of this work is that Mitigation of voltage collapse is done by assigning available generators to the appropriate distribution buses and not by using FACTS devices. But minimum reactive power required for the operation of the system is to be maintained. This concept is innovative in the process of mitigation of voltage collapse. The implementation of the algorithm can also be done by a MATLAB program.

REFERENCES

[1]. F. A. Shaikh, RamanshuJain ,MukeshKotnala, NickeyAgarwal New Techniques for the Prevention of Power System Collapse , International Journal of Electrical and Electronics Engineering (IJEEE) ISSN (PRINT): Vol-1, Iss-3, 2012, Page No. 2231 – 5284.
[2]. Claudia Reis, F.P. Maciel Barbosa, A Comparison of Voltage Stability Indices , IEEE MELECON 2006, May 16-19, Benalmádena (Málaga), Spain, Page No. 1007-1010.
[3]. Moghavvemi M., and Faraque M., 1999. Power system security and voltage collapse: a line outage based indicator for prediction , INT J ELEC POWER. Page No. 455-461.
[4]. Vectorization (mathematics) – Wikipedia, the free encyclopedia en.wikipedia.org / wiki / Vectorization_(mathematics).
[5]. Huamin Zhang and Feng Ding, On the Kronecker Products and Their Applications, Hindawi Journal of Applied Mathematics. Volume 2013 (2013), Article ID 296185, 8 Pages.
[6]. A Quadratic Programming Page. www.numerical.rl.ac.uk/people/nimg/qp/qp.html.
[7]. IBM CPLEX Optimizer – United States.www.ibm.com / software / commerce / optimization / cplex-optimizer/.
[8]. TOMLAB Optimization for MATLAB® | TOMLAB Optimization tomopt.com / tomlab/.
[9]. MINQ: Quadratic Programming www.mat.univie.ac.at/~neum/software/minq/.
[10]. The KNITRO solver – Ziena Optimization LLC | Knitro (R) for www.ziena.com / knitro.html.
[11]. TORSCHE Scheduling toolbox for Matlab – Faculty of www.fel.cvut.cz / en / en / vv / tymy / torsche.html.
[12]. Reshape array - MATLAB reshape - MathWorks India www.mathworks.in/ help/ matlab/ ref/ reshape.html.
[13]. A thesis by Daniel Axehill,Division of Automatic Control Department of Electrical Engineering Linköpingsuniversitet, SE-

581 83 Linköping, Sweden.

[14]. Steven J.(Steven Joseph) ,Application of a reduced quadratic programmingtechnique to optimal structure design, Fenves ,Carnegie Mellon University

[15]. R.Wiebking,,Selected applications of all-Quadratic programming , Springer Link.

[16]. JAE K. SHIM Department of Accountancy , School of Business Administration, California State University , Long Beach, California,A survey of quadratic programming applications to business and economics.

[17]. Mahmoud Moghavemi, A Line Outage study for Prediction of Static voltage collapse Published in IEEE Power Engineering Review August 1998, Page No. 52-54.

[18]. P. Petitclair, Y,Besanger, Bacha, N.Hadjsaid, FACTS Modelling and Control; Application to the Insertion of a STATCOM on Power Systems IEEE Industry Applications Society Annual Meeting, Lousiana, October 5-6, 1997, Page No. 2213-2217.

[19]. KarimBelmokhtar; Hussein Ibrahim, A new reactive power management strategy to enhance the behaviour of the Wind Turbine Generator driven a DFIG under grid faults ,Electrical Power and Energy Conference (EPEC), 2015 IEEE ,Pages:16 - 21, DOI:10.1109/EPEC.2015.7379920,Referenced in:IEEE Conference Publications.

[20]. ZettyAdibah Kamaruzzaman1,*, Dynamic voltage stability of a distribution system with high penetration of grid-connected photovoltaic type solar generators, 2 PE Department of Electrical, Electronic, and Systems Engineering Faculty of Engineering and Built Environment UniversitiKebangsaan Malaysia, Malaysia,Copyright © JES 2016 on-line journal/esrgroups.org/jes

BIOGRAPHIES

Dr V Chayapathy is presently working as Associate Professor in Dept of EEE, RV College of Engineering, Bangalore. His research interests includes renewable energy sources, power systems and smart grids. He has 34 years of teaching experience imparting knowledge transfer to students and corporates.

Dr G S Anitha, is presently working as Associate Professor in Dept of EEE,RV College of Engineering, Bangalore. Her research interests includes renewable energy sources, power systems and smart grids. She has 33 years of teaching experience imparting knowledge transfer to students and academicians.