

Enhancement of Voltage Stability in Power System Using Voltage Stability Constraint – Optimal Power Flow and Particle Swarm Optimization Algorithm

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Abstract - In power systems the voltage stability improvement is a worthwhile issue. The customers of power utilization have been increased day by day. Because of this the electrical equipment used in the generation, transmission and distribution are highly modified but all in this three factors the voltage stability is the important factor. Here this research developed a Voltage Stability Constraint – Optimal Power Flow (VSC-OPF) algorithm to improve the voltage stability and reduction in losses of system and another case done here is using PSO (Particle Swarm Optimization Algorithm) to find out the best voltage stability improvement. The standard IEEE 30 bus system has been used to evaluate the projected method. The simulation results demonstrates the effectiveness of the proposed VSC-OPF based on the line voltage stability index and the best voltage stability improvement by the means of PSO algorithm. The results are verified through coding using MATLAB SOFTWARE.

Index Terms - VSC-OPF (Voltage Stability Constraint – Optimal Power Flow Algorithm), voltage stability, VCPI (Voltage Collapse Proximity Indicator), PSO (Particle Swarm Optimization Algorithm)

I. INTRODUCTION

In power system there are number of factors are important for the power transmitting, the factors are the voltage, current, power factor, generating unit, transmitting capacitance, inductance, resistance, etc.,. Here this research is for the voltage stability in bus system is considered and the results are done to improve the voltage stability. Here the important factor used is the VCPI indicator. This indicator indicates the value between 0 and 1.0. 0- indicates the no load condition and 1.0 – indicates the voltage collapse condition. In literature survey many paper are consider as the reference. To maximise the voltage stability in deregulated system an optimal dispatch with VSC using the bifurcation technique was applied [3], and for reduction of the market cost for the reactive power, the system energy losses, and simultaneously increasing the voltage stability by decreasing the largest LSI (Lmn) of the network is referred[4], the FVSI and LQP are used as objective functions in the optimal location of the FACTS devices for reducing the system losses and the voltage stability raising [5], Voltage Collapse Proximity Indicator has more accuracy and robustness in predicting voltage collapse [6],when we comparing it with Voltage Collapse Proximity Indicator index it has some advantages namely its simple , fast to calculate , flexible for simulating any type of topological and load modifications in system and its application for real time simulation [7], L-index is used as objective function for voltage stability enhancement in both normal [8-11] and contingency conditions [12,13], the reactive power dispatch (ORPD) problem using ant colony optimization (ACO) algorithm [14] is also taken as reference for below voltage stability improvement process. The Voltage Collapse Proximity Indicator has great accurateness and robustness in identifying voltage collapse [15]. Also the VCPI index is simple, flexible for simulating any type of topological and load changing in network and real time simulation. This paper focused on calculating the base case load of each load bus and VCPI value of all load bus. If the load is increased in particular load bus beyond the maximum limit the voltage collapse occurred in the system. The VCPI indicator has two limit values such as (no load condition) and 1 (over load condition).This research consists of the following content the paper is organised with the following contents. The description of VCPI and formula for calculating the VCPI values are given in Section 2. The load flow analysis is explained in Section 3. The problem formulation with various constraints is shown in section 4. The conclusion and future progress in section 7.

II. BASIC FORMULA USED

Basic formulas used in this research work are given below it consist of the formula for calculating the VCPI value, $P_{r_{max}}$ value and $Q_{r_{max}}$ values. This formulas are explained with the help of the below shown single line diagram.

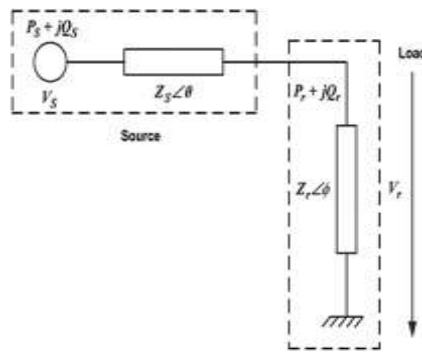


Fig. 1 Transmission Line Model

$$VCPI (power) = \frac{Pr}{Pr(max)} = \frac{Qr}{Qr(max)} \quad (1)$$

Formula for calculating Pr_{max} and Qr_{max} are shown below

$$Pr(max) = V_s^2 * \cos\Phi / Z_s * 4\cos^2((\theta - \Phi)/2) \quad (2)$$

$$Qr(max) = V_s^2 * \sin\Phi / Z_s * 4\cos^2((\theta - \Phi)/2) \quad (3)$$

Pr_{max} – Maximum Value of Active Power, Qr_{max} – Maximum value of Reactive power, V_s – is the sending end voltage, Z_s – impedance of the line, θ – Angle of line Impedance, $\Phi = \tan^{-1} \frac{Qr}{Pr}$, Φ – Load impedance phase angle.

III. TEST CASE BUS SYSTEM

The IEEE-30 bus system represented in the Fig is used to verify and investigate the effectiveness and performance of proposed approach. The IEEE 30-bus system includes six generators at buses 1, 2, 5, 8, 11 and 13, four transformers at lines 6-9, 6-10, 4-12 and 28-27, 21 loads and 41 transmission lines. The figure shows the single line diagram of IEEE-30 bus system.

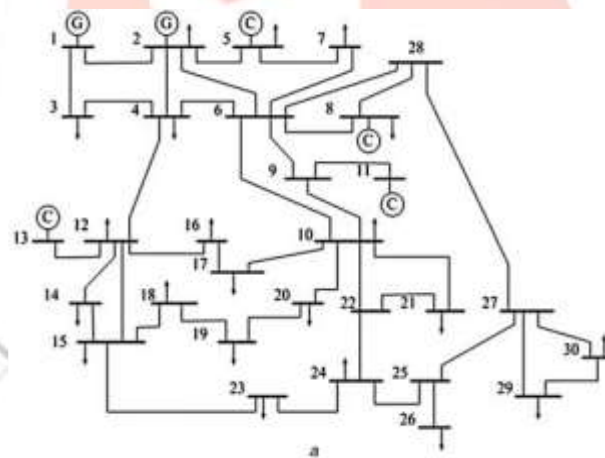


Fig.2 IEEE Standard Bus System

IV. PROBLEM FORMULATION AND OBJECTIVE FUNCTIONS

The objective function subject to several inequality and equality constraints.

$$\text{Minf}(x,u) \quad (4)$$

Subject to

$$g(x,u) = 0 \quad (5)$$

$$h(x,u) \leq 0 \quad (6)$$

The above used functions are defined as follows f- the main function to be reduced , x- vector of state variable, u- vector of control variable, g- equality constraint, h- system operating constraint.

Objective Function

a. Fuel Cost (FC)

The important intend is to reduce the fuel cost. The quadratic functions are used to model the generator cost curve can be expressed as

$$FC = \sum_{i=1}^{Ng} (a_i + b_i P_{Gi} + c_i P_{Gi}^2) \$/h \quad (7)$$

FC – Total fuel cost , Ng – Number of generator buses, P_{Gi} –Active power output of the ith generator and a_i, b_i, and c_i –Fuel cost of ith generator.

b. Voltage Stability Improvement

The acceptable voltage stability level should be maintained under normal, stressed and contingency operating conditions is important in power system operation. For this condition the (VCPIT) is projected as the objective function to maximise the system total stability.

VCPIT is the addition of systems voltage stability indices of all lines it is determined by the expression,

$$VCPIT = \sum_{i=1}^{Nl} VCPi \quad (8)$$

VCPi – VCPI for line i, Ni – number for transmission lines in the system.

c. Conventional Constraints

There are two categories of constraints are consider in the OPF problem, they are defined between the equation (9-13),

i. Equality constraints

$$P_{Gi} - P_{Di} = V_i \sum_{j=1}^N V_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) \quad (9)$$

$$i=1, \dots, N$$

$$Q_{Gi} - Q_{Di} = V_i \sum_{j=1}^N V_j (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij}) \quad \text{Eq... (10)}$$

$$i=1, \dots, N$$

ii. Inequality constraint (consist of system operating and the security limits)

$$P_{Gi}(\min) \leq P_{Gi} \leq P_{Gi}(\max), i=1, \dots, Ng \quad \text{Eq.....(11)}$$

$$Q_{Gi}(\min) \leq Q_{Gi} \leq Q_{Gi}(\max), i=1, \dots, Ng \quad \text{Eq.....(12)}$$

$$V_i(\min) \leq V_i \leq V_i(\max), i=1, \dots, Ng \quad \text{Eq.....(13)}$$

N-number of total buses in system, P_{Gi} –True power & Q_{Gi} – Reactive power generation both of bus i, P_{Di} –True power & Q_{Di} – Reactive power demand both of bus i, G_{ij} – Transfer conductance & B_{ij} – Susceptance both are between bus i and j, the phase angle difference between the voltage at i and j is - θ_{ij}

d. Voltage Stability Constraint

The system is to be kept clear to voltage collapse condition and to reduce the highest L-index value are the main aim of new voltage stability constraint.

The voltage stability limit in addition is formed as

$$VCPImax \leq VCPilimit \quad \text{Eq... (14)}$$

VCPilimit - the system security level can be ensured by the desired threshold value VCPImax determines the index maximum value and it is given by

$$VCPImax = \max (VCPi), i=1 \dots N1 \quad \text{Eq... (15)}$$

N1 – number of total lines in the system

V. VOLTAGE STABILITY CONSTRAINT – OPTIMAL POWER FLOW , PARTICLE SWARM OPTIMIZATION EXECUTION AND FLOW CHART

a. Voltage Stability Constraint – Optimal Power Flow

The fmincon toolbox of MATLAB software is used to solve Voltage Stability Constraint – Optimal Power Flow approach.[17]

The below flow chart shows the VSC-OPF algorithm

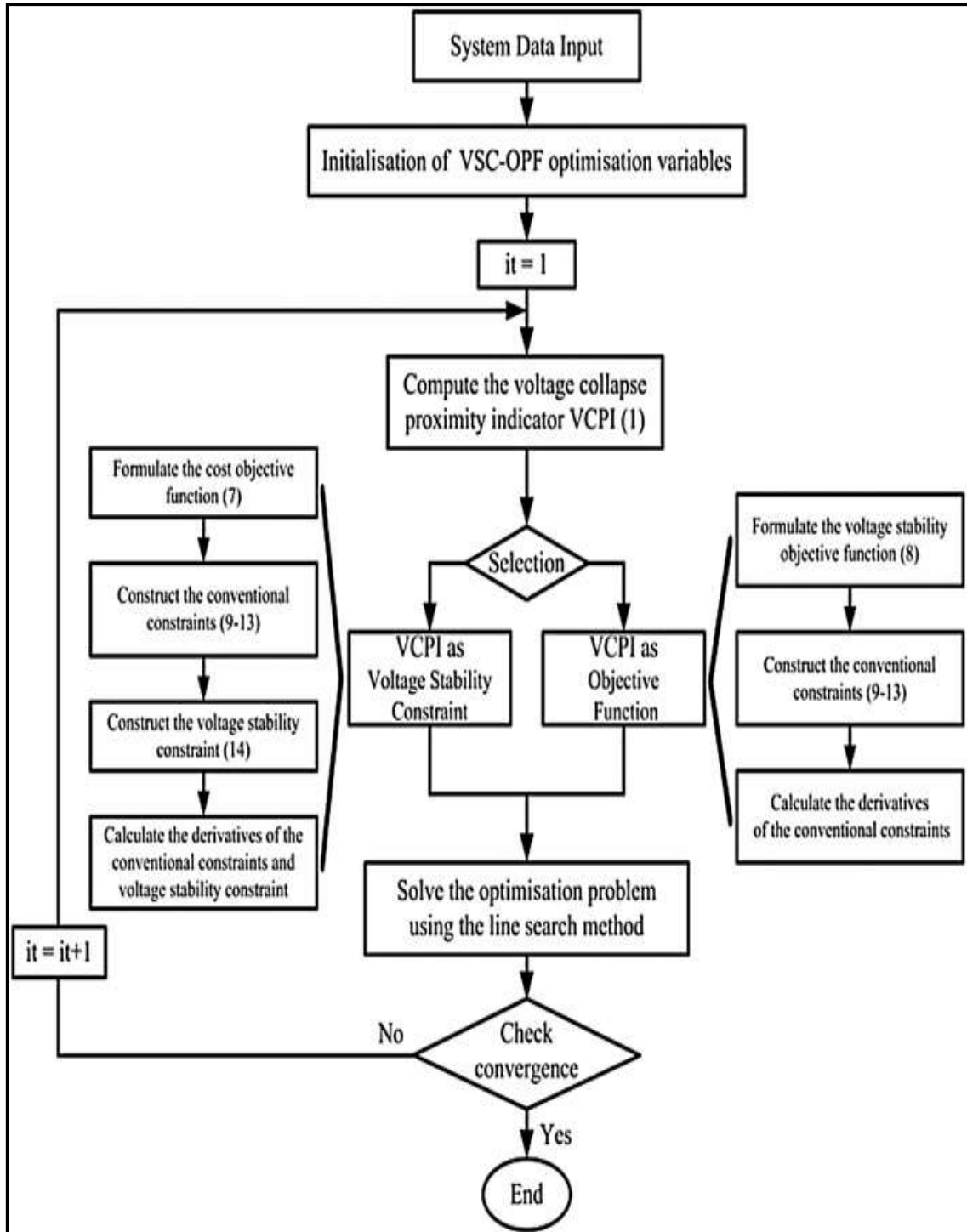


Fig.3 Flow chart of VSC-OPF Algorithm

Steps involved in solving VSC-OPF algorithm are explained below

- I. Analysis the given system data
- II. Initialise the VSC-OPF approach that consist of reducing (7) subjected to power flow (9) ,(10) and technical limit(11)-(13)

III. Find VCPI values of all lines by the equation (1). And identify the line with the maximized VCPI index value.

IV. If the aim of the optimisation analysis is to limit the value of the VCPI index between the limit of 0 to VCPIlimit to attain a essential voltage stability limit and to learn the cause of the security voltage on generation cost, then the approach with the VCPI as the voltage constraint is completed as follows

- Formulate the cost objective function(7)
- Construct the conventional constraint given by (9)-(13)
- Construct the voltage stability constraint given by(14)
- Calculate the first and the second derivatives of conventional constraint
- Calculate the first and the second derivatives of the voltage stability constraint
- Solve the optimisation algorithm by the line search method.

V. Main objective is to raise the overall voltage stability and the reduction of the system losses, then the VCPI is used as an objective function. OPF is derived as shown below

- Formulate the voltage stability objective function (8) Calculate the conventional constraint given by (9) – (13)
- Calculate the derivative of the conventional constraints.
- Solve the optimisation problem by the line search method

VI. The execution of the algorithm stops when the voltage stability condition has been achieved when the objective function and the control variable converge, if not repeated from step 3.

b. Particle Swarm Optimization

Particle swarm optimization (PSO) is a population based stochastic optimization technique. PSO imparts numerous similitudes to transformative computational procedures, for example, Genetic Algorithm (GA). The framework is instated with a populace of arbitrary arrangements and scans for ideal by refreshing ages. Notwithstanding, dissimilar to GA, PSO has no development administrators, for example, hybrid and transformation. In PSO, the potential solution called particles, fly through the problem space by following the current optimum particles. The detailed information will be given in following sections. The below figure shows the basic flow of the Particle swarm optimization (PSO) algorithm.

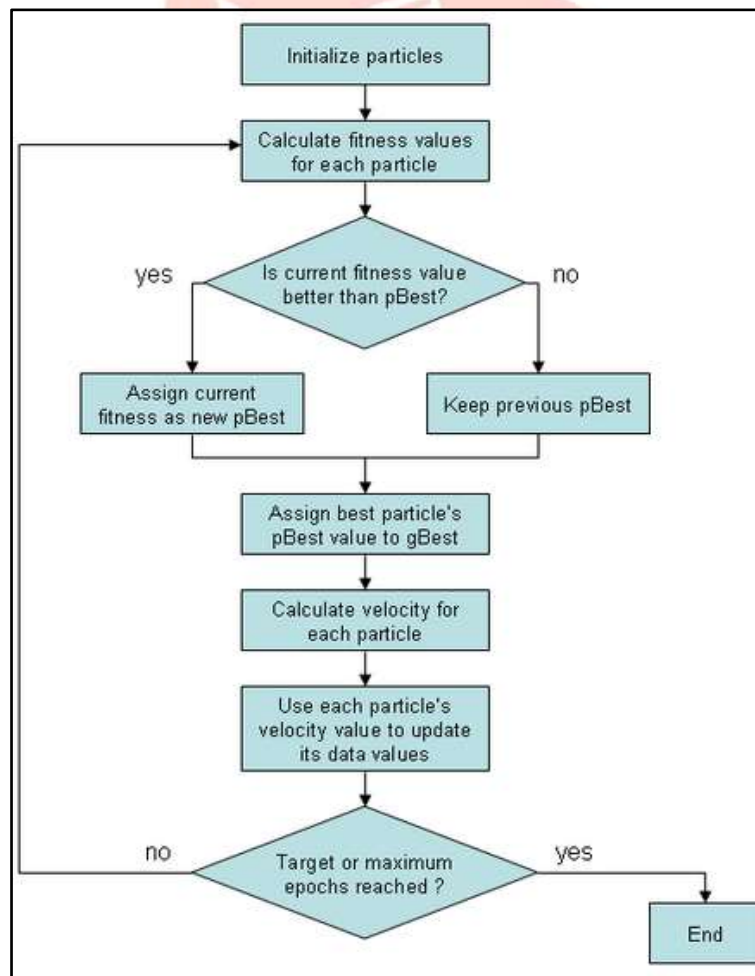


Fig.4 Flow chart for PSO Algorithm

In this paper work the input of PSO algorithm is given from the (VSC-OPF) approach and the process goes on and the best voltage improved case is taken as the output. By using the Particle Swarm Optimization Algorithm, the best out by giving the input from the proximity indicator is obtained.

VI. OUTPUT AND DISCUSSION

To obtain the result the test bus system used in the proposed paper is IEEE-30 bus system. The IEEE-30 bus system consist of the following elements, Six generators at buses 1,2,5,8,11 and 13, four transformers at lines 6-9, 6-10, 4-12 and 28-27, 41 transmission lines and 21 loads.

a) VCPI value for all the 41 transmission lines

By using the formula given in equation (1) – (3) the values of VCPI for 41 transmission lines are calculated. The table shows the output VCPI of all the transmission lines

Table 1 VCPI Value with Normal Load Flow

S.No	Transmission Line	VCPI(P _r)
1	1	0.2285
2	2	0.3573
3	3	0.2099
4	4	0.0814
5	5	0.3949
6	6	0.2750
7	7	0.0651
8	8	0.0330
9	9	0.0823
10	10	0.0296
11	11	0.0605
12	12	0.1242
13	13	0.0000
14	14	0.0712
15	15	0.1519
16	16	0.0560
17	17	0.0695
18	18	1.1554
19	19	0.0573
20	20	0.0175
21	21	0.0275
22	22	0.0495
23	23	0.0144
24	24	0.0176
25	25	0.0679
26	26	0.0209
27	27	0.0608
28	28	0.0363
29	29	0.0006
30	30	0.0395
31	31	0.0484
32	32	0.0232
33	33	0.0082
34	34	0.0721
35	35	0.0338
37	37	0.0961
38	38	0.1564
39	39	0.0609
40	40	0.0044
41	41	0.0255

b. IEEE 30 Bus System Voltage Stability Improvement

Case Study

- **Case 1:** Cost function.

In this case, the minimisation of the fuel cost of generation is considered as an objective function. The generator cost coefficients for the IEEE 30-bus system are defined in result and discussion table.

- **Case 2:** Cost function with the voltage stability constraint

In this case, the VCPI is included as the voltage stability constraint in the OPF model. This will allow limiting the VCPI index of the most critical line in the system and then increasing the voltage stability margin of the system. Consequently, the optimal solution can satisfy the economic and the system security requirements simultaneously.

- **Case 3:** Total Sum of the VSI

From the system security point of view, an objective function which incorporates an improvement of the system voltage stability is found to be more efficient. As the VCPI index value indicates the proximity of the system to the voltage collapse, the minimisation of the sum of the voltage stability indices (VCPIT) is selected as an objective function, such that the overall system voltage stability is improved. Thus, the lower the value of the VCPIT, the better the voltage stability.

Table 2 Voltage Stability Improvement

OBJECTIVE FUNCTION			
Cases	Case - 1	Case - 2	Case - 3
$Q_{gen}, MVAR$	113.94	104.02	105.10
P_{loss}, MW	11.742	2.324	2.860
$VCPI_{max}$	0.1564	0.1478	0.1428
$VCPI_T$	4.4993	4.3268	4.1962
$FC, \$/H$	8906.15\$/hr	5835.07\$/hr	576.89\$/hr

c. Result of PSO (Particle Swarm Optimization)

Here we obtain the best voltage stability improvement between the bus system the input is given form the VCPI indicator and cases are tested through the coding the results are that the best voltage stability improvement in bus system 8. The results are shown in the below table 3.

Table 3 Best Voltage Stability Improvement in Bus System

OBJECTIVE FUNCTION	
$Q_{gen}, MVAR$	105.08
P_{loss}, MW	0.109
$VCPI_{max}$	0.4365
$FC, \$/H$	79.43 \$/hr

GRAPHICAL OUTPUT

IEEE 30 BUS SYSTEM VOLTAGE STABILITY IMPROVEMENT

6.5.1 Cost Function

In this case, the minimisation of the fuel cost of generation is considered as an objective function. The generation cost coefficients and real power loss and VCPI values such as $VCPI_{total}$ and $VCPI_{max}$ for the IEEE 30-bus system are defined in the table 6.5 of voltage stability improvement.

6.5.2 Cost function with the voltage stability constraint

In this case, the VCPI is included as the voltage stability constraint in the OPF model. The generation cost coefficients and real power loss and VCPI values such as $VCPI_{total}$ and $VCPI_{max}$ for the IEEE 30-bus system are defined in the table 6.5 of voltage stability improvement.

6.5.3 Total Sum of the VSI

From the system security point of view, an objective function which incorporates an improvement of the system voltage stability is found to be more efficient. The generation cost coefficients and real power loss and VCPI values such as $VCPI_{total}$ and $VCPI_{max}$ for the IEEE 30-bus system are defined in the table 6.5 of voltage stability improvement.

The graphical comparisons of the various values such as $Q_{gen}(MVAR)$, $P_{loss,MW}$, $VCPI_{max}$, $VCPI_{total}$ are shown in below graphs these values are taken from the various there cases which are explained above

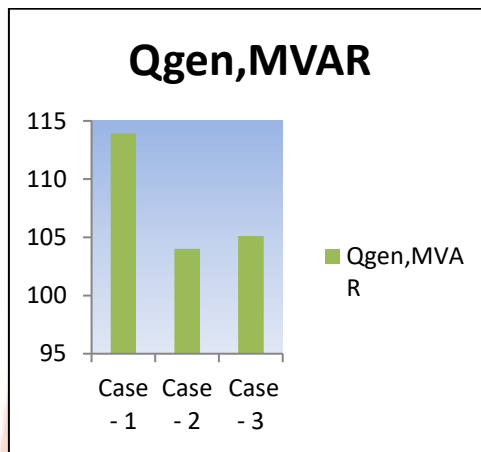


Fig.5 Graph for Output Comparison of $Q_{gen}(MVAR)$

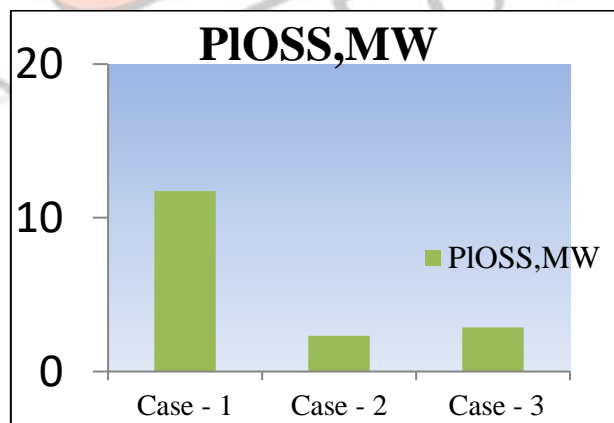


Fig.6 Graph for Output comparison of $P_{loss,MW}$

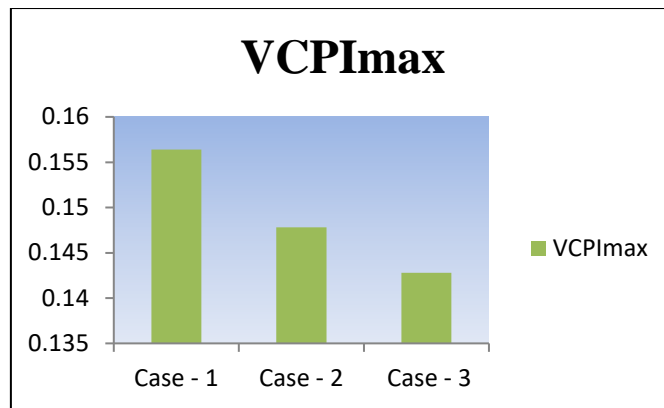
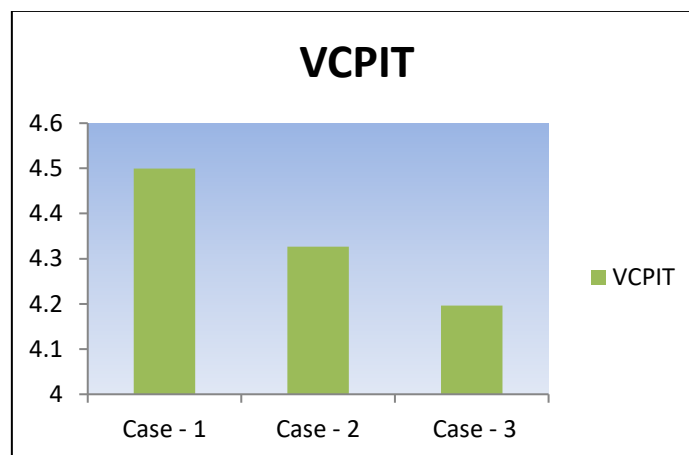
Fig.7 Graph for Output Comparison of VCPI_{max}

Fig.8 Graph for Output Comparison of VCPIT

VII. CONCLUSION AND FUTURE ENHANCEMENT

This study presents a novel Voltage Stability Constrained Optimal Power Flow (VSC-OPF) approach based on static line voltage stability indices to simultaneously improve voltage stability and minimize power system losses under stressed and contingency conditions. The proposed methodology uses a Voltage Collapse Proximity Indicator (VCPI) to provide important information about the proximity of the system to voltage instability. It can be concluded that VSC-OPF is the better solution in terms of improving voltage stability and Voltage Collapse Proximity Indicator (VCPI) indicates the voltage collapse condition when the load is increased in IEEE 30 bus system. The three case studies are done using VSC-OPF algorithm and also the best voltage stability improved bus is find by using PSO algorithm. In future all the case studies and voltage stability improvement is tested using the Genetic algorithm and also the same case is tested for IEEE – 57 bus system.

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