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Stability Enhancement using Voltage Stability Constrained Optimal Power Flow

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***Abstract*—Voltage stability is one among the issues in planning of modern power systems because they are operated under heavily loaded condition with minimum stability margins. So, inclusion of voltage stability criteria in the operation of power systems began taking great attention. This study presents a novel voltage stability constrained optimal power flow (VSC-OPF) based on static line voltage stability indices to simultaneously increase voltage stability and minimise power system losses under stressed and contingency conditions. The proposed methodology uses a voltage collapse proximity indicator (VCPI) to provide significant information about the proximity of the system to voltage instability. The VCPI index is incorporated into the optimal power flow (OPF) formulation in two ways; first it can be added as a voltage stability constraint in the OPF, or used as a voltage stability objective function. The proposed approach has been evaluated on the standard IEEE 30-bus under different cases. The proposed voltage stability constrained OPF is implemented with MATLAB and the results are obtained.**

I. INTRODUCTION

The planning and the operation of large interconnected power systems with concern for system stability have become main concerns in the daily operation of modern power networks. Voltage stability step up is a not an easy issue in planning the power systems. In recent years, several blackouts related to voltage stability problems have arise in many countries. The study of voltage stability should be taken into account in power systems have to operate closer to their limits. As modern systems are being operated under heavily stressed conditions with reduced stability margins, inclusion of voltage stability criteria in the operation of power systems have received greater attention. This study presents a voltage stability constrained optimal power flow (VSC-OPF) approach based on static line voltage stability indices to improve voltage stability and minimise power system losses under stressed and contingency conditions. Voltage stability is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal conditions and after being subjected to a disturbance. Voltage stability states that the ability of a power system to maintain steady acceptable voltage at all buses in the system under normal conditions and after being focus to a disturbance. Voltage stability depends on the ability to maintain or restore stability between load demand and load supply from the power system. V*oltage collapse* refers to the process by which the progression of events accompanying voltage instability leads to a blackout or abnormally low voltages in a significant part of the power system. Many factors contribute to the process of system collapse because of voltage instability strength of transmission system, power-transfer levels, load characteristics, generator reactive power capability limits and individuality of reactive power compensating devices. In (4)focused on the performance of different line voltage stability indices such as LMN index, fast voltage stability index, voltage collapse index, voltage collapse index, LQP index as well as traditional Jacobian index are discussed and it has been seen that voltage collapse index gives the best result.(4)describes of different line voltage stability indices such as LMN index, fast voltage stability index, voltage collapse index, voltage collapse index, LQP index as well as traditional Jacobian index and obtained than voltage collapse index gives the better result among the indices. The voltage stability index is calculated numerically with multi node system (7) but assumptions are made at generating node and current nodes. The paper proposes (2) voltage collapse in power system determined by using voltage magnitude and voltage angle at bus. When loading of power system is increased Voltage collapse takes place which can be determined by the concept of maximum power transfer between the two neighboring lines. In when loading of power system is increased Voltage collapse takes place which can be determined by the concept of maximum power transfer between the two neighboring lines (5). The voltage collapse proximity indicator (VCPI) is calculated by using two elements $VCPI_{power}$ and $VCPI_{loss}$ which gives the high degree of accuracy and reliability when both of the two indicator are equal to 1 then collapse is reached as discussed in (9).In (1) a voltage stability index and identify areas of the system most prone to voltage collapse using powerflow solution from base load to the voltage stability limit is proposed. In (12) an algorithm for monitoring and improving stability of the system under contingency condition using normal load flow range from 0 to 1 with optimal setting of control devices like VAR compensator and on-load tap changing (OLTC) transformer is presented. The paper (1) deals with the possible use of multi object methodologies in order to improve the modeling of power system during the scheduling and the working stage. The possible use of several objective functions leads to better optimization and move the operating points so as to obtain an improved system. The stability of this in a power system network is studied on (13). In (8) the active power transmit problem is associated with guaranteeing adequate voltage stability levels in power systems is formulated. It provides the optimal

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solution which achieves both minimized generation cost and improved voltage stability level. In (14),(15) method to evaluate composite power system reliability indices incorporating the voltage stability margin criteria is presented. To compute an optimal power flow (OPF) computation algorithm, considering the steady state voltage stability margin. Voltage stability constrained optimal power flow (VSC-OPF) approach based on static line voltage stability indices to at the same time increase voltage stability and minimise power system losses under stressed and contingency conditions.

II. FORMULATION OF VOLTAGE COLLAPSE PROXIMITY INDICATOR

A power system is a network containing components such as generators, transmission lines, loads and voltage controllers. Voltage collapse proximity indicator (VCPI) can increase the accuracy and reliability on the standard IEEE test systems with different load nodes.

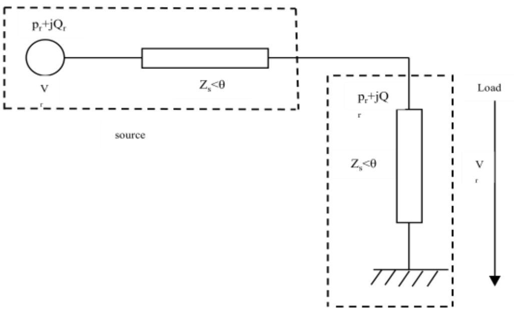

Fig.1. Single Transmission Line Model

This indicator is adopted in our study to investigate the stability of each line of the system by determination of the critical line referred to a bus. The VCPI index is based on the concept of maximum power transferred through the lines of the network shown in fig 1.The VCPI index is based on the concept of maximum power transferred through the lines voltage collapse proximity indicator is calculated using the formula given below

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

$$P_{r(max)} = \frac{Vs^2}{Zs}\ \frac{cos\emptyset}{4cos^2(\frac{\emptyset-\theta}{2})} \quad (2)$$

$$Q_{r(max)} = \frac{Vs^2}{Zs}\ \frac{sin\emptyset}{4cos^2(\frac{\emptyset-\theta}{2})} \quad (3)$$

III. PROBLEM FORMULATION

The main purpose of the OPF problem is to resolve the optimal control variables for minimising an objective function subject to some equality and inequality constraints. The problem is generally formulated as follows

$$min\ f(x, u)$$

subject to

$$g(x, u) = 0$$
$$h(x, u) \leq 0$$

where represent the f is the objective function to be minimized, g is the equality constraints, h is the system operating constraints. x is the vector of the state variables and u is the vector of the control variables. The control variables are generator active power outputs and bus voltages. The state variables are the voltages and the angles of the load buses. The objective functions, the conventional constraints and the voltage stability constraint.

IV. CONVENTIONAL CONSTRAINTS

A. *Equality Constraints*

Represent the non-linear power flow equations:

$$P_{Gi} - P_{Di} = vi\sum_{j=1}^{N} Vj(B_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) \quad (4)$$

$$Q_{Gi} - Q_{Di} = vi\sum_{j=1}^{N} Vj(B_{ij}\sin\theta_{ij} + B_{ij}\cos\theta_{ij}) \quad (5)$$

B. *Inequality Constraints*

Include the system operating and the security limits:

$$p_{gi}^{\ min} \leq p_{gi} \leq p_{gi}^{max} \quad (6)$$

$$Q_{gi}^{\ min} \leq Q_{gi} \leq Q_{gi}^{max} \quad (7)$$

$$Vi^{\ min} \leq V_i \leq V_i^{max} \quad (8)$$

where N is the total number of buses in the system; P_{Gi} andQ_{Gi} are the active and the reactive power generations at bus i; P_{Di} and Q_{Di} are the active and the reactive power loads of bus i; θ_{ij} is the phase angle difference between the voltages at buses i and j.

V. FUNCTIONS FOR THE SYSTEM

A. *Fuel Cost*

The objective function is to minimise the total fuel cost (FC) of the system. The generator cost are modelled by quadratic functions and can expressed as

$$FC = \sum_{i=1}^{Ng}(a_i + b_i P_{Gi} + c_i P_{Gi}^2) \quad (9)$$

where Ng is the number of generator buses ai, bi and ci are the fuel cost coefficients of the i_{th} generator and P_{Gi} is the real power output of the i_{th} generator.

B. *Voltage Stability improvement*

Maintaining the acceptable voltage stability level under standard, stressed and contingency operating conditions is an important concern in power system planning and operation. For this aim, the minimisation of the total VSI formed as an objective function to enhance the overall voltage stability of the system. The VCPI is the sum of the voltage stability indices for all the lines of the system and it is mathematically evaluated as

$$VCPI_T = \sum_{i=1}^{N_1} VCPI_i \quad (10)$$

where $VCPI_i$ is the VCPI for line i and N_1 is the number of transmission lines in the system.

C. *Voltage Stability Constraint*

Generally, the voltage magnitude limits for each bus are used as the voltage constraints. yet, the voltage limits alone are not sufficient to assurance to acceptable voltage stability level of the system under different operating conditions. In this work, a voltage stability constraint based on the VCPI is added to the classical OPF. The aim of this new voltage security constraint is to limit the maximum value of the line index and then move the system far away from the voltage collapse.

The additional voltage stability constraint is formulated as

$$VCPI_{max} \leq VCPI_{limit}$$

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where VCPIlimit is a desired threshold value to ensure a certain system security level and VCPImax is the maximum value of the VCPI index defined as

$$VCPI_{max} = \max VCPI_{i}$$

Where Nl is the total number of lines in the system

VI. IMPLEMENTATION OF THE VSC-OPF

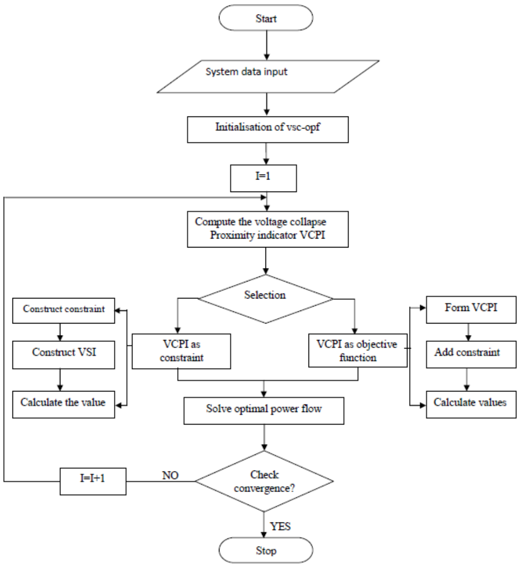

fig. 2 implementation of the vsc-opf

VII. RESULTS AND DISCUSSION

In this simulation study, the VCPI index is included in the optimisation problem in two ways. First, it can be added to the OPF constraints as the new voltage stability constraint. The VCPI index can be minimised by formulating the index as the objective function of the optimisation. The two approaches are applied for the voltage stability enhancement and the power losses minimisation in the stressed and the contingency conditions on the system. fig 3 represent voltage magnitude of the system with VCPI

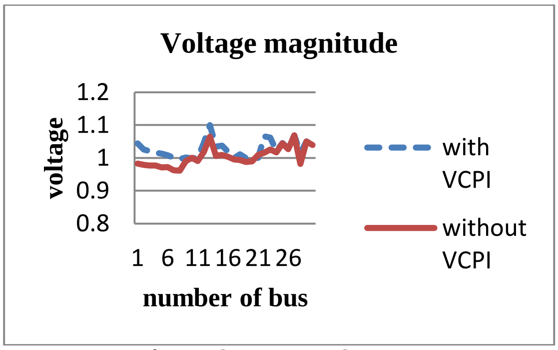

fig. 3 voltage magnitude curve

A. *VCPI with stressed conditions*

In Fig 4 is to analyse the system in stressed conditions, the active and the reactive loads of each bus are increased to 140% of the base load conditions. The VCPI index value is below indicating a system voltage safe operation point. However, the obtained voltage stability level is small and assumed not sufficient. On the VSC-OPF is carried out to shift the system for away from the voltage collapse and to obtain a new operation point with an adequate voltage stability margin.

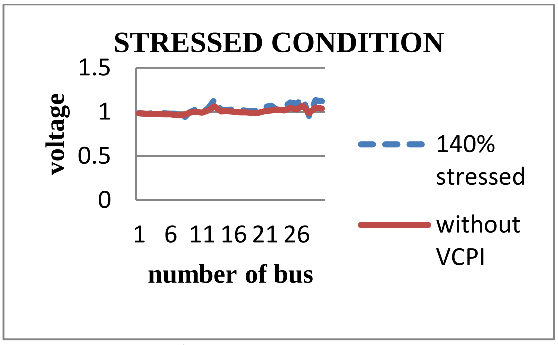

fig 4. stressed condition

B. *VCPI with contingency*

In fig 5 shows the line outage contingency generally causes undesirable operating conditions and has a significant effect on changing the system security that could lead to the voltage collapse. Therefore to maintain the system security against the voltage collapse, it is important to estimate the effect of the contingency conditions of the system.

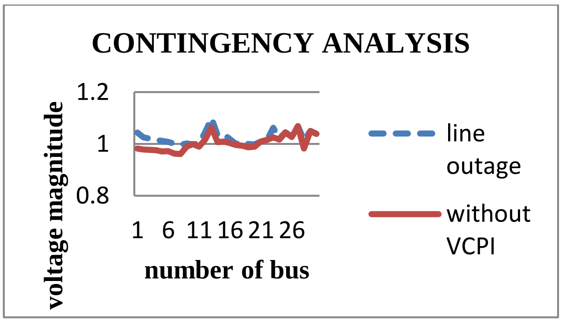

fig 5. contingency analysis

VIII. CONCLUSION

Voltage collapse proximity index (VCPI) was calculated using interior point algorithm under normal condition and incorporating as voltage constraint for the load bus The effectiveness and the robustness of the proposed VSC-OPF based on the VCPI index are tested and demonstrated on the IEEE 30-bus The simulation results obtained under the stressed and the line outage contingency conditions are clearly show the potential of the proposed approach to enhance the power system improving the system voltage stability.

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