INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

A PATH FOR HORIZING YOUR INNOVATIVE WORK

POWER SYSTEM TRANSIENTS AND SMALL SIGNAL STABILITY

Dr.S.M.ALI[1], NIGAMANANDA PANIGRAHY[2], *PUNYASHREE PATTANAYAK[3]

1. Professor of Electrical Engineering, KIIT University, Odisha, India.
2. Junior manager in Enzen Global Solution Solution, Bangalore, India.
3. 1st year M.TECH in Power and Energy System, KIIT University, Odisha, India.

Accepted Date:

21/10/2012

Publish Date:

01/11/2012

Keywords

Power system stability

Synchronism

Transients

Corresponding Author

Ms. Punyashree Pattanayak[3]

1st year M.TECH in Power and Energy System, KIIT University, Odisha, India

Abstract

Power system stability, is the ability of power system to reach a new steady state or equilibrium after a disturbance. Power system stability is a term applied to alternating –current electric power systems, denoting a condition in which the various synchronous machines of the system remain in synchronism, or “in step”, with each other. Conversely, instability denotes a condition involving a loss of synchronism, or falling “out of step”. Occurrence of a fault in a power system causes **transients.** To stabilize the system, load flow analysis is done. Generally the fault occurs in the load side. Power system transients are power-quality disturbance. Power system transients are caused by sudden changes in system topology or parameters. One of the problems associated with photovoltaic generation systems (PV) is the unstable output caused by the insulation fluctuation. This paper includes, the analysis of various types of transients, there causes of occurrence and the influencing factors. Then this describes the Small Signal Stability and there examples.

INTRODUCTION

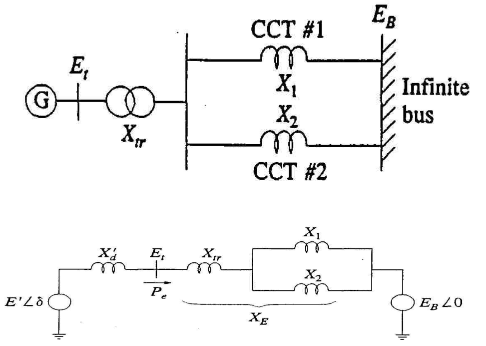
During recent years, with the ever-increasing demand of electric power, the power system has been growing more and more complicated. Particularly with the deepening of the power system marketing reform, transmission network is required to be open to power stations and consumers, which adds to the difficulty in operating a power system. Under such new circumstances, a power system could no longer be operated in a conservative way, so the significance of power system transient stability preventive control is projecting.

The term "transient" originates from electric circuit theory where it denotes the voltage and current component that occurs during the transition from one (typically sinusoidal) steady-state to another steady-state. Electric circuits are described by means of differential equations, whose solutions are the sum of a homogenous solution and a particular solution. The particular solution corresponds with the steady-state; the homogeneous solution corresponds with the transient. In electric circuit theory a transient is always associated with a change in steady state due to a switching action. In power systems the term transient is used in a slightly different way: it denotes those phenomena in voltage and current with a short duration. There is no clear limit, but phenomena with duration of less than one cycle (of the power-system frequency, 50 or 60 Hz) are generally referred to as *transients*.

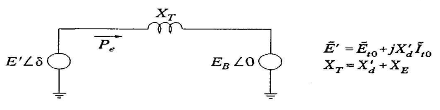
The interest in power system transients has traditionally been related to the correct operation of circuit breakers and to overvoltage due to switching of high-voltage lines. But more recently transients are viewed as a potential power-quality problem. This places new requirements on characterization and analysis of transient waveforms. Relations have to be established between waveform characteristics and equipment performance; methods have to be developed to extract information on the cause of transient waveforms; and methods are needed to quantify site and system performance. Power system transients are due to a range of causes, the main ones being lightning strokes to the wires in the power system or to ground and component switching either of network components or of end-user equipment. Generally the fault occurs in the load side.

Power system stability, is the ability of power system to reach a new steady state or equilibrium after a disturbance. Power system stability is a term applied to alternating –current electric power systems, denoting a condition in which the various synchronous machines of the system remain in synchronism, or "in step", with each other. Conversely, instability denotes a condition involving a loss of synchronism, or falling "out of step". Occurrence of a fault in a power system causes transients.

ELEMENTARY VIEW OF TRANSIENT STABILITY



(a) Equivalent circuit



(b) Reduced equivalent circuit

Figure A Elementary Representations

Generator's electrical output power is

$$P_e = \frac{E'E_B}{X_T}\sin\delta = P_{\max}\sin\delta$$

With the stator resistance neglected, P_e represents the air-gap power as well as terminal power

CLASSIFICATION OF TRANSIENTS

In terms of classification, power system phenomena can be divided into three classes.

- Events that can be classified by their fundamental frequency magnitude. These events contain parts where the voltage magnitude goes through significant changes for long periods. These changes are well apart in time so that magnitude estimators have no difficulties in resolving them. This class consists of the majority of fault-induced events, transformer saturation, induction motor starting, etc. Examples are voltage dips (with duration typically between 50 ms and several seconds) and interruptions (with duration from several seconds up to many hours).
- Events that present significant changes in the fundamental frequency magnitude but of short duration. The extraction of the voltage magnitude becomes problematic for these events. This class contains fuse-cleared faults and self-extinguishing faults.

- Events of very short duration (*transients*) for which the fundamental frequency magnitude does not offer important information. For this class, the higher frequency components of the signal must be considered for a thorough characterization and classification.

Power system transients, based on waveform shapes, can be classified into two categories :

1. oscillatory transients
2. impulsive transients

TABLE 1

Waveform based classification	Event-Based Classification
Impulsive Transients	Lightning
Oscillatory Transients	Capacitor Energizing Restrike during capacitor de-energizing Line or cable Energizing
Multiple Transients	Current Chopping Multiple Restrikes Repetitive Switching Actions

CATEGORIZATION OF TRANSIENTS BASED ON WAVEFORM SHAPES AND THEIR UNDERLYING CAUSES (OR EVENTS)

A. *Impulsive Transients*

An impulsive transient is a sudden change in the steady state condition of voltage, current or both, that is unidirectional in polarity (primarily either positive or negative) [9]. Impulsive transients are normally characterized by their rise and decay times. They are damped quickly by the resistive circuit elements and do not propagate far from their source. The most common *cause of impulsive transients* is lightning. When a lightning stroke hits a transmission line (direct stroke) an impulsive overvoltage is induced [10]. Lightning overvoltages can also be induced by nearby strokes to the ground or between clouds. These overvoltages are of lower magnitude than those produced by direct strokes. Fig. 1 shows an impulsive transient measured in a 132 kV network. As can be seen from the figure, modeling an impulsive transient as a sudden rise followed by an exponential decay does not hold in this case. This turns out to be true for many measured transients. In the above case, the voltage waveform shows a sudden rise followed by a sudden drop and an oscillation with a relatively small amplitude.

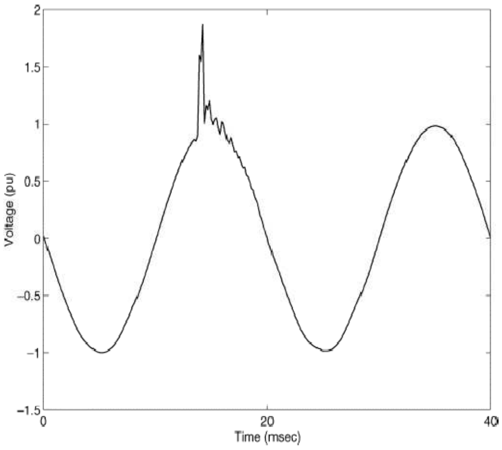


Figure 1 Voltage waveform of an impulsive transient

B. Oscillatory Transients

Oscillatory transients show a damped oscillation with a frequency ranging from a few hundred Hertz up to several megahertz. Mathematically, oscillatory transients are the homogeneous solution to linear differential equations. As the electric power system can, as a good approximation, be described by a set of linear differential equations, oscillatory The system of Fig. 2 is simulated in EMTP for energizing the 12.5 kV capacitor bank when a fixed capacitor bank is connected to the 480 V bus. The line is modeled using lumped elements, therefore the influence of travelling waves is neglected. The short circuit level of the source is 250 MVA. The capacitor being switched is

transients are the “natural transients” in electric power systems. Therefore oscillatory transients dominate over impulsive transients. *A typical example of an oscillatory transient is caused by the energizing of a capacitor bank*. The oscillation frequency is mainly determined by the capacitance of the capacitor bank and the short-circuit inductance of the circuit feeding the capacitor bank.

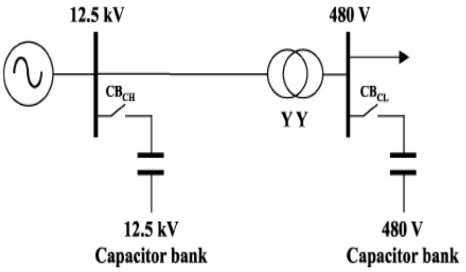


Figure 2 Distribution system for the simulation of voltage amplification due to capacitor energizing

1) Capacitor Energizing With Magnification:

2.5MVAr and the capacitor bank at 480Vis 170 kVAr delta connected. The resulting transients at the high and low voltage buses are shown in Fig. 3. The peak value at low voltage is 2.5 pu, significantly higher than the peak at high voltage. Fig. 4 shows the spectrum of the transients. The transient at the 12.5 k bus shows a peak close to 450 Hz. The spectrum of the transient at the 480 V bus shows two peaks: one at the same frequency as the transient at 12.5 kV and another around 700 Hz. Their amplitudes are almost equal. The presence of a second capacitor in the vicinity of the capacitor that is being switched produces a transient which is the combination of two frequency components. Formulas for the calculation of these frequencies are given in. Furthermore, more resonance frequencies appear if more capacitors are close.

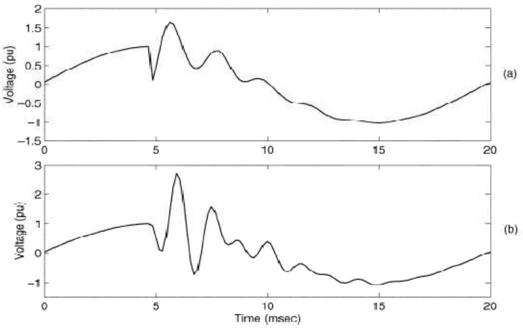


Fig. 3. Voltage waveforms during capacitor energizing. From top to bottom: (a) at 12.5 kV; (b) at 480 V (ATP-EMTP simulation).

b. Capacitor Energizing Without Magnification:

For a different capacitor size at the low voltage bus, the peak voltage is reduced significantly. For example, if the 480-V capacitor bank is reduced to 40 kVAr, then the switching of the 2.5 MVAr capacitor bank at the 12.5 kV bus bar produces an overvoltage of 1.5 p.u. at 480 V, as shown in Fig. 5. This is almost equal to the overvoltage of the high voltage side and significantly lower than the overvoltage of Fig. 3.

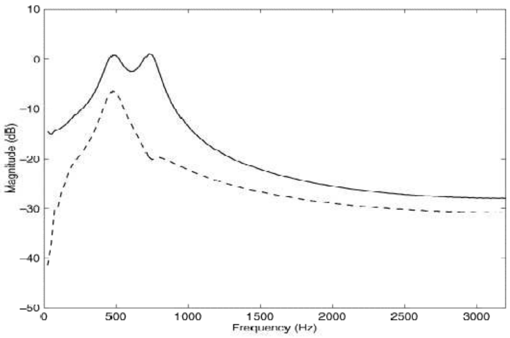


Fig. 4. Spectrum of voltage transients shown in Fig. 3: at 12.5 kV (dashed line) and at 480 V (solid line).

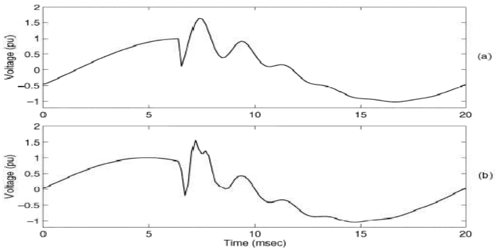


Figure 5 Voltage waveform during capacitor energizing. From top to bottom (a)125kv (b)480kv

2) Line Energizing

Energizing of transmission lines is another possible cause of oscillatory transients. The transmission line can be modeled as a lumped capacitor, which would result in the same oscillations as for capacitor energizing. However such a model neglects the travelling waves that occur at the beginning of the transient. Fig. 6 shows the voltage transient caused by the energizing of a 160-km open-ended line at the source side and at the end of the line. The voltage at the end of the line approaches 2.0 p.u. and this is the main concern from an insulation point of view. The overvoltage at the source side is approximately 1.4 p.u. The latter transient is the one spreading through the system and thus the one of concern from a power-quality viewpoint. In both cases there is an initial overshoot followed by an oscillatory transient in the waveform.

C. Multiple Transients With a Single Cause

The previously given examples all contain just one transient, due to one single switching action. However *in many cases* the transient waveform is due to more than one switching action leading to overlapping transients. During switching in a three-phase system the switching actions in the individual phases rarely take place at the same time instant. In such events are analyzed by separately considering the phase-to-phase and the phase-to-ground voltages.

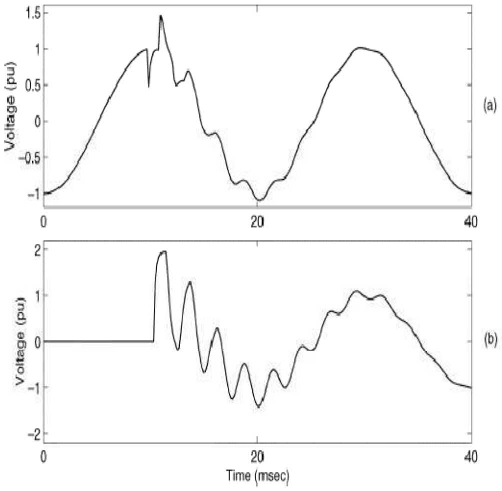


Figure 6 Voltage Waveform, from top to bottom (a) source side (b) end of the line

Other examples of multiple transients with a single cause are “current chopping” and “restrike.” Current chopping occurs when the current during opening of a circuit breaker becomes zero before the natural zero crossing, resulting in high overvoltages. Restrike may occur when a capacitor is de-energized by a slowly-moving switch. The voltage over the capacitor increases faster than the voltage-withstand of the gap between the contacts of the switch. An example of multiple restrikes is shown in Fig. 7. As shown in the figure multiple restrikes can lead to an escalating voltage over the capacitor leading to an internal flashover and serious damage to the equipment. Therefore it is important to detect even single restrikes at an early stage. The last row in Table I briefly summarizes some possible classes of multiple transients with a single cause.

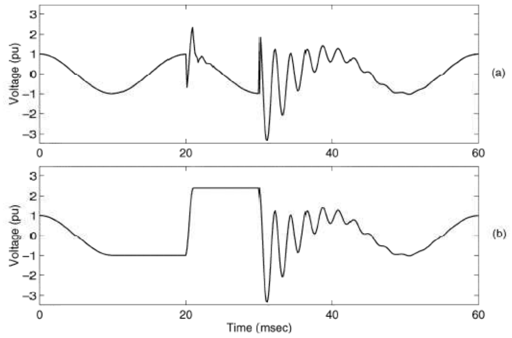


Figure 7 Voltage Waveform for multiple restrikes during capacitor de-energizing, (a) line side, (b) capacitor side.

TRANSIENT STABILITY PREVENTION CONTROL

In order to ensure power network security under the circumstances of power marketing mechanism, a higher requirement to the transient stability preventive control is raised: to perform an overall optimum concerning both economy and security, with all the possible contingencies taken into consideration at the same time. To achieve such a goal, transient stability-constrained optimal power flow (TSCOPF) serves as an ideal tool. It is illustrated in Figure 8 the process of transient stability preventive control based on OPF. Given the economy of operating power system, it is assumed that the initial operating point of the system before generation rescheduling is based on the optimal result of OPF. Therefore, the solution procedure of our method may be described concisely by the following

Steps:

Step 1: Solving a standard OPF problem. Various methods may be adopted to complete this step,

Step 2: Check to see if the solution of the OPF respects stability constraints for all contingencies.

These contingencies may be determined in the contingency screening segment, while the stability state can be examined through method of numerical integration.

Step 3: If the system remain stable under all contingencies, it would be obvious that the operating point of the system is already within the stable region, and it is the most economically favorable operating point within the stable region. In that case, generation rescheduling is not necessary at all. In other cases, move on and carry out Step 4 to Step 5.

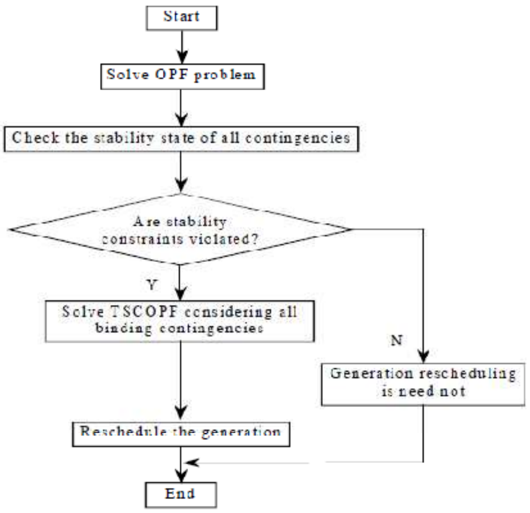


Figure 8 Overall procedure of transient stability preventive control based on OPF

Step 4: Solving a TSCOPF problem which considers all of the binding contingencies. This step is the key part in the whole procedure of transient stability preventive control.

Step 5: Rescheduling generation in accordance with the optimal solution of TSCOPF. The adjustments of active generation need to be decreased (-) / increased (+) for every machine are given by:

$\Delta P_i = P_{iTSCOPF} - P_{iOPF}$ (I € S_G)

Where S_G = Set of generators

VARIFICATION OF TSCOPF PROGRAM

The TSCOPF problem is a large-scale nonlinear programming problem and the question about how to verify the validity of the solution is of great significance. Based upon a well-tested OPF program, writing in FORTRAN by the Power System Laboratory of Hiroshima University we implemented a TSCOPF program. To test the validity of the mathematical model, the algorithm and the program, we have designed a verification procedure as follows: From the TSCOPF solution of our proposed method, besides achieving the optimal operating point, as a byproduct we also can obtain the swingcurves of all machines, and we call them dynamic responses (A). Assigning the achieved optimal operating point as the initial operating point, we perform a transient stability analysis by adopting a CRIEPI.s (Central Research Institute of Electric Power Industry, Japan) program to the same chosen model systems, under the same circumstances. The results of this program are the swing curves of all machines, and we call them dynamic responses (B). Then compare the dynamic responses (A) with the dynamic responses (B) to check their coincidence. If the result shows that they are the same, it would be convincing to confirm that the TSCOPF solution is right. Otherwise, the TSCOPF solution may not hold water. Factually, the result of our test demonstrates the coincidence of the two dynamic responses, so that the validity of our proposed method is successfully verified. Figure 9 illustrates this process. Furthermore, it should be noted that, as all the contingencies are considered at the same time, the sequence of contingency constraints does not affect the solution result. This algorithm will converge to the optimal solution no matter what the sequence of contingency constraints is.

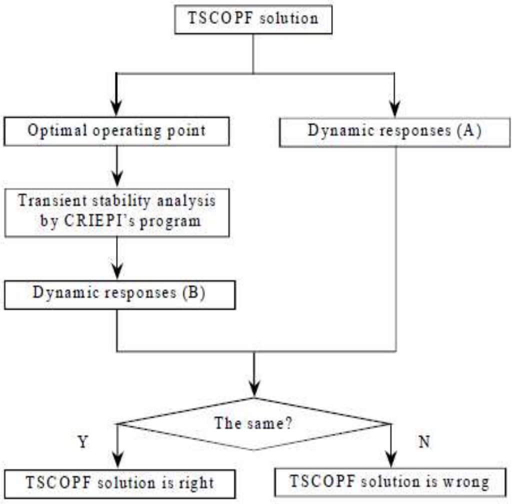


Fig.9-Verification of TSCOPF Program

FACTORS INFLUENCING TRANSIENT STABILITY

(a) How heavily the generator is initially loaded.

(b) The generator output during the fault. This depends on the fault location and type.

(c) The fault clearing time.

(d) The post-fault transmission system reactance.

(e) The generator reactance. A lower reactance increases peak power and reduces initial rotor angle.

(f) The generator inertia. The higher the inertia, the slower the rate of change angle.

This reduces the kinetic energy gained during fault, i.e. area A_1 is reduced.

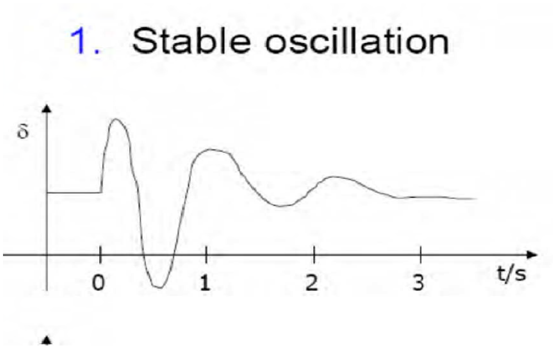
(g) The generator internal voltage magnitude (E^{l}). This depends on the field excitation.

(h) The infinite bus voltage magnitude E_B.

DYNAMIC STABILITY ANALYSIS (Small Signal Stability)

- Small-signal stability is the ability of the power system to maintain synchronism when subjected to small disturbances.
- A disturbance is considered to be small if the equations that describe the resulting response of the system may belinearized for the purpose of analysis.
- The small-signal stability problem is usually one of insufficient damping of system oscillations.

EXAMPLES OF STABILITY



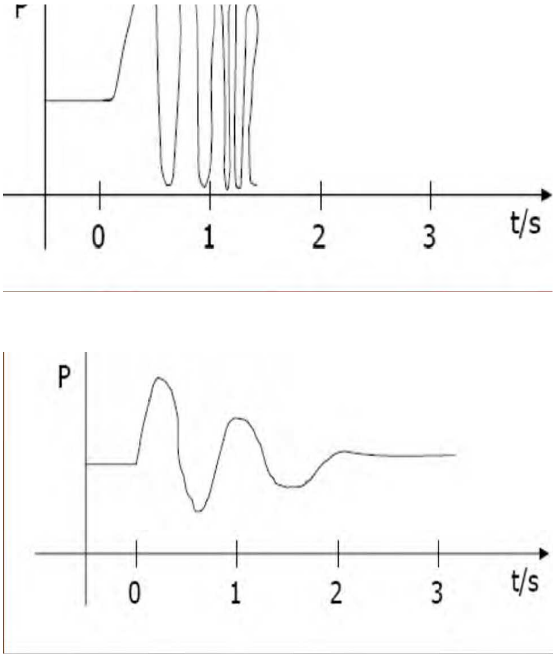


Figure 10

DYNAMIC STABILITY ANALYSIS

The analysis of dynamic stability can be performed by deriving a linearized state space model of the system in the following form

p X = A X + B u

Where the matrices A and B depend on the system parameters and the operating conditions.

• The Eigen values of the system matrix A determine the stability of the operating point.

• The Eigen value analysis can be used not only for the determination of the stability regions, but also for the design of the controllers in the system.

The novel features of the proposed method:

- It is not necessary to reduce the power system network to eliminate non-generator buses. The same network used for load flow studies can also be used for the dynamic stability calculations.
- The development of system model proceeds systematically by the development of the individual models of various components and subsystems and their interconnection through the network model.

CONCLUSION

Transient stability constrained optimal power flow (TSCOPF) being its tools, this method is to achieve the most economically point within the stable region, so as to realize the harmonious coordination and combination of economy and security when operating power system. This seminar illustrates the detailed procedure of the proposed transient stability preventive control method, and it also offers the related mathematical model and solution procedure. In the second part of this seminar, we analyze respectively the preventive control results of a of this proposed method. In the final part of this seminar we illustrate the dynamic stability of the power system.

For future work, larger test systems with more stability constraints will be tested to show how this methodology can work in practical large size networks.

REFERENCES

1. A. A. Fouad and J. Z. Tong, .Stability Constrained Optimal Rescheduling of Generation., IEEE Trans.on Power Systems, 8(1): 105-112.

2. V. Miranda, J. N. Fidalgo and J. A. P. Lopes, RealTime Preventive Actions for Transient Stability Enhancement with a Hybrid Neural Network Optimization

3. Approach. IEEE Trans. on Power Systems, 10(2): 1029-1035.

4. D. H. Kuo and Bose A, Generation Rescheduling Method to Increase the Dynamic Security of Power Systems., IEEE Trans. on Power Systems, 10(1): 68-76.

5. D. Gan, Z. Qu and H. Cai, Methodology and Computer Package for Generation Rescheduling., IEE Proceedings - Generation, Transmission and Distribution, 144(3): 301-307.

6. Y. Xue, T. V. Cutsem and M. Pavella, Real-time Analytic Sensitivity Method for Transient Security Assessment and Preventive Control., IEE Proceedings-Generation, Transmission and Distribution, 2004; 135(2): 107-117.

7. M. L. Scala, M. Trovato and C. Antonelli, On-line Dynamic Preventive Control: An Algorithm for Transient Security Dispatch. IEEE Trans. on Power Systems, 13(2): 601-610.

8. D. Gan, R. J. Thomas and R. D. Zimmerman, .Stability constrained Optimal Power Flow., IEEE Trans. On Power Systems, 2005; 15(2): 535-540.

9. Y. Yuan, J. Kubokawa and H. Sasaki, A Solution of Optimal Power Flow with Multi-contingency Transient Stability Constraints., IEEE Trans. on Power Systems, 2010; 18(3): 1094-1102.

10. A. S. El-Bakry, R. A. Tapia and T. Tsuchiya, On the Formulation and Theory of the Newton Interior-Point Method for Nonlinear Programming., Journal of Optimization Theory and Applications, Vol.89,No.3, pp 507-541.,2011

11. H. Wei, H. Sasaki and J. Kubokawa, An Interior Point Nonlinear Programming for Optimal Power Flow Problems with a Novel Data Structure., IEEE.