Generation Coordination for Transient Stability Enhancement using Particle Swarm Optimization

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Abstract -- This paper presents a security constrained power system dynamic performance enhancement using particle swarm optimization (PSO) based on time domain simulation (TDS). The key feature of the security monitoring is the critical fault clearing time. Time-domain simulation is used to determine the unstable point of the power system based on bisection technique to reduce computation time. The Independent System Operator (ISO) should plan hours-ahead or days-ahead rescheduling to determine the optimal allocation of generated power from each generator based on the expected system disturbances. The objective is to find proper adjustments of the generated power that maintain acceptable security levels throughout the system and minimize system losses. The generation rescheduling (GR) is considered as a necessary remedial action to improve the system transient stability during the disturbances. PSO is used to determine the most suitable generation coordination among system generators.

***Index Terms*—Transient stability, security, particle swarm optimization, generation rescheduling.**

I. NOMENCLATURE

P_G, P_D, P_L	Generation, demand and losses active power
Q_G , Q_D, Q_L	Generation, demand and losses reactive power
S	Line power flow
V, θ	Voltage magnitude, voltage angle
P_{exist}	The losses at the critical operating point
N_A, N_B	Number of generators in group A and B
ΔP_{GA}, ΔP_{GB}	Change in generation in group A and B
Δ P	Incremental generation rescheduled
T_{mA}, T_{mB}	Inertia constant of generator in group A and B
S_{GA}, S_{GB}	MVA rating of generator in group A and B
α_A, α_B	Rescheduling Coefficient in group A and B

II. INTRODUCTION

Electric power systems are increasingly becoming more and more stressed as the electric load continuously increase and fewer generation and transmission capacities are added. As a result, any fault in the power system must be cleared for the system to return to a normal operating state without loss of synchronism and separation of some generators. The ISO should perform transient stability simulations to select situations that derive operating security limits offline. These limits used on online dynamic security monitoring by Energy Management System (EMS) at the control center. A variety of dynamic security assessment techniques have been proposed. Many of these techniques depend on transient energy function (TEF) [1, 2] or TDS [3, 4] or hybrid [5].

The energy function method has been used to provide a quantitative measure of the degree of system stability based on energy margin but it required computational efforts and restrictions regarding modeling details. Alternatively, TDS provides several advantages in system modeling and investigation of dynamic behavior [4]. [The time to fault clearing is called fault clearing time (FCT)]. The maximum fault clearing time before the system goes out of the domain of stability is called critical clearing time (CCT). CCT for the most severe fault is important measure of the power system stability margin [6]. During network disturbances, the power generators have to provide immediate support by increasing or changing the currently generated power supplied to the grid. This immediate change is restricted by the power system inertia during the initial few hundred milliseconds. Most turbines are unable to yield the fast torque response required to act in such small level in transient stability. The aim of preventive control is to prepare the system when it is in steady state, so as to make it able to face the expected contingencies in the future. The purpose of the work is to find a generation configuration with improved transient stability behavior in order to make the transient unstable cases for the worst contingency stable by rescheduling the generation while satisfying operational constraints and minimizing power losses. GR is considered as a practical preventive or remedial control action to improve the system security during any contingency by increasing the CCT or the transient energy margin without changing the required total generation [1, 2].

A contingency check of the rescheduling operating point has to be done and if necessary, more rescheduling calculated until no contingency is sever. In this paper, pre-contingency GR is achieved such that: i) power losses should be minimized or at least kept at the same level, ii) improvement at one bus should not cause limit violations at other buses, iii) improvement system instability for particular contingency must not make unstable behavior with a different contingency. TDS is used to determine the relevant unstable equilibrium point (UEP) and the corresponding critical generator by changing the fault period for each contingency based on

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bisection technique [7] as shown in Figure 1. The calculation in the proposed method is simple and direct; GR depends only on ratings, inertia constants of the machines and their rotor angles with respect to (w. r. t.) center of angles (COA) at the fault clearing time. The problem is how much of the optimal power should be rescheduled and how this power should be coordinated between generators. The problem is formulated as constrained optimization problem and PSO is used to solve this optimization problem.

III. DESCRIBTION OF THE METHOD

A. Problem Formulation

The problem formulation can be described as follows:-

Max CCT (P_G, Q_G)

S.T. $\Sigma P_G - \Sigma P_D - \Sigma P_L (V, \theta) = 0$ (1)

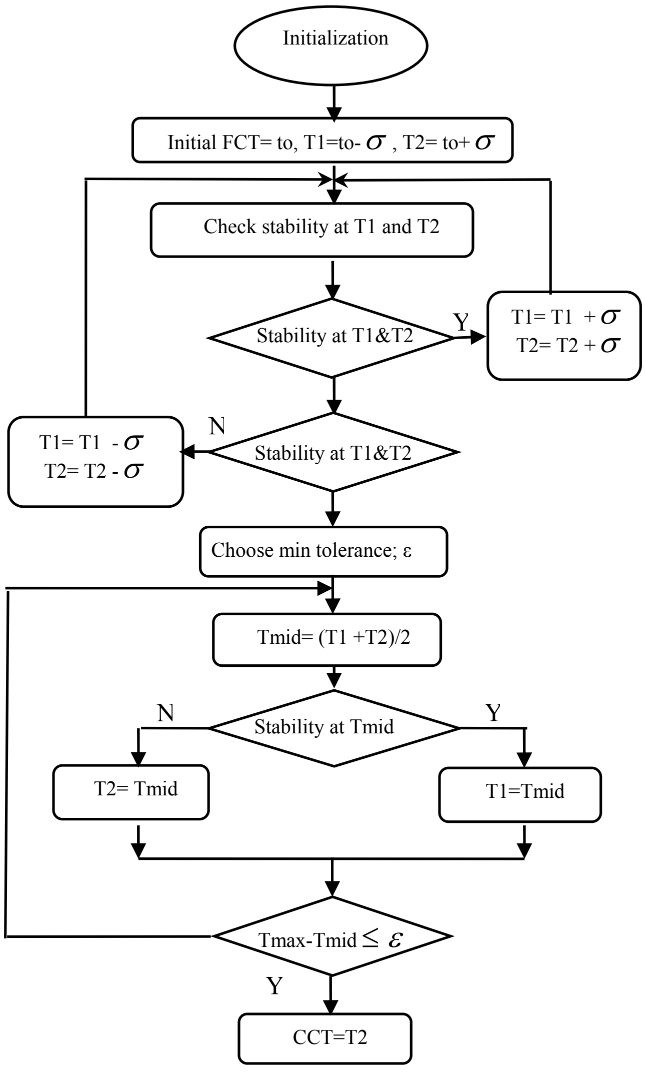

Fig.1. Estimation of CCT by bisection technique

$\Sigma Q_G - \Sigma Q_D - \Sigma Q_L (V, \theta) = 0$ (2)

$S (V, \theta) < S^{max}$ (3)

$V^{min} \leq V \leq V^{max}$ (4)

$P_G^{min} \leq P_G \leq P_G^{max}$ (5)

$Q_G^{min} \leq Q_G \leq Q_G^{max}$ (6)

$\Sigma P_L \leq \Sigma P_{exist}$ (7)

The basic steps of proposed method to solve the dynamic security-constrained generation rescheduling of power system using PSO can be summarized as follows:

Step 1. Using state estimation or optimal power flow to obtain the system operating condition.

Step 2. Select the expected contingency types and positions.

Step 3. Bisection technique (shown in Figure 1) is used to determine CCT for each contingency.

Step 4. Rank the contingencies according to CCT and classify generators according to change of rotor angles.

Step 5. If the security margin of the worst case is below an unacceptable level, apply PSO technique to establish a preventive GR to improve system transient stability.

Step 6. Check improvement of system dynamic performances with full system analysis at all buses, if no go to step 5.

B. Bisection Technique

In the first stage of the optimization process, a bisection method is used to find CCT for each fault at selected Buses to avoid the repetitive time-consuming with step increase fault durations [7]. As shown in Figure 1, first initial fault clearing time (FCT=to) is assumed and CCT limits are (to ± σ). The limits are chosen such that the system is stable at lower value and unstable at higher value. The dynamic response of the system is evaluated at mid-point. If the system is stable, the lower limit (T1) is replaced by mean value (Tmid). Otherwise, the higher value (T2) is replaced by Tmid in the next calculation. After calculation of CCT at all contingencies the worst contingency is obtained by ranking CCT. This process is repeated every time we need to calculate CCT. According the time response of all generators during the worst contingency, the generators are divided into two groups based on their rotor angles w. r. t. COA at UEP.

C. Optimization

PSO is an evolutionary computation technique that is used to solve many of complex nonlinear problems in power system such as economic dispatch [8], FACTS sizing and allocation [9], dynamic security border identification [10], and others. It is a multi-particle (operating point) search technique that constitute a swarm through search space looking for the global optimal point (maximum or minimum) that lie inside the predefined borders. The borders represent the constraints that govern the place of the system operating point. PSO is used to solve the GR optimization problem. The constraints in equation 1-7 are taken as borders for particles moving.

The rate of rotor angle change is proven to be a good sensitivity index for generators response during the contingencies [6, 11]. The rotor angle of each machine will move within certain border with respected to COA during stable operation. During unstable operation, time response of rotor angles is used to classify all generators into two groups as seen in Figure 2. Group A are those generators (N_A) with positive sensitivity and so, the generation for this group should decrease while group B are generators (N_B) with negative sensitivity at the critical contingency and generation should increase to compensate the change in group A. PSO used to compute the optimal amount of power needed to be shifted iteratively from most advanced generators to the least advanced generators and this amount is involved by generators in each group based on their inertia and capacities using the following formula:

$$\alpha_{iA} = \frac{T_{miA} S_{GiA}}{\sum_{k=1}^{NA} T_{mkA} S_{Gk}^{A}} \quad , \; \alpha_{jB} = \frac{T_{mjB} S_{GjB}}{\sum_{K=1}^{NB} T_{mkB} S_{Gk}^{B}} \tag{8}$$

$$\Delta P_{GiA} = \alpha_{iA} \Delta P \quad , \; \Delta P_{GjB} = -\alpha_{jB} \Delta P \tag{9}$$

$$\sum_{i=1}^{NA} \alpha_{iA} = 1 \quad , \; \sum_{j=1}^{NB} \alpha jB = 1 \tag{10}$$

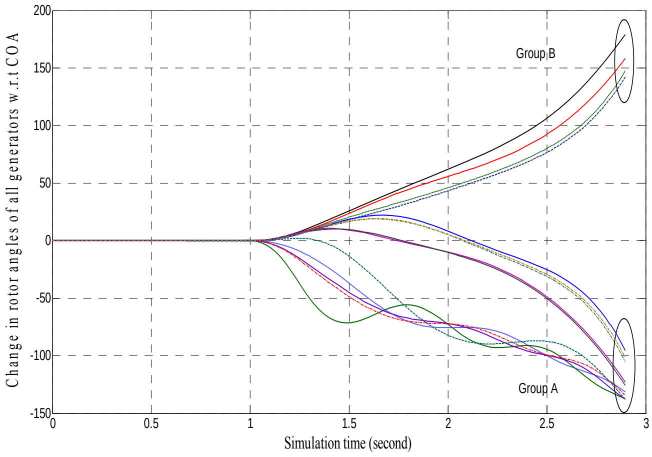

Fig.2. Rotor angles time response for 66 bus system during unstable behavior.

During the iterative process, the particle minimize the power losses and maximize the CCT is selected to be the global best operating point.

IV. Numerical Examples

Two power systems are selected for testing the validation studies of the proposed algorithm: a four-machine two-area 11-bus benchmark system [12], and a sixteen-machine three-area 66-bus system [13]. The test systems are subjected to a set of contingencies and the contingency is always a three phase self-clearing faults to calculate CCT. In performing GR, it is assumed that the total generation and loads are held constant. The change in system losses is compensated by slack bus.

A. Four-Machine, 11- Bus System

A single line diagram is shown in Figure A1 in Appendix A. A three phase fault at each bus without a generator connection is applied and after ranking using CCT for each fault, the worst case is the fault at bus 5 and the generator connected to bus 1 is the corresponding critical generator CCT 328.0 milliseconds. Figure 3 shows the rotor angles w. r. t. COA for this contingency before applying GR. The generators are easily identified into two groups A (G1, G2) and B (G3, G4) by their advanced angles at the UEP. Table I contains the data after generation coordination using PSO. PSO technique gives an accurate estimate of the amount of generation to be shifted from the critical machines. The CCT is improved to 545 milliseconds with reduced system power losses. Figure 4 plots the angles of all generators w. r. t. COA after the generation rescheduling at Bus 5 with 500.0 milliseconds self-clearance fault, which clearly show that system stability.

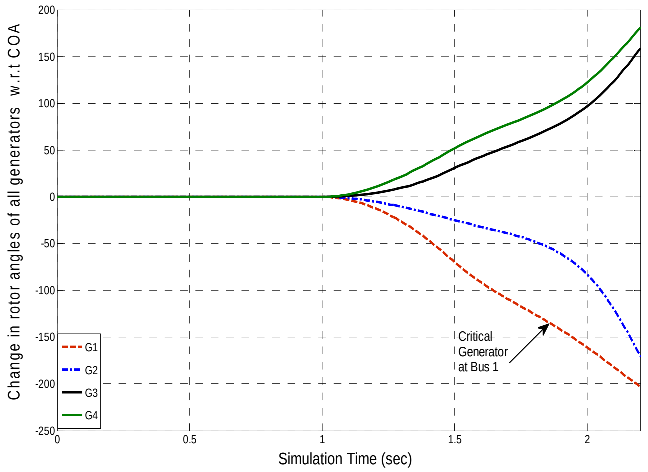

Fig.3. Rotor angles with fault at Bus 5 for 11 bus system.

Table I: GR data for four-machine, 11 busses system

Faulted Bus	CCT at G1 Before and after GR		Power losses (MW)		Shifted power		Generation (MVA)	
	B	A	B	A	ΔP	ΔQ	Before	After
Bus 5	328	545	35.5	28.5	90.8	14	1:1034+i228 2:1000+i26 3:1000+i85 4:1000+i267	989+i218 955+i17 1042+i90 1042+i272

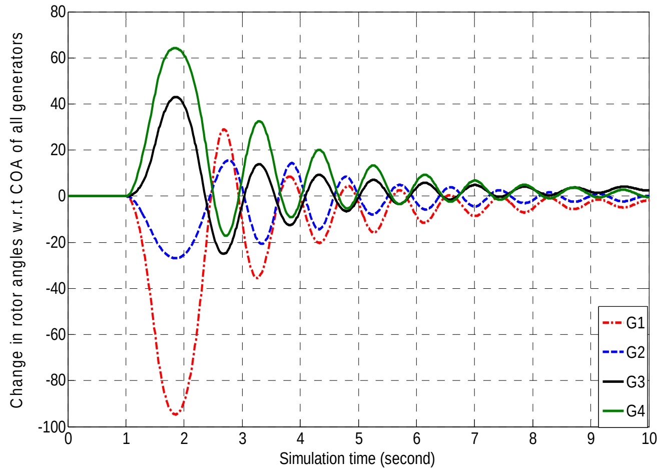

Fig.4. Rotor angles w. r. t. COA after GR for 11-Bus system

B. Sixteen-Machine, 66- Bus System

The PST 16-Machine, 66-Bus Test System is shown in Figure A2 in appendix A. The system consists of 3 areas with 16 generators, considering the voltages at all the 16 generator bus nodes (PV) are constant. A three phase fault is applied at the remaining 50 buses to determine the critical fault and corresponding critical generator. Figure 5 shows the time response of rotor angles w. r. t. COA of all generators at the worst contingency when the fault at bus 2 in area A with CCT 115 milliseconds, while the corresponding critical generator is G1 at bus 2 in area A. The system losses are 307.48 MW.

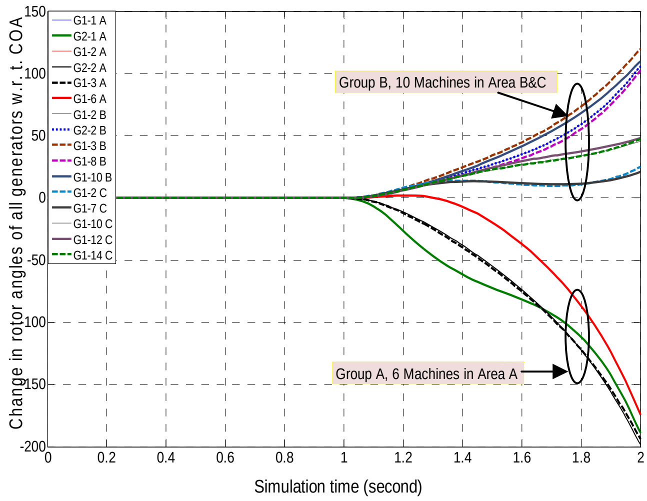

Fig.5. Rotor angles for 66-Bus system at critical fault.

The system generators split into two groups A & B as shown in Figure 5; PSO is applied to determine the optimal amount of generation to be coordinated between generators to improve the system transient stability. The results obtained with the optimization program show that the CCT increased to 160.63 milliseconds and the losses reduced to 238.94 MW. The power to be rescheduled from group A to Group B is 250.153+j 6.66 MVA.

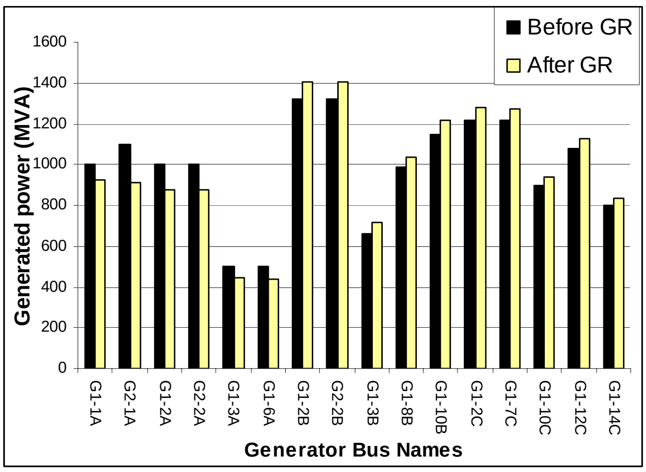

Fig.6. Generation in 16-Machine after and before using PSO

The results show that the critical generator is transferred from area A to be at bus 10 in area B, so using GR we can monitor the position of the critical generator at the critical fault. Figure 6 shows change in generated power after and before applying PSO to obtain optimal GR. Figure 7-8 show the dynamic response during 140-millisecond three phase faults at bus 2 (previous critically faulted bus). These Figures show that the system is transiently stable.

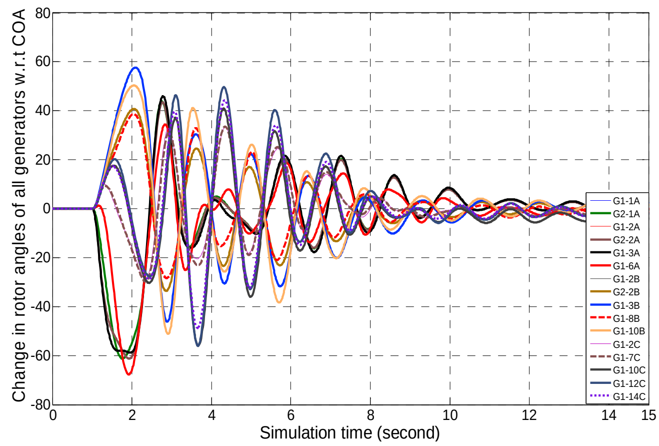

Fig.7. Rotor angles w. r. t. COA for 66-Bus system after GR

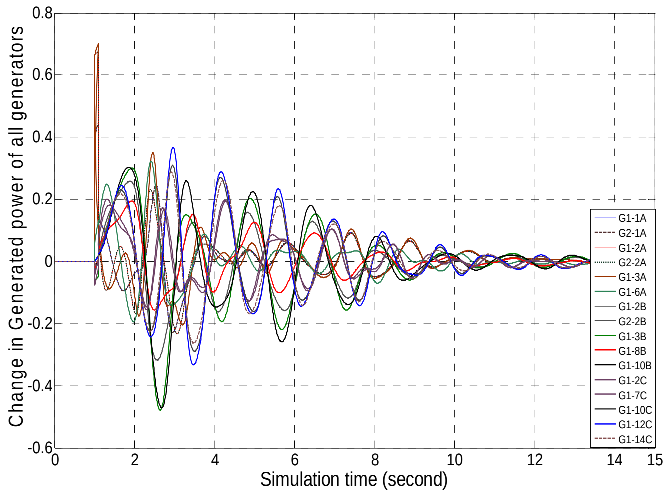

Fig.8. Transient stability for 66-Bus system after GR

IV. CONCLUSIONS

The proposed method consists of classifying critical and non-critical generators based on their transient behavior during the most dangerous contingency and PSO was applied for allocating generation to improve system transient stability by maximize the critical fault clearing time under the condition of minimizing system power losses. The results show that not only the transient stability improved by GR but also the position of critical fault and corresponding critical generator can be controlled. The bisection technique has been incorporated into conventional time domain simulation in order to speed up the transient stability border identification and reduce the consumed time in calculations. Numerical tests demonstrate that PSO based on TDS is effective in improving the system transient stability for large scale power systems by driving a preventive Generation Rescheduling with a reasonable degree of accuracy. The algorithm has a flexibility and robustness in convergence and excellent for real power application so it can be applied to systems with any detailed modeling level without limitations. A farther search is required to include the latest PSO techniques in studying security assessment and transient stability improvement. This is a matter for future work.

V. APPENDIX A

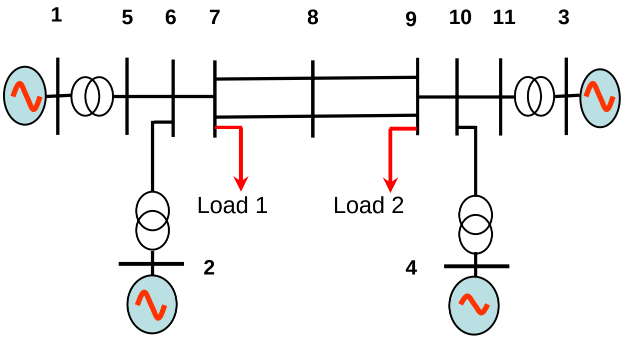

Figure A1. Four-machine, 11-bus power system

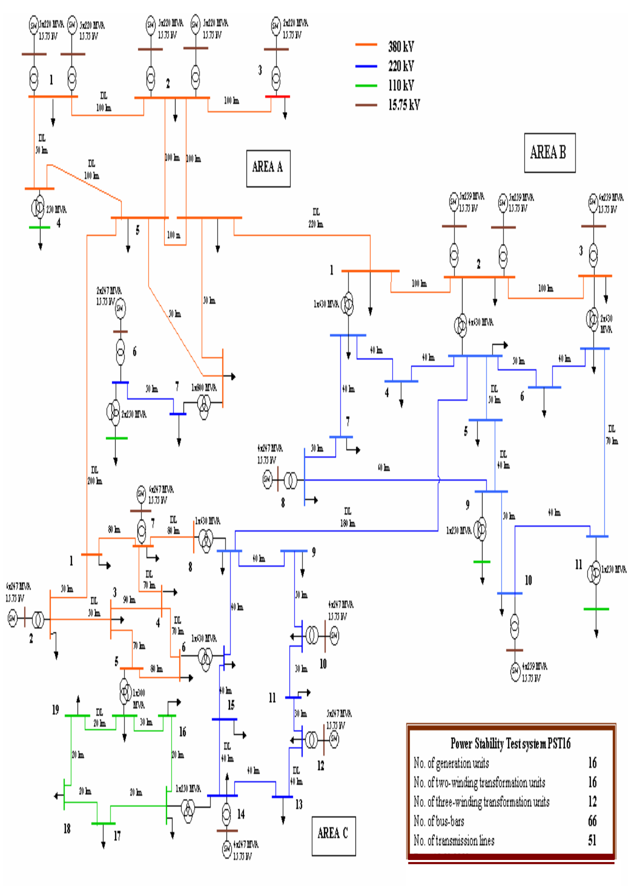

Figure A2. Sixteen-machine, 66-bus power system

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