Design of a transient stability scheme to prevent cascading blackouts

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ABSTRACT

This paper presents a novel optimization technique of the settings for various emergency controls in an electrical power system. The goal of this technique is to prevent a cascading blackout and retrieve a new equilibrium operation point following a severe contingency. The main stabilizing actions are tripping generators together with load shedding. This problem is a complex mixed integer programming problem and it is very difficult to solve by ordinary optimization methods such as mathematical approaches. Genetic Algorithms are search algorithms based on the mechanics of natural selection and natural genetics, and are subject to survival of the fittest among string structures. Since the Genetic Algorithm approach is very successful at solving combinatorial optimization problems, it has been applied to solving the problem of cascading blackouts. A Genetic algorithm approach is used to find the optimal combination of generators and loads to be tripped in order to regain a new state of equilibrium in operation, and hence, to prevent the system from failing in this cascading manner. These solutions are evaluated by using the hybrid transient energy function, and the GA optimization technique is able to select the best solution. The two cases tested in order to assess the feasibility of this technique were the 14-bus IEEE network and the 20-machine, dynamically-reduced England Network. The results presented in this paper show that global or near-global optimum solutions can be ascertained within reasonable amounts of time by this new method.

Keywords: Cascading blackout, Genetic Algorithm, Power system stability.

1. INTRODUCTION

A major blackout is when a large area or a complete area of a power system collapses. The main cause of a major blackout is a succession of cascading failures that trip a transmission line or some generation units. A partial blackout may start with a severe fault which can cause a large variation in power flow and busbar voltage which, in turn, can cause the outage of generation units or transmission lines. This certainly causes imbalance in the demand for and generation of power. This sort of disturbance can be the beginning of a cascading blackout when it spreads uncontrollably in the power system. For economic reasons, most power systems operate at the minimum level required for stability. This makes the likelihood of converting a local blackout to a major blackout very high. This gives rise to the necessity of having an appropriate scheme to prevent a cascading blackout from becoming a major blackout. [1]
A variety of emergency controls are used to prevent cascading blackouts. These emergency controls are generator tripping, fast-valving, load shedding and excitation controls. According to Machowski [2], however, generators and load tripping are the most effective control. Due to this fact, generators and load tripping were considered as the main emergency controls in this technique.

Mathematical optimization methods have been used over the years for power system control problems. However, the solution for large-scale power systems is not easy to obtain by way of ordinary mathematical optimization methods. This is due to the fact that there are many uncertainties in power system problems such as complexity, size and geographical distribution. It is also very much preferred that the solution for power system be a global optimum solution. However; this can not be reached by mathematical methods. All of these factors therefore make it necessary to use a global search technique such as a genetic algorithm. [3]

2. GENETIC ALGORITHM

Genetic algorithm is sort of global search technique used in optimization problems by imitating the mechanisms of natural selection and genetics. An increasingly better approximation of the desired solution can be produced by applying the principal of survival of the fittest. In each generation, a new set of approximations of the solution are chosen according to fitness evaluation. The more 'fit' the approximation is, the higher likelihood it has to be selected to reproduce the next generation by using operators borrowed from natural genetics. Thus, the population of solutions is improved from one generation to the next with respect to their fitness evaluation. So, the least fit individuals are replaced with new offspring, which come from a previous generation, and which are better suited to the evolution of the environment.

Fig (1) shows the Genetic Algorithm Flowchart. In the first step, a set of possible random solutions is created. Every solution in the population (which can also be called an individual or a chromosome) is represented by a string of numbers that in turn represent the number of variables in the problem. Every variable is encoded in a suitable coding format (binary, integer, etc.).

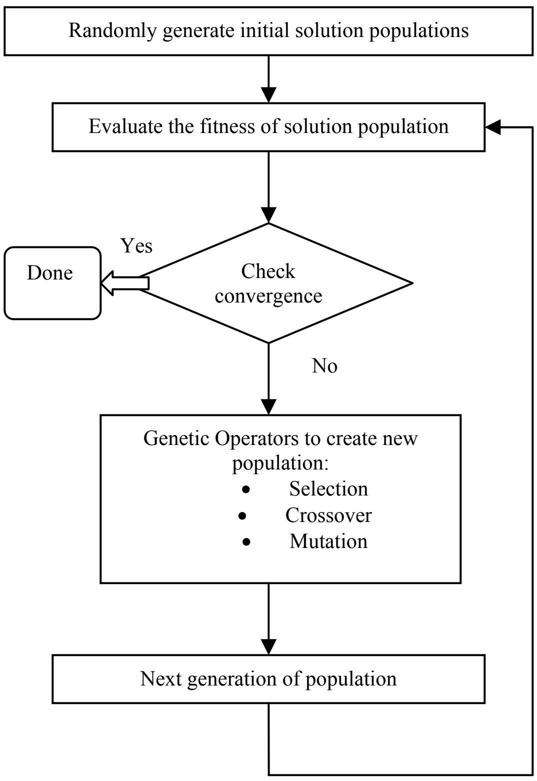

Fig (1) GA Flowchart

In the second step, every chromosome is applied to the fitness function (also called the objective function) to produce an output of fitness values. In accordance with their fitness values a probabilistic technique, such as the Roulette Wheel [4], is used to select the chromosomes that will contribute to the production of the next generation. The reason for this selection process is to keep the best and most fit chromosomes and increase the number of their offspring in the next generation, eliminating the least fit chromosome.

Having selected the parents, the crossover process then takes place by the exchange of genetic information between the selected chromosomes in order to form two new chromosomes (also referred to as children or offspring). This helps to avoid sticking in local optima.

In order to ensure that GA will search different zones of the search space, a mutation is applied by randomly selecting and changing the structure of a limited number of chromosomes. This process is repeated until all solutions converge into one optimum solution. [3]

3. STABILITY EVALUATION

For the simulation and stability evaluation, PSSENG (a *power system simulator*) [6] [7] was used to decide whether the system is stable or not since it is able to give clear assessments of the stability or instability of a system. The stability evaluation algorithm on PSSENG, which is based on time domain simulation output, can classify the simulation cases into the following categories:

1. Transiently unstable class
2. Oscillatory unstable class
3. Poorly damped stable class
4. Well damped stable class

For the two unstable classes the stability index is expressed by the severity index. Unstable cases with a detection of pole-slipping are classified in the transiently unstable class. The time taken for the system to pole-slip is used as the severity index in this class. Other unstable cases, without a detection of pole-slipping, are classified as being in the oscillatory unstable class. In this class, the calculation of the severity index is more complicated than in the previous one. The maximum magnitude of the rotor swing among all other generators is used as the main indicator of the severity index. Moreover, the frequency deviation and generator's active power are also used as auxiliary measurements in addition to the maximum rotor swing of the machine in order to give an accurate severity index. For the stable classes, the examination of the machine's rotor swings can give a decent indication of how stable the system is. The swing amplitudes can help to identify the extraction of the envelopes of the rotor swing curve for all machines. The swing of the envelopes can be approximately defined as an exponential function

$$S(t) = A\, e^{bt} \qquad (1)$$

The value of b is the system time decay which is used as an index for the degree of stability. If b is less than 12s the case is classified as being in the well damped stable class, or, if more than 12s, as being in the poorly damped stable class. [5]

4. PROBLEM FORMULATION

A severe fault may lead to blackouts in some local areas. Under certain circumstances, some small blackouts can lead to a major blackout. However, having a prepared scheme to resolve this problem can help to prevent such a transition. In order to produce this sort of scheme or solution, the production of the scheme should be treated as a constrained optimization problem. This will make the produced scheme meet the following requirements:

- As less power as possible will be tripped
- The system stability will be maintained

5. GENETIC ALGORITHM IMPLEMENTATION

5.1. Encoding

Before applying GA to an optimization problem, an encoding scheme must be decided upon. The encoding scheme should map all possible solutions of the problem into symbol strings (chromosomes).
Since the aim of our optimization problem is to minimize the amount of tripped power and tripped generations that can stabilize a power system network, the power of the generator will be considered in the structure of the chromosomes. Therefore every generator and load will be numbered from o to K, where K = number of generators + number of loads, and each chromosome is composed of S unique integers (S< K) with each integer corresponding to a certain generator or load. For instance, chromosome with a value of 5214309 means that the elements number 5, 2, 1, 4, 3 and 9 are the ones that might trip.

5.2. Selection

The Roulette Wheel technique is used as the probabilistic technique to select the chromosomes.

5.3. Crossover

In this Algorithm the Midpoint for exchanging information was applied.

5.4. Fitness Function

The fitness function provides an evaluation of the chromosomes' performance in the problem domain.
In this particular problem, the objective of the fitness function is to grade each chromosome with respect to the following aspects:

- Stability class: The stability evaluation algorithm will rank the chromosome according to its stability class, as mentioned in section III
- Amount of generated and load power: The chromosomes are evaluated in terms of the amount of tripped power they possess. The higher the amount of tripped power, the lower the rank of the chromosome.
- System decay rate: This index is used only for the two stable classes in order to specify the degree of stability. The lower the system decay rate, the higher the rank of the chromosome.
- Severity Index: This index is used only for the two unstable classes to specify the degree of instability. The higher the severity index the lower the rank of the chromosome.

The corresponding fitness function can be written as

$$FF = \begin{cases} SC + \dfrac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \dfrac{1}{TDR} & \text{Stable case} \\ SC + \dfrac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \dfrac{1}{SI} & \text{Unstable case} \end{cases} \tag{2}$$

Where: SC represents the stability class and is equal to 30 for well damped stable, 10 for poorly damped stable, 5 for oscillatory unstable, or 0 for transiently unstable. NL is the number of predetermined shedding loads, ΣMVI is the summation of the amount of load reductions, TDR is the time decay ratio and SI is the severity index.

6. NUMERICAL EXAMPLES

Two cases are presented in this paper. The first is that of the IEEE 14-bus network and the second case is that of the 20-machine dynamically-reduced England network. For both cases the applied faults were artificially chosen in order to drive the system into the region of instability.

6.1. IEEE 14-Bus Network

Following the experience of many previous experiments, the GA operators were selected as follows:
Number of generations = 50
Size of chromosomes = 8
Number of chromosomes =50
Mutation rate =5%
The 14-bus system is shown in Fig (2) below. The network consists of 11 loads, 2 generators and 3 synchronous condensers.

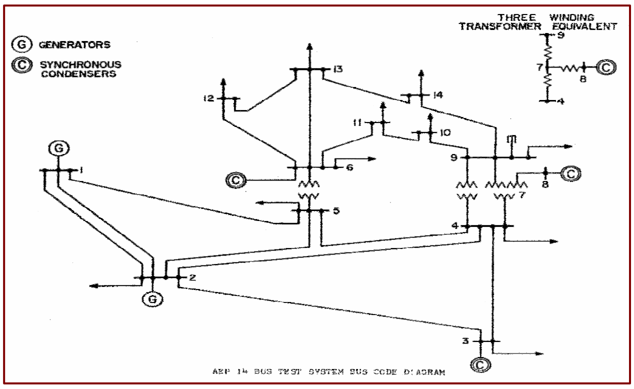

Fig (2) IEEE 14-bus Network

Two three-phase faults were applied on bus 2 and bus 5 at 0.2s while the system was fully loaded. Consequently, the line 2-5 switched out. The faults on bus 2 and bus 5 were cleared at 0.09s and 0.12s, respectively, after the contingency. This severe contingency succeeded at destabilizing the system as shown in Fig (3).

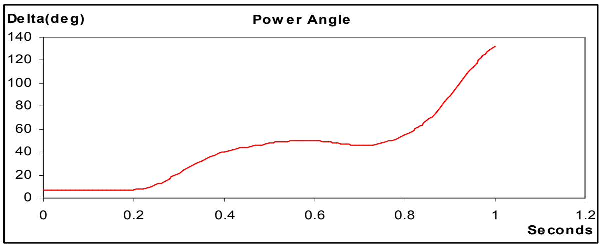

Fig (3) Rotor angle of G1 without any

Due to the simplicity of the IEEE 14-bus network, the stability control scheme can be achieved on the 5th generation as shown in Fig (4), which shows the convergence characteristics of the Genetic Algorithm.

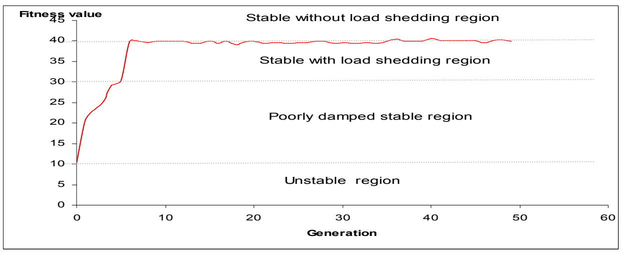

Fig (4a) GA average of solutions

As a result, the network can be stabilized, as shown in Fig (5), simply by tripping two synchronous condensers which are connected to bus 6 and 8 at 0.24s after the contingency.

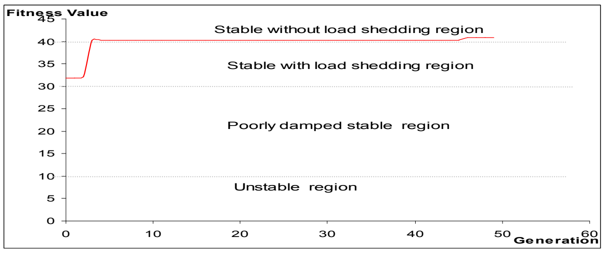

Fig (4b) GA highest Solutions

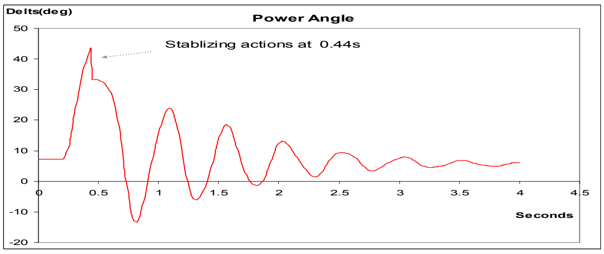

Fig (5) Rotor angle of G1 with control

Obviously, the algorithm proves its robustness by ascertaining a solution without any disruption to consumers, i.e., zero load shedding. The simulation results, shown in Fig (3) and Fig (5), illustrate the rotor angle of the main generator (the generator connected to bus 1).

6.2. 20-machine dynamically-reduced England Network

The GA operators were selected as follows:
Number of generations =75
Size of chromosomes = 10
Number of chromosomes =150
Mutation rate =5%
In the second numerical example, the algorithm was applied to the practical 20-machine, 100 bus dynamically-reduced England Network. The test system data are listed in [8] and are available from the authors. The model covers the main 400KV system and extends to cover some of the Scottish system.
This network is sufficiently complex, therefore making it amore than suitable model with which to prove the validity of the algorithm on a realistic power system network.
Two three-phase faults were applied on bus DIN04 and bus PENT4 at 0.2s while the system was fully loaded. Consequently, the line DIN04 - PENT4 switched out. The fault on bus DIN04 and bus PENT4 were cleared at 0.09s and 0.12s, respectively, after the contingency. This severe contingency did indeed manage to destabilize the system, as shown in Fig (6).

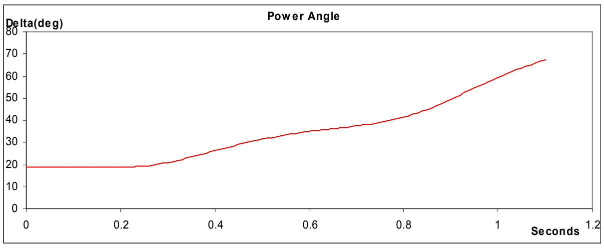

Fig (6) Rotor angle of Wylfa Generator without any control actions

It is noticeable from the convergence characteristics in Fig (7) that before the 9th generation, all solutions evolved toward the ultimate solution by means of load shedding. Due to the high capability of Genetic Algorithm to discover the solution space, however, the solutions evolved toward a better solution after the 9th generation, without any load shedding action, i.e., global minima.

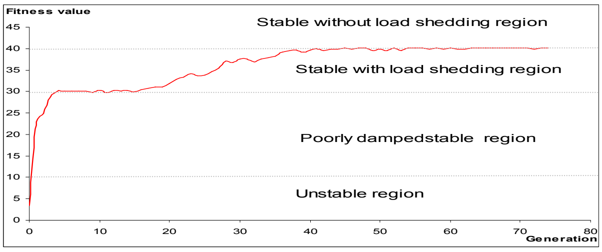

Fig (7a) GA average of solutions

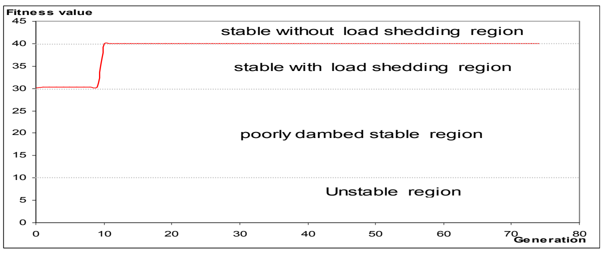

Fig (7b) GA highest Solutions

The global solution was to trip the following generators: DINORWIG, TRAWS and FIDDLWRS at 0.29s after the contingency. Fig (8) shows the rotor angle of the Wylfa generator, which is one of the most affected generators and can; consequently, give a good indication about the whole network.

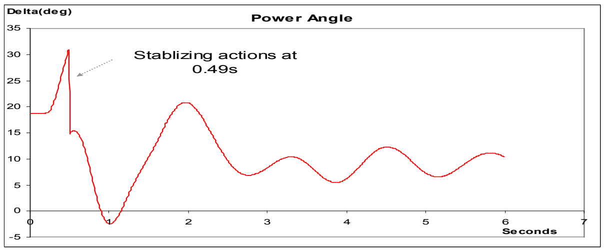

Fig (8) Rotor angle of Wylfa Generator with control actions

7. CONCLUSIONS

The objective of the optimization technique is to derive combinations of various controls to stabilize unstable transient events that could cause cascading blackouts. Using the new technique described here, Global or near global optimum solutions were obtained for both the case of the 14-bus network and the 20-machine dynamically-reduced England Network. Power systems can maintain their stability by a scheme of load and generator tripping.

In order to guarantee the robustness of the algorithm, the size of the population should be sufficiently large in order to allow discovery of the whole solution space.

This scheme can be enhanced to include more stabilizing actions, such as system islanding and fast valving, in order to convert this stabilizing scheme into a comprehensive defence plane.

Further work will focus on enhancing the scheme in terms of its speed so that the scheme can be used in an on-line environment.

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