

# Comparison between PSO and GA in System Restoration Solution

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**Abstract** — The use of the Evolutionary Computation (EC) grew in interest recently. Among various Evolutionary Computation approaches, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are used in optimization problems; they have much in common but also have some differences. This paper presents a decision support tool based on Particle Swarm Optimization Technique (PSO) and Genetic Algorithm Technique (GA). This tool is applied to electrical power system restoration after an incident. The operator support systems play an important role in a performance of the complex process involving decision-making problems of combinatory nature. The techniques are based on the change of system functional configuration and consist in the use of the maximization of power demand supplied and minimization of the number switched lines. These techniques also avoid the overload of system lines. A case study is introduced.

**Index Terms**—Artificial Intelligence, Evolutionary Computation, Genetic Algorithm, Particle Swarm Optimization, Power System Restoration, Swarm Intelligence.

## I. INTRODUCTION

ELECTRICAL Power Systems have presented a natural growth due to the increase in demand and consumption of electrical energy. The development of the system increases the complexity of its supervision, control, and energy demand supply management [1-3]. The possibility of faults along the line is inherent to the system or even greater due to the rise in electrical system complexity and natural factors [1]. Thus, after fault occurrences, it is extremely important that the electric power system restoration be quick to guarantee the power demand supply and the customer's satisfaction [4,5]. The restoration is the process of changing the open/closed status of switches, loss reduction, load balancing, and restoration [6]. New technologies have been developed aiming at the operation of energy transmission and distribution systems in large scale. These are related mainly to automation, protection, control, and support of operators systems in critical

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situations. New technologies targets computational time efficiency, and are supplied with a certain degree of intelligence implemented through techniques that belong to the Artificial Intelligence area, such as Genetic Algorithms-GA [7,8, 9] and Particle Swarm Optimization-PSO [10, 11,12].

This paper compares the application of PSO and GA as an optimization technique to the restoration schemes for a distribution system. Reconfiguration for restoration is a combinatorial problem involving the searching of an enormous space of solutions. The target reconfiguration is an optimization and decision-making process which considers the maximization of the number of loads supplied associated to the minimization of the numbers of closed switches, and avoids the overload in the system lines. The distribution system test case is described in [7].

## II. RESTORATION OF ELECTRICAL POWER SYSTEMS

The electric energy distribution system presents a radially topological structure. In this kind of system, if all the switches are closed, there will be formation of meshes. For a system with  $k$  meshes,  $k$  switches have to be open in order to preserve the radial structure of the topology; where only one switch must be open in each mesh, that is, there must be at least one normally open switch in each mesh. Thus, the reconfiguration of the system is done by closing these normally open switches in order to restore the system in an optimized way; however it retains the radial topology [13].

The present approach supposes that there are lines with normally open switches, lines with normally closed switches and lines without switches. For an optimized reconfiguration, the decision-making involving the switches, which must be closed, is done so as to maximize the supplied loads and minimize the number of closed switches [13]. This process must happen fast and dynamically. It should provide a simple, objective, and efficient solution to the operator [1,3]. Considering fault occurrence on a single line of the distribution system, with the characteristics mentioned above, the closing of a single switch is enough to restore the system. This fact generates a new way for energy transmission, to supply the greatest possible number of load affected by the fault.

## III. GENETIC ALGORITHMS

Genetic Algorithm is an iterative procedure that keeps a

population of individuals, which represent a possible solution to a particular problem, [14,15]. Genetic Algorithm constitutes a search technique, inspired by the evolution process of the living being, based on Darwin's natural selection [16]. Considering the biological systems as a whole, it is observed they have developed strategies of behavioral adaptation along their evolution. This enabled their survival and perpetuation of their species. The environmental pressures caused these strategies to have a strong impact on the biological organisms. This impact created deep changes in the organisms. Components of a Genetic Algorithm are: a) *Individuals*: each possible solution to the optimization of the problem is codified in one string. Each string is an individual. b) *Population*: set of individuals. c) *Genetic operators*: they are functions applied to the populations. They allow the process to get new populations. d) *Fitness Function (Evaluation)*: operators and guides for the attainment of new populations. Fig. 1 shows that each iteration of the Genetic Algorithm corresponds to the application of a set of four basic operations: function of evaluation, election, crossover, and mutation [14]. At the end of this iteration a new population is created. This represents a better approach to the solution of the optimization problem of the previous population.

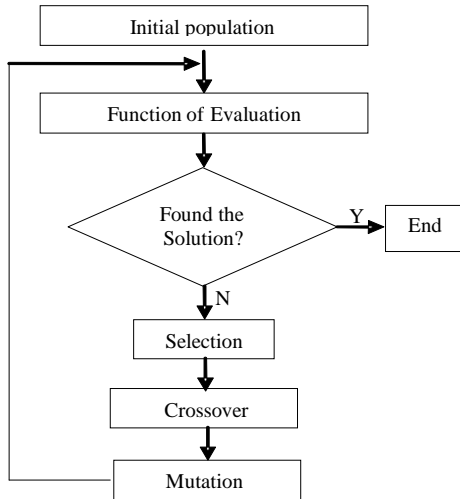


Fig. 1. Basic Structure of Genetic Algorithm.

#### IV. PARTICLE SWARM OPTIMIZATION

Swarm Intelligence is an optimization technique based on social behavior [17]. PSO is an optimization algorithm based on a population of individuals that present the ability to interact among each other as well as with the environment. Since the individuals are social, they also have the knowledge about their neighbor's behavior and the accomplishments in such a way learning and cultural transference [18]. The cultural adaptation process is based on three fundamental principles: assessment, comparison, and imitation. In PSO algorithm, each particle swarm is a candidate solution to the problem. Such particles are distributed into a space of  $n$  dimensions (problem domain), each one having a determined position and velocity at each time instant. The best individual position of each particle is called *local best parameter* and the

best position of all the particles is called *global best parameter*. The performance of each particle is measured through a function called *rule function*, which varies according to the problem being dealt with. It simulates the "environment" in which the individual is inserted [18]. The learning of the particles is embedded in the position and the velocity updating equations. At each time instant, the displacement of each particle is looking for the best position and its velocity is updated. The updating of the velocity depends on a comparison of the particle current position with the local best and global best parameters. The velocity equation also depends on random constants and the inertia weight. The importance of inertia lies in the fact that the function has to avoid the early convergence in a local best parameter and provides the particles ways to find the global best parameter. This process occurs continuously until all the particles converge to the global best parameter results, which is the best solution to the problem.

#### V. ALGORITHMS IMPLEMENTATION

To implement the GA and PSO approach in the restoration problem is necessary to structure the information of power system according to environment of the application of GA and PSO. For this proposal, the large scale Distribution\_System\_01 is used [7], Fig. 4.

##### A. Genetic Algorithm Implementation

Each individual receive a *value*. Therefore, how much bigger is the individual value it will be better. In other words, how much bigger is the individual value it will has more possibility of being the potential solution of restoration. The individual value is determined by the Eq. 1:

$$\text{Value}(\text{individual}) = 0.5 \times f_1(x) + 0.1 \times f_2(x) + 0.3 \times f_3(x) + 0.1 \times f_4(x) \quad (1)$$

Where:  $f_1(x)$  = Total of Supplied Loads/ Total of Unsupplied Loads;  $f_2(x) = 1/(\text{Amount of Loop} + 1)$ ;  $f_3(x) = 1/(\text{Overload Factor})$ ;  $f_4(x) = 1/(\text{Total of Overload Lines})$ .

According to Eq. 1, the weights are chosen empirically. For this work, the criterion of judgment is based on unsupplied loads with the weight of 0.5, followed by overload factor of system with the weight of 0.3, overload transmission line number with the weight of 0.1, and number of created loops with weight of 0.1. The parameter of Crossover Rate is 0.9 and the Population is constituted by 12 individuals. In the following, various GA parameters are presented.

**Chromosomes Structure** - Each gene of the chromosomes presents the information of a switch that composes just one transmission line of system. This switch is normally opened – NO in the original configuration. The normally closed – NC switches don't compose the chromosome. If the original configuration of system presents  $N$  lines NO then each chromosome will has  $N$  genes. The gene is a binary number, 0 or 1. The value 0 means that the switch state is NO – normally open or without energy. The value 1 means that the switch state is NC – normally closed or with energy. Now it is necessary to structure the information of power system. Each line of the system is represented by two consecutive nodes,

according to Fig.6. In this scheme, the full lines are switches NC, the hatched lines are switches NO, and there are three circuits. A data base is created for storing the information about system lines. They are: line identification, initial node, final node, status of line, maximum power of line, Node (Load), Demand Power, and Circuit.

**Chromosomes Evaluation** - The chromosomes require an evaluation procedure for their feasibility. Several functions are presented in order to identify the chromosomes potentially and its validation.

**Function Unsupplied Loads** - This function identifies the amount of loads without energy along the system after a contingency.

**Function Loop** - The distribution system presents a radially topological structure. In other words, the system can't present the formation of meshes or loop. Then the Function Loop identifies the number of loop formation during the restoration process.

**Function Overload Factor** - Each system line possesses a transmission capacity, that is, a maximum power. The Function Overload Factor deals with the maximum and current power.

The maximum power parameter is in the data base but the current power parameter must be calculated by using a *Load Flow Program*. The Function Overload Factor is determined by Eq. 2:

$$OF_i = \frac{\sum_{m=1}^N (MP_m - CP_m)}{N} \quad (2)$$

Where:  $N$  = Number of transmission lines closed;  $i$  =  $ith$  chromosome;  $m = 1, 2, \dots, N$  (Transmission Lines);  $OF_i$  = Overload Factor for the chromosome  $i$ ;  $MP_m$  = Maximum Power of transmission line  $m$ ;  $CP_m$  = Current Power of transmission line  $m$ .

**Function Overload Lines** - This function is a sub-product of Function Overload Factor. It determines the number of overload transmission lines.

### B. Particle Swarm Implementation

PSO Technique is applied to get a restoration solution based on the system functional configuration changes [11, 12]. It is obtained by Algorithm 1, Fig. 2, whose purpose is to close Normally Opened Switches- NO. When the solutions presents overloaded lines, the program makes use of the Algorithm 2, Fig. 3, whose objective is to open Normally Closed Switches-NC in order to remove the overload. In both of the algorithms each particle represents a solution of a given problem. In the proposed approach, the problem is defined as the restoration of electric power distribution system. The solution is defined as being the switches that must have their final status changed. Each particle is represented by a matrix, where the number of lines is equal to the total number of particles established and the number of columns is equal to the number of NO - Algorithm 1 - or NC - Algorithm 2. The switches may assume binary values, 0 or 1, where 0 means opened switch and 1 means closed switch. It was verified using tests accomplished empirically with the computer program that 10 particles is the

ideal number to work with in both of the algorithms.

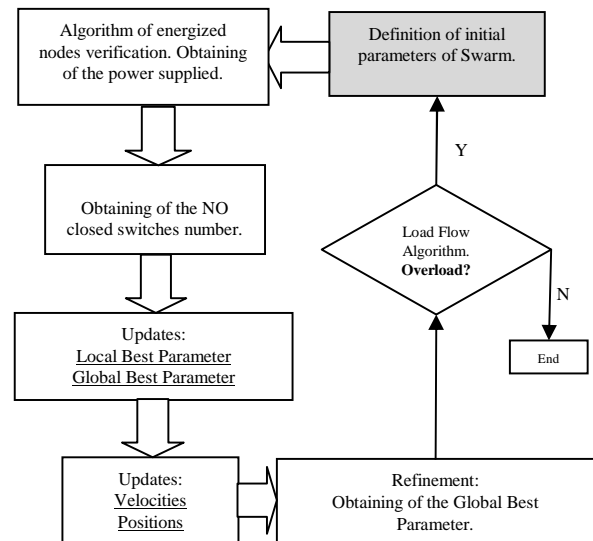


Fig. 2. Flowchart of Algorithm 1.

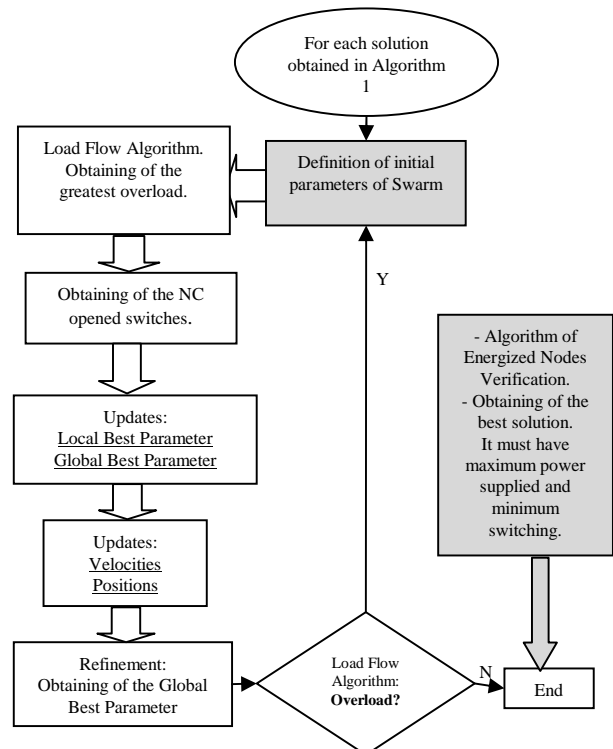


Fig. 3. Flowchart of Algorithm 2.

Firstly, in each algorithm the numbers of particle colony is generated randomly, as well as the velocities, local best and global best parameters. This is done by using random constants and considering the initial velocities equals to zero. At each iteration of the process, the velocities are updated and also the positions of the particles based on the velocities. The local best and the global best parameters are only updated in case they are considered better than the previous iteration. This is established by the *rule function*, which measures the quality of each individual in the swarm. The proposed velocity

equation is normalized due to work with discrete numbers, 0 or 1.

However, the interval is extended to [-1;1] with the purpose of increasing the velocity values number and improving the program efficiency during its execution. This means that: closed switch is equal to 1 and opened switch is equal to -1. This new interpretation may be explained as: at the end of a particle position updating, if the velocity value is lower than 0.6 (in case of Algorithm 1) or -0.6 (in case of Algorithm 2), then it is rounded to -1, otherwise to 1.

The velocity equation is written trying to guarantee the approximation of the particles to the global best parameter and not to the local best parameter. The formulas used in PSO were defined in [11,12], and they are:

$$v(t + 1) = w * v(t) + (1 - w) * [r * (l(t + 1) - x(t + 1)) + (1 - r) * ((g(t + 1) - x(t + 1)))] \quad (3)$$

$$v(t + 1) = (1 - w/1.5) * v(t) + (w/1.5) * [r * (l(t + 1) - x(t + 1)) + (1 - r) * ((g(t + 1) - x(t + 1)))] \quad (4)$$

$$x(t + 1) = x(t) + v(t + 1) \quad (5)$$

$$w = (1 - t / ni) \quad (6)$$

Where:  $i$  = counter for the number of particles;  $t$  = counter for the number of iterations;  $v(t)$  = particle velocity  $i$  in the iteration  $t$ ;  $x(t)$  = particle position  $i$  in the iteration  $t$ ;  $r$  = random constant, random number between 0 and 1;  $l(t)$  = local best parameter of particle  $i$  found in the iteration  $t$ ;  $g(t)$  = global best parameter found in the iteration  $t$ ;  $w$  = inertia weight in the velocity equation;  $ni$  = total number of iterations;  $np$  = total number of particles.

Equation (3) is only used in Algorithm 1 and (4) is only used in Algorithm 2. Equation (5) is position updating and (6) is inertia weight updating, and they are used in both of the algorithms. The program will repeat Algorithm 1 until a NO switch to be closed or the maximum iteration number is reached. The rule function is related on the restoration problem. First, the Algorithm 1 uses the *Algorithm of Energized Nodes Verification*, which creates a list of the status of each node, with or without energy. Each line of the system is represented by two consecutive nodes. All the status nodes are verified. By applying this analysis to the whole system, then the power of the energized nodes are added. One of the criteria specified for the algorithm optimization is to maximize the amount of the power demand supplied to the system. Finally, the Algorithm 1 applies the criterion of the minimization of the NO closed switches number. The local best and the global best parameters update if the current position presents better performance in relation to the previous iteration.

Next step, the Algorithm 1 verifies if there are overloaded lines using an adapted Load Flow Algorithm. This algorithm

has been adapted to work for radial systems and line losses are not considered. Thus, the computational program obtains the power flow in each line of the distribution system. The current power flow in each line is compared with its maximum capacity. In case there are overloaded lines, the program saves this solution and returns to Algorithm 1 in order to try another solution. If there are solutions without overload lines, the best solution is produced by PSO algorithm. The Algorithm 2 is used when only overloaded line solutions are produced by Algorithm 1. The Algorithm 2 searches a solution with maximum power supplied and minimum number of NC opened switches. The goal of the Algorithm 2 is to remove overload of each distribution line opening NC switches. The Algorithm 2 computes a list of the overloaded lines and tries to eliminate the overload of the line with the greatest value in each iteration of each particle. After the iterations are finished, the program returns to Algorithm 1 attempting to close another NO switch in order to maximize the power demand supplied. It is done keeping the system radially topological structure.

The best solution is chosen after an association of each possible NO closed switch (Algorithm 1) with NC opened switches (Algorithm 2) and second NO closed switch (Algorithm 1), if it exists. This solution is made by the Algorithm of Verification of Energized Nodes and Load Flow Algorithm in order to classify the solutions according to the previous defined criteria. In the case where no solution exists or the proposed algorithm finds a not appropriated solution, the methodology always blocks system restoration with power demand supplied lower than power in failure situation.

## VI. NUMERICAL EXPERIMENTS – CASES STUDY

The practical results associated to proposed PSO and GA are demonstrated in this section. For this proposal, the large scale Distribution\_System\_01 is used [7], Fig. 4. Two types of cases are illustrated as follows and the power demand supplied is 100% for all cases.

### A. Type 1 Case Study – Several Solutions

This is the type of case in which the failure on the line causes a reduction in the number of loads supplied in the system and there are several solutions of closing and opening the switches which enable to find an optimized restoration of the system. Table I presents several failure simulations on the system's lines, the PSO and GA solutions to these failures.

### B. Type 2 Case Study – Unique Solution

In this case, it is analyzed the failure on the line that causes a reduction in the number of the system loads and there is unique solution of closing and opening the switches that restores the system. Table II presents several failure simulations on the system's lines, the PSO and GA solutions to these failures.

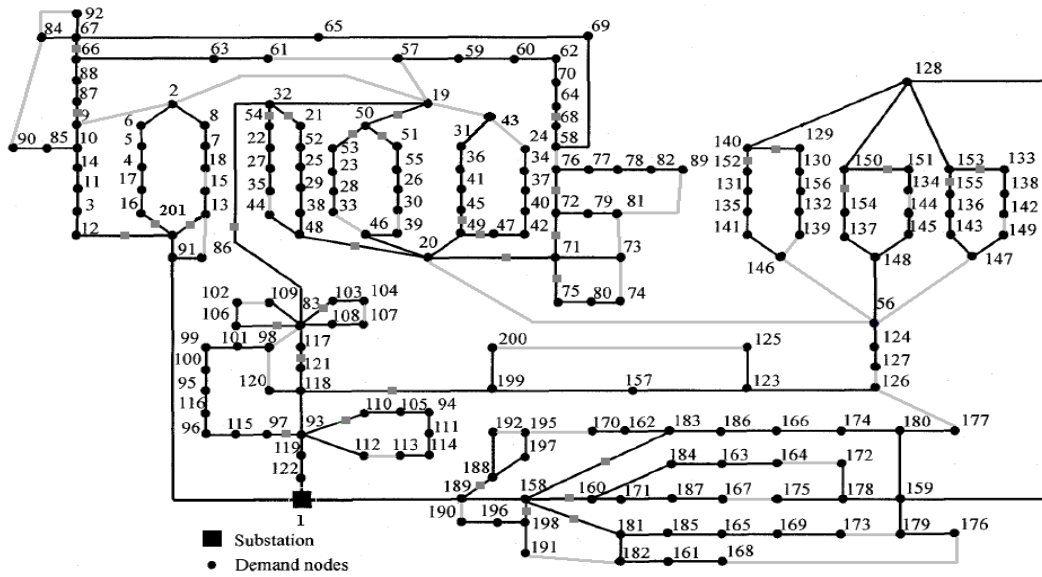


Fig. 4. Distribution Distribution\_System\_01 with all the possible lines, including functional configuration information [7]. Light lines are NO and dark lines with gray marker are NC.

TABLE I  
TYPE I CASE STUDY – SOME SIMULATIONS – SEVERAL SOLUTIONS

| Examples     |       | PSO Restoration Situation |           | GA Restoration Situation |           |
|--------------|-------|---------------------------|-----------|--------------------------|-----------|
| Failure Line | P%    | NO                        | NC        | NO                       | NC        |
| 1 - 122      | 54.51 | 2 - 19                    | 117 - 121 | 20-56                    | 48-20     |
|              |       | 126 - 177                 |           | 2-19                     | 2-19      |
|              |       | 19 - 57                   | 20 - 48   | 19-57                    | 64-70     |
|              |       | 20 - 56                   |           | 2-19                     | None      |
|              |       | 19 - 57                   | 117 - 121 | 126 - 127                | 117 - 121 |
| 9 - 10       | 89.99 | 84 - 90                   | None      | 76-58                    | 59-60     |
|              |       | 2 - 9                     | None      | 19-57                    | 20-71     |
| 13 - 201     | 99.51 | 15 - 18                   | None      | 90-84                    | 59-57     |
|              |       | 13 - 86                   | None      | 2-9                      | 62-60     |
| 19 - 32      | 93.91 | 33 - 46                   | None      | 19-57                    | 62-60     |
|              |       | 19 - 57                   | None      | 76-58                    | 2-9       |
|              |       | 2 - 19                    | None      | 2-9                      | 72-76     |
|              |       | 19 - 43                   | None      | 2-9                      | None      |
| 12 - 201     | 86.75 | 30 - 39                   | None      | 19-57                    | 62-60     |
|              |       | Unique Solution           |           | 19-57                    | 62-60     |
|              |       |                           |           | 76-58                    | 72-76     |
|              |       |                           |           | 2-9                      | None      |

CONTINUE

| Examples     |       | PSO Restoration Situation |           | GA Restoration Situation |         |
|--------------|-------|---------------------------|-----------|--------------------------|---------|
| Failure Line | P%    | NO                        | NC        | NO                       | NC      |
| 56 - 148     | 99.19 | 20 - 56                   | None      | 126-127                  | 38-48   |
|              |       | 126 - 127                 | None      | 20-56                    | 126-127 |
|              |       | 56 - 147                  | None      | 126-127                  | 135-141 |
| 93 - 118     | 62.98 | 83 - 98                   | None      | 147-56                   | 143-147 |
|              |       | 98 - 120                  | None      | 20-56                    | 38-48   |
| 99 - 100     | 98.66 | 98 - 120                  | None      | 126-127                  | None    |
|              |       | 83 - 98                   | None      | 9-1208                   | None    |
| 128 - 150    | 94.31 | 20 - 56                   | None      | 98-83                    | 62-60   |
|              |       | 126 - 127                 | None      | 19-57                    | None    |
| 153 - 155    | 97.03 | 142 - 149                 | None      | 120-98                   | 83-32   |
|              |       | 56 - 147                  | None      | 2-19                     | 83-32   |
| 1 - 189      | 62.87 | 58 - 76                   | 117 - 121 | 9-1208                   | None    |
|              |       | 126 - 127                 |           | 98-120                   | None    |
|              |       | 2 - 19                    | 117 - 121 | 83-98                    | 117-83  |
|              |       | 126 - 127                 |           | 20 - 56                  | 38-48   |
| 19 - 32      | 93.91 | 19 - 57                   | 117 - 121 | 126-127                  | 124-127 |
|              |       | 126 - 177                 |           | 126-127                  | 126-177 |
| 1-91         | 82.62 | 2 - 19                    | 117 - 121 | 19-57                    | 70-62   |
|              |       | 126 - 177                 |           | 76-58                    | 67-65   |
|              |       | Unique Solution           |           | 19-57                    | 58-68   |
|              |       |                           |           | 76-58                    | 69-58   |

P=Power Demand Supplied; NO= Normally Opened Switch Closed; NF= Normally Closed Switch Opened.

TABLE II  
TYPE 2 CASE STUDY – SOME SIMULATIONS – UNIQUE SOLUTION

| Examples     |       | PSO Restoration Situation |              | GA Restoration Situation |              |
|--------------|-------|---------------------------|--------------|--------------------------|--------------|
| Failure Line | P%    | NO                        | Failure Line | NO                       | Failure Line |
| 1 - 91       | 82.62 | 2 - 19<br>20 - 56         | 20 - 48      | Several Solutions        |              |
| 76 - 77      | 98.16 | 81 - 89                   | None         | 81 - 89                  | None         |
| 93 - 110     | 95.68 | 112 - 113                 | None         | 112 - 113                | None         |
| 128 - 140    | 93.62 | 56 - 146                  | None         | 56 - 146                 | None         |
| 160 - 184    | 98.32 | 164 - 172                 | None         | 164 - 172                | None         |
| 2 - 8        | 99.18 | 15 - 18                   | None         | 15 - 18                  | None         |
| 10 - 85      | 99.10 | 84 - 90                   | None         | 84-90                    | None         |
| 12 - 201     | 86.75 | 2 - 9                     | None         | Several Solutions        |              |
| 32 - 54      | 98.24 | 35 - 44                   | None         | 35-44                    | None         |
| 40 - 42      | 97.12 | 24 - 43                   | None         | 24 - 43                  | None         |
| 50 - 51      | 96.89 | 30 - 39                   | None         | 30 - 39                  | None         |
| 50 - 53      | 97.99 | 33 - 46                   | None         | 33 - 46                  | None         |
| 63 - 66      | 98.91 | 57 - 61                   | None         | 57-61                    | None         |
| 71 - 75      | 98.22 | 73 - 74                   | None         | 73 - 74                  | None         |
| 78 - 82      | 99.08 | 81 - 89                   | None         | 81 - 89                  | None         |
| 83 - 106     | 99.08 | 102 - 109                 | None         | 102-109                  | None         |
| 83 - 108     | 99.57 | 104 - 107                 | None         | 104-107                  | None         |
| 111 - 114    | 98.91 | 112 - 113                 | None         | 112-113                  | None         |
| 132 - 156    | 98.85 | 139 - 146                 | None         | 139 - 146                | None         |
| 138 - 142    | 97.69 | 142 - 149                 | None         | 142 - 149                | None         |
| 145 - 148    | 99.16 | 134 - 144                 | None         | 134 - 144                | None         |
| 160 - 171    | 98.58 | 167 - 175                 | None         | 167 - 175                | None         |
| 161 - 168    | 99.85 | 168 - 176                 | None         | 168 - 176                | None         |

P=Power Demand Supplied; NO= Normally Opened Switch Closed; NF= Normally Closed Switch Opened.

## VII. CONCLUSION

This paper presents a comparison for system restoration between two intelligent methods: particle swarm optimization and genetic algorithm. The main idea of the paper is to compare the performance of these two method for different unexpected open switches. Each method creates a list of switches that must be operated (open or close) in order to give the best solution for the system reconfiguration. The criterion used in the judgment is based on unsupplied loads, overload factor, overload transmission line number, and number of created loops. An illustrative example is shown and some results are presented and discussed.

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