International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 19 (2017) pp. 8120-8124

Genetic Algorithm used for Improving the Preventive Maintenance Processes for Electricity Distribution Companies

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Abstract

The objective of this work is to improve the preventive maintenance processes used by the electricity distributions companies. This paper is focused on the maintenance of a transformation module in a mid-voltage electrical substation, specifically on the times and prices. Starting from actual data of a mid-voltage electrical substation for a specific transformation module, a Genetic Algorithm was implemented in order to optimize the use of the resources assigned by the company for the preventive maintenance of this module. This optimization was done theoretically by means of simulations based on real data of the substation of a complete year. After several simulations, the proposed algorithm always shows appropriated results, which never overpass the restrictions of available economic resources and out-of-service times of the transformation module, giving the highest priority to the activities unattended for long time. Using the proposed approach, the process of preforming a preventive maintenance process can be highly improved, due to it stops being relative to the expertise of the engineer in charge, which not only produces the best results.

Keywords: Genetic Algorithm, Optimization, Preventive Maintenance, Transformation Module.

INTRODUCTION

Energy distribution companies have special departments for planning and executing the maintenance of high and mid-voltage substations. Generally, that maintenance process is just planned by means of following the directions given by the manufacturers of the different components of the system, which produces some many problems such as: materials unavailable at the moment of the maintenance, under or over-storage of specific maintenance materials, bad planning of the workforce for the execution and the most important, delays. As it is known, most of the maintenance activities imply disconnection times (out-of-service times), this means that, those maintenance activities have to accomplish with national or international regulations about disconnection times. Transformation modules are the ones which imply the most money investment and long disconnection times when it is necessary to do it preventive maintenance. Due to that, the work presented in this paper has as a target, the optimization of the resources assigned for doing the preventive maintenance to a transformation module in an electrical substation. That is why, the use optimization techniques to improve processes in distribution systems has been proposed [1-5], additionally the use of bio-inspired algorithms to solve problems in electrical engineering nowadays is more common [6], specially Genetic algorithms (GAs) are widely used [7], specifically for designing and planning power and distribution systems [8-14]. For the process of preventive maintenance in power and distribution systems some approaches have been proposed [15-18], all of them are based on GAs as optimization engine. Due to genetic algorithms are very useful for solving complex optimization problems like the ones which involve a lot of variables and restrictions, they were selected to solve the problem of preventive maintenance scheduling.

METHODOLOGY

This paper is focused on the optimization of the preventive maintenance process of a transformation module in an electrical mid-voltage substation. This specific transformation module is composed by: a power transformer (7/10 MVA, 34,5/11,4 kV), two disconnectors (34,5 and 11,4 kV), two power switches (34,5 and 11,4 kV), two lightning rods (34,5 and 11,4 kV), and an earthing system. Those components are the ones of a typical substation.

Preventive maintenance of a transformation module:

The process of the preventive maintenance of the transformation module is composed by around 150 different activities that can be applied to the components of the module, including some needed mechanical parts. When a maintenance process is scheduled only a few of those activities are programed, depending on the out-of-maintenance times of each component and the assigned budget. The Table 1 shows some of the activities to do to the components of the transformation module, during a programed preventive maintenance. For differentiate the components affected by each activity, the

Table 1 uses the next nomenclature: *D* for disconnectors, *PT* for the power transformer, *PS* for power switches, *LR* for lightning rods, *E* for the earthing components and *M* for the rest of mechanical components.

Table 1: Some of the maintenance activities applied to the different components of the transformation module.

Activity	*Comp.*
Replacement of main terminals of the AT disconnector	*D*
Maintenance of power terminals and ground connections of the AT disconnector	*D*
Adjustment of bases of the MT disconnector	*D*
General cleaning and painting of the AT disconnector	*D*
Noise level measurement in the power transformer	*PT*
Maintenance of the Busholz Relay in the power transformer	*PT*
Control tests of mechanical protections of the power transformer	*PT*
General painting of the transformer (Power transformers greater than 10MVA)	*PT*
Dynamic tests of the AT power switch	*PS*
Terminals resistance measurement of the switch of 11.4 kV	*PS*
General cleaning of the AT power switch	*PS*
Partial maintenance of the switch of 11.4 kV	*PS*
Replacement of one lightning rod (up to 34.5 kV)	*LR*
Replacement of the discharge counter of the lightning rod	*LR*
Power wires isolation measurement	*E*
Net resistance measurement of the earthing	*E*
Replacement of damaged screws in doors and structures	*M*

For the preventive maintenance process, each transformation modules have an amount of assigned activities to do, those ones were previously defined by test criterion. Each activity includes materials and workforce (those depend on the specific component), which are joint as a standardized cost function that is the base for planning the process budget.

Considering that most of programed preventive maintenance processes only affect one of the submodules of the transformation module, the experiments planted in this paper just take into account the maintenance process over one of the disconnectors, during a year (4 maintenance processes).

The proposed genetic algorithm:

In order to reach an optimum use of the assigned resources for the preventive maintenance process, an optimization process based on genetic algorithms was proposed. This algorithm takes as inputs: the assigned budget for the specific maintenance process (in USD), the disconnection times allowed for the transformation module (according with international regulations), and the dates of the last done maintenance activities, and finally it computes the best list of activities to do in that maintenance, prioritizing the components which have the longest non-attendance times and minimizing the out-of-service time, without overpassing the initial budget

Fitness function:

Due to the target of the genetic algorithm is the optimum use of the assigned resources for a specific maintenance work, it starts from the cost functions of each activity, the allowed out-of-services times, the table of last maintenance dates and the assigned budget. For defining it as an optimization problem the next list of input parameters was generated:

- *n*: Number of established activities for the preventive maintenance to the transformation module.
- *B*: Budget assigned to the execution of the preventive maintenance (in USD).
- *T*: Disconnection time of the transformation module in the substation for the maintenance (in hours).
- *AP*: Array of prices of each activity *i* including both, workforce and materials (in USD).
- *OAT*: Array of the out-of-attendance times about the maintenance of each component of the transformation module (in days).
- *AT*: Array of times for executing each maintenance activity (in hours).

Also, the algorithm uses binary variables to define if a specific activity is done or not. These binary variables are organized as an array *x* of *i* elements, where each variable is set in "1" if the activity is done and "0" if not. Starting from this vector, three functions were formulated to optimize the problem, taking into account its three main goals. The first one is a cost function $f_1(x)$, which is based on the initial budget and the cost (materials and workforce) of each activity. It pretends to minimize de difference between the total budget and the summation of the costs of all active activities, without overpassing the said budget. Thus, the budget is exploited to the maximum possible.

$$f_1(x) = \left(B - \sum_{i=1}^{n} AP_i * x_i \right)$$

The second function $f_2(x)$, is an activity attendance function. This one pretends to minimize de difference between the summation of the out-of-attendance times for all the activities and the summation of the same ones for all the active activities for the current maintenance process. Thus, the components of the transformation module with the longer out-of-attendance times, are prioritized.

$$f_2(x) = \left(\sum_{i=1}^{n} OAT_i - \sum_{i=1}^{n} OAT_i * x_i\right)$$

The third function $f_3(x)$, is an activity duration function. This function pretends to minimize de difference between the total allowed time for the maintenance process and the summation of the expecting times of all the active activities, without overpassing the said maximum time. This approximation, assumes that all the programed activities have to be done in sequence, but not in parallel.

$$f_3(x) = \left(T - \sum_{i=1}^{n} AT_i * x_i\right)$$

As the three functions were defined as minimization ones, they can be joint as only one, in order to solve just one function with the genetic algorithm. The total fitness function is shown as follows:

$$f(x) = f_1(x) + k_a * f_2(x) + k_b * f_3(x)$$

Due to each function gives different kind of output variables units (USD, days and hours, respectively), it was necessary to turn them into a unique kind of variable, by means of using proportional weights, in order to reach the same scale with the output of the three functions. As design criterion, it was decided that the three functions were weighted equal, due to each one is as important as the others. First function $f_1(x)$ is used as the main one, then the others have to be weighted by means of using the constants k_a and K_b. The weight k_a is the proportional factor between the total price of the activities and the summation of the days without attend all activities, and K_b is the factor between the total price of the activities and the summation of hours to be used for doing the preventive maintenance in the transformation module.

Restrictions:

The preventive maintenance for the said transformation module pretends to reach the three previously said main goals: taking advantage of the budget to the maximum possible, prioritizing the activities which have been longer unattended, and finally that the maintenance process does not overpass the allowed time. Therefore, the costs of the activities of the maintenance must be lower than the initial budget; this is described as:

$$f_1(x) > 0$$

Also, the summation of all the execution times of the activities has to be lower than the allowed total time, then:

$$f_3(x) > 0$$

Finally, each activity *i* of the vector *x* must be binary, then:

$$\forall i \in x: (i = 0 \vee i = 1)$$

Genetic algorithm parameters:

First, the chromosomes for each individual were defined as a binary string composed by the *x* vector, then each gen is an activity x_i and the total chromosome has 150 genes, for all the maintenance activities to do over the transformation module. Usually, when a maintenance process is programed, this one is applied only to a sub-module, for instance: over a lightning rod; then, the total amount of activities (and gens) is reduced from around 15 to 25. On the other hand, the population was defined as 50 individuals which were randomly initialized, additionally the fitness scaling of each one was proportional. The selection of individuals for the next generation was defined as a uniform distribution, likewise the mutation function. The reproduction process had a crossover of 80%, and the elitism percentage has defined as 0,05% of the total population size. The type of crossover was single point. Finally, as stop criteria two conditions were considered: a maximum time of 120 seconds per simulation and a maximum of generations of 100.

RESULTS

The results shown here, were obtained after applying the proposed genetic algorithm over the maintenance process of one of the disconnector of the transformation module. This maintenance is composed by 21 activities, so each individual has a chromosome of 21 binary genes. Likewise, the algorithm took as input data of previous maintenance processes of a real mid-voltage electrical sub-station. Starting from the initial data, four sequential simulations were performed (in the months 1, 4, 7 and 10 of the year), considering maintenance budget values of previous years, those simulations include a complete working year of the transformation module. Then, taking the original data, the first maintenance process is optimized and after that other tree projections were performed to obtain the next results. First of all, about the invested money for the maintenance, the Table 2 shows the comparison of stablished budget and the one which was actually used, for the four performed maintenances.

Table 2: Results of the comparison of the stablished budgets and the money actually used, for four maintenance processes, in a year of working.

Month	*Budget (USD)*	*Executed (USD)*	*Using percentage*
1	1.000	756,6	75,6%
4	1.000	883,3	88,3%
7	670	544	81,2%

10	1.170	838,3	71,6%
Year	**3.840**	**3.022,2**	**78,7%**

The total using percentage of the assigned budget for the four maintenances done was in average 78,7%, which overpass in about 12%, the average of the budget using percentage in the maintenance of the previous year applied to the same submodule. Also, the comparison between the estimated time and the real used time is shown in Table 3. Likewise, the percentage of unused time is in average 3,2%, which improves about 1% the one of the previous year.

Table 3: Results of the comparison of the estimated time and the used time, in four maintenance processes, in a year of working.

Month	*Estimated time (Hours)*	*Used time (Hours)*	*Unused time percentage*
1	22	21,5	2,3%
4	16	16	0%
7	24	23,5	2.1%
10	18	16,5	8,3%
Year	**80**	**77,5**	**3,2%**

On the other hand, the days of out-of-attendance of the activities of the maintenance were analyzed. The Figure 1 shows the comparison between the out-of-attendance days of each activity in the month 1 and in the month 10 (before and after applying the proposed algorithm).

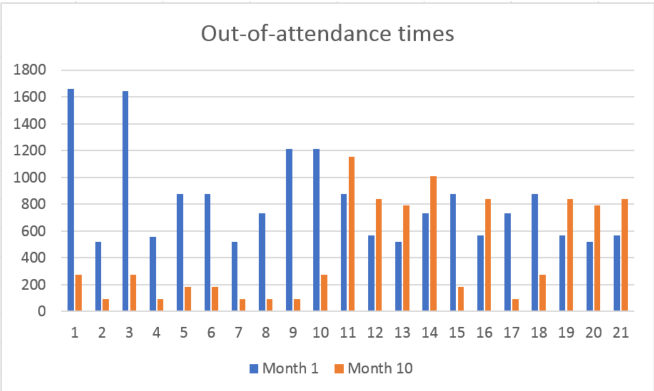

Figure 1: Days of out-of-attendance (without maintenance) of each activity for the months 1 and 10.

The figure 1 shows that 13 of the 21 activities were attended after performed the four maintenance processes, due to their out-of-attendance times were reduced. Therefore, it means that the proposed algorithm defined that the other 8 activities were not a priority at the moment of each preventive maintenance processes. In average, the total out-of-attendance time was improved in the month 10 in about 46% referring to the month 1. This algorithm, generates its own activity selection criterion based on the stablished disconnection time of the device or system to do maintenance, and the total budget, but anyway, the assigned budget almost never is totally used.

CONCLUSIONS

The resource optimization approach proposed in this paper was applied to the preventive maintenance process of transformation module in a mid-voltage electrical substation, but it is able to be replicated in any type of substation of any voltage level. The obtained results show a good potential to solve this kind of optimization problems, but also it is possible to prove other type of optimization techniques (classical or new ones) in order to compare results and performances.

Due to the random character of the GA initialization, only de 85% of the times it reaches a feasible solution, before falling in one of the stop criteria. It is possible to improve this effectiveness percentage, giving much more time (about 600 sec.) as a stop criterion, which makes hard its application on real experiments.

Due to the computing effort of evaluating the total fitness function over the 50 individuals of the population, when each one has 150 chromosomes (total of maintenance activities), the computing total time is about 3 hours. That time makes the algorithm impractical, that is why, it is proposed to subdivide the problem in their 7 submodules. Thus, the total time will be just 7 minutes, this time was obtained extrapolating the time that spent the algorithm for the disconnector (only one submodule of 21 activities), that was 64 sec. The used PC has the next features: Intel core i7 2,2 GHz processor and 8 GB of RAM.

ACKNOWLEDGMENTS

This work was supported by the District University Francisco José de Caldas, through CIDC and the Technological Faculty. The views expressed in this paper are not necessarily endorsed by District University. The authors thank all the students and researchers of the research group ARMOS for the data survey and the evaluation carried out on model.

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