Methodology for Service Restoration based Adaptive-Selective Tabu Search (ASTS)

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Abstract

The objective this paper is to present the development methodology, called Adaptive-Selective Tabu Search – ASTS, proposed to optimization of the transmission power systems restoration. The methodology is based on Tabu Search (TS) and Reactive Tabu Search (RTS) techniques with elements similar to those found in other Artificial Intelligent Methods, as elitism, aleatority and future analysis. These elements provide diversification and intensification mechanism to the search, beside of the predictive controlled characteristics. The proposed method is applied to the 20-nodes transmission real system and the simulations results obtained are satisfactory as well as the comparisons with other methodologies.

1. Introduction

The restoration of electric systems after total or partial blackouts is a job that demands an enormous knowledge of norms, instructions and, mainly, the acquired experience for the specialist, the system's operator, along the time.

In a general way, the restoration after disturbance embraces the following stages:

- Analysis and identification of the location and it disturbance causes;
- Equipments or affected area isolate;
- Preparation of the facilities for restoration;
- Equipments and facilities restoration, inside of the established criteria.

Thwarting your apparent simplicity, the restoration of electric systems is an extremely complex process, standing out as principal complication factors:

- Psychological stresses of the operators;
- Torrent of information in the Supervision System Control – SSC;
- Volume of rules;
- Safety of employees, people and facilities;
- Quality of energy;
- Dependence of other Companies and of the National Electric System Operator;
- Optimize.

It is evidenced, therefore, the need of the development of support tools to the operation and restoration of the electric systems, making her to be worth of the possible earnings through optimize computational techniques. However, the essential figure of the operator must be detached, which with holds the basic knowledge and reasoning to the well-known success of the National Interlinked System operation.

In this sense, the electric section companies and research institutions are working in the computational modeling of the "specialist" knowledge, through techniques of artificial intelligence.

The bibliographical references [1,2] evidences the great application of Tabu Search - TS and your variations in the optimize of electric systems restoration, however gone back to systems of final distribution, understood between the distribution substations and the consumers, composed by the feeders.

That is due to the fact of the final distribution systems restoration to be a combination problem, where it is wanted as answer a static picture of the system, with the configuration great second a cost function. Already the transmission and sub-transmission systems restoration is a sequence problem, where it is necessary a new optimize to each accomplished action.

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2. Tabu Search (TS)

Tabu Search is an efficient heuristic procedure applied in solutions of optimization problems, which is projected to help other optimization methods or its components escape from the local valley [3].

It is based on combing the hill climbing method of local search with the adaptive memory in order to make the search more flexible. Therefore, TS differs from other techniques that do not use memory procedures, as Simulated Annealing (SA) do is; or utilize the technique in a strict way, as branch and bound [3]. The memory application is based on procedures presented as follows:

- Flexible attributes – memory structures which enable the variation of the parameters and search past history;
- Associative adjusting mechanism – interaction between exclusion and inclusion mechanism parameters;
- Different Times Memory Function – enables intensification and diversification search.

This method can be applied in various areas, that is, financial analysis, distribution power system, environment protection, logistic, etc., and has presented optimal or near optimal results.

TS has two distinct strategies to use memory: short period memory, more aggressive, and long period one, used as a strategy for technique improvement [4, 5].

3. Reactive Tabu Search (RTS)

Reactive Tabu Search - RTS is a variation of TS original algorithm, which proposes the integration of reactive feedback schemes to determine appropriate free on-line parameters [6].

The objective of RTS is to supply bigger flexibility to technique allowing its application in resolution of most problems, as well as to avoid the trial and error methodology.

The main characteristics of this method are [7]:

- Self-tuning of tabu length (TL);
- Escape mechanism;
- Data management for storing the past history of the search.

4. Developed Methodology

The developed methodology, Adaptive-Selective Tabu Search – ASTS, is based initially only on the adaptation of TS original algorithm to apply in problem of transmission system restoration. However, during this process, the opportunity of methodology improvement was observed, incorporating some procedures of RTS; and this technique was provided with elements similar to those found in other Artificial Intelligent Methods. ASTS method incorporates elements of elitism and aleatority, similar to the parameters belongs to Genetic Algorithm (GA), characterized by natural selection and genetic operator such as mutation, respectively.

Its application is recommended to optimize the rule-based sequence problems, such as service restoration in power systems after interruption.

The characteristics and varieties in relation to Tabu Search (TS) and Reactive Tabu Search (RTS) can be expressed as follows:

4.1. Power System Modeling

The power system has the simple pattern, according to physical structure. The electrical parameters were not shaped. Service restoration was considered by recovery of lines through off conditions breakers and available voltage substation bus. To do so, the following parameters were shaped: substations, lines, breakers, and sectionalizing switches, turn on/turn off conditions of the voltage at substations and lines, and substations importance.

The region chosen for practical application of service restoration is part of power system of Mato Grosso do Sul State, where Campo Grande is located and where the main supply sources are. The system includes 20 nodes and is shown in Figure 01.

The priority of substations was determined taking into consideration the following characteristics: quantity of load in the substation, importance of these loads and significant substations to the remainder of power system. From these data, a list from the most important to the least important substation was prepared.

4.2. Tabu Rule (TR)

According to what was exposed previously for this problem, the tabu rule (TR) losses its function because, in the re-composition, the movements are not repeated and it is necessary to restrain them.

On the other hand, the importance of rules in this process was highlighted.

Tabu list (TL) is then transformed into tabu rule (TR), which is a bank of logical rules containing information of operation instructions and operator experience, necessary to the system re-composition.

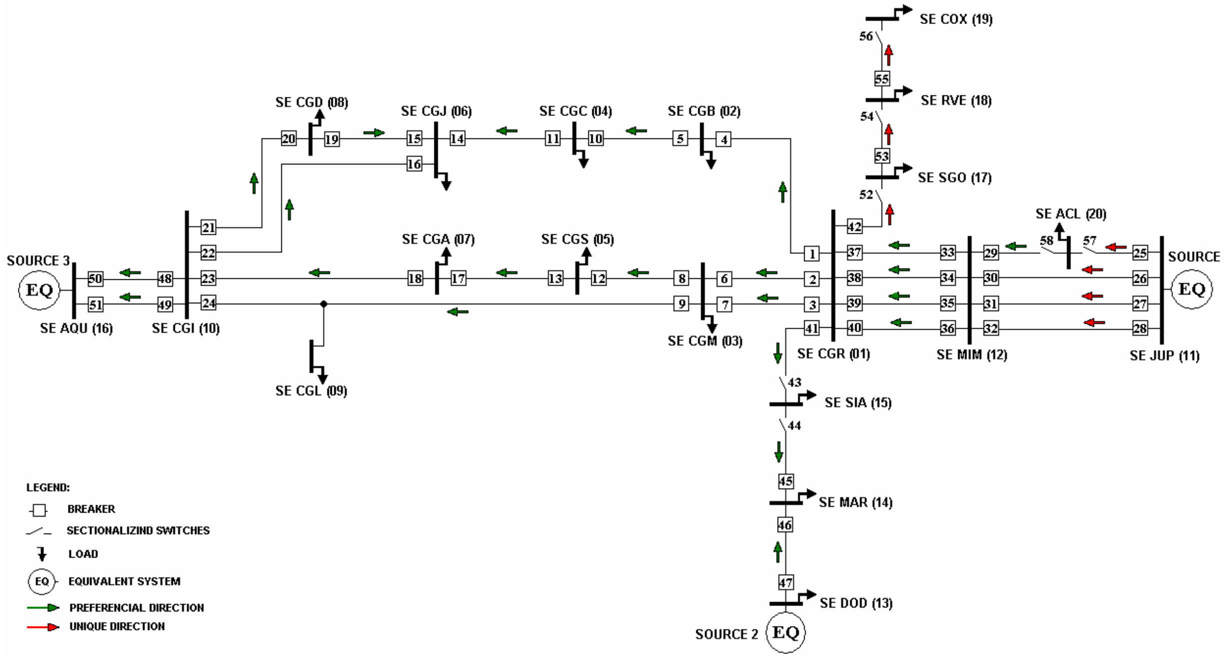

Figure 01 - Power System Modeled

It is highlighted that the complexity to the tabu rule (TR) is intrinsic to the problem it which ASTS is applied, transforming, in this case of electrical system re-composition, into the most time-consuming to be modeled for the technique application.

The rules considered in this problem involve the following characteristics:

- Voltage magnitude limits;
  Example:
  If voltage in A bus=0 and voltage in T.L. A–B=0
  Breaker 01 of T.L. A– B = open
  end
- Energy lines direction - it is verified if a determined line is being energized in a normal direction or otherwise, as well as if this inverse direction is permitted;
- Synchronism closure – the pre-conditions and permissiveness for ring or parallel closure between different sources.

There are specific rules used in more complex situations in the power system operation described below:

- Upstream Energized Lines - check the need for more lines or parallel circuits upstream to permit the continuation of the re-composition.
- Empty Lines - restricts the closure of the parallel circuits of the same empty line.

Tabu Rule (TR) results in a fundamental element in ASTS to identify and filter the electrically doable ways. This process avoids the algorithm analysis of the electrically existing ways, resulting in search improvement.

It is also used to provide subsides to the calculation of the objective function, supplying each solution analysed with punctuation for accomplishment or penalty for rules disobedience, as is presented in item 4.8 (Objective Function).

Tabu rule (TR) may be edited, so as to have alterations in the system topology and updating of operation procedures.

4.3. Aspiration Criterion

In general terms, the rules in tabu rule (TR) are not flexible, that is, they cannot be ignored or disobeyed. However, for some specific situations, aspiration criteria were created, in order to permit more coherence with reality. Such criteria allow the technique to evaluate the need for some rules demanding pre-conditions to be applied.

Some aspiration criteria are presented below:

- Inverse direction – inverts the original direction of energy of a line if the reverse direction is permitted.

- Variation of gain - changes the gain attributed to a determined action according to the system topology.

4.4. Edge Check

An "edge" between contexts to search space is estimated through an important routine for optimization of the search process. This procedure works as an intensification mechanism. It makes use of the following strategies:

- Recognizes the most important substation to be energized;
- Recognizes the energized substations;
- Verify which substation is the nearest of priority, that is, that one requiring less switching operations of the breakers for its interchange. This substation is called "edge";
- Removes the solutions which begin in longer substations than edge substation.

The elimination of out-of-edge substations can be regulate to comprehend *1, 2,….n* steps beyond the edge.

4.5. Elitism and Aleatority

The described algorithm affect, for each iteration, the election of the better answers A which will be estimated in t next steps, so that it permits the analysis not only of obtained gain in actual iteration but also the estimate of the next steps of the process.

This mechanism provides, in each iteration, an intensification of effective search in the appropriate solution space and even estimate if this favourable characteristic is held throughout the process.

Besides better solutions elected A, other solutions B are chosen, randomly, but the elements of B are different from those of A.

Conversely to elitism, the aleatority certain for B requires balance of diversification in each iteration search, and so different regions search will be explored.

However, variables A and B will make the search alternatives increase exponentially with the number of decision variables. Therefore, the determination of A and B values should depend on the problem length, on the precision level and on the desired restoration time. The determination of these parameters is estimated through self-calibration, described in 4.7.

4.6. Feedback and Future Steps

The feedback mechanism allows that chosen solutions through elite strategy and aleatority are analyzed by the following $N + K$ iterations, where N is the actual iteration and K is the number of next steps to be analyzed. The result of this analysis feedbacks the process and defines the best solution space for N iteration based on the following step.

As a result of this process, the number of next steps estimated increases exponentially with the search. Furthermore, the value search, given by the self-calibration process, should to according to the characteristics of power system in this instance.

4.7. Self-Calibration

The restoration of power system has a very large dynamics in performance of each iteration, therefore, the search process must follow this dynamics and self-adjust in each new scheme.

These procedures, called self-calibration on ASTS, allow analysising and adjusting Elitism, Aleatority and Next Steps variables to each iteration through the evaluation of the following electrical system parameters:

- Priority Substation;
- Edge Substation;
- Range Matrix – the matrix contains the number of troubleshooters to surround all substations, always two by two;
- Systemic Conditions – number of sources available to service restoration, ring closure between sources and state of system strategic substations.

4.8. Objective Function

The objective function is modeled according to the expert´s knowledge about his specific problem, in particular, under the focus of the current situation and reflection of the following actions. It should also estimate not only the local aspects of an action but also the reflection in the rest of power system.

Thereby, four main parameters used in restoration of power system were described, such as:

- Substation Restore;
- Obedience to Constraints;
- Systemic Gain;
- Restoration Time.

A weight with values between 1 and 10 responsible for desired control to service restoration was credited for each parameter.

A consequence series to possible solutions are analyzed, inside each parameter, evaluated during the rules checking. These consequences produce points accumulated in its respective values.

Therefore, objective function is calculated through the sum of the pondered parameters.

Through Tabu Rule (TR) modeling and also through the form the objective function was implemented, it has the characteristic to estimate the possible situations to the following iteration of the search.

4.9. Analysis of Results

In order to make possible not only the assessment and analysis of results obtained through ASTS method but also the comparisons with other methodologies, four parameters were established:

- Objective Function: the sum of objective function calculated in each iteration count;
- Computational Effort: the sum of state employed in computational time of the each iteration count (seconds);
- Priority: percentage that expresses the efficiency which the algorithm accomplished restoration of the most important substation in the power system;
- Gain: percentage that expresses the efficiency which the algorithm restored the highest number of substations during the first half of the process, taking into consideration the priority of each substation. It is calculated through objective function accumulated in the middle and at the end of the process.

4.10. Implementation

The ASTS methodology proposed was implemented through software Matlab v7.0, using scripts files and command sequence. The problem was constructed through a principal file, which contains the technique basic structure of the method and modules files with specific routines.

The stop criterion adopted was the conclusion of the re-composition process or its blockage due to some operation constraints.

5. Simulation

The analyses were calculated through ASTS algorithm and, to compare with other techniques, the parameters were varied to simulate, in the same way, the following techniques:

- TS Original - The elitism and the aleatory were considered fixed in 0% and without analysis of future steps, that is, the solution with larger objective function is considered the answer of the iteration;
- Exhausting Search (ES) - Considered the elitism in 100%, aleatory in 0% and the future steps were analyzed, in other words, all the feasible solutions are analyzed. Although the use of the term Exhausting Search, the solutions non feasible are eliminated, reducing the number of analyses.

The simulations were accomplished for three cases with progressive complexity levels, being considered 01, 02 and 03 available sources for restoration. The results are presented below in the graphs.

The objective demanded is the maximization of the parameters Priority, Gain and Objective Function, and the minimization of the Computational Effort.

a) One available source - Jupiá

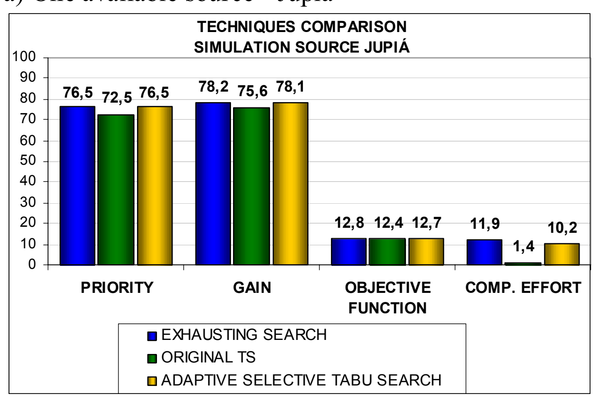

Figure 02 - Simulation with 01 source

b) Two available sources - Dourados and Aquidauana

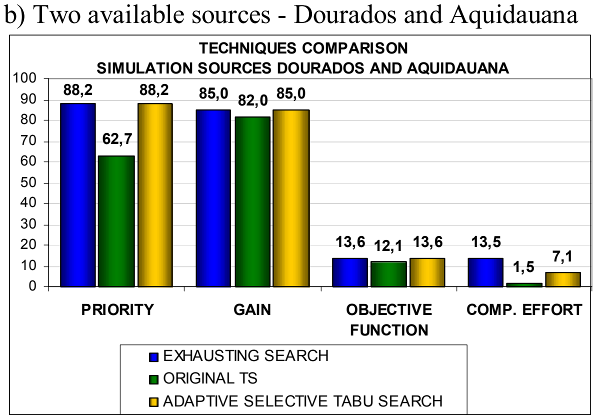

Figure 03 - Simulation with 02 sources

c) Three available sources - Jupiá, Dourados and Aquidauana

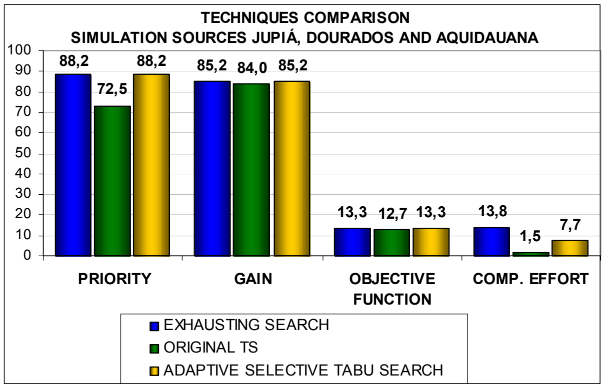

Figure 04 - Simulation with 03 sources

6. Conclusion

For the obtained results, it is observed that for the parameters Priority, Gain and Objective Function, ASTS obtained practically the same values of ES, and always better than TS.

About Restoration Time, clearly TS is faster for not evaluating the future steps. However, the gain of ASTS in relation to ES in this parameter increases according to the problem complexity. For the first case, the gain ASTS / ES is of 14,2%, passing for 44,2% in the third case.

Therefore, concluded that ASTS, although of your aleatory portion, reaches the global maximum of the problem, demonstrated through the comparison with ES. This statement also can be confirmed through an empiric problem analysis. Another important factor is the gain in answer time of ASTS in relation to ES for more complex problems.

Some improvements are susceptible to implementation in the developed methodology, about the systems gains and weights, implementation of load flow for electric answer validation, and optimize of the programming, specially related the analysis of future steps.

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