Task Force on Modern Heuristic Optimization Test Beds
Working Group on Modern Heuristic Optimization
Intelligent Systems Subcommittee
Power System Analysis, Computing, and Economic Committee

Competition

on

Emerging heuristic optimization algorithms for expansion planning and flexibility optimization in sustainable electrical power systems considering uncertainty

Problem Definitions and Implementation Guidelines

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1. AIM OF THE COMPETITION

Like in other engineering fields, the application of heuristic optimization algorithms to solve power system optimization problems is drawing researchers' attention due to their potential to deal with inherent mathematical complexities, such as high dimensionality, non-linearity, non-convexity, multimodality, and discontinuity of the search space. Moreover, the experience gained in the development and use of different types of heuristic optimization concepts motivates further research efforts to devise novel mechanisms for improved search exploration and exploitation.

One of the aims of the Working Group on Modern Heuristic Optimization under the IEEE PES Power System Analysis, Computing, and Economics Committee is to develop power system optimization test beds for evaluating and comparing the general applicability and effectiveness of emerging tools in the field of heuristic optimization (as demonstrated in 2014, 2017, 2018, and 2019 [1], [2] competitions). Therefore, as an initial step it was decided to organize a special panel at the 2020 IEEE PES General Meeting, preceded by a competition focused on the application of these tools for solving transmission expansion planning (TEP) problems proposed considering load and generation uncertainties.

The competition aims to perform a comparative assessment of the search capability of different heuristic optimization algorithms. The assessment will be based on the expected value of the objective function to be minimized. To this end, an encrypted file was prepared, based on the functionalities of the Matlab and MATPOWER toolboxes, in order to perform an automatic evaluation of the objective function and the constraints of the Optimal Power Flow (OPF), as well as to automatically collect and store the results. In this way, the OPF problems are treated as black box tasks, which should be solved for different test cases based on two selected test networks. Preliminary tests have proven optimization test cases to be solvable, but some of them are very hard-to-solve tasks, in which finding feasible solutions is a key challenge. Therefore, the participants are requested to focus exclusively on the implementation of the particular heuristic optimization algorithm to be used, which could include any special strategy for constraint handling or treatment of discrete/binary optimization variables associated with transformer and compensation devices.

Some encrypted .p and normal .m Matlab files, which are intended to easily adapt to any heuristic optimization algorithm, are included in the zipped folder named *test_bed_TEP_V01.zip*. This folder also provides complete details (in MATPOWER format) of each test system. Please read carefully the instructions given in every m-file and in the *readme.txt* file, which provide precise instructions about Matlab based procedural and implementation aspects.

The final results are automatically saved for each optimization test case in formatted .mat files contained in a zipped folder named output_data_implementation_name.zip. These results are needed to calculate the expected value of the objective function and the number of final topologies that are most repeated in the competition, so this folder must be submitted to santiago.torres@ucuenca.edu.ec, J.L.RuedaTorres@tudelft.nl, and srriverar@unal.edu.co by July 20^{th}, 2020, in accordance with the guidelines provided in this technical report. The implementation codes of each algorithm entering the competition must also be submitted along with the final results for full consideration in the evaluation. The codes submitted will be in the public domain, and no intellectual property claims be made thereon.

2. DEFINITION OF THE PROBLEMS

2.1. Overview

The transmission expansion planning (TEP) problem has been solved normally taking into account a forecast of fixed generation and load, without considering the fact that these values may vary. However, many sources of uncertainty are associated with the electric power system. In the long term, the largest sources of uncertainty in an electricity system lie in the growth of demand and generation. The growth of demand is related to the increase in the needs of society and the advancement of technological development, while the power of renewable energy generation (wind, solar, hydraulic, etc.) should be considered an uncertain value because it depends on uncontrollable weather phenomena.

The formulation of an optimal TEP problem considering uncertainty is implemented in the file named *evaluacion_particulas.p*, so different TEP test cases can be performed for two test systems selected with different sizes and structural complexities. To deal with the uncertainty in demand and generation, Monte Carlo Simulation (MS) is applied, since the MS allows input variables to be random based on probability density functions (PDFs). MS uses a probabilistic model in order to handle the uncertainty of the TEP problem. On the one hand, in order to deal with uncertainty in the demand model (represented by $d(p)$) the random data is represented by a normal distribution; on the other hand, to deal with the uncertainty in the generation model (represented by $g(p)$) the random data is represented by Weibull probability density functions, since it is the PDF that best adapts to scattered and random wind speed (see annex A). The random data in demand and generation are generated in the *uncertainty_garver.m* and *uncertainty_24IEEE.m* files.

The formulation contained in *evaluacion_particulas.p* has been developed to calculate the objective function and the constraints of all TEP tasks as well as to automatically collect and store the results in .mat files. It uses the functions to model an optimal load flow calculation available in the MATPOWER toolbox [4]-[6], which can be freely downloaded from the website http://www.pserc.cornell.edu/matpower/. In order to solve the Optimal Power Flow, it is also necessary to download the OPF solver from the website http://www.pserc.cornell.edu/tspopf/. The zipped folder *test_bed_TEP_V01.zip* contains this code, instructions on how to use it, and an implementation example with a basic particle swarm optimization (PSO) algorithm [3]. The code (except for the PSO code) is treated as a black box, so it cannot be modified by the participants.

Each participant is encouraged to work exclusively on the particular optimization algorithm to be used**.** The constraint handling (except for the number of ***n*** circuits allowed in each right-of-way) is managed internally using a penalty technique based on artificial generators, as explained in [3]. Therefore, participants only have to concern about the number of ***n*** circuits when implementing their own heuristic algorithm.

The values of $f^{'}$ and its solutions are automatically recorded in a .mat file, which will be used later in the evaluation of the performance of the algorithms. This .mat file is created by the corresponding code in the TEP.m file. It is also possible to set the following parameters in the *TEP.m* file:

- Population value (*Particle_Number*)
- Maximum number of Generations/Iterations (*Gen_Max*)
- Maximum number of allowed circuits per right-of-way (*Xmax*)

The Garver 6-bus and a slightly modified version of IEEE 24-bus test systems are used to evaluate the TEP problems. Based on the details given in [3], [7] for system buses and branches, the data of each system was structured in MATPOWER data format. Branch thermal limits were defined based on reference values given in [3], [7]. Table 1 shows a comparative summary of the characteristics of all test systems and the following subsections contain the description of the optimization test cases to be performed for each system. Annex A contains the codes structure, the files description, and the mathematical model proposed for this competition.

Table 1: Composition of test systems

Item/System	**Garver 6-bus system**	**IEEE 24-bus system**
Generators	9 (with one wind plant with ±5% uncertainty in the node 3)	36 (with two wind plant with ±5% uncertainty in the nodes 15, 16 and one solar plant with ±5% uncertainty in the node 18)
Loads/Buses	6 (each load with ±5% uncertainty)	24 (each load with ±5% uncertainty)
Lines/cables	15	41
Candidate right-of-ways	15	41
Maximum number of circuits (**Set *Xmax in TEP.m. Line 33.***)	5	5

2.2. Garver 6 bus system

2.2.1. Dispatchable generation TEP test case

- **Objective function:** to minimize the total investment cost of a number of transmission circuits added to the electric system for each Monte Carlo simulation.
- **Constraints:** only the maximum number of circuits set in the TEP.m file (the other constraints are internally handled).
- **Optimization variables:** 15 discrete variables.
- **Scenarios:** 1, corresponding to a long-term loading condition.
- **Considered contingencies (N-1 conditions):** not at the moment.
- **Maximum number of function evaluations:** 5,000 (for each Monte Carlo simulation).
- **Maximum number of iterations:** set by the participant.

2.2.2. No-dispatchable generation TEP test case

- **Objective function:** to minimize the total investment cost of a number of transmission circuits added to the electric system for each Monte Carlo simulation.
- **Constraints:** only the maximum number of circuits set in the TEP.m file (the other constraints are internally handled).
- **Optimization variables:** 15 discrete variables.
- **Scenarios:** 1, corresponding to a long-term loading condition.
- **Considered contingencies (N-1 conditions):** not at the moment.
- **Maximum number of function evaluations:** 5,000 (for each Monte Carlo simulation).
- **Maximum number of iterations:** set by the participant.

2.3. IEEE 24-bus system

2.3.1. Dispatchable generation TEP test case

- **Objective function:** to minimize the total investment cost of a number of transmission circuits added to the electric system for each Monte Carlo simulation.
- **Constraints:** only maximum number of circuits set in the *TEP.m* file (the other constraints are internally handled).
- **Optimization variables:** 41 discrete variables
- **Scenarios:** 1, corresponding to a long-term loading condition.
- **Considered contingencies (N-1 conditions):** not at the moment.
- **Maximum number of function evaluations:** 12,000 (for each Monte Carlo simulation).
- **Maximum number of iterations:** set by the participant.

2.3.2. No-dispatchable generation TEP test case

- **Objective function:** to minimize the total investment cost of a number of transmission circuits added to the electric system for each Monte Carlo simulation.

- **Constraints:** only maximum number of circuits set in the *TEP.m* file (the other constraints are internally handled).
- **Optimization variables:** 41 discrete variables
- **Scenarios:** 1, corresponding to a long-term loading condition.
- **Considered contingencies (N-1 conditions):** not at the moment.
- **Maximum number of function evaluations:** 12,000 (for each Monte Carlo simulation).
- **Maximum number of iterations:** set by the participant.

3. IMPLEMENTATION ASPECTS

The *TEP.m* file contained in *test_bed_TEP_V01.zip* allows participants to select the TEP test case and scenario to be solved as well as to call the implementation routine written for their optimization algorithm and to decide whether or not to employ the shared-memory parallel computing functionality of Matlab's Parallel Computing Toolbox.

3.1. Experimental setting

- **Monte-Carlo Simulations**: In this competition, this value is set at 500 times in *TEP.m* for each test system (with variable *n_exp* in the Line 35).
- **Stop criterion:** *TEP.m* is configured to automatically terminate a Monte Carlo simulation upon completion of the maximum number of function evaluations or the maximum allowed number of iterations. Lines 185-198 of *PSO.m* provides an example on how to stop a current run in the participant's algorithm implemented.
- **Initialization:** uniform random initialization within the search space.
- **Encoding:** if the algorithm requires encoding, the encoding scheme should be independent of the specific optimization tasks and governed by generic factors such as search ranges, dimensionality of the problems, etc.
- **Algorithm tuning:** the participants are allowed to tune their algorithms. The details of the tuning procedure, corresponding dynamic ranges of the algorithm's parameters, and the final parameter values used should be provided to the organizers and thoroughly discussed in the panel as well.

The following steps summarize the steps to solve the TEP problem:

i. Generate the initial population of scenario *i* (*psocreacioninicial.m*).
ii. Generate a power injection and demand value (using normal distribution and Weibull funtion) of scenario *i* (*uncertainty_garver.m* or *uncertainty _24IEEE.m*).
iii. Apply the logic of metaheuristics to generate new individuals *j* (*PSO.m*).
iv. Solve Optimal Power Flow for each individual *j* (*evaluacion_particulas.p* and *Topologia_Red.m*).
v. Until the stop criterion is met, repeat the steps (iii) and (iv).
vi. Repeat the steps (i) through (v) *n_exp* times (in this competition *n_exp* is set at 500 times).

vii. Calculate the expected cost of the cost function and the number of final topologies that is most repeated (*TEP.m*).
viii. Build the histogram of the final topologies cost for the *n_exp* scenarios.

3.2. Submission of results

Four (4) *.mat* files, corresponding to each test system and contained in a zipped folder named *output_data_implementation_name.zip*, must be submitted along with the algorithm implemented.

The file *output_data_implementation_name.zip* together with the implementation codes of the algorithm being used must be submitted to santiago.torres@ucuenca.edu.ec, J.L.RuedaTorres@tudelft.nl, and srriverar@unal.edu.co by July 20th, 2020. Details on the computing system and the programming language used must also be provided. Attempts at deliberate manipulation of the *.mat* files are discouraged.

4. REFERENCES

[1]. 2017 Competition Evaluating the Performance of Modern Heuristic Optimizers on Smart Grid Operation Problems, Test Bed 1: Stochastic OPF based active-reactive power dispatch by Sergio Rivera, Andres Romero, José L. Rueda, Kwang Y. Lee, István Erlich. Available online: http://sites.ieee.org/psace-mho/2017-smart-grid-operation-problems-competition-panel/

[2]. 2019 Competition & panel: Emerging heuristic optimization algorithms for expansion planning and flexibility optimization in sustainable electrical power systems by José Rueda, Santiago Torres, Sergio Rivera. Available online: https://site.ieee.org/psace-mho/2019-expansion-planning-and-flexibility-optimization-in-sustainable-electrical-power-systems-competition-panel/

[3]. S. P. Torres, C. A. Castro "Expansion planning for smart transmission grids using AC model and shunt compensation" IET Generation, Transmission & Distribution 8 (5), 966-975, 2014.

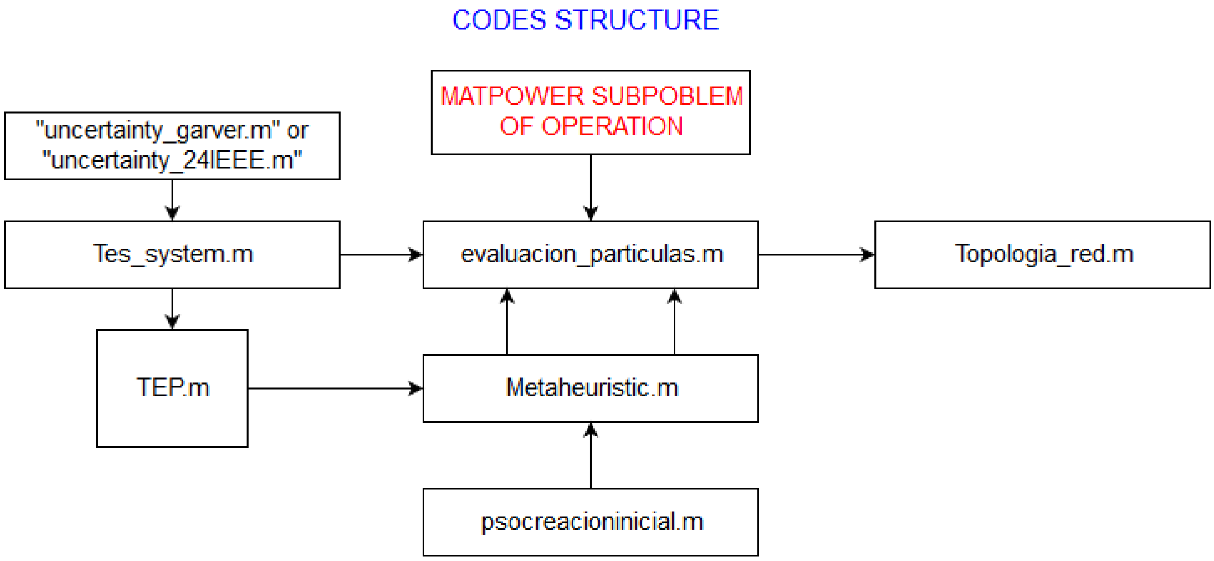
[4]. http://www.pserc.cornell.edu/matpower/

[5]. http://www.pserc.cornell.edu/tspopf/

[6]. R. D. Zimmerman, C. E. Murillo-Sánchez, and R. J. Thomas, "MATPOWER: Steady-State Operations, Planning and Analysis Tools for Power Systems Research and Education," IEEE Transactions on Power Systems, vol. 26, no. 1, pp. 12-19, Feb. 2011.

[7]. Rider, M.J.: 'Transmission system expansion planning using DC-AC models and non-linear programming techniques', D.Sc. Thesis in Portuguese, University of Campinas, Sao Paulo, Brazil, 2006

5. ANNEX A
5.1. Code Structure



5.2. File Descriptions

1.- The file *TEP.m* is where you configure the parameters of your metaheuristic algorithm, e.g. the limits of the decision vector X, the metaheuristic function that you want to use.

2.- The *PSO.m* file is the sample metaheuristic file, it must be changed by your algorithm.

3.- The initial *psocreacion.m* function contains the simplest way to initialize the initial population, randomly.

4.- The *uncertainty_garver.m and uncertainty_24IEEE.m* functions contains the Monte Carlo simulation technique to generate uncertainty in both demand and generation in a $\pm 5\%$ range.

5.- The function *evaluacion_particulas.m* contains the evaluation of the objective function using the AC model through matpower. It contains the modifications related to the topology, the calculation of the cost of the topology, etc.

6.- The *Topologia_Red.m* file changes the parameters of the data file according to the transmission topology that evaluates the metaheuristic.

5.3. Mathematical model

The mathematical model is divided into two problems: i) the expansion master problem and ii) the operational problem. In this formulation, the wind energy source is modeled by the Weibull probability density function, the solar energy source is modeled by lognormal density function, and the demand is modeled by a normal probability density function. The expansion master problem (each variable is similar to [3]).

$$min\, v = E\left[\sum_{(k,l)\in\Omega} c_{kl} n_{kl} + w\right]$$

The operational problem:

$$min\, w = \sum_{k\,\epsilon\,\Lambda} \alpha_1 r_{Pk} + \alpha_2 r_{Qk}$$

$$s.a.$$

$$P(V,\theta) - U(P_G) + T(P_D) - r_P = 0$$

$$Q(V,\theta) - U(Q_G) + T(Q_D) - r_Q = 0$$

$$U(\underline{P_G}) \le U(P_G) \le U(\bar{P}_G)$$

$$U(\underline{Q_G}) \le U(Q_G) \le U(\bar{Q}_G)$$

$$\underline{r_P} \le r_P \le \bar{r}_P$$

$$\underline{r_Q} \le r_Q \le \bar{r}_Q$$

$$\underline{V} \le V \le \bar{V}$$

$$S^{from} \le \bar{S}$$

$$S^{to} \le \bar{S}$$

T: Represents the probability density function associated with the demand.
U: Represents the probability density function associated with the generation (solar or wind plant).

5.4. Test Systems

Case 1
garver.m (With Dispatchable generation, with unlimited shunt compensation)

Case 2
garver_WOrdptch.m (With Non-dispatchable generation, with unlimited shunt compensation)

Case 3
case24IEEE_AC.m (With Dispatchable generation, with unlimited shunt compensation)

Case 4
case24IEEE_AC_WOrdptch.m (With Non-dispatchable generation, with unlimited shunt compensation)

5.5. Generation and demand (Uncertainty)

To deal with the uncertainty in demand and generation, to apply Monte Carlo Simulations (MS) is recommended since the MS allows input variables to be random based on probability density functions (PDFs), so that it computationally resolves all stochastic data. In order to use the MS, a probabilistic model is needed. In order to deal with uncertainty in the demand model (represented by *d(p)*), the random data is represented by a normal distribution (distributed within a $\pm 5\%$ of uncertainty range using 0.5% steps, where zero is the mean value of the distribution [deterministic data], and values away from the mean represent the uncertainty of the problem):

$$d(p) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(p-\mu)^2}{2\sigma^2}}$$

While in the generation model (represented by *g(p)*), two PDF are considered are used to represent a solar and wind plant:
The first distribution function is the Weibull function since this PDF is the one that best adapts to scattered and random wind speed:

$$g(p) = \frac{k}{c} (\frac{p(v)}{c})^{k-1} \cdot e^{\left(-\frac{p(v)}{c}\right)^k}$$

On the other hand, the second distribution function used is the lognormal function since this PDF appropriately represents to scattered and random solar radiation:

$$g(p) = \frac{1}{p\sigma\sqrt{2\pi}} e^{\{-\frac{\ln(p)-\mu^2}{2\varphi^2}\}}$$

The variability of the generation and demand is randomly chosen in an $\pm 5\%$ interval.