



Optimal expansion of an existing electrical power transmission network by multi-objective genetic algorithms [☆]

F. Cadini ^{*}, E. Zio, C.A. Petrescu

Politecnico di Milano, Dipartimento di Energia, Via Ponzio 34/3, I-20133 Milano, Italy

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ABSTRACT

In this paper, the optimal expansion of a power transmission network by addition of new connection links is addressed. Optimality is searched with respect to two objectives: the transmission reliability efficiency and the cost of the added transmission links. The multi-objective optimization problem is tackled by means of three different genetic algorithm paradigms, opportunely biased to give preference to solutions with a low number of added links, for practical applicability. The three approaches are applied to a reference power transmission network of the literature, the IEEE RTS 96; the results obtained are compared with respect to the efficacy of driving the search towards the preferred region of the solution space. Finally, an interpretation of the results is offered in terms of a properly defined reliability-based centrality measure.

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1. Introduction

In spite of the increased reliability standards and the significant technological advances, in the last decades the frequency of blackouts in electric power transmission grids has not decreased, whereas their size has worryingly increased due to growing interconnections and interdependence of large transnational regions [1].

Electrical network operators are thus seeking for effective and economic technical solutions of failure protection by means of modifications to the network connection pattern and less straining modes of operation, albeit still competitive in the deregulated market of electricity production and transmission.

The identification of these solutions entails a thorough and systematic analysis of the electrical network and its response to failures.

Given the complexity of these highly distributed and interconnected infrastructures, performing a systematic analysis of their vulnerability and robustness to failure becomes difficult if one resorts only to traditional probabilistic safety assessment (PSA) methods, so that new complementary approaches of network analysis are emerging for characterizing the network

resistance to failure and identifying its most vulnerable elements [1–6].

In this work, a method is developed for identifying strategies of expansion of an existing electrical network in terms of new lines of connection to add for improving the reliability of its transmission service, while maintaining the limited investment cost. The typical large size of electrical networks offers a combinatorial number of potential solutions of new connections, so that classical optimization techniques become inapplicable. For this reason, we resorted to a multi-objective genetic algorithm (MOGA) driven by the objectives of maximizing the network global reliability efficiency [7] and minimizing the cost of the added connections. Indeed, given the large investment costs for building a new line in an existing electrical transmission network, it is reasonable to expect that in practical applications the proposed improvements will involve the addition of only few new connections. Three approaches are proposed to restrict the search space to small numbers of new connections: (i) a novel strategy for generating the initial population in the genetic algorithm, (ii) a modified version of the weighted Pareto optimization method in which quantitative weights are combined within the concept of Pareto dominance (WP-MOGA) [8], (iii) the so-called guided multi-objective genetic algorithm (G-MOGA), based on the guided domination principle, which allows to change the shape of the dominance region specifying maximal and minimal trade-offs between the different objectives so as to efficiently guide the MOGA towards Pareto-optimal solutions within these boundaries [8]. The performance of these search approaches is tested on a case study based on the IEEE (Institute of Electrical and Electronic

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^{*} Corresponding author.

E-mail address: francesco.cadini@polimi.it (F. Cadini).

Engineers) RTS (Reliability Test System) 96 [9]. The results of the optimizations are interpreted by means of a reliability-weighted centrality measure analysis [5].

The paper is organized as follows. For completeness of the material, in Section 2 the concept of network global reliability efficiency is recalled with reference to the IEEE RTS 96 and a short introduction to the basic concepts behind the optimization procedure by multi-objective genetic algorithms is given in Section 3. In Section 4, the multi-objective optimization problem of the IEEE RTS 96 is defined and solved by the three MOGA approaches mentioned above; the results are then analyzed in terms of centrality measures. Conclusions on the outcomes of the study are eventually drawn in Section 5.

2. Global reliability efficiency of an electrical transmission network

Let us consider, as reference example, the transmission network system IEEE RTS 96 of Fig. 1 [9].

The network consists of 24 bus locations (numbered in bold in the figure) connected by 34 lines and transformers. The transmission lines operate at two different voltage levels, 138 and 230 kV. The 230 kV system is the top part of Fig. 1, with 230/138 kV tie stations at Buses 11, 12 and 24. Buses 1, 2, 7, 13, 15, 16, 18, 21, 22 and 23 are the generating units. The system is also provided with voltage corrective devices corresponding to Bus 14 (synchronous condensers) and Bus 6 (reactor).

A schematic representation of the network connection topology can be obtained in terms of the graph $G(N,K)$ of Fig. 2 [10], where the $N=24$ electrical buses are represented as nodes (hereafter also called vertices) interconnected by $K=34$ edges (hereafter also called arcs or links). The network visualization in

terms of graph has been done using the Pajek program for large network analysis [11].

The graph can be mathematically synthesized by the so-called adjacency matrix $\{a_{ij}\}$, an $N \times N$ matrix whose entry is 1 if there is an edge connecting nodes i and j and 0 otherwise [2,10]. The entries on the diagonal elements a_{ii} are undefined and for convenience are set equal to 0 (Fig. 3).

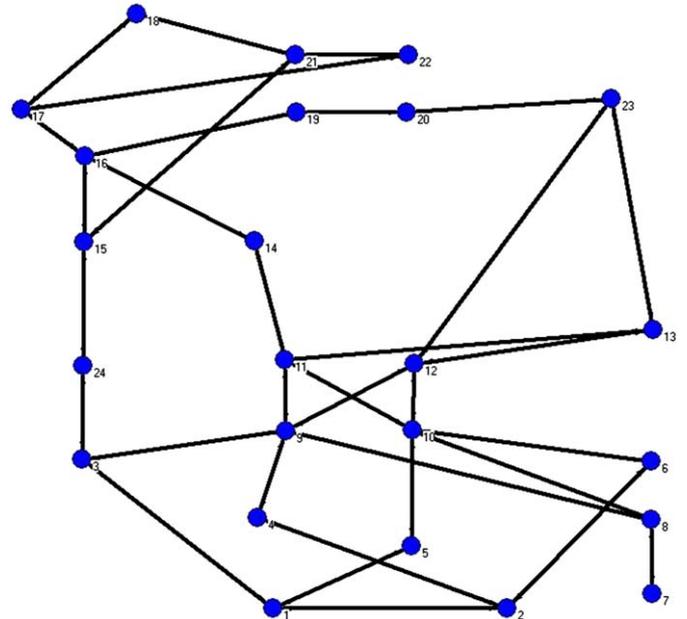


Fig. 2. The IEEE RTS 96 graph representation.

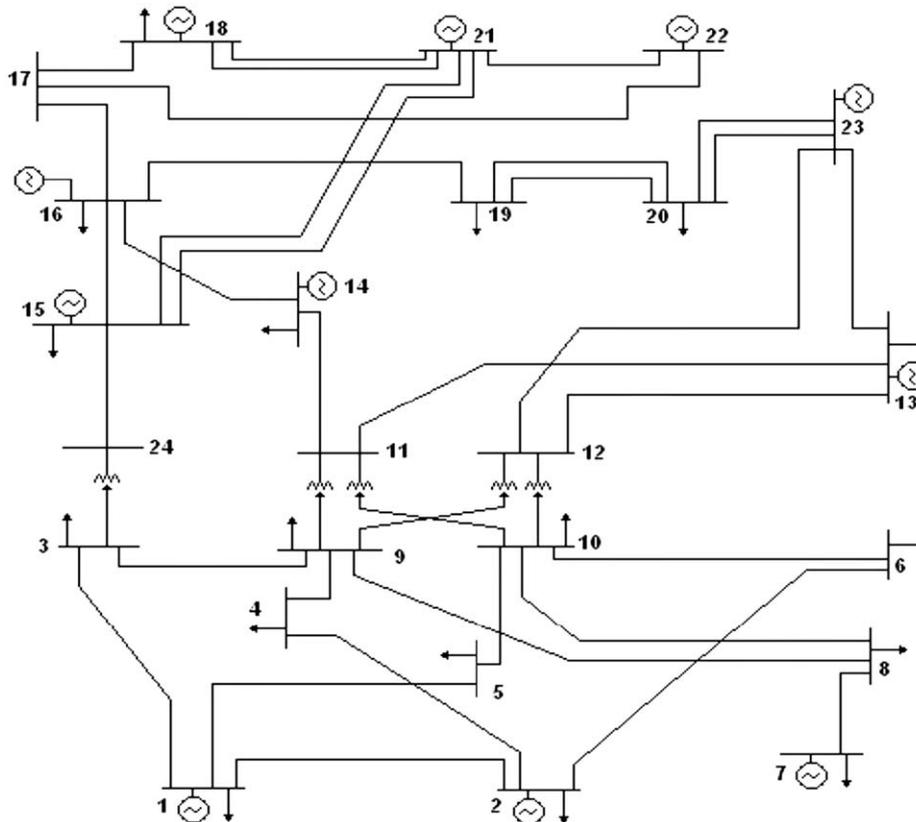


Fig. 1. IEEE RTS 96 transmission network [9]. The bold numbers label the bus locations.

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