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N–1 Security Constrained Short-Term Hydrothermal Scheduling by Self Adaptive Genetic Algorithm with PTDF

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1. Introduction

1.1. Motivation

- An optimal unit scheduling is necessary to achieve economical and reliable production.
- Obtaining optimal solution is not easy, because the objective function of SCSHTS has a non-convex MIP nature and belongs to the class of complex non-convex problems.
- The classical optimization methods cannot be applied to the SCSHTS optimization problem

1.2. Contributions

- A compact formulation for SCSHTS problem, including all thermal, hydro, system and security constraints.
- New self-adaptive penalty which requires no parameter tuning.
- New constraint handling repair mechanism for consideration the hardest constraints, especially prohibited operating zones, which are neglected in other papers, to get a significantly more realistic solution.
- Simultaneous enabling *N*-1 scenario, using the PTDF and LSC parameter, to analyze and confirm initial hypothesis for the fuel costs, but also for optimal operational planning of both the system and the required spinning reserve

2. Problem formulation

- The main objective of SCSHTS problem is to minimize the total fuel cost of thermal power plants (TPP) over the optimization period. The objective function to be minimized can be represented as:

$$\min FT = \sum_{j=1}^{J}\sum_{t=1}^{NT} F_{t,j} \cdot j$$

$$F_{t,j} = a_t + b_t \cdot P_{\mathrm{GT}t,j} + c_t \cdot P_{\mathrm{GT}t,j}^2 + \left| d_t \sin\left(e_t\left(P_{\mathrm{GT}t}^{\min} - P_{\mathrm{GT}t,j}\right)\right)\right|$$

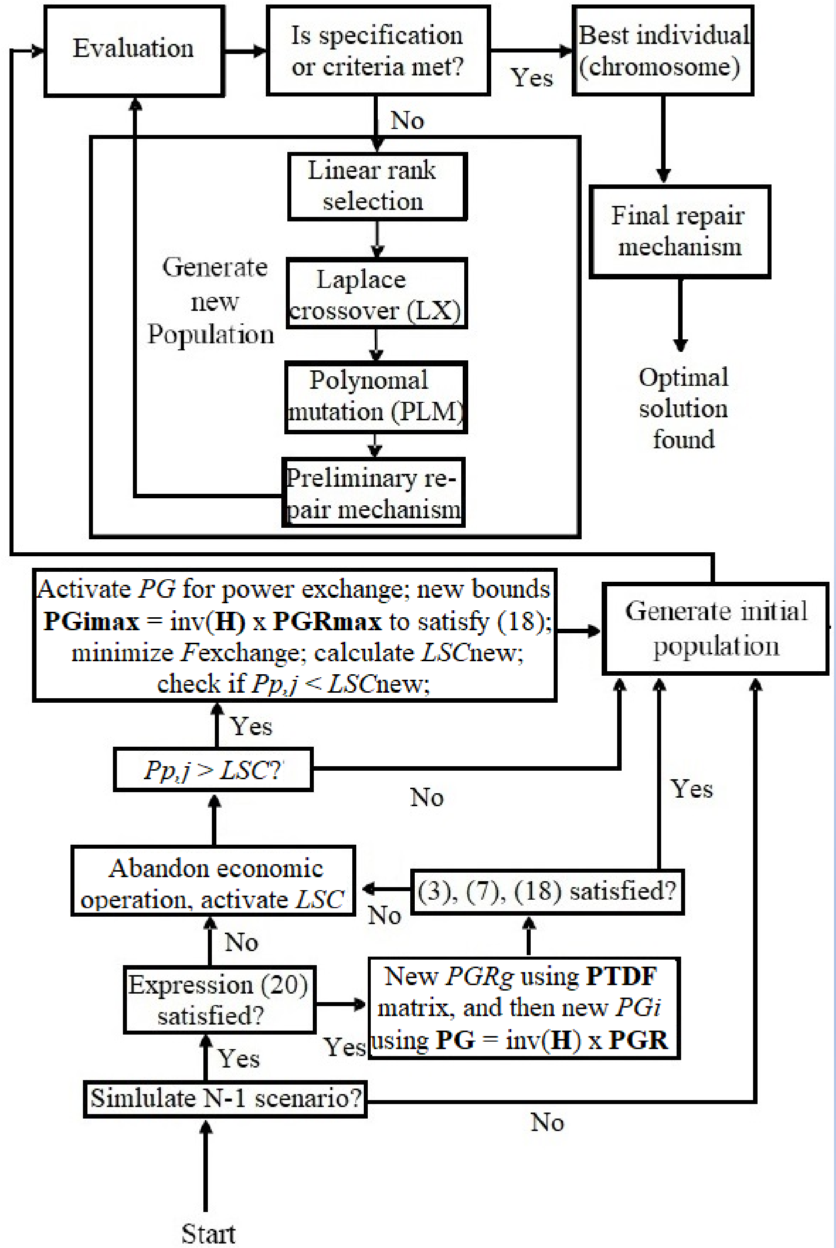
$$\forall t \in NT; j \in J$$

subject to the constraints:

- **TPP constraints**: generator constraint, prohibited operating zones, ramp rate constraint, available production constraint.
- **HPP constraints**: generator constraint, water discharge constraint, reservoir volume constraint, volume constraint of the reservoir at the beginning and end of the scheduling period, water dynamic balance constraint, available production constraint.
- **Power system security constraints**: power balance constraint, transmission line constraint, spinning reserve constraint.
- In case of *N*-1 scenario, when the system is not able to supply the load at all intervals, an additional optimization subproblem is activated, for determining the maximum power that can be delivered, i.e., Load Supplying Capability (LSC).

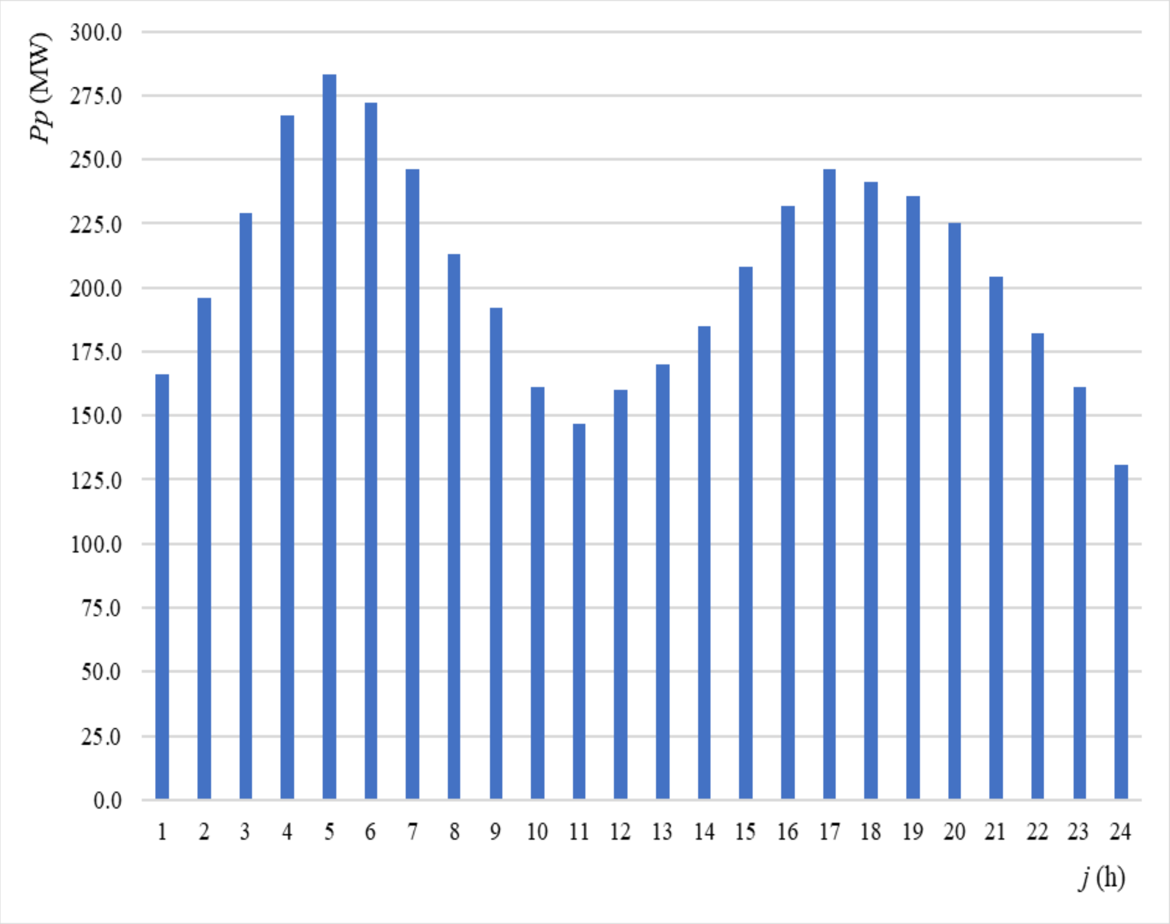
$$\max LSC = \sum_{i=1}^{NT+NH} PGi$$

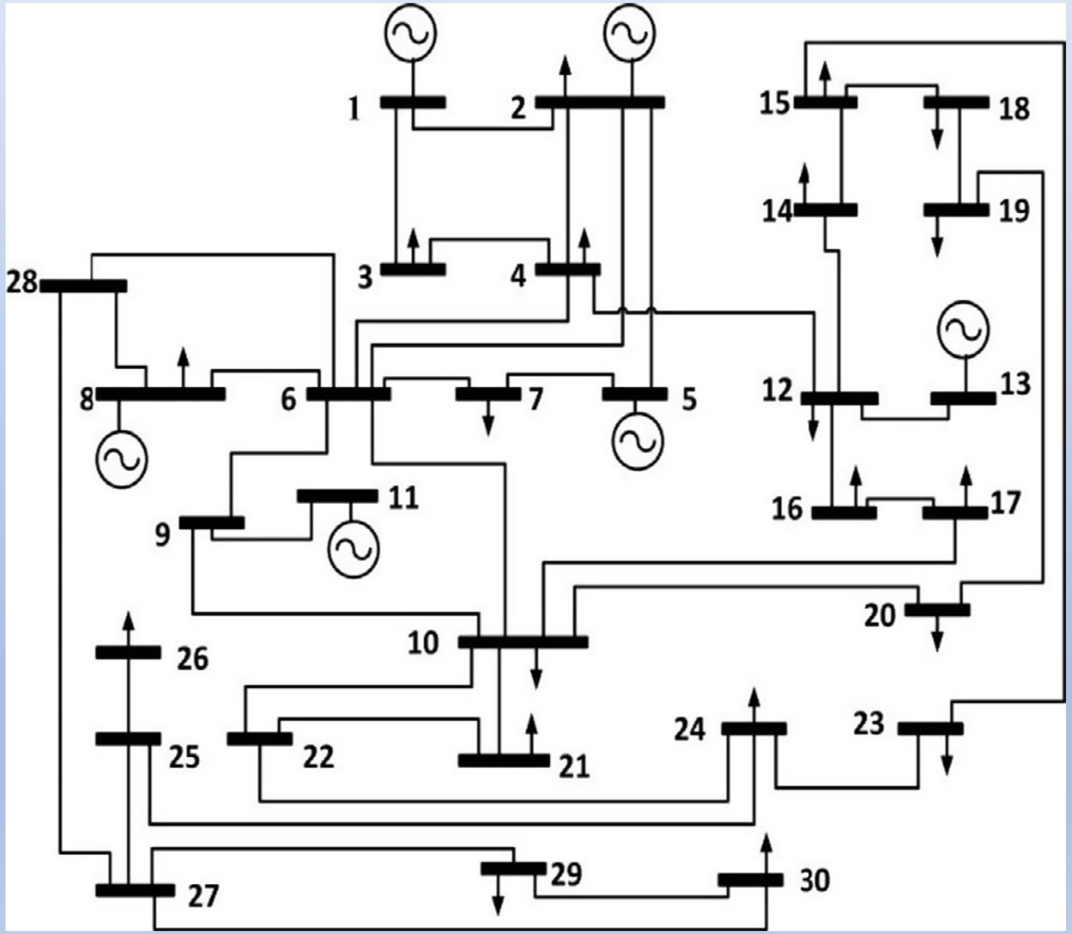
3. Block diagram of the proposed SAGA



4. Computational results

- The performance of the proposed algorithm has been evaluated using the IEEE 30 BUS SYSTEM.
- The main parameters are shown as the following: generations = 300; population = 100; elite number = 5; $V_h^{end} \geq 0.2 \cdot 10^4 \left(\mathrm{m}^3\right)$.





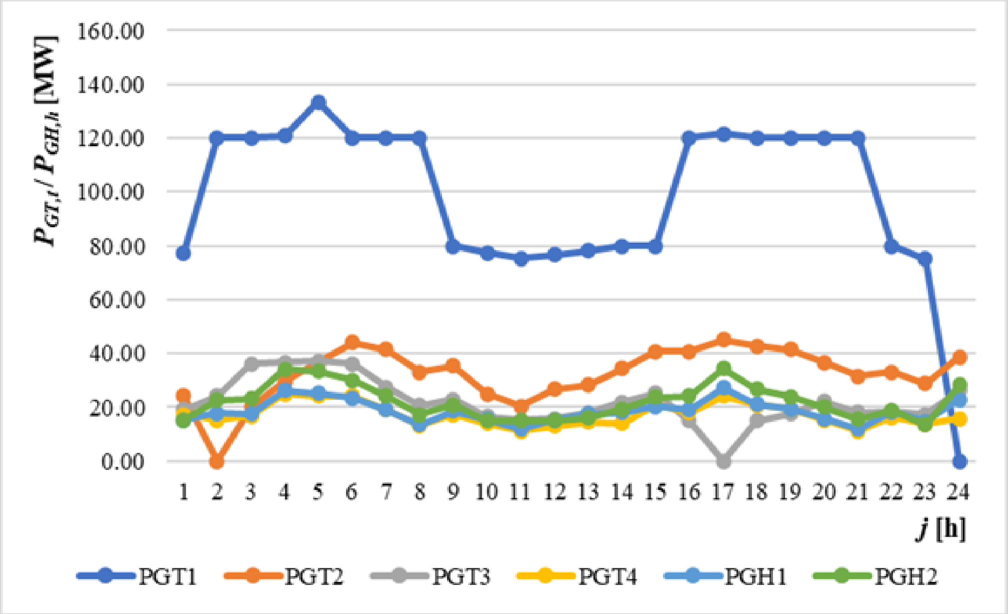


Fig. 3. Optimal generation schedule for basic scenario

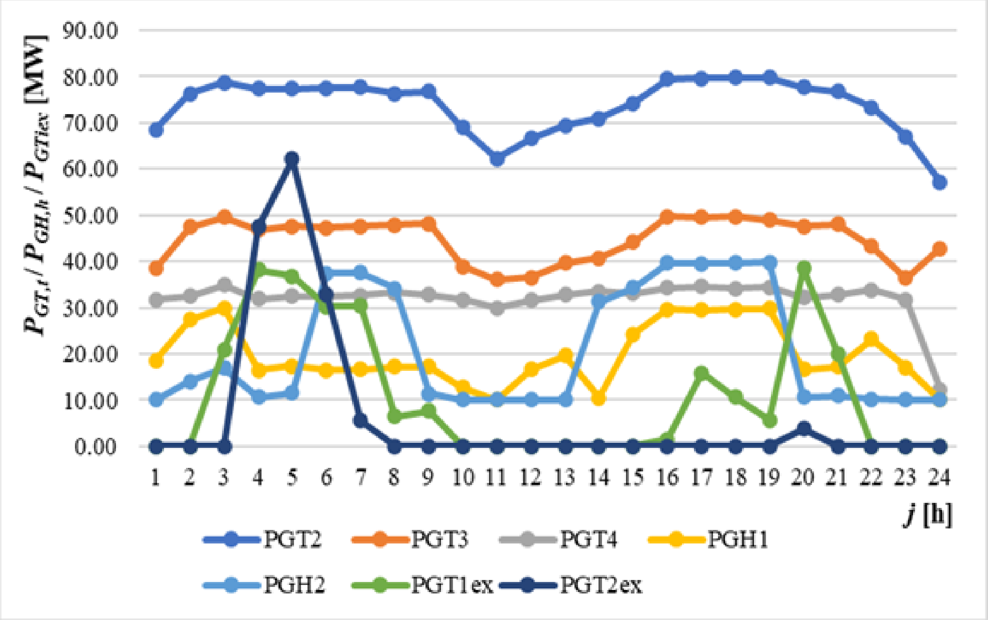


Fig. 5. Optimal generation schedule for the *N*-1 worst scenario i.e., with power exchange (outage of the TPP 1)

TABLE 5. TOTAL COSTS FOR DIFFERENT *N*-1 SCENARIOS

Scenario	$R_T + R_H > \Delta P$?	*LSC* activated?	*FT* [€]
N-1 (P_{GT1})	No	*LSC* and power exch.	35,656.06
N-1 (P_{GT2})	No	LSC	11,403.60
N-1 (P_{GT3})	Yes	No	10,589.64
N-1 (P_{GT4})	Yes	No	10,248.90
N-1 (P_{GH1})	No	LSC	12,807.89
N-1 (P_{GH2})	No	LSC	12,189.24
Basic	/	/	10,866.76

- From Table 5, it can be seen that the outages significantly affect the total costs, especially for the worst *N*-1 scenario, i.e., outage of TPP 1, in which the relative increase in total costs is as much as 228.12%, or even 24,789,3 €, which is a huge amount that should not be neglected.
- In the case of TPP3 or TPP4 outage respectively, the total costs are 2.62% and 6.03% lower, because the spinning reserve covers the power deficit, i.e., increases the power output of TPP1 and TPP2, which have lower HR. In the case of HPP1 or HPP2 outage, the total costs increase by 15.16% and 10.85%, which is quite logical. But, this power deficit cannot be covered by the spinning reserve, so the LSC is activated, i.e., the economic operation mode is abandoned. As for LSC activation, the same applies to TPP2 outage.
- Therefore, the initial hypothesis is confirmed that the total costs depend significantly on the generator outages, and from the allocated rotating reserve. This confirmed initial hypothesis must be taken into account, especially in determining the generation scheduling and allocating the required spinning reserve.

5. Conclusion

- In this paper, a SAGA has been proposed and successfully applied to solve the SCSHTS problem. The results obtained by SAGA have been compared with other evolutionary algorithms like AIS, DE, and EP. It is found that a newly proposed SAGA can produce better results (improvement of 14.71% compared to AIS, and better CPU time), which is necessary to obtain a physically acceptable solution, in terms of *N*-1 analyzes.
- Further upgrade of *N*-1 SCHTUC optimization problem, with high penetration of renewable energy. This means that the proposed Power Transfer Distribution Factor (PTDF) will be implemented in the algorithm, taking into account the applied DC load flow model. This will enable solving the *N*-1 SCHTUC, with different scenarios i.e., outage of each unit, but with spinning reserve which will be equal to installed power of the renewables (taking into account the stochastic nature of the renewables).