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Optimal distribution of reactive power by hybrid metaheuristic methods applied to the west Algerian network

***Abstract**. This research focuses on the utilization of artificial intelligence through the sequential and integrated crossover of two population metaheuristic methods: Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). These methods are applied to solve the Optimal Reactive Power Flow (ORPF) in the West Algerian network, comprising 102 nodes. The objective of this combination is to demonstrate its impact compared to non-hybrid metaheuristic methods in reducing energy losses while effectively improving various aspects such as voltage levels, the flow of active and reactive energy in the lines, transformation ratios of transformers, and the execution time of the process. Following this application, a comparative study of the results from different methods was conducted.*

***Streszczenie.** Niniejsze badania koncentrują się na wykorzystaniu sztucznej inteligencji poprzez sekwencyjne i zintegrowane krzyżowanie dwóch metod metaheurystycznych populacji: algorytmu genetycznego (GA) i optymalizacji roju cząstek (PSO). Metody te są stosowane do rozwiązania optymalnego przepływu mocy biernej (ORPF) w sieci zachodnioalgierskiej, obejmującej 102 węzły. Celem tej kombinacji jest wykazanie jej wpływu w porównaniu z niehybrydowymi metodami metaheurystycznymi na redukcję strat energii przy jednoczesnej skutecznej poprawie różnych aspektów, takich jak poziomy napięcia, przepływ energii czynnej i biernej w liniach, współczynniki transformacji transformatorów i czas realizacji procesu. Po tej aplikacji przeprowadzono badanie porównawcze wyników różnych metod. (**Optymalny rozkład mocy biernej za pomocą hybrydowych metod metaheurystycznych zastosowanych w sieci zachodnioalgierskiej**)*

Keywords: Electrical Network, Genetic Algorithm, Hybridization, Metaheuristic methods, Optimal Reactive Power Flow, Particle Swarm Optimization, Reactive Power.
Słowa kluczowe: Sieć elektryczna, algorytm genetyczny, hybrydyzacja, metody metaheurystyczne, optymalny przepływ mocy biernej, optymalizacja roju cząstek, moc bierna

Introduction

Technological progress has led to a rise in electrical energy consumption, necessitating the production and transportation of more power. Consequently, networks are becoming larger and more complex. That's why any organization responsible for electricity production strives to ensure, at all times and in all locations, the supply of active and reactive powers demanded by customers, while minimizing energy losses.

The Optimal Reactive Power Flow Problem (ORPF) aims to maximize benefits for all electrical energy consumers, minimize power losses, adhere to constraints on energy transport in transmission lines, and manage the active power output of generators as well as their voltage levels. The application of new techniques inspired by artificial intelligence [1] has led to improved solutions for optimal reactive power distribution.

Using artificial intelligence (AI) to solve the Optimal Reactive Power Flow (ORPF) problem offers several advantages in terms of efficiency and precision.

Among the methods used by artificial intelligence, we find metaheuristic techniques such as genetic algorithms and particle swarm optimization, as well as their hybridization[2]..

The objective of this research is to employ a hybrid approach of metaheuristic methods in a complex real electrical energy network to minimize active energy losses, optimize generated powers, control transformer regulators, and enhance voltage profiles at different nodes of the network. To achieve this goal, we propose two hybridization techniques: a sequential and an integrative approach of two population metaheuristic methods, the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), which we have applied to the West Algerian network consisting of 102 nodes.

In this article, the sequential hybridization was improved compared to the current hybridization method [3] so as to have more efficient results.

This article is structured as follows: the first section presents the various hybridization methods, followed by a brief introduction to the function of the ORPF problem. The third section provides a detailed presentation of the two hybrid methods proposed to solve the ORPF problem. Subsequently, an application of sequential and integrative hybrid methods on the West Algerian network is discussed, followed by a comparison and analysis of the results.

Hybridization of metaheuristics methods

The Hybridization is a trend that has been observed in many studies over the past decade. It makes it possible to utilize the cumulative advantages of different metaheuristic methods [2][3].

The origins of hybrid algorithms of metaheuristic methods can be traced back to Glover's work [2] ,J. J. Grefenstette[4] and Mühlenbein and al[5], These hybrid methods combine different concepts and components of different metaheuristics [6] and to this end, they attempt to merge the strengths and eliminate the weaknesses of these metaheuristics.According to the taxonomy proposed by Talbi [6],[7], the hierarchical classification of hybrid metaheuristic methods is characterized by the level and mode of hybridization. The level of hybridization can be beat (low- Each level of hybridization generates two modes of cooperation: a relay mode (Relay) and a co-evolutionary mode (Teamwork).

The combination of levels and modes of hybridization sets forth four classes of hybridization [6] which are: Low-level Relay Hybridization LRH (It includes metaheuristic methods based on a single solution in which other methods are incorporated to form a new algorithm [2]), Low-level Teamwork Hybridization LTH (This class groups population-based metaheuristic methods of one or more operators replaced by one or more optimization methods [8], [9]), High level relay hybridization HRH(In this class, the optimization methods are used sequentially thus maintaining their integrity, the final result then becomes the initial solution of the next method [8],[9]) and High level co-evolutionary hybridization HTH(This hybridization class complies with the parallel execution of the optimization methods that can communicate with each other during their execution [9]).

Taking into consideration the execution order of the hybridized metaheuristic methods, we distinguish three large hybridization types [2]:

Hybridization in series or high level relay hybridization HRH: It allows to an algorithms execution strictly after anothers termination and the information passes in one direction. An intelligent pretreatment of the results of another algorithm is also classified in this category [1].

Hybridization in insertion or low level relay hybridization LRH: In this method,the algorithms can act one on another in a more sophisticated manner, where an algorithm is considered as a subaltern element included in another algorithm [1].

Hybridization in parallel or high level co-evolutionary hybridization HTH: Hybrid methods belonging to this class are characterized by an architecture such that two algorithms A and B are involved simultaneously and each adjusts the other. Algorithms A and B share and exchange information throughout the research process[10]. Researchers adopted this method because of its important contribution in the acceleration of the research, the upgrade of the obtained solution quality, of its toughness and capacity of solving large problems. This hybridization consists of evolving a parallel different research method [11].

Problematic

The problem of optimal power distribution is based on the optimization of the reactive power. It consists of minimizing a nonlinear objective function defined with nonlinear constraints. Among the different variants of the general OPF problem, our study considers only the Optimal Reactive Power Flow ORPF formulation (1) - (7).

The objective function represents the active losses in the electrical network [3]:

$$(1)\quad P_L = \sum_{i}^{n}\sum_{j}^{m} -G_{ij}(V_i^2 + V_j^2 - 2V_iV_j cos(\theta_{ij})$$

where: P_L – active losses in the electrical network, Gij – Conductance between the Nodes i and j, Vi and Vj – voltage at the i-th and the j-th nodes, $\theta ij = \theta j - \theta i$ – phase shift of voltage between nodes i and j, n – total number of nodes.

Equality constraints represent the balance between production and consumption [3]

$$(2)\quad \Delta P_i = \sum_{j=2}^{n} V_iV_j(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) - P_i^g + P_i^l = 0$$

$$(3)\quad \Delta Q_i = \sum_{j=2}^{n} V_iV_j(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) - Q_i^g + Q_i^l - Q_i^{comp} = 0$$

where: P_i^g – active power generated in the node i, Q_i^g – reactive power generated in the node i, P_i^l – active power consumed in the node i, Q_i^l – reactive power consumed in the node i, Q_i^{comp} – compensator's reactive power in the node i, Gij – conductance between the nodes i and j, Bij – susceptance of the nodes i and j.

The constraints of inequality represent the limits of the variables [3]:

$$(4)\quad Q_{i,min}^{g} \le Q_i^{g} \le Q_{i,max}^{g}\ ,\ i=1...ng$$

where: Q_i^g – reactive power generated in the node i, ng – number of generators,

$$(5)\quad Q_{i,min}^{comp} \le Q_i^{comp} \le Q_{i,max}^{comp}\ ,\ i=1...ncomp$$

where: Q_i^{comp} – compensator's reactive power in the node i, n_{comp} – number of compensators.

$$(6)\quad a_{i,min} \le a_i \le a_{i,max}\ ,\ i=1...n_T$$

where: a_i – transformation ratio of the transformer i, n_T – number of transformers.

$$(7)\quad V_{i,min} \le V_i \le V_{i,max}\ ,\ i=1...n$$

Vi – voltage at the i-th nodes, n – total number of nodes,

Resolution Methods

In theory,it is possible to hybridize all methaheuristic methods,in practice one must be careful about the choice of methods used to obtain good cooperation between the constituents of the hybrid method. It is necessary to know how to characterize the strong points and the weak points of each method of research [12].

For the resolution of the given problem, algorithms were elaborated under a MATLAB environment, that are validated on an OPAL RT simulator and applied in the western network of Algeria. Two hybridization methods of two methaheuristic méthods GA and PSO were applied.

Sequential hybridization:

In this case, we chose to hybridize two algorithms GA [13][15]and PSO[14][15] by executing a genetic algorithm then the particle swarms optimization. This means that the solution given by the genetic algorithm is considered as an initial solution of the particle swarms optimization.

The figure 1 represents a flowchart of the sequential hybridization algorithm.

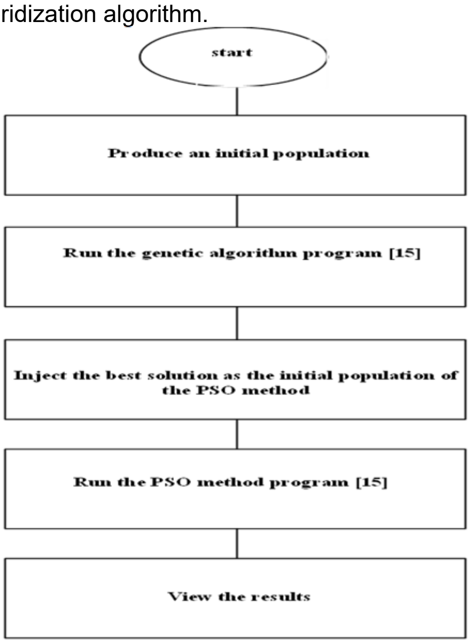


Fig.1. Flowchart of the sequential hybridization (SH) algorithm.

Integrative hybridization:

In this case, we chose to hybridize the two algorithms, inserting the particle swarms optimization into the genetic algorithms; in other words, instead of performing the last step of the mutation of the genetic algorithms, we replace it with the mechanisms of the PSO.

The figure 2 represents a flowchart of the integrative hybridization algorithm.

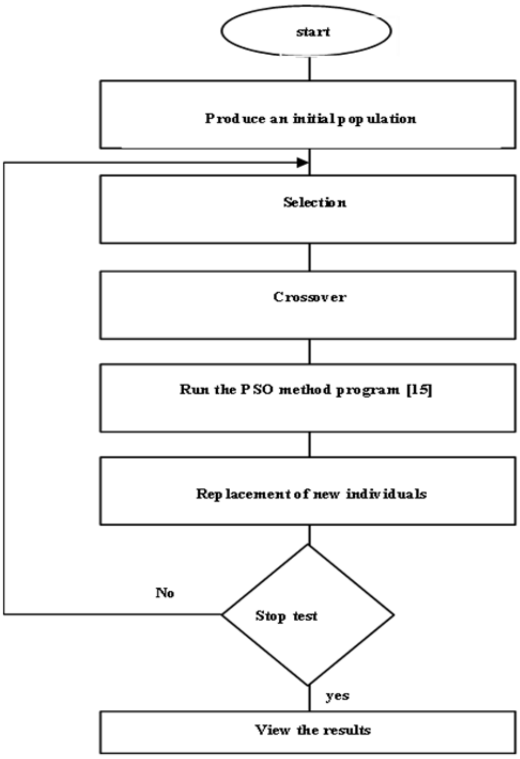


Fig.2. Flowchart of the integrative hybridization (IH) algorithm.

Illustration

The resolution of the problem of the Optimal Reactive Power Flow and the control of the voltage in the west Algerien network was realised by the sequential and integrative hybridization of GA and PSO.

The main data of the West Algerian network and the critical limits of the control variables are represented in Tables 1, 2 and 3[3].

Table 1. Main data of the West Algerian network

Number of charges nodes	92
Number of nodes of generations	10
Number of lines	119
Number of transformers	14

Table 2. Node voltage limits

Voltage	Minimal value (p.u)	Maximal value (p.u)
400 kV	0,9	1.1
220 kV	0,9	1.1
60 kV	0,9	1.1

Table 3. Limitations of the control variables

Variables	**Minimal value**	**Maximal value**
a_i	0.9	1.1
Q_1^g	-170	350
Q_6^g	-240	270
Q_{11}^g	-60	100
Q_{13}^g	-90	180
Q_{20}^g	-80	400
Q_{22}^g	-35	60
Q_{24}^g	-80	400
Q_{39}^g	-15	48
Q_{51}^g	-8	38
Q_{55}^g	-20	30

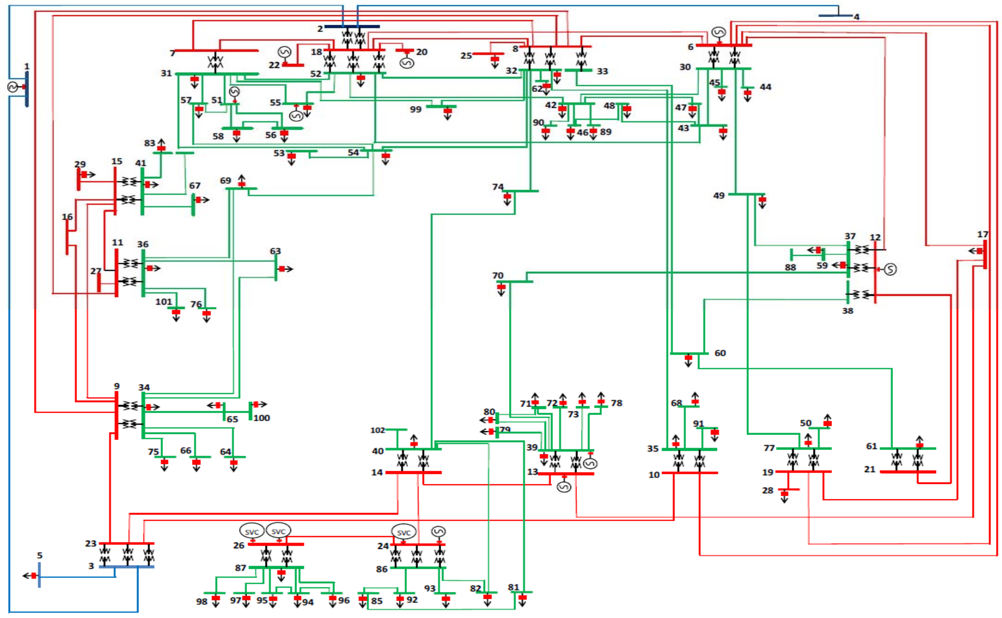


Fig.3. The One-line diagram of the Algerian Western Network with the three voltage levels 400kV (blue lines)/220kV (red lines)/60 kV (green lines)

Results and Discussion

To determine the voltage profile of nodes and active losses in the West Algerian network, we conducted a load flow program using the Fast Decoupled Load Flow (FDLF) method [3]. Subsequently, an optimization program for reactive powers was implemented using the GA [3], PSO [3], sequential hybridization of GA-PSO, and integrative hybridization of GA-PSO methods.

The node voltages of the various studied networks before and after optimization are depicted in Figures 4, 5, and 6. Reactive powers and transformation ratios are presented in Tables 4 and 5, along with the values of minimum losses in the network and the program execution time in Table 6.

Table 4. The generated powers

N° of Node	FDLF Qg (MVAR)	GA Qg (MVAR)	PSO Qg (MVAR)	GA-PSO Sequential hybridization Qg (MVAR)	GA-PSO Integrative Hybridization Qg (MVAR)
1	-236.56	-118.0137	-118.78	-160.53	-155
6	-76.28	-203.1648	269.02	-200	238.02
12	78.47	72.1691	-44.91	75.61	96.37
13	-46.1	-84.4241	-58.40	-32.93	-28.96
20	7.72	109.0077	-29.71	-25.8	38.71
22	-24.07	11.1860	60	-33.29	31.62
24	-45.18	-5.5827	-77.74	37.91	-76.27
39	116.85	-8.3191	39.29	38.86	47,82
51	-20.44	4.4141	37.2	20.43	36.63
55	6.97	25.7516	-2.09	-0.48	21.75

Table 5. Transformation Ratio

N° of Node	FDLF	GA	PSO	GA-PSO Sequential Hybridization	GA-PSO Integrative Hybridization
02→18	0.96	1.00	1.1	1.06	1.08
03→23	0.96	0.99	1.08	0.98	1.05
06→30	0.98	1.00	0.99	1.00	1.02
07→31	0.99	0.99	0.96	0.96	0.99
08 →32	0.98	1.00	0.99	0.98	1.02
08→33	0.95	0.99	0.99	0.94	1.03
09→34	0.98	0.99	0.99	1.01	0.96
10→35	0.98	0.99	1.09	1.05	1.06
11→36	0.99	0.99	1.01	1.01	0.97
12→37	0.96	1.00	0.95	1.02	0.98
12→38	0.99	0.99	0.94	0.94	0.95
13→39	1.07	0.99	1.01	0.97	1.04
14→40	0.95	1.00	1.02	1.05	1.03
15→41	0.98	0.99	1.05	1.03	1.04
18→52	0.98	1.00	1.01	0.99	1.04
19→77	1.00	0.99	1.01	1.01	0.97
21→61	0.97	1.00	0.98	1.06	0.94
24→86	0.97	0.99	1.06	0.91	1.06
26→87	0.99	1.00	0.98	1.02	1.00

Table 6. Active losses and execution time

	FDLF	GA	PSO	GA-PSO SH	GA-PSO IH
Active losses (MW)	51.06	36.60	45.07	29.19	45.82
Reduction MW		14.46	5.98	21.87	5.244
Reduction %		28.31	11.72	42.82	10.26
Execution time (s)		26.7	35.29	21.14	85.98

On the basis of the results obtained by the two hybrid metaheuristic methods and the basic metaheuristic methods applied on the western Algerian network, we note that the active losses in the network by the basic method (FDLF method) were 51.06 MW. After the application of the methods of the optimization with the genetic algorithm, the calculated active losses are 36.6 MW, for the PSO method are 45.07 MW, GA-PSO sequential hybridization are 29.19 MW and GA-PSO integrative hybridization 45.82 MW,Table 6.We also note that the GA-PSO sequential hybridization method gives a remarkable 42.82% 258 loss reduction even in execution time. It is faster compared to other methods, while the GA-PSO integrative hybridization method gives the lowest reduction losses of 10.26% and even in execution time it is the slowest, Table 6.

For node voltage in the baseline case (FDLF method), we observe that several nodes exceed the upper limits in the 220kV network (nodes 26) Fig. 5, and in the 60 kV network (nodes 86,87,94,95,96,97,98) Figure 6.(b), as well as falling below the lower limit in the 60 kV network (nodes 85,92) Fig. 6.(b). After the application of optimization methods, the voltage levels improved. We note that the GA and PSO methods yield voltage levels very close to the upper and lower limits, whereas for the two hybrid metaheuristic methods, the voltage profile is better. For the control variables (power generated and transformation ratio), the values remained within the imposed limits (Table 4, Table 5).

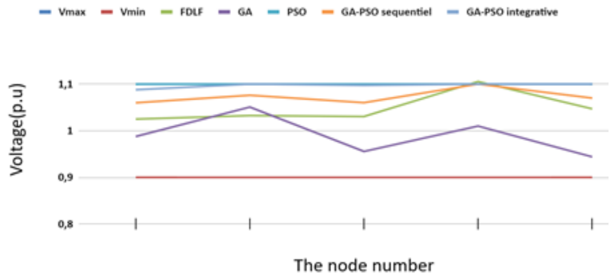


Fig.4. The voltage at the nodes of network 400 kV

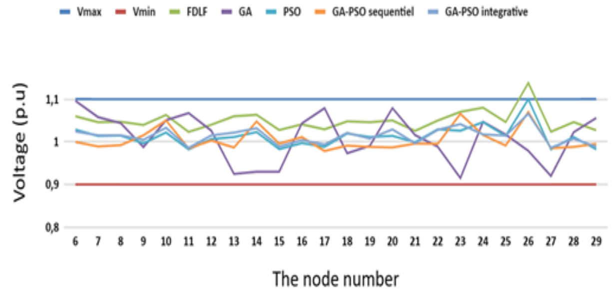
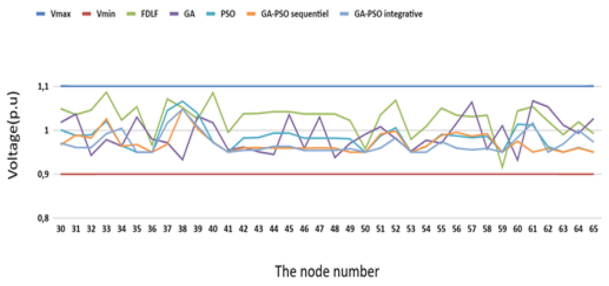


Fig.5. The voltage at the nodes of network 220 kV

a) Network 60 kV nodes numbers 30 to 65



b) Network 60 kV nodes numbers 66 to 102

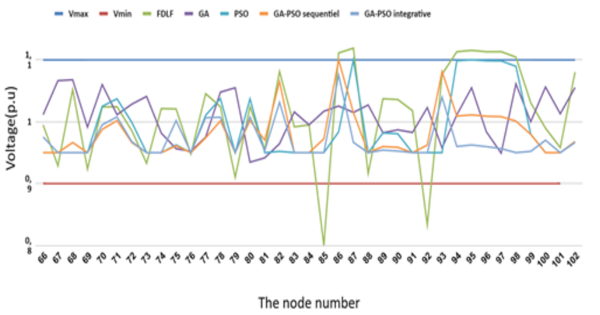


Figure 6. The voltage at the nodes of network 60 kV

Conclusions

The obtained results illustrate the effectiveness and performance of the two methods resulting from the hybridization of two population metaheuristic methods, following their application to the optimization of reactive powers and their impact on voltage levels in different nodes of the network. We observed that the hybridizations of population metaheuristic methods present a clear advantage, both qualitatively in terms of practical results such as the reduction of active loss values, while adhering to the plan of voltages, powers, and transformer regulation ratios (DTC) within the limits of allowable margins.

In conclusion, the sequential hybridization of population metaheuristics is the one that provides optimal values for active losses, due to the improved results of genetic algorithms (GA) through the sequential execution of the particle swarm optimization (PSO) method, and this also translates into more efficient execution time. Integrative hybridization of metaheuristics proves to be the least effective compared to other methods.

Furthermore, this study can be extended to: • The development of other types of hybridization. • Hybridization of GA and PSO methods with other methods to minimize losses and execution time.

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