Optimal Reconfiguration of Radial Distribution Networks for an Hourly Variation in Daily Load Consumption

Raida Sellami, Imene Khenissi, Rafik Neji and Tarek Bouktir

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Raida SELLAMI
Department of Electrical Engineering University of Sfax ENIS
Tunisia, Sfax
sellamiraida1991@gmail.com

Imene KHENISSI
Department of Electrical Engineering University of Sfax, ENIS,
Tunisia, Sfax
khenissiimen009@gmail.com

Rafik NEJI
Department of Electrical Engineering University of Sfax ENIS
Tunisia, Sfax
rafik.neji@gmail.com

Tarek BOUKTIR
Department of Electrical Engineering
University Ferhat Abbas, Sétif1, Algeria, Sétif
tbouktir@gmail.com

***Abstract*— As the load characteristic of the distribution system varies over time, the network topology also changes from one point of consumption to another. The methodology addressed in this study consists of alternating distribution network switches for different load points on the daily consumption curve, two scenarios are investigated, with a major goal of obtaining the most optimal configuration of the test network while reducing the total losses of active power and also improving the voltage profile. To deal with, an improved PSO methodology coupled with MATPOWER toolbox was applied on the IEEE 33-bus radial distribution network and the results found demonstrate the effectiveness of reconfiguration procedure for enhancing the test system performance.**

Keywords*— *optimal reconfiguration, power losses, daily consumption curve, particle swarm optimization (PSO).

I. INTRODUCTION

Far from being a luxury, electricity is today the most essential form of energy for the development of a country. Thus, any interruption in electrical energy can have enormous consequences [1].

As a result of political decisions, the liberalization of the electricity market increases competition between energy distributors aiming to ameliorate the energy supply and gain more profits by choosing an appropriate topology when operating the electricity distribution networks [2-3].

The reconfiguration of power lines is becoming an important tasks for reducing losses and improving the reliability of radial distribution networks (RDN). So far, most researchers have studied the static problem of network reconfiguration by using a fixed loads level and due to the time-varying nature of the loads in the distribution systems, the reconfiguration found present a sub-optimal solution [4]. With a variable demand for a load characteristic over time, the reconfiguration problem presents a complex problem of a combinatorial nature [5]. Moreover, the determination of a reconfiguration topology considering time-varying variables such as daily load consumption profile present a dynamic problem and the solution found present the optimum annual reconfiguration scheme.

The rest of this work is presented as follows: the formulation of the problem characterizing the present study is well detailed in Section 2. Section 3 gives an idea on the optimization method chosen and applied in our reconfiguration strategy. The simulation procedure, the results obtained and the discussions of the work are displayed in Section 4. This work is thus closed by a conclusion which is given in Section 5.

II. PROBLEM REPRESENTATION

The Optimal Reconfiguration of Distribution Network consist on a multi-objective, nonlinear, discrete, multistage planning problem [6-7].

In the present project, finding a new optimal system configuration with minimum total power losses (Plosstot) and with an improvement in voltage magnitude enables to achieve the main objective of this study expressed in Eq. (1) [8].

$$F_{Objective} = \min (P_{losstot}) \quad (1)$$

$$\text{With } P_{losstot} = \sum_{X=1}^{nb} K_X R_X \left(\frac{P_X^2 + Q_X^2}{V_X^2}\right) \quad (2)$$

The objective function cited above is subject to various constraints [9-10]:

- Branch current constraint: $I_X < I_{Xmax}$ (3)
- Node voltage constraint: $V_{min} \leq V_x \leq V_{max}$ (4)
- Network Topological Constraint:
  - Network's structure should always remain radial (this indicates that no loops are allowed in the networks),
  - All load must be connected to the network (each and every bus should be connected via one path to the substation).

Where,

X	the branch number,
nb	the total branch numbers,
K_X	the state of switch where 0 means open state and 1 means close state,
R_X	the resistor of branch X,
P_X	the active power of branch X,
Q_X	the reactive power of branch X,

V_X	the up-layer node voltage of branch X,
V_{min}	the minimum allowable voltages of node X,
V_{max}	the maximum allowable voltages of node X,
I_X	the current of branch X,
I_{Xmax}	the extreme allowable current of branch X.

III. Particle Swarm Optimization Methodology (PSO)

Particle swarm optimization (PSO) present a modern heuristic optimizer [11]. Firstly introduced by Kennedy and Eberhart in 1995.

Inspired by the social behavior of bird flocking or schools of fish, it has proven to be robust in solving complex and non-linear optimization problems on an ongoing basis. Since it is considered an optimization method, it gives a population-based research methodology in which individuals call particles to change their position over time. Particle swarm optimization does not need any mathematical information or any statistical error function because as a heuristic and stochastic algorithm [12-13-14].

The PSO uses a vectored research space where particles fly in a multidimensional research space; each particle in a research space proposes a solution to the problem. During a flight, the best position visited by particles in the problem search space, according to his own experience, is called the "personal best particle", P_{best}. In addition, the best position among the neighboring particles is called a "global best position", G_{best}, made use of the best position encountered by himself and his neighbor [15-16-17].

The behavior of a given particle consists in a compromise between three possible moves: trends: Follow its own speed, Return to its best performance, Go to the best performance of its informants [18].

At each new iteration, the velocity of each particle is updated using the current velocity and its distance from Pbest and Gbest as mentioned in this equation [19-20]:

$$v_i^{k+1} = w^k . v_i^k + c_1 . r_1 . (pbest_i - x_i^k) + c_2 . r_2 . (gbest - x_i^k) \quad (4)$$

Where,

c_1, c_2	the acceleration constants,
k	the current iteration number,
w^k	the inertia weight factor,
r_1, r_2	the random numbers within the range [0, 1].

The velocity of a particle is updated and the current position of each agent can be modified by using the above equation [21]:

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (6)$$

Where,

v_i^k	the velocity of particle i in the search space at iteration k,
x_i^k	the current position of particle i in the search space at iteration k,

The PSO work's technique is well explained by the detailed flow chart of Fig.1.

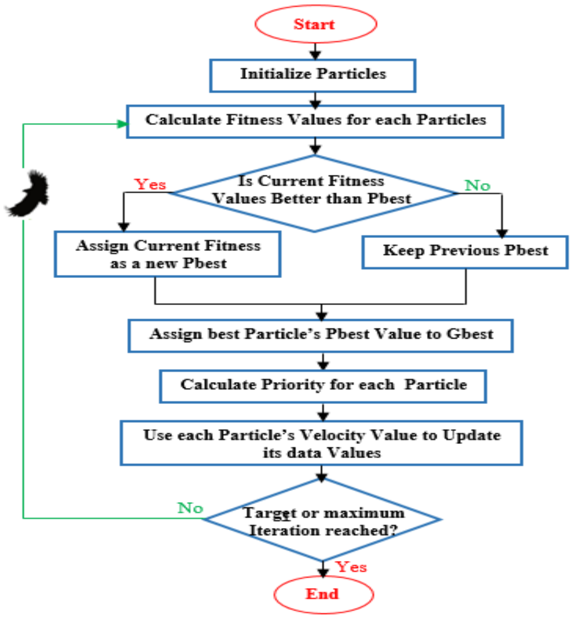

Fig. 1. Flow chart of Particle swarm optimization (PSO)

IV. Case Study

To assess the reliability of the planned method, the process of optimal reconfiguration with PSO optimization is tested on a standard IEEE 33-bus radial distribution network (RDN) with various scenarios including the goal of improving network performance (maximization of voltage deviations) and also to meet the major objective of our study (minimization of the total losses of real powers).

The test system, IEEE 33-bus RDN, consists of one main feeder and three laterals. As shown in Fig. 2, this network mainly has:

- 33 buses,
- 32 sectionalizing switches, which are closed in the normal state,
- 5 tie switches, which are normally open.

Hence the initial state vector is of the form, X= [33, 34, 35, 36, 37].

In this study, two various scenarios are tested on the cited RDN:

Scenario 1: Reconfiguration of the test system at a well-defined load consumption point,

Scenario 2: Reconfiguration of the test system over a time interval based on a daily load consumption curve,

Taking into account the state of the system under normal operating conditions which represent the initial state of the network. The IEEE 33-bus radial distribution network therefore has operating voltages of 12.66 kV, a power base of 100 MVA, a total power load of 3715 kW, an initial real and reactive power losses of 202.67 kW and 135.14 kVAR, respectively.

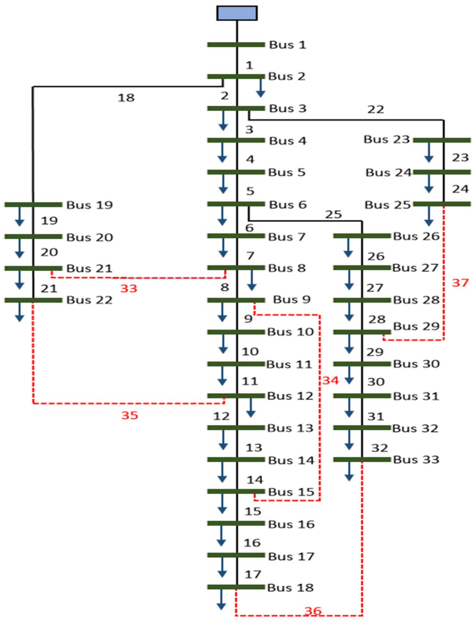

Fig. 2. IEEE 33-bus RDN model before reconfiguration.

A. *Scenario 1: Reconfiguration at a well-defined load consumption point*

Reconfiguration of the IEEE 33-bus RDN network using the improved PSO method applied during scenario 1 resulted in a new optimal configuration of the test network thus modifying the states of different branches thus verifying that the test network still remains radial and that the connected loads are all supplied. In this case, the final state vector corresponding to this so-called optimal topology is X = [7, 9, 14, 32, 37] as shown in figure 3. Where,

- solid lines indicate branches in service,
- dotted lines indicate out of service branches.

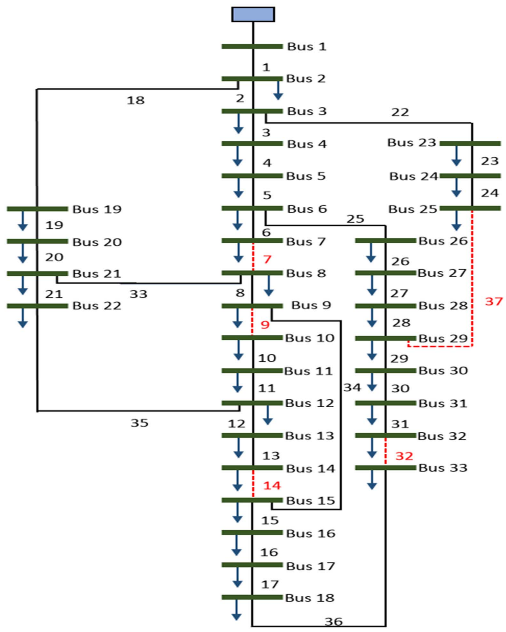

Fig. 3. IEEE 33-bus RDN model after reconfiguration

The results obtained by applying the first scenario clearly show an improvement in the voltage levels and a decrease in the total active power losses of the RDN. Fig. 4 shows the voltage magnitude at each bus for the base system topology and the optimal one.

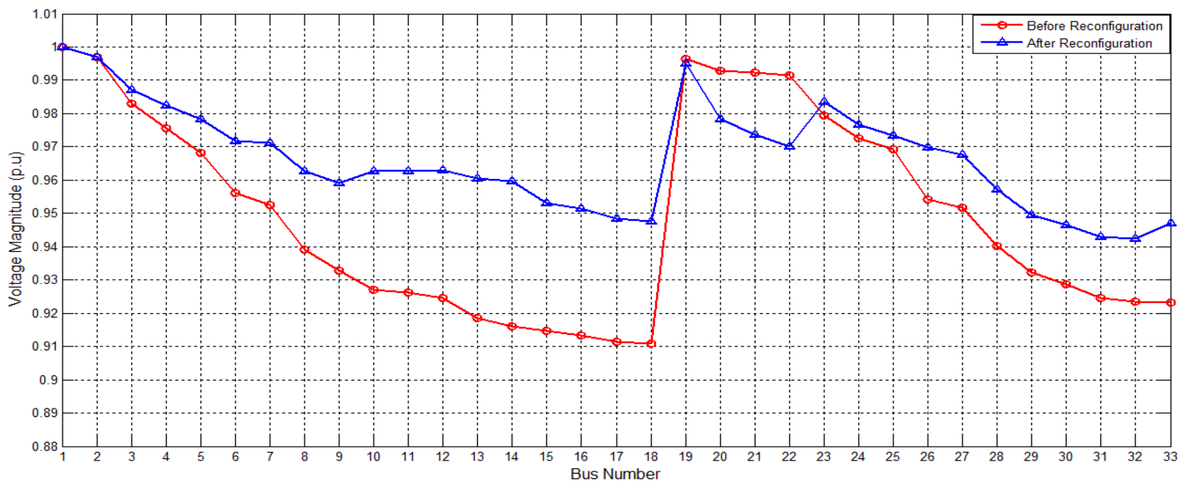

Fig. 4. Voltage profiles of the test network before and after reconfiguration (scenario 1)

Fig. 4 demonstrates that the minimum voltage characterizing the initial case is found at bus 18 with an amount of 0.9131 pu. After reconfiguration, a new topology is obtained with an optimal voltage profile and the minimum voltage corresponding to this case is found at bus 32 with a new value equal to 0.9425 pu.

All results found following the application of PSO optimal reconfiguration in a special load consumption point are detailed in table II. After using the PSO algorithm of literature, the total losses are reduced from 202.67 kW to 139.90 kW. So, the reduction rate after finding the optimal state is equal to 30.97 %. By applying the proposed PSO reconfiguration procedure, the reduction rate of power losses increases with an optimal value equal to 31.17 %.

It is remarkable that the results obtained clearly reflect the impact of the optimal reconfiguration of the RDN on the reduction of the total losses of active power with a remarkable improvement of the voltage levels.

TABLE I. Results of reconfiguration of the test RDN (Scenario 1)

Reconfiguration conditions	**Before reconfiguration**	**After reconfiguration**	
		Literature	**Proposed Algorithm**
Disconnect Network switches	7-8, 9-15, 12-22, 18-33, 25-29	7-8, 9-10, 14-15, 28-29, 32-33	7-8, 9-10, 14-15, 25-29, 32-33
Minimum voltage (p.u)	0.9131	0.9412	0.9425
Real power loss (kW)	202.67	139.90	139.49
Percentage (%) of Loss reduction	-----	30.97	31.17
Saving Power (kW)	-----	62.77	63.18

B. *Scenario 2: Reconfiguration over a time interval based on a daily load consumption curve*

It is obvious that a topology which is optimal at one time is no longer for another. For example, a configuration that is optimal for peak hours may no longer be optimal for off-peak hours due to the change in the behavior of loads on the network, for this the simulation of scenario 2 becomes essential [2]. Network reconfiguration using the proposed Particle Swarm Optimization method on IEEE 33-bus RDN for the second scenario consists in applying the same reconfiguration technique studied in a specific load consumption point (scenario 1) but now over a whole load consumption time interval (the day was segmented into 24 hours) and this from a load consumption curve of the day of 30/11/2018 according to [RTE, 18] presented in Figure 5.

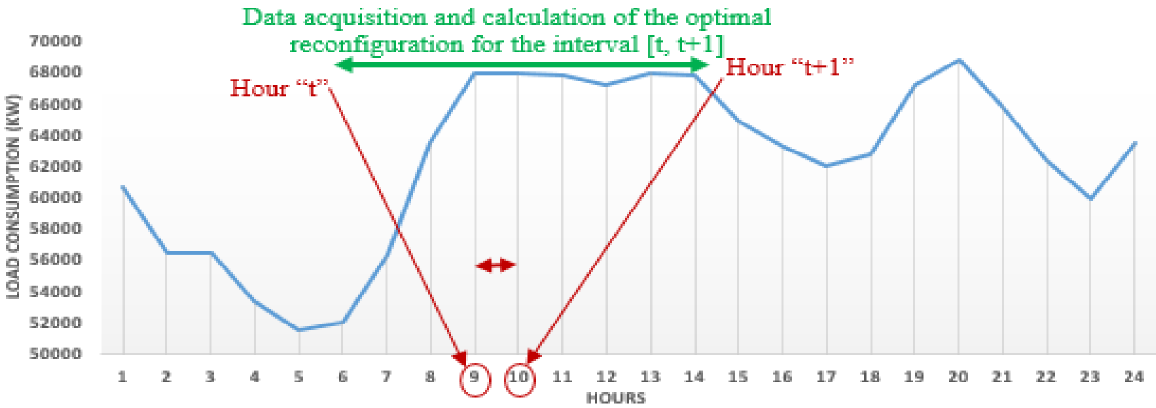

Fig.5. Typical evolution during the day of electricity consumption for the day of 30/11/2018 [RTE, 18]

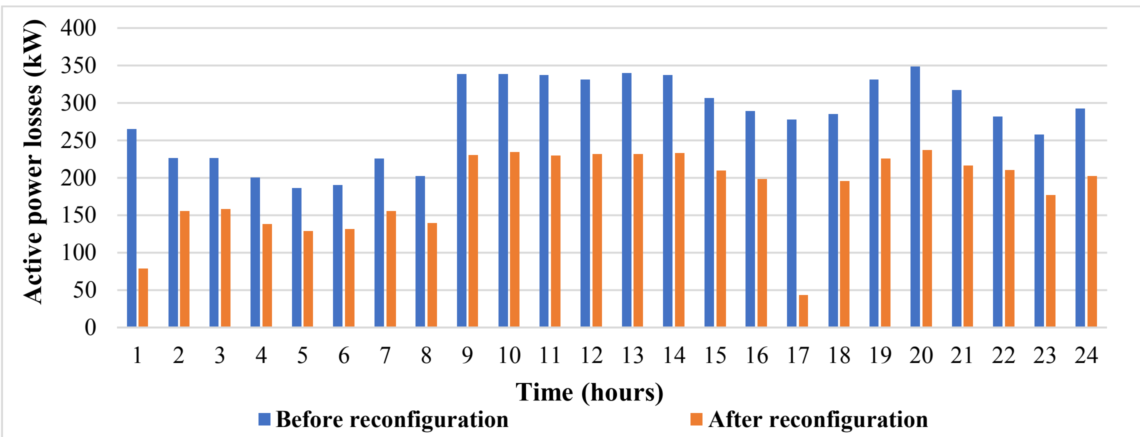

Fig. 6. Hourly variation of power losses through the day 11/30/2018

The results of the feeder system in relation to the above mentioned procedure are reported in Table II where the last column of the table clearly shows the various change to be made in switcher's topology while going from one consumption point to another during the 24 hours of the day.

TABLE II. Results of reconfiguration of the test RDN (Scenario 2).

Hours	Before Reconfiguration			After Reconfiguration			% of P.losses reduction	Number of switches change
	Switches	P.losses	Vmin	Switchers	P.losses	Vmin		
01.00	33, 34, 35, 36, 37	265,1167	0,9074	2/15/33/34/37	78,4037	0,91985	70,4267	4
02.00		226,1921	0,9146	7/9/14/32/37	155,8185	0,9392	31,1123	1
03.00		226,1921	0,9146	7/11/14/32/37	157,9858	0.9392	30,1541	1
04.00		200,3498	0,9196	7/9/14/32/37	138,4150	0.9427	30,9134	0
05.00		186,1298	0,9225	7/9/14/32/37	128,8028	0.9447	30,7995	0
06.00		190,0363	0,9217	7/9/14/32/37	131,4460	0.9442	30,8311	0
07.00		225,3154	0,9147	7/9/14/32/37	155,2294	0.9393	31,1054	0
08.00		201,9476	0,9193	7/9/14/32/37	139,4934	0.9425	30,9259	0
09.00		338,5554	0,8953	7/9/14/32/37	230,8872	0.9258	31,8903	0
10.00		338,5554	0,8953	7/9/14/32/37	233,8872	0.9258	30,9161	1
11.00		337,4440	0,8955	7/11/14/32/37	229,8563	0.9260	31,8831	2
12.00		330,9373	0,8965	6/9/14/32/37	231,6299	0.9214	30,0079	1
13.00		339,6103	0,8951	7/9/14/32/37	231,2845	0.9257	31,8971	1
14.00		337,4440	0,8955	7/11/14/32/37	233,1431	0.9260	30,9091	1
15.00		306,6542	0,9004	7/9/14/32/37	209,5029	0.9294	31,6811	1
16.00		289,3981	0,9033	7/9/14/32/37	198,0511	0.9313	31,5645	4
17.00		277,5433	0,9053	4/12/22/32/33	42,9656	0.9542	84,5193	4
18.00		285,4140	0,9039	7/9/14/32/37	195,4025	0.9318	31,5372	0
19.00		330,9373	0,8965	7/9/14/32/37	225,5634	0.9267	31,8410	0
20.00		348,4776	0,8938	7/9/14/32/37	237,1255	0.9248	31,9539	0
21.00		317,0229	0,8987	7/9/14/32/37	216,3684	0.9282	31,7499	2
22.00		281,5149	0,9046	7/14/32/35/37	210,6321	0.9235	25,1791	1
23.00		257,5811	0,9088	7/9/14/32/37	176,8493	0.9351	31,3423	1
24.00		292,3941	0,9028	7/9/14/28/32	201,8234	0.9296	30,9755	

This summary table clearly shows that over the 24 hours, we consider that there are 7 reconfigurations which have been calculated as being optimal for losses over contiguous hour intervals. For example, the reconfiguration [7/11/14/32/37] is optimal for the hours {02.00, 10.00, 13.00} of the day. However, the changes between these reconfigurations during a day could be a heavy task for network operation and even a waste of time and energy, hence the idea is to choose a single reconfiguration used throughout the day. We identify, among the 7 resulting configurations, the one that would lead to the lowest power losses (objective of our study) and maintain it during all the day which will be the reconfiguration of the hour 17.00 of the daily consumption curve allowing to have a minimization of power losses equal to 84% comparing to losses in the initial state without reconfiguration as it is shown in Fig.6.

V. CONCLUSION

The study discussed in this paper highlights, on an example of an IEEE 33-bus RDN and for a possible daily load consumption curve, that the operation of distribution networks with the topology identified as optimal for a specific point belonging to the load consumption curve, is not optimal when switching from one load consumption point to another during the 24 hours of all the day.

The results obtained by applying PSO method combined with MATPOWER toolbox and following calculations of the so-called sub-optimal reconfiguration at each time point of the load curve, have demonstrated the effectiveness of this improved procedure to identify the optimal reconfiguration for the entire interval of the given consumption curve (a daily load consumption), leading to significant reductions in power losses with a significant improvement in the voltage profile.

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