KNOWLEDGE BASE FOR ELECTRICAL DISTRIBUTION NETWORKS RECONFIGURATION

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Abstract - In this paper we summarize the main idea of radial distribution network (RDN) operation. We present the criteria used for RDN reconfiguration and, than we describe the proposed reconfiguration method, based on meshed networks power flows. Using Prolog language, via production rules, the proposed reconfiguration method is implemented in a knowledge base. For a large 20 kV RDN from Romania, we analyze the obtained results. Finally, we present the main important conclusions.

Key words: radial & meshed distribution network, network reconfiguration, knowledge base, Prolog language

1. INTRODUCTION

Electrical distribution networks are design as interconnected meshed networks; however, they are arranged to be radial in operation. The network (feeders) configuration problem is to find a radial operating structure that optimizes network performance while satisfying operating constraints. Most of the overhead and underground electric power distribution systems must operate in radial configurations. They are named radial distribution network (RDN). Normally open and normally closed switches are located along the network in strategic points. By altering the topology to a different radial configuration, one might obtain losses reduction, improvement in the network voltage profile, and betterment of reliability indices. When a fault occurs, the fault region can be isolated and a new radial configuration might restore the rest of the load.

Optimal operation of a distribution system may be achieved through a combination of methods. Reconfiguration is an important method among them. Numerous works have been reported in the literatures that propose methods for optimal reconfiguration of radial distribution systems.

Reference [1] proposes a reconfiguration method using a Simulated Annealing technique. References [2–4] have proposed different branch exchange techniques for network reconfiguration. Reference [5] has proposed a set of three algorithms for distribution feeder reconfiguration. Reference [6] proposed an alternate method for branch exchange using a heuristic approach. Reference [7] has proposed a branch exchange type algorithm for the determination of change in power loss due to branch exchange.

The reconfiguration problem that determines the best possible configuration considering the above criteria and constraints can be modeled as a non-linear mixed integer problem, what produces an enormous search space due to the combinatory nature of the problem. Many approaches have been considered to address such a problem, particularly conventional integer programming algorithms, heuristic algorithms and mixed heuristic combinatory algorithms to better explore the search space [8–12].

This paper presents the criteria used for network reconfiguration and proposes a new method based on power flow for meshed distribution network reconfiguration. The main advantage of the proposed method is that the algorithm avoids the repeated search of the branch used in reconfiguration. The method was implemented using Prolog (a declarative environment) and production rules, and then it was tested using two 20 kV RDN. The first test distribution network (DN) has 13 buses and 18 branches and has two 110/20 kV power substations. The second network is a real DN from Timisoara (Romania) area and has 87 buses, 92 branches and 5 power substations (110/20 kV). Finally, some considerations and conclusions are presented.

2.THE PROPOSED DN RECONFIGURATION METHOD

The proposed DN reconfiguration method uses the results of the meshed network power flow to determine the branches used in reconfiguration. To compute the power flow, the power system simulator POWERWORLD (PW) is used.

The consumers are modeled using their daily load curve (with 48 tiers, one for each half hour). This daily load curve is established as a characteristic curve for each consumer for a medium to long time horizon (e.g. a season), in this period the DN configuration stays the same. The daily load curve is determined using statistical and probabilistic approach and the measured consumption values for a long time horizon. From the consumption time series, the mean square deviation and mean value for each load is determined, accepting a Gaussian (normal) distribution for the consumed power.

Considering the aspects presented in the above paragraph, 48 different operating states were determined corresponding to the 48 tiers from the daily load curves. Using the PW simulator, 48 different operating states are computed (for the meshed DN). For each branch, 48 load percentage levels reported to maximum transfer capacity are determined. Using these 48 values, for each branch of the DN a mean value of the load for the considered time horizon is determined.

The method principle consists in disconnecting the branches with minimum load flow in the meshed state. Disconnecting those branches, the new operating state is similar with the meshed DN but the losses are smaller compared with other reconfiguration solutions. If two branches with different load flows from the meshed DN are disconnected, the total losses will increase much slower when the branch with small load flow is disconnected. It was taken into account that the meshed network has the lowest level of losses compared with every reconfigured RDN.

The process of identification of the branches which will be disconnected considers the mean percentage load flow of each branch of the DN and follows the algorithm described below:

1. The branches are ordered ascending using the mean percentage load flow of every branch.
2. The branches which are part of radial ramifications (and are not used in reconfiguration) are eliminated from the list.
3. The number of branches used in reconfiguration is determined:

$$nr\_trons\_rcfg = (laturi - noduri + 1) + (statii - 1) \qquad (1)$$

where:

nr_trons_rcfg – the number of branches used in reconfiguration;
laturi – the number of DN branches;
noduri – the number of DN buses;
statii – the number of DN power stations.

4. Considering branch no.1 to branch *nr_trons_rcfg* in the list determined at step 2, for each branch opened the corresponding loop is determined and the radial ramifications resulting from this process is eliminated from the branch list.
5. Step 4 is repeated until *nr_trons_rcfg* is reached. The resulted network is no longer meshed and the links between the power stations are also opened.

The algorithm presented above was implemented in an application called RDNR (Radial Distribution Network Reconfiguration), developed in PROLOG language. RDNR uses data from PW simulator and determines the branches which will be used to obtain the minimum loss network configuration.

3. IMPLEMENTING THE METHOD IN PROLOG

The reconfiguration method described above was implemented in the Prolog declarative programming environment as production rules. The explanations corresponding to each rule are presented below, preceded by character %:

```
reconfig  if                     % the general reconfiguration rule
     radial,                     % radial branches elimination
     bubble_sort(Lr,LS),         % branch load flow ascending sort
     debuclare(Contor,LS).       % identification of used branches in
                                 % reconfiguration

radial if                        % initial elimination of radial branches
     find_database(L),           % current step branch list
     retract(continua(_)),       % eliminates the bookmark for further
     search  elim_radiale(L),    % eliminates the radial branches at current
                                 % step
     continua("YES"),!,radial.   % radial rule recursive call

radial.                          % the search stops if there are no
                                 % radial branches

elim_radial([]) if !.            % eliminates the radial branches form the
                                 % branch list

elim_radial([tr(_,Ni,Nf,_,_)|Lista]) if     % branch delimited by buses
     ramificatie(Ni),                       % ramification is not radial
     ramificatie(Nf),!,
     elim_r(Lista).

elim_radial([tr(_,Ni,Nf,_,_)|Lista]) if     % the branch connected directly
      noduriStatie(NodStatie),              % with the power station
      apartine(Ni,NodStatie),               % will not be eliminated
      ramificatie(Nf),!,                    % from the list
```

```
      elim_r(Lista).

elim_radial([tr(_,Ni,Nf,_,_)|Lista]) if     % the branch connected directly
      noduriStatie(NodStatie),              % with the power station
      apartine(Nf,NodStatie),               % will not be eliminated
      ramificatie(Ni),!,                    % from the list
      elim_r(Lista).

elim_radial([tr(N,Ni,Nf,F,S)|Rest]) if      % the other branches are
      retract(trn(N,Ni,Nf,F,S)),!,          % eliminated from the list
      assert(continua("YES")),
      elim_r(Rest).

debuclare(0,_).          % determines the branches used in reconfiguration
debuclare(Contor,[tr(N,Ni,Nf,F,S)|Rest]) if
      retract(trn(N,Ni,Nf,F,S)),% deletes from current database the branch
                                % used in reconfiguration
      stergeRadial(Ni),  % deletes the initial radial branches from start bus
      stergeRadial(Nf),  % deletes the initial radial branches from end bus
      ContorN=Contor-1,  % the counter decreases from nr_tr_rcfg to 0
      debuclare(ContorN,Rest). % recursive call for the rest of the list

stergeRadial(Nod) if     % if Nod is a bus for a power substation then the
      noduriStatie(L),   % deleting process is stopped
      apartine(Nod,L),!.
stergeRadial(Nod) if     % if Nod is a bus for a ramification then the
      ramificatie(Nod),!.% deleting process is stopped
stergeRadial(Ni) if      % deletion of other branches
      retract(trn(_,Ni,Nf,_,_)),!,stergeRadial(Nf).
stergeRadial(Nf) if
      retract(trn(_,Ni,Nf,_,_)),stergeRadial(Ni).

ramificatie(Ni) if       % checks if in bus Ni is a ramification
      trn(_,Ni,Nf1,_,_),trn(_,Ni,Nf2,_,_),Nf1<>Nf2,!.
ramificatie(Ni) if
      trn(_,Ni,Nf1,_,_),trn(_,Nf2,Ni,_,_),Nf1<>Nf2,!.
ramificatie(Nf) if       % checks if in bus Nf is a ramification
      trn(_,Ni1,Nf,_,_),trn(_,Ni2,Nf,_,_),Ni1<>Ni2,!.
ramificatie(Nf) if
      trn(_,Ni1,Nf,_,_),trn(_,Nf,Ni2,_,_),Ni1<>Ni2.
```

4. CASE STUDY

The presented method was tested first on a test DN with 13 buses and 18 branches, called RDN13. The network is supplied from two 110/20 kV power substations. The power substations are connected with a 110 kV single circuit power line. The actual distribution network has 11 buses at 20 kV with 3 independent loops and 1 radial branch. The network and its main parameters are presented in Fig. 1. All the parameters of RDN13 are presented in detail in [13]. The load values for the buses were determined using the characteristic daily load curves for each consumer, presented in the above paragraphs.

As it can be observed from Fig. 1, the branch list in ascending order of load, identified by the RDNR application is: 6-13 cu 1.81 %, 11-12 cu 8.37 %, 5-6 cu 10.70 % şi 7-9 cu 11.23 %.
In the first stage, after opening branch 6-13, 11-12 and 7-9, the initial 3 loops were abolished. In the second stage of the application, branch 5-6 is opened (this branch connects the two power substations).

After the reconfiguration proposed by the RDNR and computing the power flow for the new network with PW, the losses of active power increased with 7,4% (from 0,963 MW to 1,018 MW) and the losses of reactive power increased with 2% (from 3,730 MVar to 3,803 MVar). The bus voltages were in admissible range, the lowest one was in bus 9 (20,121 kV). Fig. 2 gives some information about the reconfigured network.

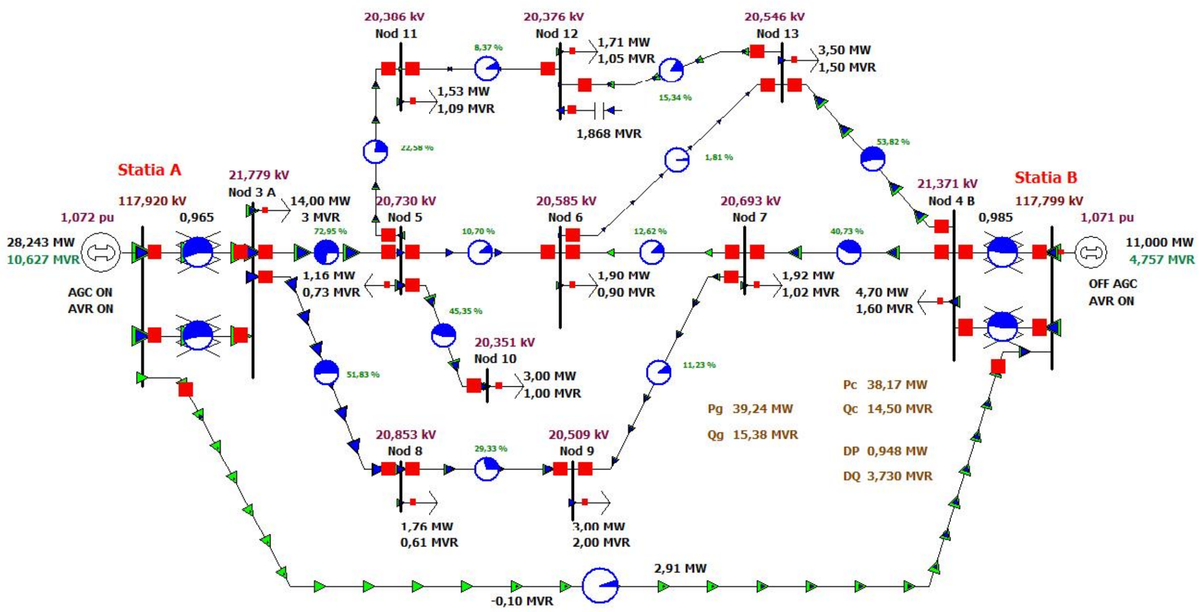

Fig. 1. RDN13 – meshed network

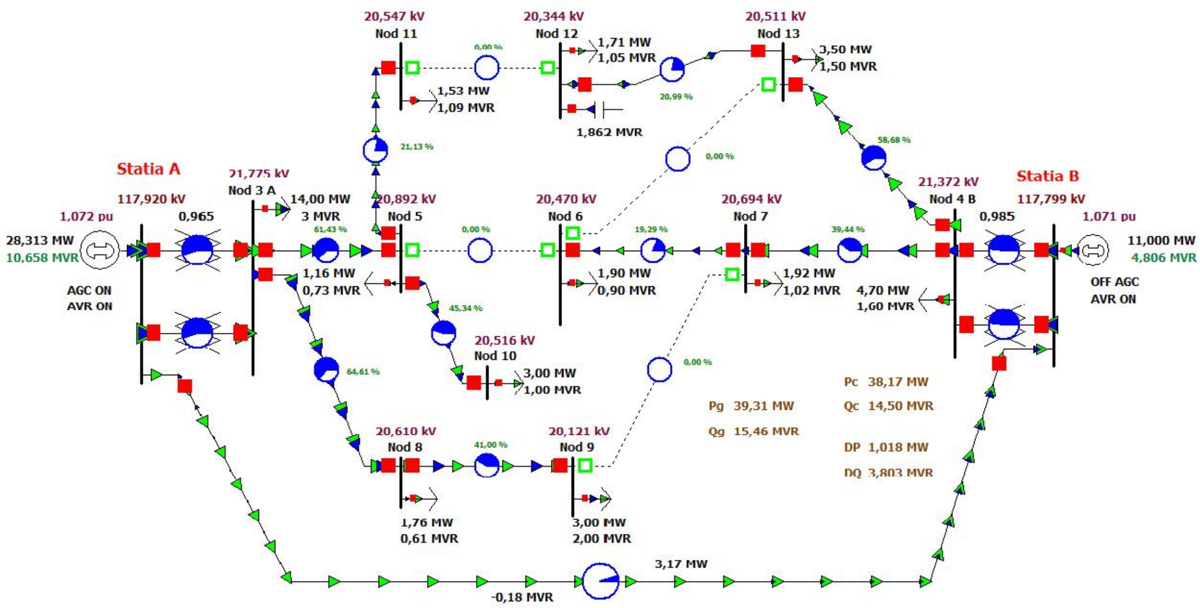

Fig. 2. RDN13 – Reconfigured network

For RDN13, a small network, were analyzed other reconfiguration solutions (e.g. instead branch 11-12 was used 12-13 etc.). In all these solutions, the computed power flow resulted in increased values of losses compared with the solution given by the RDRN application, fact which confirms the correctitude of the proposed method and software application. In Fig. 3 is presented the case when branch 12-13 was used in the reconfiguration process, instead of 11-12 (which was determined with RDRN software application). As it can be observed, the active and reactive power losses are bigger than in the RDRN solution.

The proposed method and software application was also tested on a real DN, from Timisoara (Romania) area (RDN87) and has 87 buses (81 at 20 kV and 6 at 110 kV) and 92 branches (82 at 20 kV). The network is supplied from five 110/20 kV power substations. The power substations are interconnected with five 110 kV single circuit power lines. RDN87 has 3 independent loops and 25 radial branches. The network (in the reconfigured operation state) is presented in Fig. 4. All the parameters for RDN87 are detailed in [13]. The load values for the buses were determined using the characteristic daily load curves for each consumer, presented in the above paragraphs.

After the reconfiguration using RDNR, the active power losses increased with 3% (from 0,70 MW to 0,72 MW) and the reactive power losses increased with 7,7% (from 2,71 MW to 2,92 MW). All the voltages were in normal range. As in the previous case study for RDN13, all other reconfiguration solutions were inferior compared with the solution given by RDNR software application.

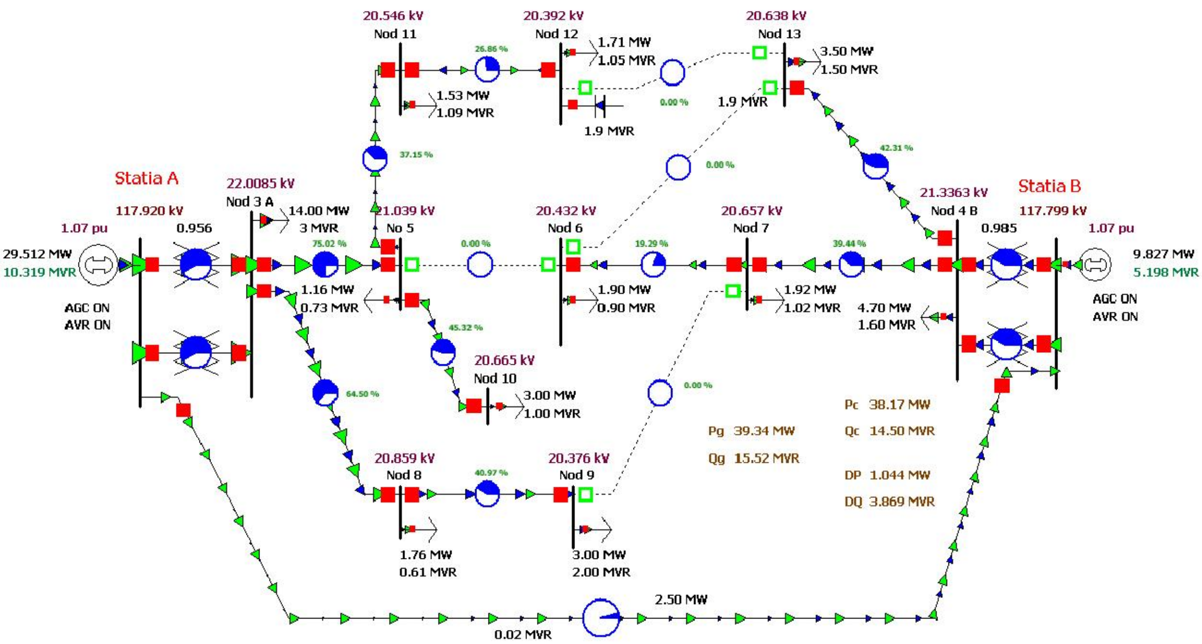

Figure 3. RDN13 – wrong reconfiguration solution

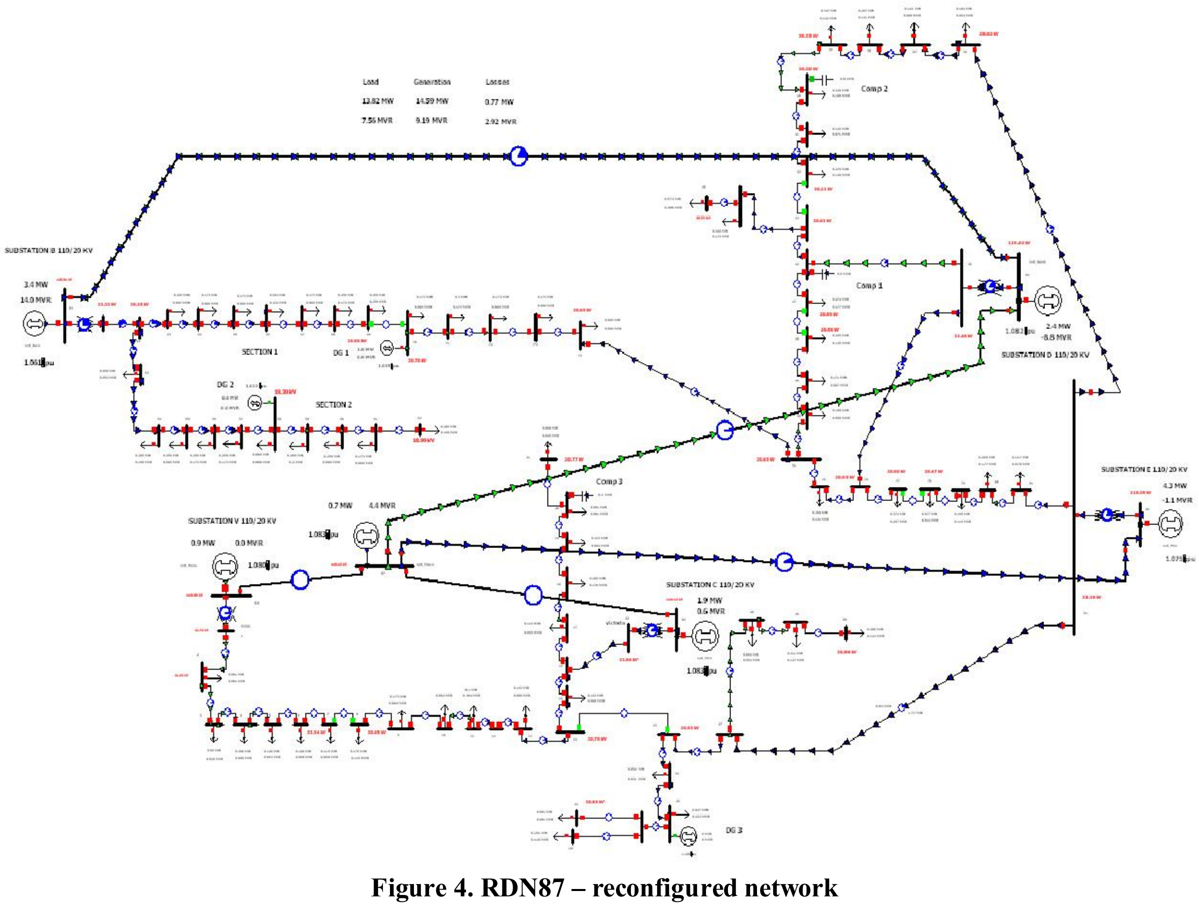

Figure 4. RDN87 – reconfigured network

CONCLUSIONS

The proposed reconfiguration method based on mean power flow computation in meshed distribution network is efficient because it establishes directly the best reconfiguration solution with minimum losses. In other methods presented in literature, the optimal solution is determined with great computational effort and it must consider large sets of reconfiguration variants.

RDNR software application which uses the proposed method is a complementary tool for PW simulator. It uses logical inference, which is a technique specific to artificial intelligence.

The proposed method was used in two case studies, one for a 13 bus DN (RDN13 with 18 branches) and one for a real DN (RDN87) with 87 buses and 92 branches.

The results of the case studies presented and other results obtained by the authors, confirm the validity and the efficiency of this method for reconfiguring the RDN.

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