A topological reconfiguration procedure for maximising local consumption of renewable energy in (Italian) active distribution networks

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Distribution networks are facing great changes, due to the strong increase in distributed generation, often driven by renewable energy sources. Designed to deliver electrical power from the transmission system to the final consumers, they are now becoming active and may inject power into the transmission network. In case of large distribution network, a portion of the system can be absorbing power from the transmission grid, while another portion injects power into it. In order to satisfy the power balance as much as possible at the local level, the distribution system operators are interested in the minimization of the power exchange with the transmission network, maximizing the local consumption of distributed generation energy. This paper presents a topological reconfiguration procedure, based on the branch exchange technique, for the maximization of the local consumption of renewable energy. A case study is presented, based on a real distribution network located in northern Italy.

Keywords: distribution networks; optimization; renewable energy; topological reconfiguration.

1 Nomenclature

DG	Distributed Generation
DN	Distribution Network
DSO	Distribution System Operator
HV	High Voltage
MV	Medium Voltage
NPL	Neplan Programming Library
PV	PhotoVoltaic
TSO	Transmission System Operator

2 Introduction

In the last decade the Distribution Network (DN) way of working has changed dramatically: the introduction of Distributed Generation (DG) units, based both on renewable or on conventional sources, can in fact reverse the direction of power flows in the MV lines and even in HV/MV transformers. In addition to this, DG and consumption can be unevenly allocated, making it possible to have certain network portions with prevailing generation and other ones with prevailing consumption. The different zones can be fed by the same HV/MV substation or sometimes, even if they belong to the same Distribution System Operator (DSO), they can be fed by different HV/MV substations.

The DNs are weakly meshed but are operated in a radial configuration in order to guarantee a reliable and safe operation under fault conditions (Lavorato et al. 2012; Gohokar, Khedkar, and Dhole 2004). It is however possible, for the DSO, to change the network topology by operating the available remotely controllable circuit breakers, closing normally open and opening normally closed lines. Normally open lines are usually called *tie-lines*, and are equipped with *tie switches*, while normally closed lines are equipped with *sectionalizing switches*. Network reconfiguration can be performed during normal operation of the system, in order to reduce network losses, improve the voltage profiles, or improve other DN performances , or for service restoration after a fault (Chiang and Jean-Jumeau 1990a).

Different methodologies have been proposed for network reconfiguration and for different objectives. Chiang and Jean-Jumeau (1990a) propose a modified *simulated annealing* methodology for both loss reduction and load balancing. The proposed methodology is then implemented and the perturbation mechanism that produces new network configurations is the closure of one or more tie-lines, followed by the opening of the same number of normally closed lines, chosen randomly in the loops which were just formed (Chiang and Jean-Jumeau 1990b).

Wagner, Chikhani, and Hackam (1991) compare instead different methods, based on *linear programming* or *heuristic* techniques, for real-time implementation of the network reconfiguration for loss reduction. The results show that the linear programming methods are not suitable for real-time applications while heuristic methods may lead to a small reduction in loss savings (they do not necessarily provide the global optimum) but are reliable and fast.

Jeon and Kim (2000) propose a hybrid algorithm which combines the advantages of *simulated annealing* and *tabu search*. The objective of their study is again the loss reduction in a distribution system. A parallel tabu search algorithm is instead proposed for active power loss minimization by Mori and Ogita (2000); one of the key points in this algorithm is the decomposition of the solution neighbourhood into sub-neighbourhoods.

A different possibility for distribution networks reconfiguration is represented by *fuzzy reasoning* approaches (Ebrahimi and Mohseni 2001). In their paper they present a multi-purpose reconfiguration of distribution systems, aiming at five objectives: loss reduction, load balancing, voltage profile improvement, least service interruption and minimum switching actions. Prasad et al. (2005) propose instead a *fuzzy mutated genetic algorithm* for both improving the voltage profile and reducing power loss.

An interesting novelty introduced in the objectives of the optimization of distribution systems by Campoccia, Sanseverino, and Zizzo (2009) are *safety issues*: besides the classic objectives of loss minimization and load balancing, the authors consider the variation in the single line to ground fault current due to the network reconfiguration.

In this paper, a new and interesting objective for the DSO, related to the maximization of local consumption of renewable energy is studied. If a DN is supplied by more than one HV/MV transformer, this objective can be reached by balancing the loading of the different HV/MV transformers feeding the different network zones, minimizing in this way the power injected into the HV grid.

The main advantages of the previously described objective are the following:

- easier management for the Transmission System Operator (TSO) due to the reduction of peak value of power injected in the transmission network;
- creation of nearly self-sustainable network islands, with reduced dependence from the National transmission system;
- reduction of power flows through MV and HV lines and thus of losses;

In addition to this, the accounting of the DSO performances in terms of losses and computed revenues is rapidly changing. The Italian *Authority on Energy* has recently defined a draft of a new regulation that is now open to comments and is going to be published soon (AEEGSI 2015). This new regulation regards the procedure for the evaluation of the *standard* losses, defined as the losses of a typical DN configuration. This value is used to determine rewards or penalties attributed to the DSOs: in case the actual losses on the DN are lower than the *standard* ones the DSO will receive a reward and a penalty in the other way round. This regulation, among other parameters, will also consider the phenomenon of power flow inversion at the HV/MV transformers and its effects on the DN losses, taking it into account in the computation of the DSO's reward.

In order to tackle the above mentioned problems, the DSO should rely on a model of the distribution network and use its simulation results as a tool for optimising its performances. Within a previous research project (Breganni et al. 2015) the use of a commercial network analysis tool has been considered as a critical issue in order both to ensure the quality of analysis results and to exploit a tool which is already in use by the DSO. In the same research, the definition of a network operator that could ensure the satisfaction of the radiality constraint in an automatic way has been implemented using the *branch exchange* (Baran and Wu 1989) technique that will be briefly described in the following.

The rest of this paper is organized as follows: the two main blocks of the topological reconfiguration procedure are presented, explaining how the alternative radial networks are generated and how the performances of the different networks are evaluated. A case study, based on a portion of the network of the North Italian town Vercelli is then presented, and used for the discussion.

3 Procedure for the topological reconfiguration

The procedure for the topological reconfiguration has been developed under the framework of the *SVPP - Smart Virtual Power Plant* research project (Breganni et al. 2015). Thanks to the

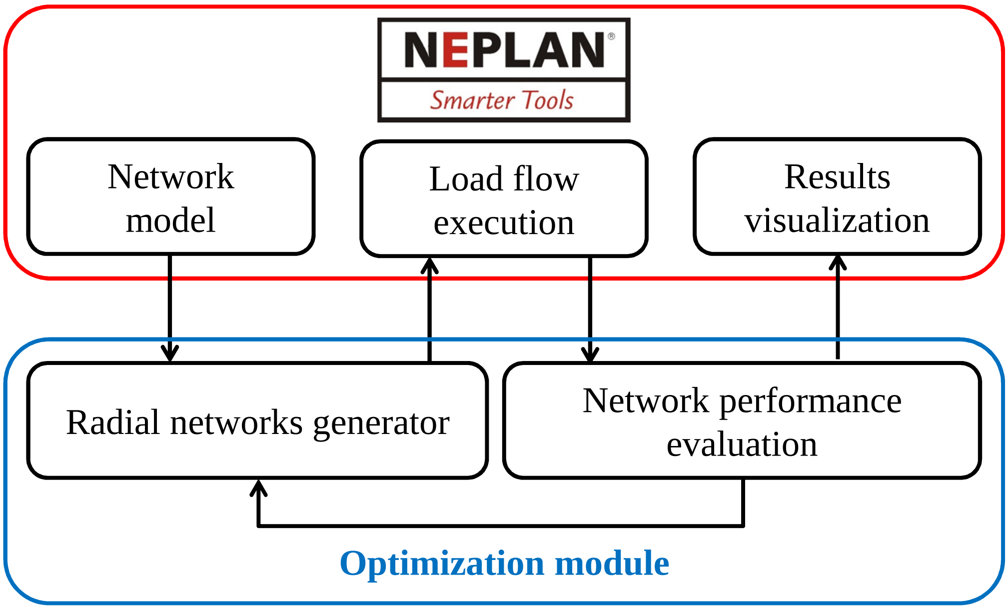

Figure 1: Interactions between Neplan and the optimization module.

Neplan Programming Library (NPL), the optimization module is structured as a *plug-in* to the commercial analysis software. The optimizer exchanges all the required network data with the commercial network simulator Neplan® (NEPLAN 2015), which is used to input the network data via its graphic interface, to run the load flows and to visualize the optimization results.

The network optimizer is made of two main modules: the first module creates the alternative radial configurations that can be derived from the base one by closing tie branches and opening sectionalizing switches. The second module analyses the load flow results (calculated by Neplan) for the alternative configurations and returns the ID of the network topology that satisfies the optimization criteria (Figure 1). In the following the two modules are described.

3.1 Generation of alternative radial networks

Starting from the base radial network configuration, firstly the lines with open switches are identified as *tie-lines*. The tie-lines switches are then closed, one by one. By exploiting the radiality of the original network, every time a tie-line switch is closed a loop is formed, making the network not radial any more. At this point, the lines belonging to the new loop are detected (Gohokar, Khedkar, and Dhole 2004) building the loop incidence matrix (eq. 1):

$$C = \left[-\frac{(A_l k^T)^T}{u_l} \right] \tag{1}$$

where C is the loop incidence matrix, A_l the bus incidence matrix for the tie-lines, u_l the unity matrix for tie-lines and k the path incidence matrix for the branches.

Among the lines belonging to the new loop, the elements identified as "switchable", that is the ones that can be remotely controlled by the DSO, are extracted, and one of them is opened, restoring the radial condition. Using this *branch exchange* procedure (Baran and Wu 1989), a new radial network configuration is produced. The procedure is repeated for every "switchable" line in every loop that can be generated in the base network, making it possible to explore all the possible network configurations that can be obtained from the original one by means of one *branch exchange* move.

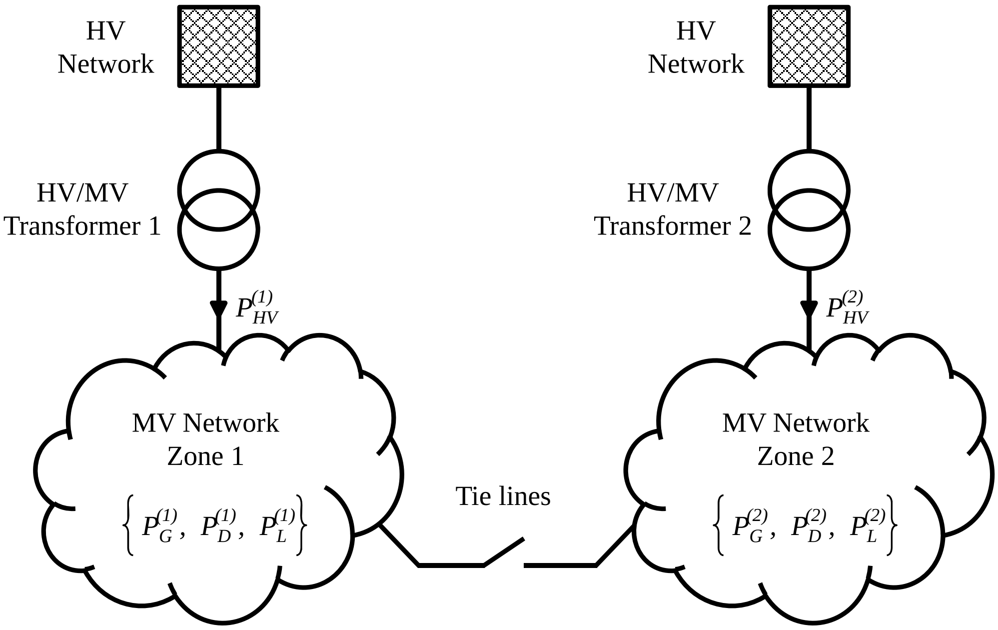

Figure 2: Schematic representation of power flows through HV/MV transformers.

3.2 Performances evaluation

After the generation of the alternative topologies, they are given back to Neplan for the calculation of the load flow solutions. The results can then be used by the second module for the performances evaluation.

The main quantities that are normally taken into account for distribution networks optimisation are active power losses, voltage profiles, reliability indices, etc. (Alonso, Oliveira, and Zambroni de Souza 2015). In this paper the focus is instead put on the local consumption of renewable energy, produced by distributed generators, which is to be maximized.

For this purpose the quantities considered in the optimization process are the power flows through HV/MV transformers. In Figure 2 a schematic representation of a very simple distribution system fed from the HV network by only two HV/MV transformers is presented. By making reference to Figure 2 the following quantities are considered:

- the power flowing from the HV network to the distribution network through HV/MV transformers, $P_{HV}^{(1)}$ and $P_{HV}^{(2)}$, in general $P_{HV}^{(i)}$;
- the power generated in the MV system sections 1 and 2, $P_G^{(1)}$ and $P_G^{(2)}$, in general $P_G^{(i)}$;
- the power consumed in the MV system, $P_D^{(1)}$ and $P_D^{(2)}$, in general $P_D^{(i)}$;
- the power losses in the MV system, $P_L^{(1)}$ and $P_L^{(2)}$, in general $P_L^{(i)}$;

For each network configuration, the active power which flows from the HV transmission grid to the MV distribution network $P_{HV}^{(i)}$, which is given by the balance expressed in eq. (2), is evaluated for all HV/MV transformers.

$$P_{HV}^{(i)} = (P_D^{(i)} + P_L^{(i)}) - P_G^{(i)} \tag{2}$$

The network reconfiguration problem, aiming at the maximization of DG which is locally consumed, is formulated as Wald's *maximin* optimization (Wald 1945), and is defined as:

$$
\begin{aligned}
&\max_x f(x) = \min_{i=1}^{N_T} P_{HV}^{(i)}(x) \\
&\text{s.t.} \\
&\quad g(u) = 0 \\
&\quad V_{min} \le V_j \le V_{max} \\
&\quad S_k \le S_{kmax}
\end{aligned}
\tag{3}
$$

where x is the id of the alternative network configuration and N_T is the number of HV/MV transformers feeding the distribution network. The constraints are the power flow equations $g(u)$, the voltage limits V_{min} and V_{max} and the branch capacities S_{kmax} respectively on every node j and every branch k of the DN.

By applying the optimisation procedure, the configurations having a large amount of power injected in the HV network are considered as *bad* because they are characterised by a large negative value of power (passive or load convention used).

For instance, let's consider a DN connected to the HV system by means of two equal transformers and that their loads are: $P_{HV}^{(1)} = 110$ MW and $P_{HV}^{(2)} = -10$ MW that is the second transformer is feeding a power of 10 MW to the HV network. The DN net power balance is given by $P_{net} = P_{HV}^{(1)} + P_{HV}^{(2)} = 100$ MW. Let's suppose that, by network reconfiguration and by neglecting losses variations, the net power balance could be brought to a configuration with $P_{HV}^{(1)} = 50$ MW and $P_{HV}^{(2)} = 50$ MW. The new configuration would give rise to a lower value of losses on the transformers and would avoid an imbalance of 10 MW of power injected into the HV network.

4 Case study

The procedure for the topological reconfiguration described in the previous sections has been tested on the MV distribution network of the Northern Italy town Vercelli. The distribution network in Vercelli is managed by Atena S.p.A. (ATENA 2015) and serves an area of around 65 km^2. Two HV/MV substations feed 220 MV/LV substations through around 450 km of MV lines.

For the case study of this paper, as a simplified example, only a portion of the network, fed by one of the two HV/MV substations, called *Vercelli Sud*, (Figure 3) is considered. Network data for the test case are available in the Appendix. This portion of network was chosen because of the presence of DG (mainly Photo Voltaic (PV) systems) in MV and in LV.

In *Vercelli Sud* substation two HV/MV transformers are present, both of them with a rated power of 25 MVA, feeding two separate busbars called *red busbar* and *green busbar*. Each busbar feeds, at its turn, four MV lines along which are connected globally 48 MV/LV substations.

The MV/LV substations supply both MV loads and MV/LV transformers for LV loads or DGs. In order to simplify the network model the MV/LV transformers are not explicitly represented and the LV loads are directly connected to MV busbars; to keep into account the MV/LV transformers and LV cables losses, the active power of LV loads is corrected with an appropriate coefficient.

In *Vercelli Sud* network only one tie-line is present (line L3420, in the dashed box in Figure 3). In the normal network configuration used by the DSO in Vercelli the circuit breaker of this line in the substation N240593 is open. By applying the *branch exchange* procedure on this tie line, it is possible to transfer load and/or generation power from one transformer busbar to the other, performing thus the modification of the transformer loadings.

The load and generation values are obviously variable during the year. For the case study presented here a summer day with peak generation and low loads was chosen. The optimization that will be presented is valid for this single snapshot: in this case the net power supply coming from the HV grid is $P_{net} = 2.372$ MW; a further possibility would be to include the load curves in the optimization process in order to obtain an average optimum, that is valid for a certain time span (de Oliveira et al. 2014).

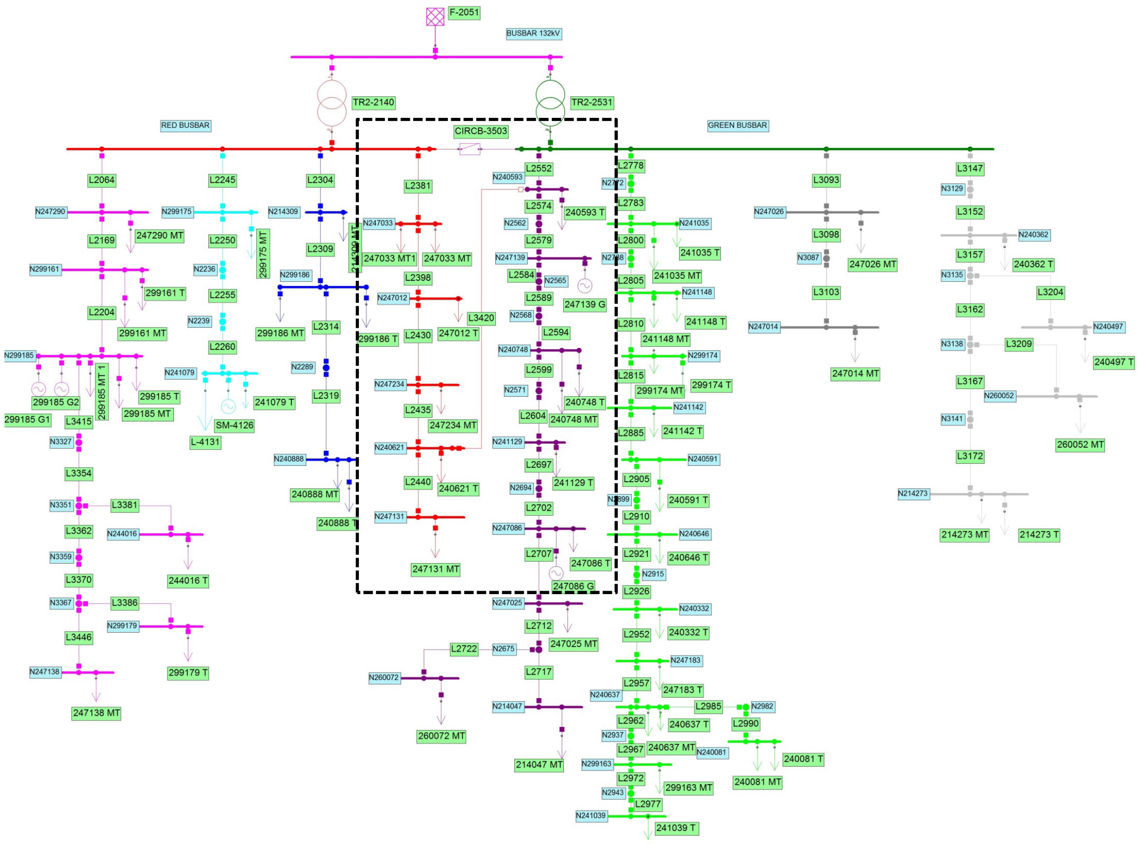

Figure 3: *Vercelli Sud* distribution network

5 Discussion

By looking at the DN shown in Figure 3, the closure of tie-line L3420 creates the loop constituted by lines: L2381, L2398, L2430, L2435 and L2552. In the hypothesis that all these lines are switchable, i.e. at least the circuit breaker at one end is remotely controlled, this generates five network configurations alternative to the base case.

For each of the five alternative configurations, network data are calculated by the Neplan load flow procedure and results are presented in Table 1. The studied parameters are: P_{HV}^{Min} the minimum value of power flow through the HV/MV transformers in the network, as defined in Equation 3, P_{Loss} the total network losses and ΔU^{Max} the maximum percentage voltage drop in the network.

As it can be seen by the analysis of the results, configuration $ID = 1$ is the one that maximizes

Table 1: Network performances of the explored configurations (best performances are highlighted with bold characters)

ID	Description	P_{Loss}	ΔU^{Max}	P_{HV}^{Min}
		kW	%	MW
0	Base case	**8.086**	0.1908	-0.264
1	Opened line 2552 - closed tie 3420	8.110	0.2230	**0.268**
2	Opened line 2381 - closed tie 3420	9.221	0.1922	-0.908
3	Opened line 2398 - closed tie 3420	8.263	0.1838	-0.435
4	Opened line 2430 - closed tie 3420	8.176	**0.1837**	-0.359
5	Opened line 2435 - closed tie 3420	8.177	0.1870	-0.359

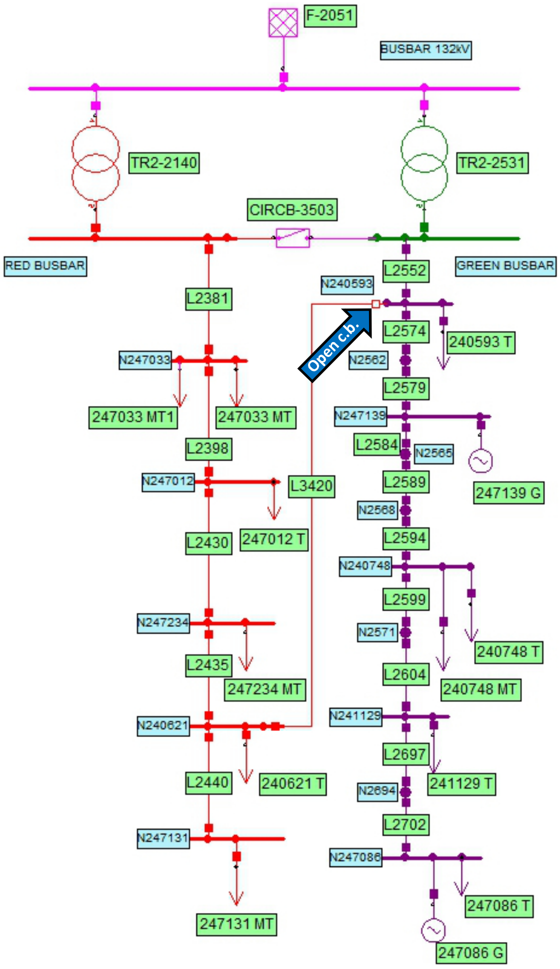

Figure 4: Zoom - network $ID = 0$.

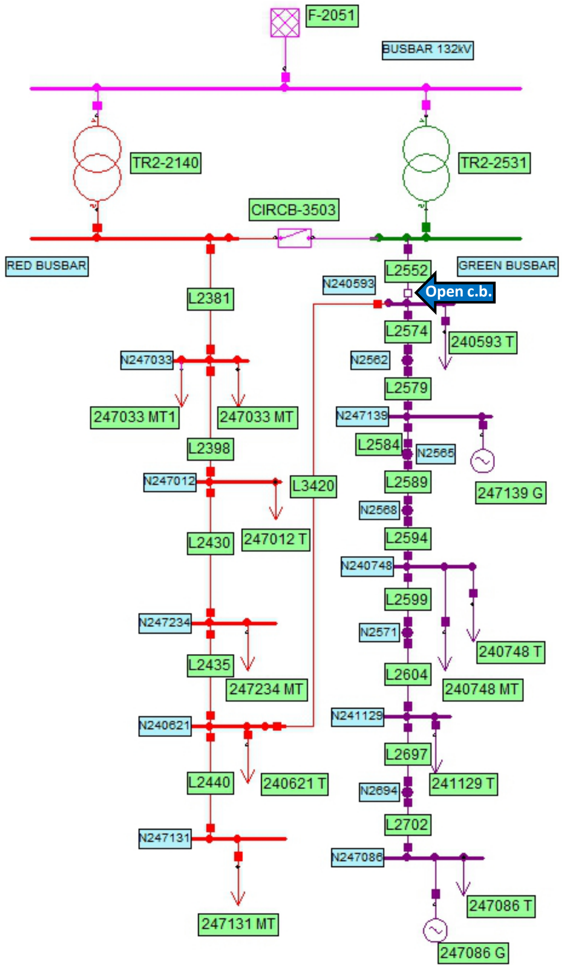

Figure 5: Zoom - network $ID = 1$.

the local consumption of DG energy. In fact the minimum value of the power flow through the HV/MV transformers is positive, meaning that power is flowing from the HV to the MV network. In all other network configurations P_{HV}^{Min} is negative, meaning that one of the two HV/MV transformers is injecting power in the HV network. A zoom of the loop for the base case and for the optimized network is reported respectively in Figure 4 and Figure 5.

In the present case, however, the configuration that maximizes the local consumption of DG energy does not provide the best performance for the other objectives. The best configuration from the power losses perspective is in fact $ID = 0$, i.e. the base case, while from the voltage drop perspective it is $ID = 4$ (in Table 1 the best performances are highlighted with bold characters). One of the reasons for this behaviour is the fact that, when the objective of the local consumption of DG is met, the reduction of the losses in the HV/MV transformers does not compensate the losses increase in the MV lines.

The relations between the different objectives are highlighted in Figure 6 and Figure 7, where are considered respectively ΔU^{Max} vs $-P_{HV}^{Min}$ and P_{Loss} vs.$-P_{HV}^{Min}$. In these figures the sign of P_{HV}^{Min} has been changed, so optimal solutions are those which minimize both parameters, and the non dominated solutions (Pareto optima) are identified by red markers.

6 Conclusion

The work presented shows that the use of a network simulator and optimizer can be a valid help to the DN management. This is valid in general and it has been shown that it can be useful also

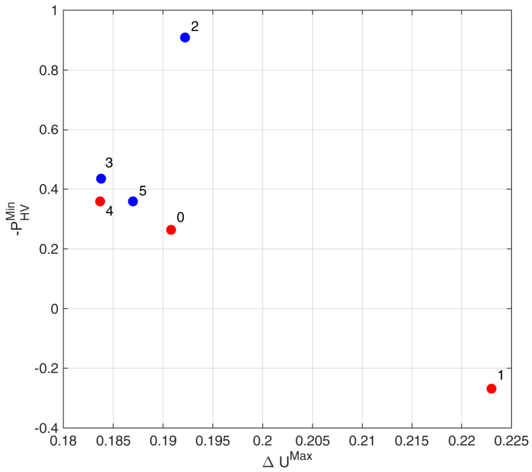

Figure 6: ΔU^{Max} vs $-P_{HV}^{Min}$

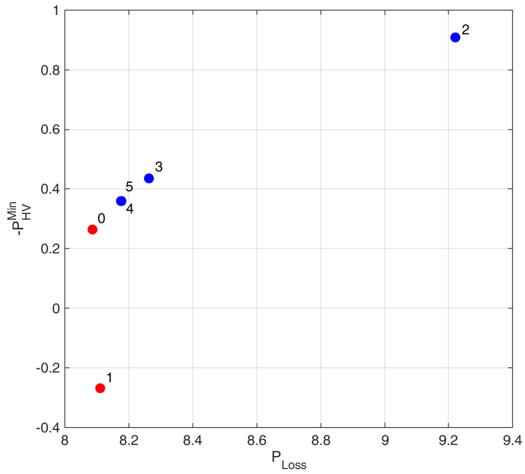

Figure 7: P_{Loss} vs.$-P_{HV}^{Min}$

for the unbalanced case where part of the DN is injecting power to the transmission network while other parts are absorbing power. The maximization of local consumption of DG sources is a target *per se* but can be of great help in the increase of performances both of the DN and of the whole electrical system.

This target is achieved by the use of an optimization procedure linked to a commercial network simulation software, thus relying on accurate and reliable analysis results.

The use of the procedure has been presented as an *off-line* tool aiding the choices of the DSO but it could be also embedded in a *on-line* network manager reconfiguring the DN topology in order to increase its efficiency.

7 Acknowledgement

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Appendix

Network data for the test case are shown in Table 2, Table 3, Table 4 and Table 5.

Table 2: Line parameters

Name	Sen. n.	Rec. n.	L [km]	r [Ω/km]	x [Ω/km]	c [μF/km]	b [μS/km]
L2064	RED B.	N247290	0.29	0.151	0.158	0.31328	98.42

Table 2: Line parameters (*continued*)

Name	Sen. n.	Rec. n.	L [km]	r [Ω/km]	x [Ω/km]	c [μF/km]	b [μS/km]
L2169	N247290	N299161	0.13	0.151	0.158	0.31328	98.42
L2204	N299161	N299185	1.447	0.151	0.158	0.31328	98.42
L2245	RED B.	N299175	0.394	0.151	0.158	0.31328	98.42
L2250	N299175	N2236	1.101	0.161	0.095	0.313	98.332
L2255	N2236	N2239	0.526	0.189	0.163	0.2897	91.012
L2260	N2239	N241079	0.077	0.119	0.152	0.35033	110.059
L2304	RED B.	N214309	0.75	0.151	0.158	0.31328	98.42
L2309	N214309	N299186	0.847	0.151	0.158	0.31328	98.42
L2314	N299186	N2289	0.677	0.151	0.158	0.31328	98.42
L2319	N2289	N240888	2.11	0.123	0.152	0.35033	110.059
L2381	RED B.	N247033	0.435	0.151	0.158	0.31328	98.42
L2398	N247033	N247012	0.38	0.119	0.152	0.35033	110.059
L2430	N247012	N247234	0.17	0.119	0.152	0.35033	110.059
L2435	N247234	N240621	0.292	0.119	0.152	0.35033	110.059
L2440	N240621	N247131	0.1	0.298	0.17	0.24909	78.254
L2552	GREEN B.	N240593	0.211	0.119	0.152	0.35033	110.059
L2574	N240593	N2562	0.035	0.151	0.158	0.31328	98.42
L2579	N2562	N247139	0.38	0.119	0.152	0.35033	110.059
L2584	N247139	N2565	0.262	0.119	0.152	0.35033	110.059
L2589	N2565	N2568	0.81	0.151	0.158	0.31328	98.42
L2594	N2568	N240748	0.025	0.119	0.152	0.35033	110.059
L2599	N240748	N2571	0.279	0.119	0.152	0.35033	110.059
L2604	N2571	N241129	0.06	0.151	0.158	0.31328	98.42
L2697	N241129	N2694	1.014	0.119	0.152	0.35033	110.059
L2702	N2694	N247086	0.056	0.151	0.158	0.31328	98.42
L2707	N247086	N247025	0.056	0.151	0.158	0.31328	98.42
L2712	N247025	N2675	0.258	0.189	0.163	0.2897	91.012
L2717	N2675	N214047	1.126	0.189	0.163	0.2897	91.012
L2722	N2675	N260072	0.135	0.298	0.17	0.24909	78.254
L2778	GREEN B.	N2772	0.091	0.151	0.158	0.31328	98.42
L2783	N2772	N241035	0.12	0.119	0.152	0.35033	110.059
L2800	N241035	N2788	0.278	0.119	0.152	0.35033	110.059
L2805	N2788	N241148	0.297	0.151	0.158	0.31328	98.42
L2810	N241148	N299174	0.333	0.151	0.158	0.31328	98.42
L2815	N299174	N241142	0.32	0.151	0.158	0.31328	98.42
L2885	N241142	N240591	0.27	0.119	0.152	0.35033	110.059
L2910	N2899	N240646	0.28	0.151	0.158	0.31328	98.42
L2905	N240591	N2899	0.19	0.119	0.152	0.35033	110.059
L2926	N2915	N240332	0.481	0.119	0.152	0.35033	110.059
L2921	N240646	N2915	0.28	0.151	0.158	0.31328	98.42
L2957	N247183	N240637	0.355	0.119	0.152	0.35033	110.059
L2952	N240332	N247183	0.289	0.119	0.152	0.35033	110.059
L2972	N299163	N2943	0.07	0.151	0.158	0.31328	98.42
L2967	N2937	N299163	0.305	0.151	0.158	0.31328	98.42
L2962	N2937	N240637	0.01	0.119	0.152	0.35033	110.059
L2990	N2982	N240081	0.21	0.417	0.144	0.199	62.518
L2985	N240637	N2982	0.048	0.298	0.17	0.24909	78.254
L2977	N2943	N241039	0.345	0.119	0.152	0.35033	110.059
L3103	N3087	N247014	0.268	0.119	0.152	0.35033	110.059
L3098	N247026	N3087	0.189	0.151	0.158	0.31328	98.42
L3093	GREEN B.	N247026	0.63	0.151	0.158	0.31328	98.42
L3147	GREEN B.	N3129	2.164	0.151	0.158	0.31328	98.42

Table 2: Line parameters (*continued*)

Name	Sen. n.	Rec. n.	L [km]	r [Ω/km]	x [Ω/km]	c [μF/km]	b [μS/km]
L3167	N3138	N3141	0.542	0.417	0.144	0.199	62.518
L3162	N3135	N3138	0.736	0.417	0.144	0.199	62.518
L3157	N240362	N3135	0.17	0.417	0.144	0.199	62.518
L3152	N3129	N240362	0.026	0.119	0.152	0.35033	110.059
L3172	N3141	N214273	0.032	0.151	0.158	0.31328	98.42
L3209	N3138	N260052	0.055	0.645	0.159	0.1623	50.988
L3204	N3135	N240497	0.38	0.719	0.165	0.15038	47.243
L3354	N3327	N3351	1.799	0.221	0.376	0.00963	3.025
L3370	N3359	N3367	0.182	0.202	0.097	0.0086	2.702
L3362	N3351	N3359	0.498	0.221	0.376	0.00963	3.025
L3386	N3367	N299179	0.064	0.906	0.424	0.0086	2.702
L3381	N3351	N244016	0.154	0.906	0.122	0.0086	2.702
L3420	N240593	N240621	0.485	0.119	0.152	0.35033	110.059
L3415	N299185	N3327	2.172	0.151	0.158	0.31328	98.42
L3446	N3367	N247138	0.944	0.202	0.097	0.0086	2.702

Table 3: Loads

Name	Node	P_D [MW]
299161 MT	N299161	0.0858
299161 T	N299161	0.038
299185 T	N299185	0
299185 MT	N299185	0
299175 MT	N299175	0.24
241079 T	N241079	0.0608
247290 MT	N247290	0.005
214309 MT	N214309	0.0279
299186 T	N299186	0
299186 MT	N299186	0.0375
240888 T	N240888	0
247033 MT	N247033	0.15
247012 T	N247012	0.076
247131 MT	N247131	0
240621 T	N240621	0.095
247234 MT	N247234	0
240593 T	N240593	0.15
240748 T	N240748	0.096
240748 MT	N240748	0.0236
241129 T	N241129	0.025
247025 MT	N247025	0.426
247086 T	N247086	0.01
260072 MT	N260072	0.375
214047 MT	N214047	0
241035 T	N241035	0.025
241035 MT	N241035	0.0627
241148 MT	N241148	0.0042
241148 T	N241148	0.04
299174 MT	N299174	0.297
241142 T	N241142	0.04
240591 T	N240591	0.025
240646 T	N240646	0.025

Table 3: Loads (*continued*)

Name	Node	P_D [MW]
240332 T	N240332	0.016
247183 T	N247183	0.016
240637 MT	N240637	0.25718
240637 T	N240637	0.04
240081 MT	N240081	0
240081 T	N240081	0.016
299163 MT	N299163	0.0195
241039 T	N241039	0
247026 MT	N247026	0.27
247014 MT	N247014	0.24476
240362 T	N240362	0.02
214273 T	N214273	0.01
240497 T	N240497	0.01
260052 MT	N260052	0
244016 T	N244016	0.038
299179 T	N299179	0.038
247138 MT	N247138	0
240888 MT	N240888	0.1179
214273 MT	N214273	0.6456
247033 MT1	N247033	0.324
299185 MT 1	N299185	0
299174 T	N299174	0.016
L-4131	N241079	0.01857

Table 4: Distributed generation

Name	Node	P_G [MW]
247139 G	N247139	0.539352
299185 G1	N299185	0.6048
299185 G2	N299185	0.933
247086 G	N247086	0.03625
SM-4126	N241079	0.081

Table 5: Transformers parameters

Name	S_r [MVA]	U_{r1} [kV]	U_{r2} [kV]	u_{kr} [%]	u_{Rr} [%]
TR2-2140	25	132	15	13.96	0.5
TR2-2531	25	132	15	11.3	0.5