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Online Optimizer for Distribution Networks on Neplan

S. Breganni*, F. D'Urso*, A. Giarratana[§], P. Gregoraci[†], M. Manzini[†], E. Pons[‡], M. Repetto[‡],
L. Vandoni* and G. Zamboni[§]

* Emisfera Società Cooperativa

Via Quarantadue Martiri, 165, Verbania Fondotoce (VB), 28924, Italy, francoURSO@emisfera.it

[†] ATENA Spa

Corso Palestro, 126, Vercelli, 13100, Italy, mario.manzini@atenaweb.net

[‡] Politecnico di Torino, Dipartimento Energia

C.so Duca degli Abruzzi, 24, Torino, 10129, Italy, enrico.pons@polito.it

[§] HAL SERVICE Srl

Via Osella, 13, Borgosesia (VC), 13011, Italy, giancarlo.zamboni@halservice.it

Abstract—The paper presents a software module, developed within the Neplan network analysis tool environment, allowing a dialogue between the network simulator and external data. The tool is focused on the analysis of distribution networks and it has been used for two main aims: to keep the network model updated with data measured on the field (load values, status of switches etc.) and to couple the network simulator with an external topology optimizer. The procedure has been applied to the analysis of a distribution network owned by ATENA SpA in the Northern Italy town Vercelli. Plug-in working is explained and some preliminary results obtained are discussed.

Keywords—Distribution network, Network monitoring, Network optimization, Smart grid.

I. NOMENCLATURE

| | |
|-------|--------------------------------------|
| API | Application Program Interface |
| DG | Distributed Generation |
| DLL | Dynamic Link Library |
| DN | Distribution Network |
| DSO | Distribution System Operator |
| ICT | Information Communication Technology |
| IPsec | Internet Protocol Security |
| NAT | Network Address Translation |
| NPL | Neplan Programming Library |
| PPP | Point-to-Point Protocol |
| PV | PhotoVoltaic |
| SSL | Secure Sockets Layer |
| SSTP | Secure Socket Tunnelling Protocol |
| TCP | Transmission Control Protocol |
| TLS | Transport Layer Security |
| VPN | Virtual Private Network |
| XML | eXtensible Markup Language |

II. INTRODUCTION

In the last decade the DN way of working has changed in sensible way: the introduction of DG units, based both on renewable or on conventional sources, can in fact reverse the direction of power flow inside the lines. Due to this reason, DSOs have the need to monitor the state of the network and to find its best arrangement in order to keep its efficiency at high level [1]. Notwithstanding these new requirements, the

operation of DN must comply to the radial topology in order to guarantee a reliable and safe operation of the network under fault conditions [2], [3].

The concept of *smart grid* can be applied to DN if an ICT infrastructure is set-up that enables the monitoring of the actual conditions of the network and the implementation of modifications to its configuration. In any case the use of network simulation tools is crucial to help the decision of DSOs in particular cases where the loads or the DG power productions are keeping the DN under stress conditions.

The use of efficient and state-of-the-art network simulators is obviously another key issue. A modern software tool with high-level Graphic User Interface helps the DSO in the input/output of the network model, while well tested simulation procedures provide certified results on which reconfiguration operations can be made in a reliable way.

Starting from the previous considerations the *SVPP Smart Virtual Power Plant* research project has been developed aiming at the creation of a software tool able to interface the commercial network simulator Neplan[®] with external procedures. Thanks to the Neplan features that allow the dialogue with its internal data structure and the execution of commands via a DLL, these modules have been used to interface Neplan with data acquired from the medium/low voltage substations and to couple the simulator with an external specially devised optimiser.

In the following, the structure of the data exchange is outlined and afterwards a description of the data acquisition system is given as well as the outline of the network optimisation block. Finally some results are presented and discussed.

III. NEPLAN INTERFACE WITH EXTERNAL SOFTWARE

The commercial software Neplan [4] has been used to easily build the network model, via the provided graphic interface. The network model contains all peculiar network characteristics, such as its topology, data about each line, bus and load, the parameters of the transformers, etc. Neplan can be extended by plug-ins via an API, making the dialogue with external software modules possible.

A. Interface with field measured data

The interface with field measured data provides measured data such as voltage and current levels, active and reactive power values from the physical network. In the context of the SVPP project, we have installed three such systems, that can be used to read measures in three different network buses, as better explained later in this paper.

The measures are read via a serial port by a local device, which then exposes them, via http, inside a VPN. A Windows-based software, then, reads them on regular intervals, and stores all measures inside a MySQL database.

All measures read from the field are used to keep the network model up-to-date, and can also be viewed on line via a web interface, from which they can then be exported to a spreadsheet.

B. Interface with the optimizer

The network optimizer has been implemented as a Neplan plug-in. Neplan provides a C/C++ API called Neplan Programming Library (NPL). This API is based on a TCP/IP bus and allows for reading and modifying all the characteristics of a network model.

Using the C++ programming language we have created a DLL that conforms to the Neplan plug-in specifications. This DLL can be opened from within Neplan and exports the network topology to an XML file, and then invokes a program file written in Matlab that, starting from the XML file, computes all possible topologies that fulfil the radial constraint for the same network.

Alternative network configurations or operations are created using a valid transformation operation, that can be one of the following:

- A network reconfiguration, by opening/closing switches (this is the only operation implemented in the current prototype);
- A modification in the parameters of transformers;
- A new connection of two unconnected network nodes;
- The introduction of energy storage devices.

Each alternative network configuration is passed back to the Neplan plug-in, again using XML files. Neplan, via the DLL, reads the new configurations and computes the load flow for each alternative. These values are passed again to the Matlab program, that calculates which is the optimal network topology, given one or more optimization criteria, that include:

- minimizing network losses;
- minimizing voltage drops;
- avoiding that cables are used close to their current rating;
- minimizing the distance from nominal voltage in all network buses;
- minimizing energy exchanges with the HV national transmission network, to maximize the employment of local renewable sources.

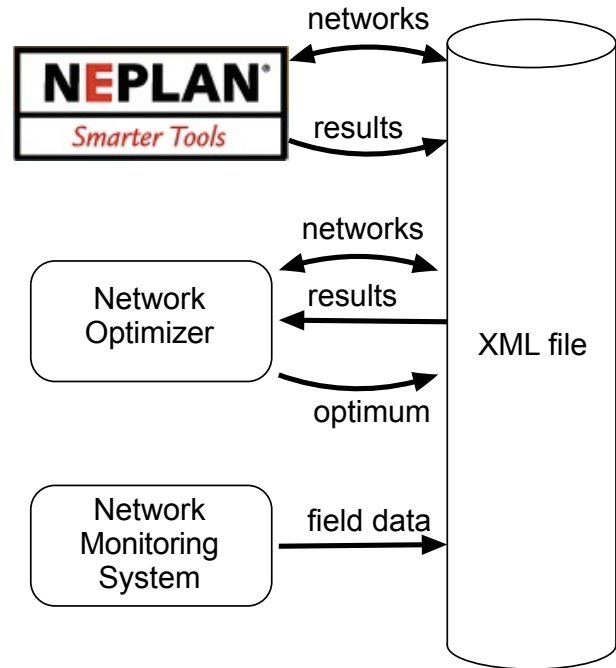


Fig. 1. Flow of information between Neplan and optimiser plug-in.

The Neplan plug-in provides a user interface allowing for the selection of one or more optimization criteria and assigning them a relative weight. The network optimization algorithm adopts a technique that allows to deal with multiple weighted criteria.

At the end, the Neplan plug-in passes back the optimal network configuration to Neplan, to have it visible on the graphical interface as if it was created by the user. A schematic flow of data between the Neplan module and the optimiser plug-in is represented in fig. 1.

C. Data exchange format

The data exchange format between the Neplan plug-in and the Matlab program is based on an XML representation of the network. In particular we use two files:

- <network name>_load.xml contains information about the loads;
- <network name>_branch.xml contains information about lines, transformers and network topology.

For each load, the load XML file provides a unique ID, a name, the rated active(in MW) and reactive (in Mvar) power, and the ID and name of the bus to which the load is connected. Here an example:

```

<NET_LOAD>
  <LOAD>
    <ID>2730</ID>
    <NAME>247086 MT</NAME>
    <P>0.1</P>
    <Q>0</Q>
    <FROM_ID>2666</FROM_ID>
    <FROM_NAME>N247086</FROM_NAME>
  
```

```

</LOAD>
...
</NET_LOAD>

```

For each line, the branch XML file provides a unique ID, a name, the IDs of the connected buses, two flags that indicate whether the switches at the sending and receiving buses are open or closed, the values of line resistance and reactance, and a flag indicating whether the branch can be remotely controlled, that is if its on/off status is a degree of freedom of the optimisation procedure. Here an example:

```

<NET_BRANCH>
  <BRANCH>
    <ID>2722</ID>
    <NAME>L2722</NAME>
    <Sen>2675</Sen>
    <Rec>2681</Rec>
    <SenON>1</SenON>
    <RecON>1</RecON>
    <R>0.298</R>
    <X>0.17</X>
    <S>1</S>
  </BRANCH>
  ...
</NET_BRANCH>

```

where the parameter `<S>1</S>` means that the branch is *switchable*.

Besides information on MV lines, the branch XML file also provides information on HV/MV transformers, including primary and secondary nominal voltages, rated power, relative short-circuit voltage, and copper losses. Here an example:

```

<NET_BRANCH>
  ...
  <TRAFO>
    <ID>2531</ID>
    <NAME>TR2-2531</NAME>
    <Sen>2123</Sen>
    <Rec>2501</Rec>
    <Ur1>132</Ur1>
    <Ur2>15</Ur2>
    <SenON>1</SenON>
    <RecON>1</RecON>
    <Sr>25</Sr>
    <UKPC>12</UKPC>
    <URPC>1</URPC>
    <S>0</S>
  </TRAFO>
  ...
</NET_BRANCH>

```

IV. NETWORK MONITORING SYSTEM

As described previously in this document, in order to acquire the data needed to feed the simulation model, three measurement installations were implemented in three different sites of the network: the MV/LV substations named specifically *Larizzate*, *Carengo* and *Novacoop*. Obviously three measurements in the considered portion of distribution network are not

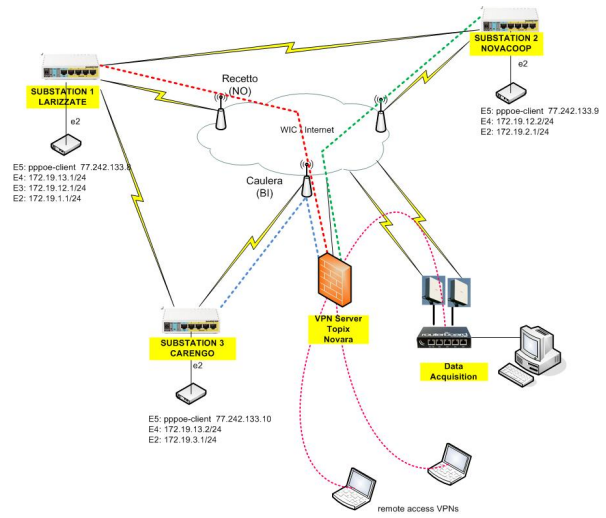


Fig. 2. Communication network.

sufficient to provide the network status, but these installations are a starting point for future developments and were used to demonstrate the feasibility of the system.

A. Sensors

Field data acquisition is operated by an ABB M2M MOD-BUS Network Analyser, which measures the relevant electrical quantities and stores them in its internal memory. All these data can be read via an RS-485 port using the modbus protocol. In order to interface that port to the communication network an ethernet/RS485 adapter was used. A custom c++ software driver has been implemented to handle remote data acquisition using the TCP connection protocol.

B. Communication

The communication network is IP-based. All remote sensors are connected to the central server through SSTP (Secure Socket Tunnelling Protocol) tunnels over the Internet. Furthermore, sensors are connected together over a wireless Intranet so that the Internet connection of each sensor can act as a backup connection for the other ones. Such *distributed failover solution* avoids the single point of failure and guarantees a very high degree of service continuity in case of fault.

Fig. 2 explains the distributed failover solution architecture and how it works in case of fault: *Larizzate*, *Carengo* and *Novacoop* sensors are connected to the Internet. Furthermore, *Larizzate* is connected to *Carengo* and *Novacoop* through a hiperlan 5 GHz link. When all Internet connections are working, each sensor establishes a secure SSTP tunnel to the SSTP concentrator over its own internet connection. Suppose the *Carengo* Internet connection fails like depicted in fig. 3. The heal check script running on *Carengo* router detects Internet failure and the dynamic routing protocol re-routes outbound traffic over the *Carengo-Larizzate* wireless link so that *Carengo* sensor can be reached by the server exploiting *Larizzate* Internet connection.

SSTP guarantees secure encrypted data flow between sensors and server. It is basically a PPP (Point-to-Point Protocol)

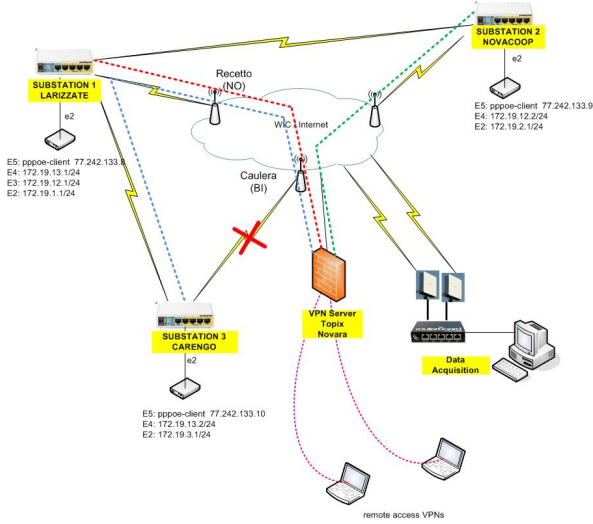


Fig. 3. Communication network behaviour in case of fault.

tunnel running on a SSL tunnel, specifically a TLS 1.0 tunnel in our deployment. In our scenario SSTP is the best choice because:

- it works on a SSL connection, like a secure website, therefore it can work without problems with any Internet connection as long as port TCP/443 is not filtered, which is a very rare condition. It does not suffer NAT like IPsec for example.
- It works in client/server fashion, like common dial-up VPN connections, therefore it does not require fixed public IP address.
- It provides a good level of encryption and data integrity.

The only drawback is that, like any IP-over-TCP tunnel, it has a large overhead and can suffer poor performances if the connection has not an adequate excess of bandwidth compared to the data stream. However, in our scenario, this is not a problem since bandwidth requirements are very low.

V. OPTIMIZER

The network optimizer is made of two main modules: the first module receives as an input the base network configuration and gives as output all the possible radial configurations that can be derived from the base one. The second module receives as input the load flow results (calculated by Neplan) of all the previously generated configurations and returns the ID of the network topology that satisfies the optimization criteria. In the following the two modules are described.

A. Radial networks exploration

The XML file `<network name>_branch.xml` is used to create a matrix containing the full topology of the base, or reference, network configuration, including the HV buses and the HV/MV transformers. Starting from this configuration, all the lines with open switches are identified as tie-lines.

Subsequently, the tie-lines switches are closed, one by one. 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 [3], among them the group of lines identified as “switchable” is extracted, and one of them is opened, restoring the radial condition. A new network configuration is produced for every “switchable” line in every loop.

B. Performances evaluation

After the generation of the alternative topologies, Neplan calculates the solution of the load flow for each of them and returns the results for the performances evaluation. In the first prototype of the optimizer the following results are used in the performances evaluation:

- active power losses in the MV lines;
- active power losses in the HV/MV transformers;
- voltages at the MV buses.

The active power losses are summed for each configuration to calculate the total network losses. For what concerns the voltage profile, the largest absolute voltage difference with respect to nominal value in the network is found for each configuration and this represent the performance of the network from the voltage profile viewpoint. A weight is used to consider both criteria (after normalisation) in the performances evaluation, as showed in eq. (1).

$$f(x) = (1 - w)P_{LossNorm}(x) + w\Delta U_{MaxNorm}(x) \quad (1)$$

where:

| | |
|----------------------|---|
| x | is the id of the alternative network configuration; |
| w | is the assigned weight; |
| $P_{LossNorm}$ | are the total normalized network losses; |
| $\Delta U_{MaxNorm}$ | is the maximum normalized voltage drop. |

Both criteria are considered as they often lead to different optimization results, as will be showed in the case study.

VI. CASE STUDY

The software modules described in the previous sections have 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. and serves an area of around 65 km². 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 is considered, fed by one of the two HV/MV substations, called *Vercelli Sud*, (fig. 4). This portion of network was chosen because of the presence of DG (mainly PV systems) in MV and in LV. The PV nature of the DG creates a power flow difference between winter and summer seasons. In this way different optimized network configurations can be found in different periods of the year.

In *Vercelli Sud* substation two HV/MV transformers, with a rated power of 25 MVA, feed two separate busbars called *red*

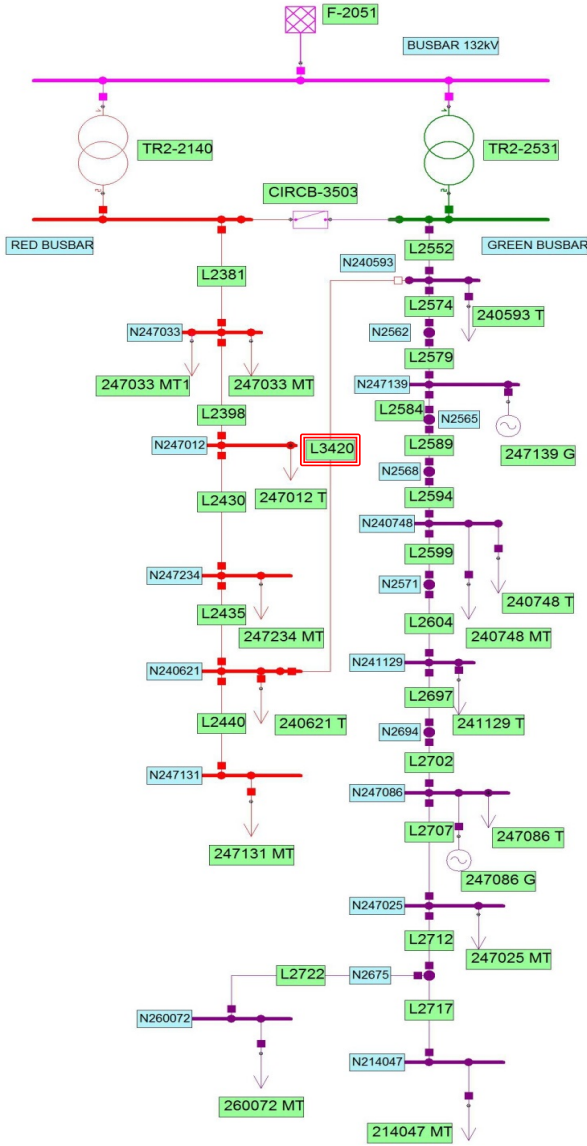


Fig. 5. Zoom on the loop in Vercelli Sud distribution network

TABLE II. ALTERNATIVE NETWORKS PERFORMANCES - SUMMER

| ID | Description | $P_{LossNorm}$ | $\Delta U_{MaxNorm}$ |
|----|--------------------------------------|----------------|----------------------|
| 0 | Base configuration | 8,4000E-01 | 8,0539E-01 |
| 1 | Opened line L2552 - closed tie L3420 | 8,4648E-01 | 7,9196E-01 |
| 2 | Opened line L2381 - closed tie L3420 | 1,0000E+00 | 1,0000E+00 |
| 3 | Opened line L2398 - closed tie L3420 | 8,6243E-01 | 8,6118E-01 |
| 4 | Opened line L2430 - closed tie L3420 | 8,5071E-01 | 8,3825E-01 |
| 5 | Opened line L2435 - closed tie L3420 | 8,5060E-01 | 8,3629E-01 |

appears to be the one with opened line L2552 (configuration 1).

A summary of the network performances calculated by the optimizer with the Neplan load flow results with typical summer loads and generation values, are instead presented in table II.

With typical summer load and generation values, the best

option from the losses perspective is not any more configuration 5 but configuration 0, i.e. the base case.

VII. CONCLUSION

In this paper a software module, developed to work with Neplan, has been presented. It allows a dialogue between the network simulator and external data. It has been used for two main reasons: to keep the network model updated with data measured on the field and to couple the network simulator with an external topology optimizer. The overall system has been applied to the distribution network in Vercelli.

Neplan software environment has shown to be robust and reliable with very good capabilities for dialoguing with external data and with external software through third parts developed DLLs.

The network optimization was performed on a real network topology, with real load and generation values. The results show that seasonal differences can exist in the optimized topologies. The DSOs should therefore consider to periodically change the network configuration in order to minimize network losses and/or voltage drops.

The computation time required by the optimizer is quite small but, as it is now performed, the enumeration of all possible network configurations can become large, especially for big distribution systems with many tie-lines. For the presented case study, the total time required for radial networks exploration was 1,68 s, while for the performance evaluation 1,01 s, both including files reading and writing.

In the future other features will be added to the online optimizer, such as the possibility to work with different standardized data formats, the use of optimization strategies that do not require a full exploration of network topologies and the possibility to include other objectives in the optimization process (maximization of the distance from current rating of lines, minimization of energy exchanges with the HV transmission network, etc.)

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