

# Development of procedures in power system software environment for automatic data import and management of active distribution networks within the framework of ATLANTIDE project

L. Meneghini, R. Turri - DII Dipartimento di Ingegneria Industriale - University of Padova - Italy

A. Mari - SINT Ingegneria Srl - Italy

**Abstract:** This paper describes the procedures to import data of distribution network models into a simulation environment, starting from a standard database built within the framework of the project ATLANTIDE. The aim is to create network models which can be used to evaluate the effectiveness of the controls that become possible on a Smart Grid. In particular, two different logics of HV/MV On Load Tap Changers control, when used in electrical distribution networks to regulate the voltage in presence of Distributed Generation, are compared. The software NEPLAN<sup>®</sup>, associated with NEPLAN Programming Library (NPL), has been identified as a versatile and suitable tool to create an interface with existing databases, to carry out simulations on the Smart Grids and assess possible benefits of the implemented procedures.

**Keywords:** Distribution network, Smart Grid, Distributed Generation, OLTC

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## 1 Introduction

The upgrade and development of distribution networks across the European Union is one of the key challenges to securing a sustainable and competitive energy future.

Today's distribution networks are primarily based on large central power stations with one way power flow from the network to the passive consumer. In the future, a more flexible and interactive distribution network is required, that is a smart electricity grid or, as commonly known, a Smart Grid. This term implies a network that integrates and efficiently manages the behaviour and actions of all users connected (loads and generators), in order to ensure an economically efficient operation of the electrical system, with high levels of safety, continuity and power quality. In addition, Smart Grids will increase the use of Distributed Generation and Renewable Resources.

The re-engineering process from current distribution networks to Smart Grids encompasses a complex range of issues covering market design, organizational, regulatory and technical issues. Research activities are needed to develop new technologies which will make distribution networks stronger and smarter. In particular, this means enriching the networks with information technologies such as sensors, digital meters and a communication network.

In this context, the paper examines two logics of HV/MV On Load Tap Changers control, in order to regulate the voltage on distribution networks in

presence of Distributed Generation. These logics of management are tested on the ATLANTIDE clustered industrial network model. The objective is to test which of the proposed methodologies adapts better to the evolution scenario of electrical system which, as mentioned, will allow a greater hosting capacity of Renewable Resources. The software NEPLAN<sup>®</sup>, with aid of NEPLAN Programming Library (NPL), has been identified as suitable tool to achieve the intended purposes.

## 2 The ATLANTIDE project

ATLANTIDE, acronym of "*Archivio TeLemAtico per il riferimento Nazionale di reTI di Distribuzione Elettrica*" that is "*Digital archive for the national electrical distribution reference networks*", is a three-year research funded project which has the ambition to realize a repository of reference models for both passive and active LV and MV distribution networks, specifically tailored to the Italian distribution system. The reference models will be used for the simulation of medium and long term predictable scenarios, taking into account the development of the distribution system, according to the load profile evolution and the challenges caused by the widespread integration of Distributed Generation and Renewable Resources.

The group of participants includes Electric System Departments of the University of Cagliari, Napoli and Padova. The presence of an industrial partner, ENEL Engineering and Innovation, which is also the project leader, provides a solid link with the

world of energy distribution and the real issues related to it.

In order to provide stakeholders with a useful common benchmark for studies on distribution systems, ATLANTIDE aims at establishing a digital archive of reference networks, by providing a comprehensive set of case studies. The use of standardized reference networks will allow the comparison of innovative distribution schemes and operation strategies. In particular, the main project output will be:

- models of reference network configurations typical of the Italian territory;
- models of loads and generating units;
- models of typical and innovative electrical components;
- set of development scenarios of distribution systems in the next future.

The main expected outcome of the project is a database easily accessible and upgradeable [1], [2].

### 3 Data structure of ATLANTIDE project

The data structure used in ATLANTIDE is organized in three spreadsheets. In each of these, multiple sheets may be found, which contain in tabular form:

- elements of topology and electrical data related to the reference network to be represented (e.g. industrial, rural and urban);
- parameters of the components to be used in the reference network (e.g. lines, transformers and rotating generators);
- trends of the load and generation profiles that characterize the utilities and power plants, for the creation of the reference scenarios.

The identification of the fields in each sheet occurs through the recognition of a header.

This approach allows:

- the reorganization of the files;
- the addition of new fields in an existing sheet;
- the insertion of any additional sheets.

The ATLANTIDE network representation and data structure have been designed to ensure expandability and flexibility in order to be able to deal with networks and scenarios with increasing levels of complexity and size.

### 4 Automatic import of the network with NEPLAN Programming Library (NPL)

The preparatory phase before importing a reference network includes the creation of a data library for lines, transformers and rotating generators, according to the data structure of ATLANTIDE, as

well as the addition of user defined symbols for the graphical representation of the network elements. Both operations are performed directly in NEPLAN®. The addition of new symbols is necessary to improve the graphics displayed in the project.

The import procedure is achieved accounting for the ATLANTIDE database data structure, by acquiring these latter from a text file rather than directly from the above mentioned spreadsheets. This is done to avoid the increase in the required computational effort.

The procedure of automatic import of both data and graphic information of the reference network is developed using some functions contained in the NPL. In fact, this contains a set of C/C++ library functions which allow to access directly the project file through a user written C/C++ routine.

The user has the possibility to add elements on the network using the library function "AddElement". Elements may be displayed in the project with functions as "AddGraphicTo" for the topological elements (nodes and lines) and "AddSymbol" for the components (transformers, loads, generators and feeders). The components are connected to the respective nodes using the NPL library function "AddLinkToSymbol".

Furthermore, it allows accessing and modifying any variable of all element types using the function "SetParameter". The parameters can also be loaded from a data library file with "UpdateElementWithLibraryData" function.

It is then possible to execute any analysis like Load Flow, Short Circuit, Reliability, etc. by using the library function "RunAnalysis".

Moreover, the NPL allows also to access the simulation results with a function "GetResult".

A C/C++ batch program may then be written to perform all the above functions as a whole.

The batch program must include the header file (NeplanProgrammingLibrary.h) and a link to the NPL library file.

The compiling of the C/C++ project results into a dynamic link library (\*.DLL file), as reported in Figure 1. This DLL may then be run from NEPLAN® for the model build-up [3].

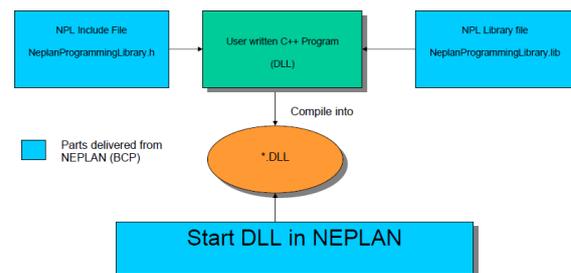


Figure 1 - NPL overview

To help the user in the choice of the data to load, a main dialog has been conceived, where the files of interest related to the reference network (e.g. project file, input files, library file, output file, etc.),

may be loaded, as shown in Figure 2. This dialog may be modified according to customer needs.

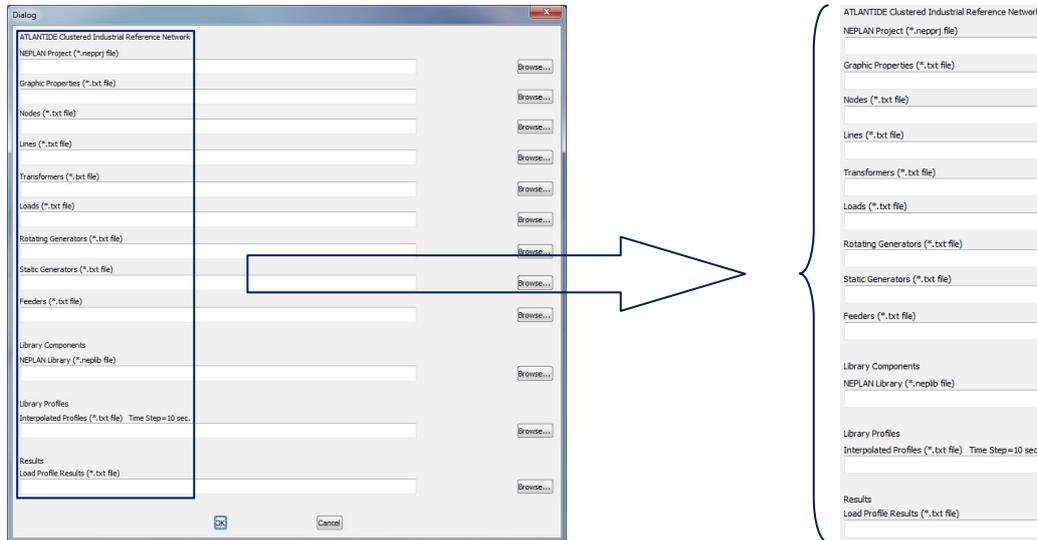


Figure 2 - Dialog shown when running the DLL

The import of the network in the simulation environment is made first by acquiring the topological elements and then the components. The final result of the import procedure, tested on the ATLANTIDE clustered industrial network, is

represented in Figure 3. This import procedure, developed by means of NPL, may be extended to any type of distribution networks taken from ATLANTIDE digital archive.



Figure 3 - ATLANTIDE clustered industrial reference network

The imported distribution network has a radial structure which counts up to 100 nodes, one of which at 132 kV (HV), whereas the remaining are at 15 kV (MV). At the HV substation, a 25 MVA transformer equipped with an OLTC with 21 Tap and a percentage variation per Tap of 1%, is connected. Seven feeders leave from MV substation busbar, each of them connecting distributed generators of various nature.

In the network of Figure 3 three significant nodes are highlighted, namely: the MV busbar node (N\_002), the node where the lower voltage may be calculated (N\_033) and the node with the higher voltage (N\_083).

In order to perform the calculation of Load Flow in the time domain, the daily profiles of load and generation are also imported. The values of these profiles are interpolated with the desired time step in pre-processing (e.g. in a spreadsheet) and, subsequently, they are acquired as text file so as to make a Load Flow with load profiles available, where the controls and making of decisions become possible step by step.

In Figures 4 and 5 the trends of the daily profiles of load and generation which have been assigned to different network elements are respectively shown. The load profiles are related to three types of consumers (residential, industrial and commercial), whereas for generation three types of production plants (photovoltaic, wind and cogeneration) have been considered.

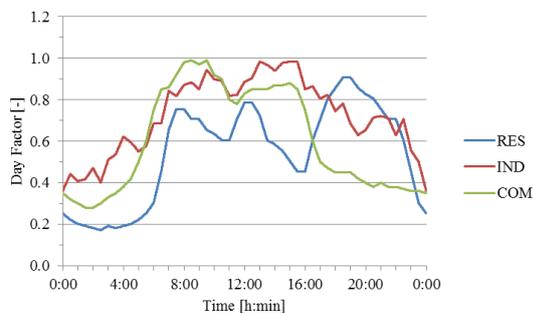


Figure 4 - Daily load profiles

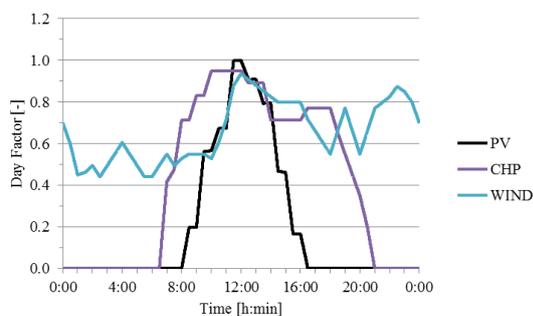


Figure 5 - Daily generation profiles

In the case under examination, the simulation is carried out on a daily span.

The results of the calculation of the daily Load Flow are stored in a text file, to be available for post-processing and charts. In particular, Figure 6 shows the voltage profiles on critical nodes of the ATLANTIDE industrial network, with reference to time period 8:00-18:00.

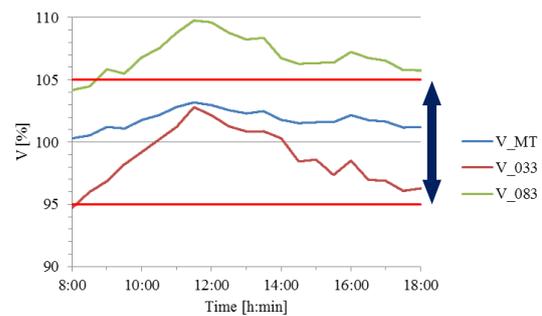


Figure 6 - Voltages on significant nodes of the ATLANTIDE industrial network

It is clear from the figure that the voltage at node N\_083 does not remain within the limits set by the regulations ( $\pm 5\%$  for the distribution system), due to the power injected by the group of rotating generators there connected. The peak voltage reaches, at 11:30, a value close to 110% of the nominal.

This condition makes the clustered network an interesting case study, to evaluate control techniques to avoid not acceptable conditions.

## 5 Voltage regulation in distribution networks

The voltage regulation, that is the task of maintaining the rms value of the voltages within the an allowable range, is one of the aspects which may limit the availability of distribution networks to include Dispersed Generation. In fact, a modernization of the networks is required in order to support a bi-directional power flow along the distribution lines or on the connection transformers to the transmission system.

The techniques for voltage regulation, so far implemented in electrical distribution systems, are simplified and managed locally in the primary substations, thus making the need for real time information coming from the peripheral nodes either limited or null. These procedures consist of:

- control of the Tap Position of OLTC in automatic mode;
- setting of the no load tap changers in MV/LV transformers (this is usually achieved in order to face a condition which is liable to change);
- use of local reactive compensation devices, in order to control the power factor of

loads and power flows along the lines and transformers.

In the next future, an intelligent system of voltage regulation must be able to ensure the rms values of voltages at each peripheral node within the permissible values, under the variable operating conditions of the network [4].

### 5.1 Traditional OLTC control

In order to improve the voltage profiles on the clustered industrial network, the well known control logic which acts on the Tap Position of OLTC of the HV/MV transformer has been tested.

This logic monitors the MV busbar voltage  $V_{MT}$  and compares it with a reference voltage  $V_{ref}$ , this latter defined by the distributor according to the network characteristics. If the voltage difference  $\Delta V$  is outside the Dead Band (sensitivity band of OLTC) a timer device comes into operation sending to the OLTC, after a preset delay, the tap changing command.

In order to evaluate the effects on the voltage regulation of the network, this has been implemented in NEPLAN® by means of NPL [5]. Figure 6 shows the voltage profiles on critical nodes of the network model and the Tap Position of the OLTC, with reference to the time period 8:00-18:00.

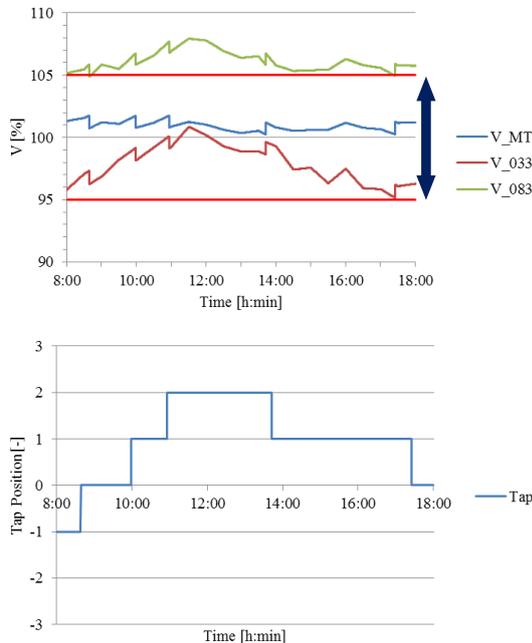


Figure 7 - Voltage profiles on significant nodes of the ATLANTIDE industrial network and OLTC Tap Position, as obtained by traditional control

A comparison between the results of Figures 6 and 7 shows that the OLTC control contributes to limit the voltage at node  $N_{083}$ . However, particularly

when the generation of PV plants is high (at around 12:00), this is not enough to avoid the voltage to overreach the maximum allowed limit of 105%. As a matter of fact, a value close to 108% of the nominal voltage may be read. On a daily basis, the OLTC performs only 12 switching operations, which is not high if compared to up to date OLTC ratings (up to 300,000 switching operations without maintenance and 600,000 without the replacement of contacts). On the other hand, the OLTCs are delicate and expensive devices, therefore it is advisable to optimise the number of switching operations.

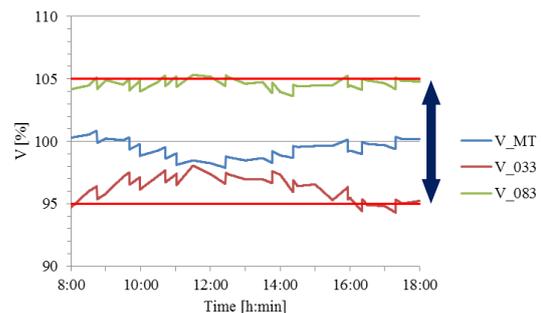
### 5.2 Distributed control of OLTC

As above described, the traditional control of OLTCs installed in primary substation transformers may not always solve some critical conditions in voltage regulation, particularly in case of high penetration of Distributed Generation.

In literature, alternative solutions have been proposed that allow to directly relate the operating state of a distribution network with the OLTC control. This is possible by linking the information collected via the measurement of remote node voltages and/or powers with the voltage control devices. It is then clear that a growing role of the signal measuring and transmission facilities is required in order to make the networks smarter.

In order to bring back the rms values of voltages within the limits, a control logic that allows to obtain a better management of the voltage profiles has then been simulated. With this procedure, the OLTC voltage setting point  $V_{ref}$  may be adjusted according to the network requirements at the most critical nodes (pilot node control), however constraining the reference voltage  $V_{ref}$  at the regulated node in the range of allowable voltages ( $\pm 5\%$  for the distribution system).

This distributed control based on this advanced management of OLTC, has again been implemented in NEPLAN® through NPL and tested on the ATLANTIDE industrial network [5]. The voltage profiles on critical nodes and Tap Position of OLTC, with reference to time period 8:00-18:00, are shown in Figure 8.



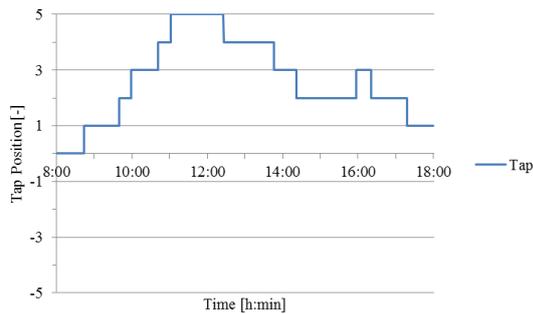


Figure 8 - Voltage profiles on significant nodes of the ATLANTIDE industrial network and OLTC Tap Position, as obtained by OLTC distributed control

The distributed control of OLTCs allows to keep the voltage values within a narrower range, thereby reducing the deviations from the nominal value. As a drawback, as Figure 7 shows, this control mode may result in a reduction of voltage values in other network nodes (e.g. N\_033), yet remaining above the minimum limit. On a daily basis, the OLTC is called to tap 31 times, still an acceptable value although leading to a shortening of the time between maintenance interventions.

## 6 Conclusions and future developments

In this paper the results of the implementation of different OLTC control logics have been presented, which allow to manage electrical distribution networks in presence of Distributed Generation.

## 7 References

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Significant case study networks have been taken from ATLANTIDE digital archive and converted into NEPLAN® models. This conversion has been possible by use of the tool NPL, and the implemented import procedure, based on an industrial network, fits any kind of networks to be derived from this important archive.

Two applications have been tested for assessing the effectiveness of different voltage controls, namely the traditional control, based exclusively on local measurements in primary substation, and the distributed control, which rather considers the operation state of the distribution network by monitoring sensitive network nodes and selecting the appropriate reference voltage  $V_{ref}$ .

The results obtained show that distributed control of OLTCs allows a better management of the voltage profiles, within the range of variation permitted by the regulations. However, it is evident that this control method is not sufficient (alone) in the case of high unevenness in distribution of production plants and loads. In particular, this procedure reduces, yet not eliminating, the problems of adjusting the voltage in the distribution networks with high penetration of Distributed Generation.

An interesting future development is the implementation through NPL of a control aimed to the involvement and coordination of active users, showing how all the distributed resources may be significant for the management of the network.