

ADVANCED ACTIVE DISTRIBUTION SIMULATIONS WITH THE ATLANTIDE WEB CLOUD FACILITIES

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ABSTRACT

The paper presents some significant results of the activities being carried out within ATLANTIDE, an Italian Research Project, for studying the active distribution networks under different evolutionary scenarios. In December 2013 ATLANTIDE project reached the final stage and the repository, the on-line power system models and the social forum are on-line and free for use.

INTRODUCTION

The paper presents some significant results of the activities being carried out within ATLANTIDE, an Italian Research Project, for studying the active distribution networks under different evolutionary scenarios. ATLANTIDE is a three years research project funded by the Italian Ministry of Economic Development under the framework of the Italian Research Fund for the development of the Italian Power System project. In December 2013 ATLANTIDE project reached the final stages and its main product is the publication of the networks and tools database in the website.

ATLANTIDE aimed at designing and realizing a web based archive of models to be used for research and development activities in the context of active LV and MV distribution networks, specifically tailored to the Italian distribution system but easily extendable to other systems. The representative and reference networks, models of generation sets and loads, and other equipment (e.g., switchgear and relays, Distribution Management System (DMS), etc.), stored in a database that contains their typical characteristics, are easily accessible and upgradeable.

The website is structured as follows [1]. The first section represents the digital archive of the components and network models. References models constitute a comprehensive dataset to be used for studying medium and long term predictable scenarios, taking into account the development of the distribution system originated by the load consumption evolution, the widespread integration of distributed and renewable generation, and distribution storage devices.

The second section, the most innovative one, allows the user to perform on-line simulations by using the representative networks available in the repository or

user-defined case studies. User-defined case studies can be designed with a Graphical User Interface or directly uploaded as excel files.

The ATLANTIDE website has also a blog-like *Home* where users can share their simulation results and discuss with other registered users, members of the ATLANTIDE community. This kind of social-network interaction will play a key role in the creation of a common field of discussion for those who are interested in Distribution Network study and innovation, which is one of the final ATLANTIDE goals.

ATLANTIDE FORMAT

Reference networks, network elements library and the profiles library are stored in an internal Database. The database is based on a flexible data structure that allows an easier interaction with stakeholders interested in interfacing ATLANTIDE with already existing network simulation environments.

A distribution network can be described by a suitable set of dataset and by their mutual interactions. The ATLANTIDE data structure is based on layers (Figure 1): the *network layer* or topological layer that stores the information on the network topology, the *load* and *generation layers* that contain the load and generation information (position, rated power capacity, type, etc.), and the *automation and control layer* that is a dataset with the position and type of automation and protection devices as well as the future, smartgrid oriented, intelligent devices [2]. Further layers can be easily added to describe more complex cases.

Layer elements all refer to libraries where information on the types of components and profiles is saved. In Figure 1 the layers, libraries, and profiles with their interactions are shown. In particular, the *Types library* is the object where the common information on network components is saved; the *Profiles* library contains the data on load and generation patterns with different time scales according to the type of analysis.

The Database in the website can be easily increased by importing new networks, types and profiles libraries with spreadsheet format files. The format can be easily converted in open formats or made suitable to the most common power system software.

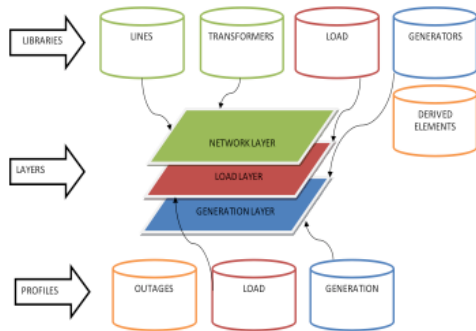


Figure 1. ATLANTIDE data structure and interaction flows.

THE ATLANTIDE WEBSITE

The portal website is structured in three main parts:

- Social space (forum like) for sharing models, studies and researches within the community of users and stakeholders.
- Repository of reference and representative networks (the network digital archive).
- Interactive network simulation and advanced planning interface.

The archive and the network simulation tools are described in the next sections.

NETWORKS DIGITAL ARCHIVE

The pages of the network digital archive are: *Networks* | *Profiles library* | *Types library*.

The networks stored in the database are listed in the *Network page*. For each network the following fields are used:

- the name of the network,
- a flag that identifies if the network is representative or not (the star means “reference” network),
- a brief description in the notes field,
- the number of lines,
- the number of nodes,
- the author of the network (i.e., the registered user that uploaded it), and
- the date of the last uploading.

The interactive Graphic User Interface allows the registered user to visualize a network and edit it by using the component drag&drop palette (Figure 2).

Network layers are described in these areas. The information on the network topology are stored with the list of transformers, loads, generators and lines and relevant position on the network.

In the *Profiles library page* loads and generators with their relevant curves are described.

- Load consumption,
- Generators production,
- Energy cost,
- Active Demand contribution and participation,
- Non linear load behaviour.

Each profile can be downloaded, uploaded and plotted. A compressed coding of profiles, which makes use of calendar coefficients (day, week, month, year), reduces

the amount of data for load and generation representation and enables the simulation of future “evolutive” scenarios.

In the *Types library* page, every component type is described. Different types of generators, inverters, transformer, busbars, nodes, and conductors are considered. The *Types page* lists the attribute to describe each type in terms of electrical characteristics, efficiency, reliability, etc..

A registered user can import his own network model from an existing file (Excel “ATLANTIDE format”) or create a new network on the website. Importing a new network can be subdivided in three steps:

- importing the profile library;
- importing the types library;
- importing the components layers (topology, generation, load and storage layers).

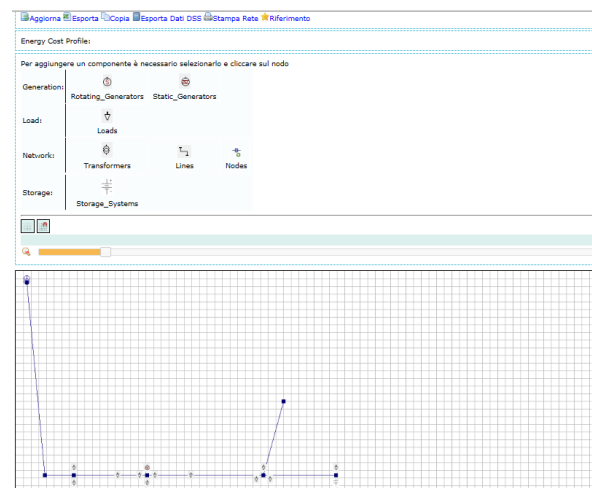


Figure 2. Drag&drop palette that allows the user to design his own network or modify an existing one.

NETWORKS SIMULATION

In Figure 3 the layout of the *Networks Simulation* interface is shown. By choosing the network and the component layers, the user creates the scenario of the simulation. Power Flow calculations, Centralized and Distributed DMS/EMS, Harmonic and Short Circuit analysis, Voltage Dips calculations, and Reliability analysis are features of the tools available in the ATLANTIDE website. The power system simulation engines are OpenDSS and a proprietary code written in MATLAB. The most important functionalities of the ATLANTIDE simulation environment are described in the following sections.

Load Flow Calculations

The Load Flow (LF) calculation is the base for each other study that will be performed with the ATLANTIDE simulation tools. The LF is based on the classical Newton-Raphson algorithm developed by the authors or can be performed with the OpenDSS engine (particularly for unbalanced networks). Snapshot or

time-series load flows can be carried out within the website. Users can download LF results that are delivered as graphics and spreadsheet files.



Figure 3. Network simulation interface

Smart grid simulation with centralised control

In active distribution networks, the Distributed Energy Resources (DER) share responsibilities for network operation with the Distribution System Operator (DSO). By exploiting DG active and reactive power dispatch, storage devices and active demand, DSO may reduce technical barriers to renewable integration and increase the hosting capacity of the network. The DSO may also have the opportunity to manage electricity flows by using flexible network topologies (i.e., network reconfiguration) [3]. The complete scheme of the developed Active Distribution System (ADS) is reported in Figure 4 that shows a centralized DMS constituted by a suitable Optimal Power Flow (OPF) used by an Energy Management Systems (EMS).

The DMS, the core of the active management, supervises the network operation by gathering measures of the main electric parameters, executing the state estimation and, if necessary, sends the set points to DERs. The DMS communicates with the Intelligent Electronic Devices (IEDs) that will be widely deployed across the distribution network with protection and operation purposes. IEDs need a communication network that must be highly reliable, scalable, secure, and robust [4].

The OPF in the EMS optimizes an objective function that is the sum of the operational expenditures related to the active management of a given distribution systems by making all technical constraints (e.g., line thermal limits, nodal voltage, reserve, etc.) complied with. The economical optimization is based on price signals that guide the participation of DER in Volt/VAR regulation, and the use of storage devices as well as the bids from active demand. In order to take into account the operation of storage systems in the optimization, a window on future time must be included in the

optimization. Indeed, the optimal usage of storage depends not only on instantaneous data, but also on the previous and future operation decisions. Once the time horizon (typically a day) and the time interval (e.g., 1 hour, but even shorter) are defined, at the beginning of each time interval the DMS receives not only the current status of the network and the energy market prices, but also forecasts for the incoming time intervals. Actual and envisaged data are used to make decisions at each time interval. Since the algorithm has been conceived for real time applications, at each time interval the optimization is run again using the current state of charge of storage as starting value. The OPF takes into account what is going to happen in the incoming time intervals to find the optimal profile of electrical storage operation by optimizing the most convenient time intervals to charge or discharge the storage [5].

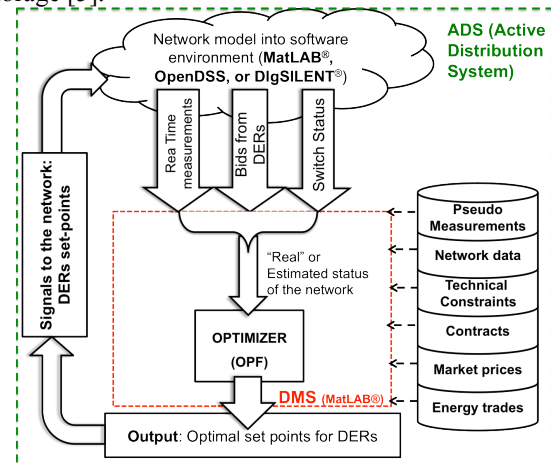


Figure 4. Scheme of Active Distribution System tool.

With reference to the Active Demand (AD), following the experiences made in other EU project, the AD model is expressed as a variation of load with respect to a reference profile representing the load without any participation to demand side any integration [6]. The model introduces the concept of flexibility that is the power an active user makes available to a DMS expressed as a power reserve provision (downward or upward) related to a specific price/volume bid.

From a computational point of view, the ADS model exploits a Linear Programming (LP) optimization algorithm to reduce the computing time for real scale applications and to increase the capability to handle many different operating constraints [3]-[5]. The revised simplex method, used to solve the sparse LP problem, is computationally efficient, accurate, and suited to large and sparse LP problems [7].

Smart grid simulation with decentralised control

The Distributed-ADS is based on a Network Supervisor (NS) whose aim is to generate suitable controlling signals to be forwarded to the users, in order to pursue

some objectives that may be of technical (e.g. voltage control or current control for resolving congestions) or economical (e.g. losses reduction) nature. D-ADS was originally design for a real-time use and it has been adapted for simulation studies in ATLANTIDE. After that, some sort of active cooperation from the active users (DGs, responsive loads or storage systems) is expected, in order to respond to the request signals forwarded by the NS.

Voltage regulation

The D-ADS network control strategy is based on the adaptive regulation area selection presented in [8], which consists in the identification of a number of clusters each one composed by MV network buses which are electrically close (electric distance evaluated by a sensitivity analysis of the distribution network) and have similar working conditions (e.g. similar bus voltage magnitude). Subsequently, a pilot bus is identified for each area, to evaluate the local worst operating condition (e.g. maximum voltage magnitude deviation), so the NS can compute the voltage set-point variation to send to the active user controllers to correctly manage their distributed resources, as schematically depicted in Figure 5. If necessary, by applying the same principle, a more targeted area separation would be possible considering also other variables (e.g. current measurements) in order to dynamically adjust the areas configuration as the power flows vary.

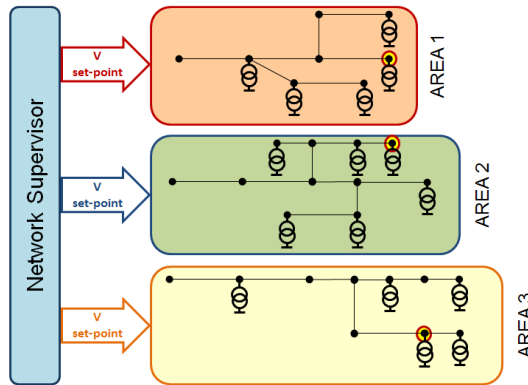


Figure 5. Conceptual scheme of the D-ADS coordinating the distributed voltage regulation: the voltage set point variation for each pilot bus is computed by the Network Supervisor and sent to the relative area.

On-Load-Tap-Changer

In this scheme the NS coordinates the action of the OLTC transformer located at the primary substation in order to better fulfill the network voltage regulation targets. In practice, the OLTC operates a sort of bus voltage conditioning prior to the application of the area identification procedure, modifying its reference voltage so as to center the network bus voltage spread around the nominal level, thus facilitating the subsequent reactive power regulation action.

Current regulation

The network supervisor depending on overloaded branches, flow direction, and active customers location

identifies current regulation areas. A sensitivity analysis supports network supervisor decision and automatize the selection of customers whose operation could alleviate congestion problems. For the scope, a procedure originally developed for transmission networks has been exploited and applied to distribution networks [9].

Technical-economic constraints

An important issue in distributed network management is the availability of users in participating to the regulation. Such availability will depend, provided the technical viability of the users' devices, on their willingness to participate or not on the basis of economic benefits and/or constraints.

As mentioned above for the ADS centralized control achieved by means of a cost optimization, a similar control mechanism can be easily implemented in a demand/response system of network services between network operator and end-users, based on costs and prices. An example of the effect of user capability reduction is depicted in Figure 6.a, where the subscript "cap" (capability) indicates availability of the relevant quantity on the basis of technical constraints, whereas subscript "disp" indicates a reduction of the capability caused by economic constraints. In this particular case, the capability reduction is due to the user own choice of preserving a given reservoir (e.g. for possible more rewarding services) rather than providing the full capability to network requirements. A further example is given in Figure 6.b, which refers to the implementation of a demand/offers mechanism of active power. By assuming that the total network power in the area is ΔP_{TOT} offer price of p_1 , the single unit may autonomously assess its convenience in providing the requested action (in this case a reduction of the production), indicated with ΔP_{p1} . After all the units in the area have reacted to this first request, if the objective is not reached, the network supervisor increases the offer price to p_2 and the procedure is repeated.

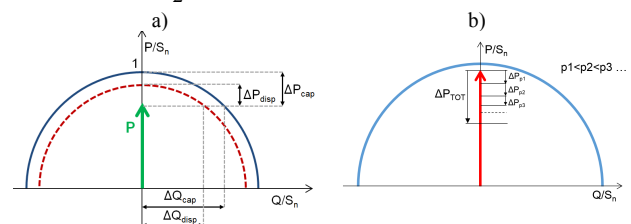


Figure 6. a) Example of the reduction of capability available for network services. b) Reduction of regulating active power in a demand/offers system.

Short Circuit Analysis

Two methods for short circuit analyses have been implemented. One calculates maximum and minimum prospective short-circuit currents according to the IEC Standard 60909 while the other one uses symmetrical components decomposition useful also for voltage dips and swells analysis in the framework of voltage quality studies.

Reliability Analysis

The model proposed in [1] was first implemented for reliability analyses. The model, based on logical relations and matrix operations in the framework of the Failure Modes and Effects Analysis (FMEA), is able to take into account the cause-effect relation between the fault locations and the affected customers. The model was then extended to include the presence of Distributed Generation units and the effects of network topology reconfigurations subsequent a fault occurrence. The outputs of the model are the typical reliability data such as SAIFI (System Average Interruption Frequency Index), SAIDI (System Average Interruption Duration Index), CAIDI (Customer Average Interruption Duration Index) and AENS (Average Energy not Supplied).

Voltage Quality Analysis

Models for voltage quality analyses have been implemented with reference to harmonic penetration and voltage dips and swell studies. The model for harmonic penetration studies is based on direct injection method. It is fully described in [11] where it is also shown how the results of these models can be included in the multi-objective optimization approach used by the Distribution Management System model developed in ATLANTIDE.

The model for voltage dips and swell analyses starts from the calculation of the dips matrix as in [12] and implements the algorithms for the evaluation of the typical indexes such as SARFI-X (System Average Rms-Variation Frequency Indexes for retained voltage X) and SAVDA (System Average Voltage-Dip Amplitude).

Output and results

Once the user has chosen the tool and the simulation options with the interface shown in Figure 3, the simulation starts in the host ATLANTIDE server. Then, when the simulation ended the user can save the results in its own computer or in a dedicated area of the website. Figure 7 shows an example of the output of the smart grid simulation with centralised control.

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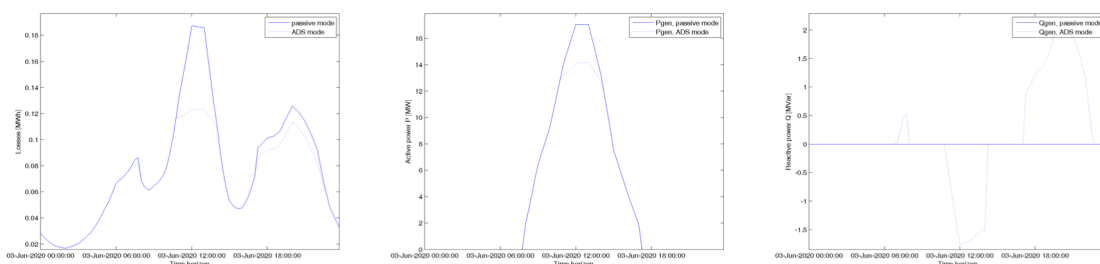


Figure 7. Daily energy losses, regulated active and reactive powers from DG as output of the smart grid simulation with centralised control.