A SIMULATION PLATFORM FOR DMS STUDIES

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ABSTRACT

This paper describes a simulation platform for the optimal operation of active distribution networks simulations. The optimal operation strategy is obtained by solving a minimization problem through a Distribution Management System model, proposed by the authors in previous works. Two software packages, Matlab and DIgSILENT PowerFactory, are employed and linked together in an automatic data exchange procedure to gather data from the network model, to solve the minimization, and to apply the optimization results on the network model. The effectiveness of the proposed procedure has been tested on the rural Italian representative network produced by the research project ATLANTIDE.

INTRODUCTION

Active Distribution Networks (ADN) have been conceived to face the issues arising from the increasing number of hosted Distributed Energy Resources (DERs). The active approach requires DERs to be coordinated and managed with the advanced applications that are enriching the functionalities of Distribution Management System (DMS). Demand Side Integration (DSI) and stationary and vehicular energy storage increase the set of controllable DERs and are another driver for implementing new functionalities in DMS.

The main objective of this paper is to present the application to representative distribution networks of an improved DMS model proposed by the authors in previous works and the description of a novel platform for the simulations [1]-[3]. Matlab and DIgSILENT PowerFactory are employed and linked together in an automatic data exchange procedure to gather data from the network model, to solve the DMS minimization, and to apply the optimization results on the network model. The effectiveness of the proposed procedure has been tested on the rural Italian representative network that is one of the deliverables of the research project ATLANTIDE [4]-[6].

The structure of the paper is the following: the first section describes the DMS model, the second one the proposed procedure that involves the two software packages and, finally, a case study is presented.

DMS MODEL

The advanced applications functions implemented in the proposed DMS are constituted by an EMS optimizer for the day-ahead and the intra-day scheduling of distributed resources. The goal of the EMS is the operation of the distribution systems at minimum costs by using an OPF algorithm. The OPF can be solved with several techniques as non-linear programming (NLP), linear programming (LP) or mixed-integer linear programming (MILP) [1]. Computing time, reliability and ability to handle many different operating constraints are fundamental requirements for real scale applications. For that reason, in the proposed algorithm, the LP has been used after a proper linearization of constraints (see [1], where more details can be found).

The problem can be formalized as a minimization of an Objective Function (OF) related to the operational expenditures, subject to power flow equations, technical and commercial constraints that can be formulated either as equality or inequality constraints. The technical constraints are the nodal voltages and the branch power flows during normal and emergency conditions, the capability curve of generators, the charge/discharge cycles of the storage devices, etc.. The control variables are the set point of generators and storage devices and the expected response of active demand.

From a computational point of view, the revised simplex method is used to solve the sparse linear programming problem. This method is computationally efficient, accurate, and particularly suited to large and sparse LP problems [7].

In the proposed implementation the EMS resort to the following operation options:

- Active power generation curtailment (GC): this option can be useful to face overvoltage conditions. The use of suitable price signals limits its usage to RES;
- Extra dispatching of active power from programmable generators, particularly effective as remedial action against voltage drop;
- Volt/var regulation with DG and storage;
- Demand Side Integration (DSI), to involve customers that participate to Active Demand (AD) programs in the active management of the network, including the payback effect [6];
- Energy losses minimization to improve the total energy efficiency;
- Storage devices charge and discharge used for load levelling and voltage regulation [3].

The flexibility of the algorithm allows the user to define terms of the OF in order to match with the specific features of networks into a given ambit (i.e., rural, industrial and urban networks). For instance, in the rural networks, characterized by long overhead lines with r/x ratio close to unity, the participation of the generators to the volt/var regulation (reactive support) is a valid opportunity that might be effective to reduce the curtailment of the renewable power production in case of overvoltage. In urban networks, the participation of the final users to AD programs for load levelling and peak shaving allows increasing the hosting capacity with few capital expenditures (e.g., the deferment of investments for the addition of a second transformer in the substation). In industrial networks, energy storage might be a much easier to implement option and the DMS can take benefit from an optimal operation of storage for both energy and regulation services.

PROPOSED APPROACH

Only few papers properly deal to the co-simulation with Matlab and DIgSILENT PowerFactory (see for instance [8]). In the proposed approach, these two software packages are employed and linked together in an automatic data exchange procedure. The network model is stored in DIgSILENT that is used for power system simulation. Matlab is used for the event coordination and for the control system, as optimization solver. During the simulations, DIgSILENT provides to Matlab the status of the network, the OPF algorithm runs in the Matlab environment, and, once the optimization is completed, Matlab inputs DIgSILENT the new optimal dispatching of the active and available resources of the networks. The automatic data exchange between the two programs is implemented in a code written partly in Matlab and partly in the DIgSILENT own programming language (DPL).
The data exchange is made using text files for triggering the Matlab activities and for triggering the DIgSILENT simulation. When the relevant trigger is set to 0, each software package waits its turn. Spreadsheet files are used for transferring the data between the two software packages.

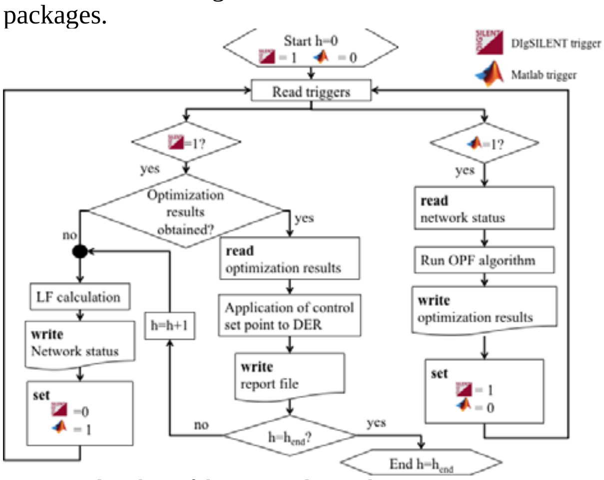

Figure 1. Flowchart of the proposed procedure.

In Figure 1 the flowchart of the proposed automatic procedure is shown. When the user starts the simulation (h=0) the DIgSILENT trigger is set to 1 and the Matlab trigger is set to 0. Once DIgSILENT has calculated the status of the network for the first time interval (with a Load Flow calculation) and the significant data have been written by the DPL script in the spreadsheet file (an Excel file with a special ID name), the Matlab trigger is set to 1 and the DIgSILENT trigger is changed to 0. Then, Matlab is allowed to read the network status, to run the DMS algorithm and, finally, to write the results of the optimization in another dedicated Excel file. At this moment the DIgSILENT trigger is changed to 1 again, and the Matlab trigger is set to 0. Now, DIgSILENT reads the novel set-points for the next time interval in the Matlab output file, and applies those optimal set-points to the active resources. Then, a new simulation run for the next time interval. During this procedure, both platforms scan and change the value of the trigger files until the time horizon of the simulation (h_{end}) has been reached.
The data exchange between the two software packages is depicted in Figure 2.

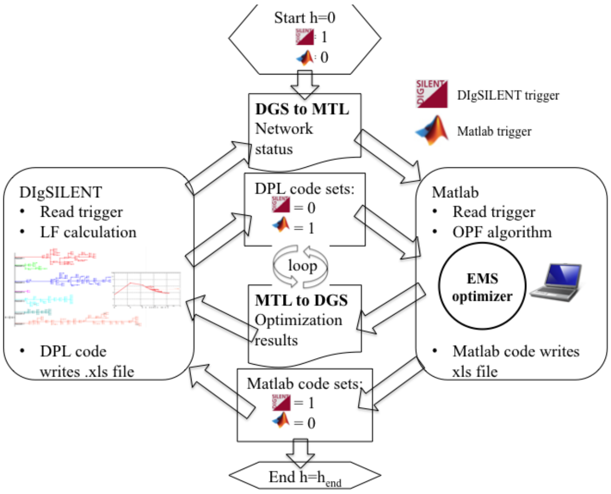

Figure 2. Data exchange between the two software packages.

CASE STUDY

The clustered version of the ATLANTIDE Italian rural representative network is used for the simulations [4]-[6]. Seven feeders with 103 MV nodes supplied by one 25 MVA HV/MV substation compose the test network (mostly small cross sectional overhead lines for a total extension of about 160 km).
ATLANTIDE project proposed different evolutionary scenarios for the distribution system as described in [9]. In this paper the BAU (Business As Usual) scenario has been considered. In the BAU it is assumed that no significant changes are imposed (e.g., no changes in the incentives for renewables) and the trend for demand and production continues without discontinuities from the past.
According to BAU, at the starting year of the studies (2010), the rural network has 7.7 MW of photovoltaic generators installed. Then, it evolves as reported in TABLE I that shows the nominal load (a mix of agricultural, residential and small industrial customers) and the generation for the years 2020 and 2030. In the rural reference network only PV has been assumed as distributed power source. According with the ATLANTIDE outcomes, it has been assumed that new generation plants appear in specific nodes of the distribution network and in definite years within the considered period, whereas the load grows smoothly with a constant growth rate. The appearance of generators in the networks is completely random, in

order to exalt the system criticalities.

TABLE I – Nominal load demand and production in the hypothesized BAU scenario

Year	Nominal demand [MW]	Installed generation [MW]	Scheduled production [GWh/y]
2010	16.3	7.7	6.4
2020	18.2	31.3	25.9
2030	19.5	52.0	42.4

The ATLANTIDE representative rural network with the indication of the generator position in the two considered decades is shown in Figure 3.

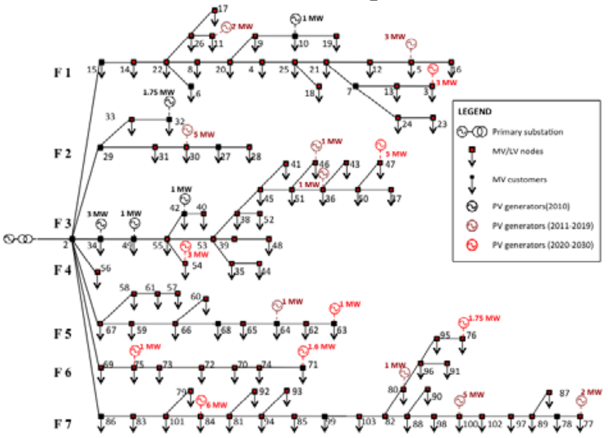

Figure 3. The ATLANTIDE representative rural network in the BAU scenario.

From the tests performed, it emerges that line overloads start to become an issue only in the last years of the examined period because of the initial small demand. On the contrary, overvoltage is a serious issue in the whole examined period because there are many nodes with overvoltage beyond the maximum allowable limit particularly in the central hours of the day (between 11:30 a.m. and 2:00 p.m.). This is a direct consequence of the PV generation that exceeds local demand and use the distribution feeders to send energy back to the transmission system. Furthermore, excessive voltage drops also happen in the evening when the residential and agricultural demand is at the peak, and no help can be expected from PV generators. These issues can be solved by building new lines or by resorting to the coordinated control of DERs' active and reactive power or, that the same, by exploiting the DMS features [10]. The PV active power control can help fixing overvoltage. The reactive power control can again help fixing overvoltage with less costs since there is less need of generation curtailment. Furthermore, with the reactive power generation from DG or from storage devices voltage drop in the evening can also be mitigated. As an example, the results for a typical summer weekday of 2010, 2020 and 2030 are reported.

Results

In Figure 4-Figure 6, the non-regulated voltage profiles of the most active feeder (F3 in Figure 3) at noon in the Wednesday of June in the considered years are shown. Nevertheless the loads and production patterns are non-homothetic there are not overvoltage neither in 2010 (Figure 4) nor in 2020 (Figure 5). On the contrary, in 2030 (Figure 6) the vast majority of nodes have voltages beyond the maximum allowable threshold (1.05 p.u.). These voltage profiles, that represent the state of the network, are the inputs for the Matlab optimization, written by the DPL code in DIgSILENT in a specific spreadsheet file.

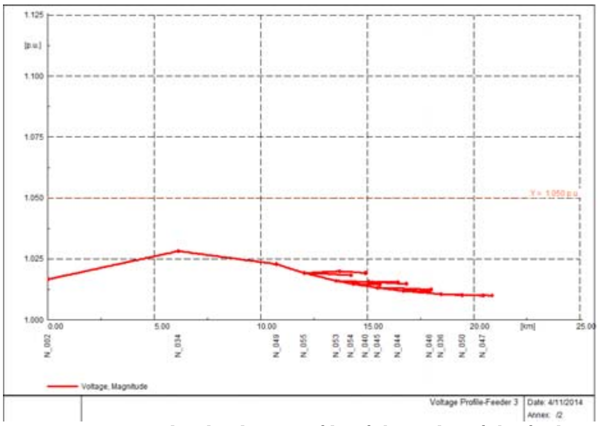

Figure 4. Non-regulated voltage profile of the nodes of the feeder F3 in a critical hour of 2010.

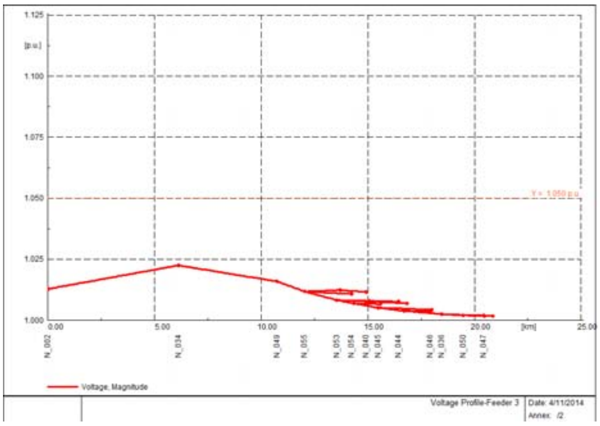

Figure 5. Non-regulated voltage profile of the nodes of the feeder F3 in a critical hour of 2020.

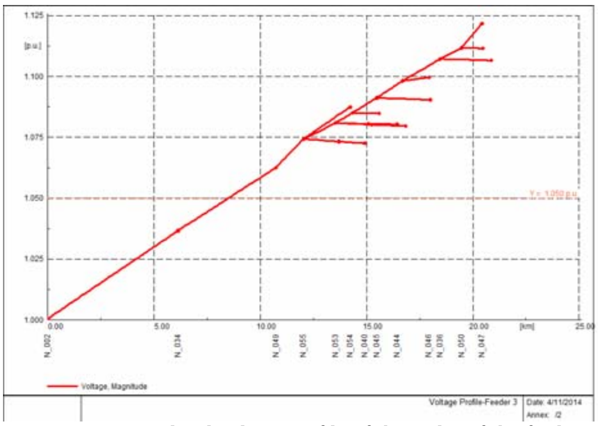

Figure 6. Non regulated voltage profile of the nodes of the feeder F3 in a critical hour of 2030.

Once the triggers command the software package shift, it is time for Matlab to run the OPF algorithm. The output of the optimization is the list of modified set-points of the generators that are requested to reduce their active production and/or exchange reactive power with the network in order to fix all network issues.
In the most critical year of the example, in the considered hour, the OPF commands the PV to reduce about 24% their production and to exchange reactive power (about 3.9 MVar negative and 1.3 MVar positive reactive power).
This result is sent to the network by writing of a special file readable by DIgSILENT. The solution of the optimization is then applied on the network and the effectiveness of control actions verified by a new LF calculation executed within DIgSILENT.
In Figure 7 the optimized voltage profile of the feeder F3 is reported: the contingencies are eliminated by the simultaneous reduction of active powers and exchange of reactive power.

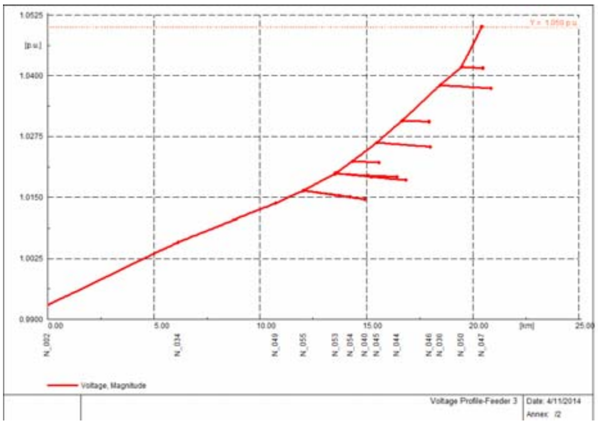

Figure 7. Optimized voltage profile of the nodes of the feeder F3 in a critical hour of 2030.

The execution time for the computations for the LF calculation and for the optimization, separately considered for the two software packages, is very small (i.e., less than 0.5 s for both the optimization and LF calculation). On the contrary, writing and reading the spreadsheet files is the most time consuming phase that should be improved for real scale applications.

CONCLUSIONS

This paper proposes a platform for smart grid simulations that can be used to assess control programs and functionalities for modern DMS. Since professional Power Systems programs do not have EMS embedded that can easily run the plenty of control algorithms developed in recent years by Academia and Research institutions, the proposed platform can be useful for many practical simulations and applications.
The presented results showed the validity of the approach in a real world case study.

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