EFFECTIVE DISTRIBUTED RESOURCES MANAGEMENT SYSTEM FOR LOCAL VOLTAGE SUPPORT

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ABSTRACT

Effective integration of active distributed energy resources (DER) requires adapted new management system solutions for network operators. This paper focuses on the realization of advanced functions such as Voltage Profile Management and Power Flow Management on the feeder, while presenting some issues relative to the implementation of these functionalities: modelling, shared data, specifications of the calculation engine for steady-state network analysis. The topics are illustrated by referring to the solutions built within the Smart Grid demonstration project Nice Grid, as proofs of concept for smart leverage tools of active resources on the distribution network.

INTRODUCTION

Within the perspective of future Smart Grids, the deployment of advanced networking technologies will tend to improve the efficiency and reliability of the power network, by enabling an integration of active DERs and by providing the framework for new services to system operators. Amongst the impacts to be addressed in distribution network operation in the presence of Distributed Generation (DG), the challenge to maintain an acceptable voltage level has become a major concern, as an increase of DG penetration can result in local overvoltage occurrences above the permissible level. A large body of literature investigates the possibilities of leverage of active power flexibility by requesting Active Demand resources and storage units for voltage control [1-2]. Some centralized or coordinated strategies rely on real-time control decisions made from advanced functions in Distribution Management System (DMS), using network devices such as OLTC, capacitor banks, voltage regulator. Other approaches, i.e. semi-coordinated or distributed strategies, tend to use a local voltage-related control of DERs, possibly associated with a coordination of network devices. This configuration emphasizes the roles of a new type of enterprise management system, dedicated to the active participation of DERs. This management system shall be able to optimize and control the potential flexibilities of DERs in the most efficient manner.
The present paper explores this latest approach. A dedicated DERMS solution (Distributed Energy Resource Management System) shall take place in the Utility Distribution information system. The requirements of effective DER participation in distribution operation and planning, like for instance the operations of voltage mitigation by the DSO, imply the capabilities to effectuate an anticipated steady-state estimation of the system variables like voltage magnitude for different time periods. The present paper is centred on some of the issues regarding the implementation of the relevant power system applications, including the modelling part, the calculation engine, the integration and use of standards for better scalability and interoperability. Each section is illustrated with the choices done within the Nice Grid project. This project, part of the European RD&D Project GRID4EU, aims at facilitating the integration and usage of DER in distribution networks, through smart grid solutions with wide replication and scalability potential [3-4].

DERMS ROLE AND CONCEPTS

To facilitate the integration of DG, utility decision systems with active management of grid-connected DERs should take advantage of the DER control capabilities for improving the reliability and overall quality of service for the electric distribution customers and producers. The current generation of Distribution Management Systems is merely dealing with an extension of the traditional set of functionalities so that DER impacts can be included or not in the analysis tools: e.g. network optimization, outage management, fault location, service restoration, and so on. In most cases, DSO lever of DER control is limited to the monitoring of the power output for the largest DERs connected on the distribution network, with a possibility of remote tripping during critical conditions. More recent Smart Grid projects aim to implement more advanced functionalities; some examples amongst them are Volt-Var Control (VVC) or optimal network reconfiguration [5].
As an alternative approach and a complementary management lever, a DERMS solution may take place in an enterprise environment as an application dedicated to active DER integration. It aims at managing the complexity of many diverse and distributed DERs, by getting their unique statuses and specific capabilities of each, and presenting these capabilities, mostly under a simplified, standardized and generally aggregated form, to other third-party applications, and finally, being able to dispatch coordinated control settings, accordingly.
Another feature, and also justification for a DERMS as a separate logical entity, is that the challenge of DER integration can take place in a whole system organization with multiple stakeholders, radically different from the traditional vertically integrated power system. Because of the distributed responsibility perimeters amongst the different participants, it may be not possible to ensure a direct control of the flexibility reserve of customer-owned DER units, both for practical and regulatory reasons. New actors, the technical or economical aggregators, may be responsible for the aggregation and the dispatching of the DERs that belong to their

respective portfolios. The aggregator is able to provide services as if the DERs were a single entity, on a specific area, through a coordination of various dispatchable flexibility assets within the electrical installations of participating prosumers. It is hence necessary to integrate the exchanges with third parties at a same level than the advanced network applications, while the coordination of the operations is managed by the distribution operator.

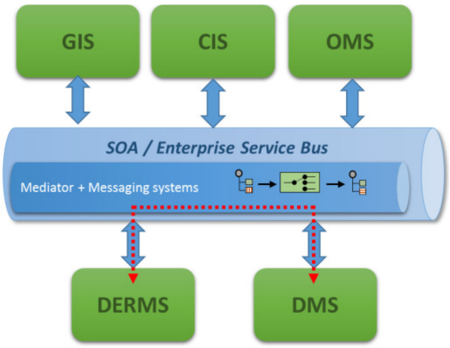

Figure 1: Example of DERMS in Utility Distribution Operation Architecture

In such a configuration, DERMS is expected to provide a facilitation service between the network operators and the commercial aggregators and/or the DER control devices, ensuring information traceability and rationalization of the data exchanges, about transaction parameters, control settings, resource statuses. DERMS shall also maintain the performance of its advanced control decisions, such as voltage control, without significant loss of accuracy due to aggregation [6]. The functionalities addressed by a DERMS instance can be very different from utility to utility, or from a demonstration project to another. The next section aims at illustrating one use case within the Nice Grid project.

ONE DERMS USE CASE: NICE GRID

The Nice Grid project is part of the joint FP7 project GRID4EU. Its objective is to demonstrate, on a large-scale distribution network area, the performance of innovative Smart Grid solutions that shall be scalable to larger areas and replicable on different countries. This project is designed to test an architecture for medium- and low-voltage distribution networks with high concentration of photovoltaic (PV) generators combined with smart end-users whose installation are capable of managing optimally their electrical needs. While there are several operation modes, one concerns the present paper: the maintenance of acceptable voltage levels for all customers under high PV generation conditions (summer Use Case).

DERMS Operations in Nice Grid are mainly based on preventive action, i.e. day-ahead or intraday scheduled operations on the DERs. On the basis of customized load and generation forecast time series for each individual end-user, it is possible for centralized scheduling applications within the DERMS instance to process these inputs to anticipate future network violations, determine a consequent flexibility resource scheduling and ensure the dispatch of the aggregated resources in an optimal way, relatively to the requirements from the network operators.

DER resources are not controlled directly, but through intermediary entities, the DER aggregators. The DERMS transaction place ensures the consistence between the network part and the DER aggregation part.

All the transaction exchanges are based on “flexibilities”, expressed on pre-defined transaction zones, also called “Commercial Locations” (CL). DERs are seen as able to guarantee the provision of upward or downward variations of active power injections or withdrawals, from a reference baseline, expressed under the form of half-hourly time series. These time series are completed with the prices associated to any reservation or activation of the proposed flexibility. Given this definition, there is no distinction between flexibility provided by controllable loads and flexibility provided by battery storage units. In Nice Grid, there is also no consideration of reactive power management.

An important point is that the operator of the coordination place shall be the Distribution System Operator, as the functionalities of the distributed management system require a complete and accurate view of the topology and the constraints of the network.

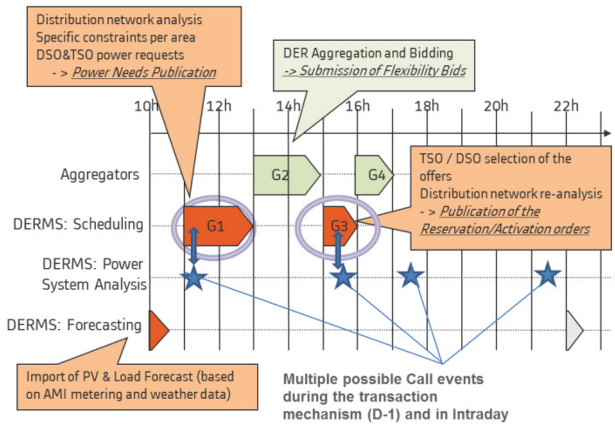

Figure 2: Day-ahead DERMS Workflow for Summer Use Case (Voltage mitigation)

A base use case is represented in theFigure 3, organised as a day-ahead transaction process ending with activation of flexibility offers in order to solve potential PV-induced overvoltage issues on the distribution network. Variants, like intraday processes, are meant to follow the same sequence with basically identical steps but on shorter time periods. Behind the transaction mechanism, several calls of power system applications are run within DERMS. Results are used during the DERMS workflow, and are accessible to DSO operators through a dedicated UI, but not being exposed to the participating aggregators. These calculations occur at several steps:

1. at the opening of the first gate, in order to prepare the publication of Power Needs at the destination of the aggregators;
2. at the time of the selection of flexibilities: after pre-selection and eventually, manual validation by DSO operators, in order to check the resolution of the violations;
3. at any time, after and in intraday, processing any information update, e.g. short-term forecasts.

The initial run of distribution system analysis calculation is crucial, as it triggers the local transaction mechanism. It has several objectives:

a) the detection of eventual network constraint violations, e.g. overvoltage;
b) the determination of secondary results, like voltage sensitivities, that provides quantification of the aggregated contribution of the different registered flexibility resource for each transaction area;
c) the validation of any supplementary external request from the TSO, so that the TSO operators can receive in advance a response message informing if the request is acceptable or not, in regard with the anticipated values of the distribution network parameters, during the considered time period.

To ensure these different requirements, the DERMS solution shall be able to run anticipated steady-state analysis of the network, implying a power flow calculation engine that relies on an electrical modelling of the distribution network including DERs. Given the Use Case, there is no other power system application needed for the Nice Grid demonstrations. The following section comments some high-level considerations relative to the power flow calculations within the DERMS.

UNBALANCED DISTRIBUTION POWER FLOW

Many power flow algorithms specifically adapted to the features of the distribution systems are described in the literature and could fit with the specific case of Nice Grid project, with a radial structure of the distribution network. In real-time, the distribution network is generally a quite balanced system at least at the medium voltage level. Nevertheless, the focus is on the overvoltage issues on the low voltage level (230/400V), as the source of perturbation at mid-day are essentially residential roof PV installations. At this level, on these residential areas, a great number of customers and producers have a 1-Ph connection. Voltage outputs are expected to be expressed per phase also. It implies to run a multi-phase unbalanced distribution power flow (DPF).

Presently, as the DERMS process are focusing on the preventive action hours in advance, there is no strong requirement in terms of execution time performance. On the other hand, considering the issues of replication and extension to other use cases, the power flow method may be also in the future the base algorithm for other power system applications for DERMS, such as network optimization, network reconfiguration, VVC, and so on. It justifies the choice to rely on the same DPF method than for distribution automation and DMS. This DPF method has proven to be robust and efficient. It already supports large libraries of equipment models. It is also suitable to the characteristics of worldwide electric distribution system: large number of nodes and branches; radial or weakly meshed structure; unbalanced and multiphase distributed load; wide-ranging impedance values.

Results of the steady-state analysis are highly sensitive to the quality of information about the loads and generation on the network for each time interval of the period. Alternative methods are available to populate the input data: default load profiles, bus load allocation (on the basis of load profile or load forecasts at the aggregated level), or individual load forecasts. The latest approach is preferred in the Nice Grid project, with an import of forecast schedules coming from third-party forecasting tools. The forecasting applications are installed into the DSO IS environment and access individual metering data of the past days from AMI system, thanks to the installation of smart meters on the whole demonstration area. Confidentiality of smart metering data is guaranteed as the data flow is internal to the DSO Information System. For each day, last version of the forecasting schedules are uploaded by DERMS, overwriting the previous values. In case of missing schedules or forecasting application failure, the default seasonal load or generation profiles are applied.

The execution of the DPF calculation is done per distribution primary substation, and for each time interval of the considered period, i.e. a set of 48 positions in order to get the results as half-hourly schedules covering the whole next day.

Another DERMS requirement regarding the DPF Engine is to support the definition of “zones of interest” on the distribution network. For instance, on a distribution network with radial operation structure, one whole MV feeder may be considered by the DSO as out of interest relatively to the DER scheduling, given its locally low rate of penetration of DG and the absence of recurrent network congestion issues. It may be quite sufficient to check the state variables on this part of the network and afterwards to represent it only by a simple equivalent model, as its indirect influence on the calculation of the flows on the neighbouring problematic areas (i.e. downstream the other feeders of the same primary substation) can be resumed at any time interval by the corresponding total power imbalance at the head of the feeder. Adequate zoning, specifying the areas of interest in terms of voltage supervision and of local flexibility resources, shall distinguish in advance the required level of details for the outputs of the power system analysis applications. On-the-fly definitions of such areas of interest can hence drastically reduce the data exchange messages between the DPF Engine and the other DERMS components, such as the DER scheduling applications.

DISTRIBUTION NETWORK MODELLING CHALLENGES

The base of active and smart network management is the modelling part. Without a trusted database, the operator of the DERMS platform may be not able to take the appropriate corrective actions. For the DERMS instance in Nice Grid project, a particular importance is hence accorded to the modelling aspects.

DERMS, GIS and DMS in the distribution utility information system are assumed to address basically the same physical network. Therefore, there is a common part of data that is shared by these separate systems operating on separate platforms. The maintenance of a canonical data model, the interface designs and the definition of data exchange workflows, shall improve data consistency and quality.

The main sources of network data are a set of RDF/XML files, which are a manual biannual export from DSO GIS

database. File contents follows the DSO custom model MSITE, which is its own standard inter-application exchange model. MSITE model is based on a 2007 version (v11r1) of the IEC 61970-301 Common Information Model (CIM). The model provides both a MV-network and LV-network description. As such, the model is based on a subset of CIM classes and relations that are relevant for the DSO, completed with specific extensions needed to support the data format of the pre-existing business applications [7].
Regarding the memory size, DERMS database represents a very minor part of the whole Geospatial Information System (GIS) database. Therefore, transformation of static data from the DMS/GIS governing schema to DERMS static database do not have to be lossless, as there is no necessity to be able to do round trip. For an initial version of DERMS instance, deployed in winter 2014, a set of custom model conversions was processed component per component, by parsing the XML export files and completing with DERMS additional specific data(as represented in the Figure 3, upper level). This approach was meant to be temporary and replaced by a central static data repository for DERMS, with automatized model deployment to the different components and applications (cf. Figure 3, lower level).

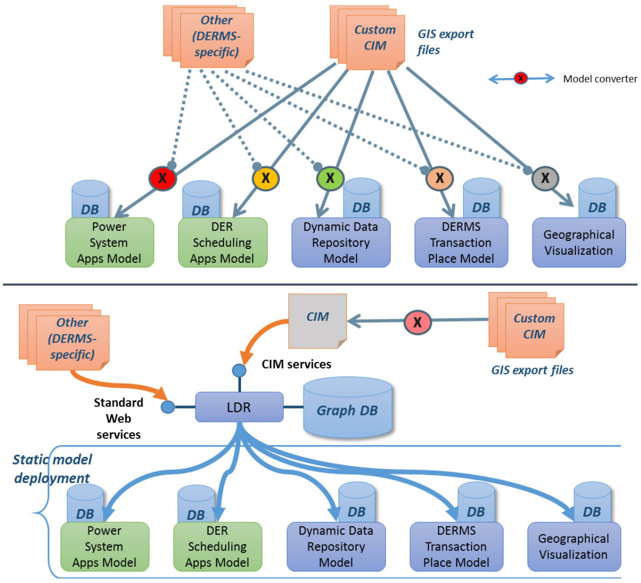

Figure 3: DERMS Static Data deployment principles in Nice Grid (upper level: initial component-driven approach; lower level: final generic architecture)

The entire model managed in the DERMS static data repository is derived from a CIM-aligned Canonical Data Model, common to different commercial products and that is commonly maintained, evolving with new standard CIM versions and extensions. Some extensions to the information model are unavoidable, required by specific software systems and may be not generic enough to be proposed for addition in standards. The extension follows the extension management recommended approaches, which guarantee that the addition of new classes, associations and attributes will stay compatible when a new official CIM version is released.
Initial conversion from the custom GIS export files is facilitated by the CIM syntax of the MSITE model. The static data repository shall be able to import any RDF/XML file as long as the meta-model or the ontology of the RDF/XML file is defined.
For the different DERMS components, e.g. the DER scheduling applications, the XML document stream payloads are defined as follows: profiles defining business data exchange format are derived from the canonical model; then the corresponding XML schemas are generated. The XSD is used rather than RDF schema because of its readability and simplicity. Static data repository is also available at run time for several application consumers. The model can be transferred to the DERMS component through different ways supported by the repository software: offline model deployment, online model deployment or runtime access.

SUBSTATION	Cim Core Substation
FEEDER	(no mapping)
BUS	Cim Wires BusbarSection
GENERATOR	Cim Production GeneratingUnit
LINE	Cim Wires ACLineSegment
SWITCH	Cim Wires Switch
FUSE	Cim Wires Fuse
BREAKER	Cim Wires Breaker
RECLOSER	Cim Wires Recloser
SECTIONALIZER	Cim Wires Sectionaliser
JUMPER	Cim Wires Jumper
LOAD	Cim Wires EnergyConsumer
SERIES REACTOR	Cim Wires SeriesCompensator
SHUNT IMPEDANCE	Cim Wires ShuntCompensator
GROUND	Cim Wires Ground
TRANSFORMER BANK	Cim Wires TransformerTank
TRANSFORMER	Cim Wires PowerTransformer
OVERCURRENT RELAY	Cim Protection CurrentRelay
FAULT DETECTOR	Cim AuxiliaryEquipment FaultIndicator
COMPOSITE SWITCH	(cim) Wires CompositeSwitch
VAULT / SWITCH CABINET	Cim Core EquipmentContainer

Figure 4: Object mapping between CIM and DERMS DPF

The Figure 4 gives an example of the mapping from CIM classes to the custom object model needed by the power system analysis applications. The characteristics of the distribution facilities (lines, switching devices, transformers, energy consumers, and others) are stored in one CIM-based XML file per each distribution substation. As seen in the mapping table, the main classes are basically corresponding; major extensions concern attributes in order to fulfil parameter fields for variants of equipment models, which do not necessarily exist in the CIM standard.

PRELIMINARY RESULTS

A first test period has been performed in summer 2014, but based on a partial deployment of the DERMS components. The experimentations aimed at avoiding any backfeed event at some distribution MV/LV substations, i.e. no authorized power re-injection on the medium voltage level. The full use case relying on a complete steady-state distribution system analysis will be tested during the summer 2015 demonstration period.
Preliminary results have been obtained from test sessions between DERMS (in Study Mode) on the development

environment, and a DSO custom power flow application, already used for planning studies. The whole Nice Grid area, as modelled for DPF Engine, presents 3 primary stations, 20kV at distribution level, about 1300 customers, 63 distributed generators, 37 MV feeders. For the purposes of the performance assessment study, the "area of interest" is restricted to a set of LV Feeders downstream two secondary MV/LV substations, with an important rate of PV installations.

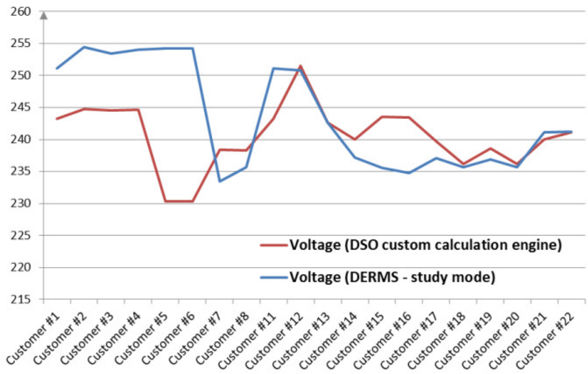

Figure 5: Comparison of voltage outputs for customers along one LV feeder (source: ERDF)

An example of results in the Figure 5 (for a moderately sunny day on August, at 02pm) illustrates the challenges relative to the voltage value calculations on the LV side. The order on the X-axis is random and does not reflect the distance of the customers from the substation. While for several customers, voltage results have the same order of magnitude for both applications, there is also an important discrepancy for a group of customers. It can be explained by a remaining divergence in the static models (generated from different sources), notably about the location of one PV producer. It is interesting to note that this divergence does not impact at all the results on the MV side.

This example helps to illustrate how the static data consistency is a major concern. To achieve an efficient voltage support control at a distributed level, there is a need of a sufficiently realistic and up-to-date view of the distribution feeders. Architecture design of the DERMS solution shall be prepared to more frequent interfacing with the other systems of the distribution operation centre, for instance to get the actual switching status in case of durable reconfiguration. Automatized deployment of consistent static models is a key feature.

It can be also noted that the installation of smart meters on the demonstration area could bring some benefits, in regard with the problem of errors in GIS database. Cross-validation using AMM data could potentially detect any errors of phase for 1-ph customer, discrepancies due to outdated / new customer connection, errors regarding the connection node, and so on.

CONCLUSION

Based on the use case of a Smart Grid demonstration project, the paper presents the DERMS functionalities and how it shall share common data with other operation and planning systems running on separate platforms. The paper presents also how the data integration complexity is tackled via a centralized data repository, taking benefits from the IEC 61970 CIM standard together with specific model conversion applied on some data originating from other external systems. This work contributes to describe how an effective integration of a management system dedicated to Active Demand and to Energy Storage resources can efficiently contribute to foster quality of supply and grid reliability at the distribution level, in presence of DG.

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