HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS TECHNOLOGY SOLUTIONS FOR FUTURE SMART DISTRIBUTION NETWORK OPERATION

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ABSTRACT

To improve the integration of distributed energy resources on distribution networks, new DMS functionalities need to be developed. To run near-to-real time DMS applications novel high performance computing and communications technology solutions can be adopted by DNO's. Therefore, this paper presents the work carried out in the HiPerDNO project regarding the development of a new generation of DMS applications and its integration with scalable and secure high performance ICT infrastructures.

INTRODUCTION

In future distribution networks, the number of sensors and instrumentation will be increased in order to help Distribution Network Operators (DNOs) to effectively monitor and control the network in the presence of Distributed Energy Resources (DER). This new instrumentation will generate larger amounts of data requiring near-to-real time analysis allowing DNOs to more effectively control the network in real-time instead of specifying all solutions in the planning phase. In order to control the network, novel Distribution Management System (DMS) functionalities such as Advanced Voltage Control or Service Restoration Algorithm (SRA) could be developed. These novel DMS functions will regularly update the configuration of network elements (tap positions, state of switches, DG's set point) in real time. Furthermore, such novel functionality requires improved observability of the network in order to be implemented effectively, which can be provided by Distribution System State Estimation (DSSE). All such new functionalities require near-to-real time execution capability to be adopted by DNO's in the near future. In order to provide such near-to-real time features, novel ICT frameworks and High Performance Computing (HPC) platforms can be adopted and integrated within actual DMS architecture.

In order to solve these issues, the European project HiPerDNO[1] [1,2] has focused on the research and development of a cost-effective and scalable HPC and data storage platform; a real-time high speed messaging system and a new generation of DMS functionalities. The high-level architecture of the system is presented in Figure 1. One can see how the High Speed Communication Systems links data sources with the SCADA and DMS. Behind the DMS, the HPC platform is available hosting the novel functionalities developed within the project [1].

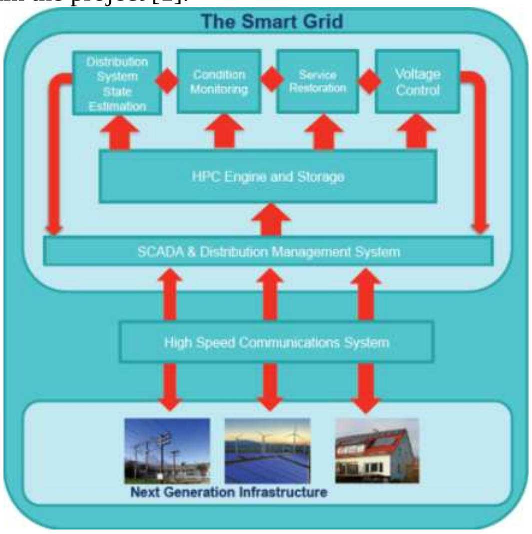

Figure 1: HiPerDNO architecture

First, this paper describes novel DMS functionalities investigated in the project. Then, the necessary features a new ICT platform requires to implement these novel functions in near to real time are presented. Finally, the integration of a DMS on the HPC platform is presented through an example.

NOVEL DMS FUNCTIONALITIES

This section presents novel DMS functionalities that have been investigated in order to improve the network monitoring and control by DNO's.

Distribution System State Estimation

To improve both Medium Voltage (MV) distribution network operation and the integration of DER with new automation functions, greater network observability is required. To do this, the HiPerDNO project has investigated DSSE to assess the state of the network in near to real-time. This function gathers real time information (sensors measurements and topology) through the SCADA and combines it with static data

1 HiPerDNO project: www.hiperdno.eu

(topology characteristics and load models for unmeasured substations), to determine the real state of the network.

State Estimation techniques are already used for transmission networks. However, to apply such techniques to distribution networks the following issues specifically related to these networks need to be resolved: usage of a limited number of sensors (cost-effectiveness), manage long computation times and ill-conditioned matrices (heterogeneous characteristics of lines and cables).

Within the HiPerDNO project different algorithms have been investigated and compared to assess their accuracy and determine the best placement for sensors. Scalable approaches have also been developed to reduce calculation times. These approaches have been implemented on the HPC platform [3].

Voltage Control Function

Within HiPerDNO a central voltage control approach has developed, which actively includes distributed generators in the process of voltage control (via the provision of reactive power) [2]. Given a voltage violation in the distribution network the controller aims to compute new settings for network installations (i.e., new OLTC tap positions and reactive power feed-in of distributed generators) to resolve the violation.

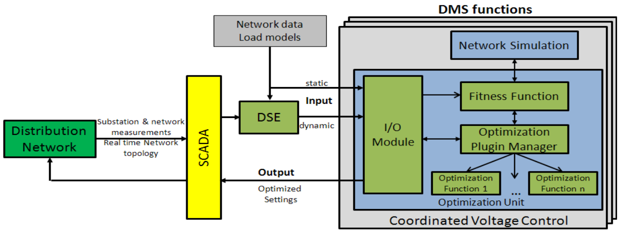

Figure 2: Centralized Voltage Control Function

The information required to operate such a central control approach includes both static as well as dynamic network information. The operation of the voltage control in outline can be seen in Figure 2, including the integration with DNO databases and DSSE acting as information sources, and connection with the Distribution network. (A more detailed description of the underlying algorithm can be found in [2]). After a stop criterion is met by the optimization (e.g., maximal number of search iterations reached or solution with acceptable quality found) the best setup found by the voltage controller is sent back to the network operator where it can be used to solve the violation. The utilisation of HPC is an important feature as time to solution is important to solve voltage violations in a timely manner.

Service Restoration Algorithm

The objective of the SRA is to provide the appropriate switching operations to restore the maximum amount of electricity after a failure in any MV element (in MV feeders or in primary HV/MV substation). The final state is a stable one fulfilling any network constraints regarding overloads, voltage drop and radial network topology. After a network fault, we are going to assume that the network has reached a new state where the faulted element is isolated. We want to restore as much power as possible without changing current radial network operation. Initially the function that we want to minimize is the Power Not Supplied (PNS). Some other considerations about secondary objectives can be considered, but always in a lower level. After comparing different algorithms, a heuristic method (Genetic Algorithm) has been retained in the HiPerDNO project to reach a faster result than when using deterministic methods.

To include the knowledge about the physics of the problem in the GA algorithm, we use different switching lists, the first one is the normally opened list (NOSE) that includes the first try candidates for closing in restoration phases, the second one is the normally closed list (NCSE) that enables the analysis of different situations where we can get a better solution through changing some elements between these two lists while we get the mutation list (MLSE). This MLSE list is initialized to NOSE list and later on, in the heuristic involved in the computation, it also includes new switches suitable for operation.

When some constraint is found, the case is not rejected but a special heuristic is started to allow opening / closing switches involved in constraint violation to relieve it.

Condition Monitoring

Condition monitoring (CM) refers to the process of monitoring some parameters of condition of in physical assets, e.g. dissolved gas analysis in transformer oil and partial discharge (PD) analysis in cables etc. It is a main component in condition or risk based maintenance. In HiPerDNO, we focus on the study of PD analysis for underground cables. Partial discharge (PD) is considered to be the main cause of long term degradation of electrical insulation.

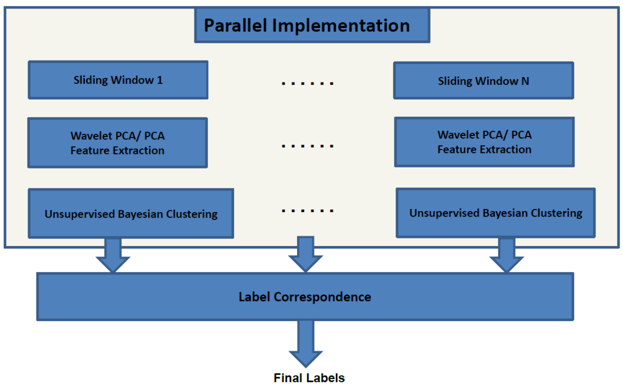

Figure 3: Parallel Implementation of CM

As one of the largest utility companies in the UK, UK Power Networks (UKPN) currently applies on-line PD monitoring technology on its MV networks extensively where more than 70 substations are equipped with the ASM system developed by IPEC Ltd. Through on-line PD monitoring systems, PD can be detected and recorded to form a comprehensive PD database which can be used for further analysis [1].

The aim of our work is to develop a novel on-line clustering system which can be used to analyse data incrementally and detect anomalous behaviour. Figure 3 shows the structure of our methodology. A sliding window implementation is used to handle data in an incremental fashion as in on-line PD system where only the most recent *N* data records are used for analysis. A new fully unsupervised Bayesian clustering algorithm is used to find cluster in the features extracted from the PD pulses using wavelet and principle component analysis techniques. To apply the learnt knowledge, we develop a label correspondence routine to incorporate the labels found in the previous sliding window to the new one.

NOVEL ICT FRAMEWORKS AND PLATFORM

The objective of this section is to present the novel ICT frameworks and the HPC platform developed in the HiPerDNO project.

Communication technology: Infobridge

InfoBridge [1] is a high-performance real-time messaging layer. It runs on top of the networking infrastructure and implements a set of publish/subscribe and point-to-point services. These services support the creation of a communication solution for data delivery, with explicitly enforced limits on times for end-to-end data delivery. InfoBridge carefully manages its internal resources during runtime to support end-to-end latency and throughput goals in large scale distributed systems such as the smart grid infrastructure.
The vast volumes of information, produced by numerous smart meters deployed in low/ medium voltage networks, pose a challenge to traditional communication technologies. InfoBridge is capable of delivering large amounts of data using a combination of novel mechanisms:

- Label switched dynamic accumulation.
- Conflation - intelligent management of data volumes, using integration of messaging software with analytic modules for efficient reduction of information flows.
- Flow control - detection of excessive load ahead of time, and prevention of congestion collapse of the communication link.

The service and APIs provided by InfoBridge can be roughly classified into a number of main categories: Data traffic, Real-time QoS and resource management and Conflation and flow control.

HPC platform

The HPC-Platform is as per Figure 1 a core part of the infrastructure, it hosts the applications that we have seen described within the previous sections, and provides the interface to the standard operational controls of the DMS. Within the normal operations of a DNO the security and resilience of any system used is paramount. This security requirement is most easily guaranteed by isolating components as much as possible. To support this the system is separated into two layers, the Operations layer, where the DMS and other functions reside and the HPC Layer, where only the HPC Engine and HPC Data service are located, operating within a model of computation and data as a service. This has led to consideration of the authorization model for the service, that only certain functions could be performed, both by certain teams but when those functions can be called. For that there was a prioritization over any other functions that were currently operating.
The HPC Layer is made up of two different types of system, the HPC Engine and HPC Data Service [3]. Overall within the design of this system it is envisaged that the components of the HPC Platform will not comprise single, discrete entities for reasons of safety, flexibility, resilience, etc. As such each component should consist of a federation of resources.
An installed HPC Engine would consist of a number of federated computational resources suitable for the applications required by the DNOs, with the nature and extent of the computational resources depending, on the specific DNO requirements. Following analysis of Cost, Availability, Technology readiness level, infrastructure flexibility and Resilience (fault-tolerance) we have concluded that the system design that would best suit DNOs would consist of a federation of clusters.
All computations are required by the DMS as services. Appropriate requests are issued from the operator-level (DMS) together with the metadata specifying both data and applications requirements. Within the HPCE a scheduler then allocates the appropriate resources for the computation to be carried out, with the results streamed back to the HPC Data System for storage. The DMS could then request the results from the HPC Data System.
The HPC Data System is designed such that it can operate as a black box storage solution, whilst supporting interfaces to deposit both file based and stream based data products.

SYSTEM INTEGRATION

In this section, the integration of different functionalities developed within the project is described. First, the characteristics of the system are presented. Then, requirements of different DMS functions developed are illustrated. Finally an example of implementation will be presented.

System design

As explained in previous sections, the system has been designed to fulfill requirements regarding resilience, security, scalability and performances. To ensure security requirements a client-server solution has been retained to separate the DMS level and the HPCE and HPC Data System. Differences on data types and timing of DMS are also integrated in the platform so that it is possible to gather different types of information: data from several sensors at one time or data from one sensor for one period.

Application characteristics

With the different functions designed to operate on a single computational resource there must be some consideration of the priority of execution each application receives. Table 1 shows the order of priority with each application only be able to be preempted by a higher priority application.

DMS	Priority	Pre-emption	Execution
SRA	1		After fault detection
DSSE	3	SRA or VC	Every "x" minutes
VC	2	SRA	After voltage violation
CM	4	Others	Hot/warm restart

Table 1: Priority requirements of different DMS functions

The table also describes the manner of execution for each application, either event driven or cyclic. For those low priority applications that are long running, for example some CM tasks we would consider the utilization of checkpointing within the application essential to allow for easy restart at or near the point of application preemption.

Example of implementation on the HPC platform

Different DMS have been developed with different software as Matlab, C++ or R. To implement these algorithms on the HPC platform, a collaborative work between different partners has taken place.

For some of the algorithms, important modifications have been integrated to improve performances when using such a platform. For some others, the parallelization concerns more input data and the initial algorithms have not been modified but adapted using parallel input data. All these algorithms have been implemented on the HPC platform and can be run from the DMS level. An example of the integration on the system is presented in Figure 4.

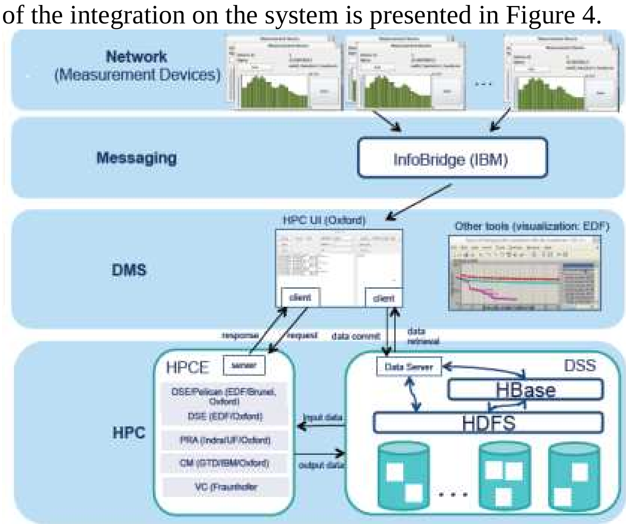

Figure 4: Integration

In this example, measurement devices have been simulated and data is generated in one computer. The data has been transmitted using Infobridge[1] to the DMS and the values are updated as DMS inputs. Once the update has been done a new HPC calculation can be run from the DMS system. Then results can be gathered from the DMS and analysis of results can be run at this level using for example a visualization tool.

CONCLUSION

A new generation of DMS applications has been developed to integrate of DER. To achieve near-to-real time performances, secure and scalable high performance ICT infrastructures were adopted. Within the HiPerDNO project, novel DMS functionalities have been developed, integrated and demonstrated on an HPC platform.

Acknowledgments

The authors thank the EC's 7th Framework Programme (FP7/2007-2013) grant agreement number 248235 for their support of the HiPerDNO research project.

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