Architecture of Virtual Power Plant for Ancillary Services

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ABSTRACT

The increased penetration of distributed energy resources opens up issues in power system as a whole. This creates markets opportunities for ancillary services; particularly TSO deals with the issues of congestion management, reserves, reactive power control etc. Literature suggests different techniques where TSO and DSO interact with each other, and in this way, DSO can offer flexibility to TSO in terms of provision of ancillary services. The paper discusses the issues that the current power system face due to the profound effects of new generating resources, and then examines in detail the way these issues are resolved in a conventional manner. Then, the paper discusses some literature proposals for the interaction between TSO-DSO for solving the issues in an efficient manner, and finally presents the architecture where a Virtual Power Plant (VPP) is developed to facilitate DSO with a platform for the provision of ancillary services.

INTRODUCTION

Distributed energy resources cause many challenges to DSO and TSO, due to the fact that the hosting capacity as in [1] is affected. It creates many issues of reactive power imbalances and other ancillary services [2], congestions etc., and appeals for significant modifications in different sectors of power system like power system protection [3] [4] [5], power quality [6] etc.

The paper is organized into four sections. Section 1 is on the issues and conventional solutions with respect to the penetration of distributed energy resources, along with some proposed literature proposals. Section 2 discusses the proposed architecture in detail. Section 3 explains the way the architecture would be helpful to DSO for the provision of ancillary services. Section 4 concludes the paper.

SECTION 1 : PENETRATION OF DISTRIBUTED ENERGY RESOURCES

Amongst many issues that arise due to the distributed generation, one major one is the congestion problem. Congestion occurs when a production unit produces more than the requirement at load, and thus it causes excess burden on transmission lines. The higher the profound effects of distributed resources, the higher would be the risk for congestion at both TSO and DSO nodes, as it further reduces the hosting capacity as in [7].

This can cause the transmission network to reach its thermal limit, bus voltage limits etc. [8]. TSO can manage the congestion through its reserves, and by controlling the generation at neighboring generators [9]. However, the control would be difficult with more distributed resources at more distribution level.

For the real power management, TSO controls the flow (to avoid congestion) through reserves (ancillary service) [10]. TSO can ask generators to run below maximum capacity. In this way, a generator can have margin to produce less or more than that capacity. This leads to the concept of upward reserves, and downward reserves. Upward reserves means the capacity of producing more by a generator in case of requirement by TSO. However, this procurement for upward reserve is not guaranteed, and therefore running below maximum capacity is a risk for generators (in terms of revenue).

TSO can ask a generator to produce less in case of congestion, and this is what downward reserve is. Generators are paid by TSO for creating these upward and downward reserves, and the exact utilization (at the time of need by TSO) is further remunerated. Generally, there is positive remuneration for upward reserves, and negative remuneration (because of fuel saving as production is reduced) for downward reserves (at the time of utilization).

To avoid such issues, and to manage these issues in a better way with less burden on TSO and conventional generators, literature suggests a more efficient co-ordination between TSO-DSO. The literature proposals, schemes [11], and the benefits are discussed in [12] [13], which in turn appeals for a DSO based platform discussed in section 2.

The rationale behind the architecture is to include different components of power system, so that the provision of ancillary services will be in an efficient manner, with effective communication between TSO and DSO for optimal utilization of capabilities.

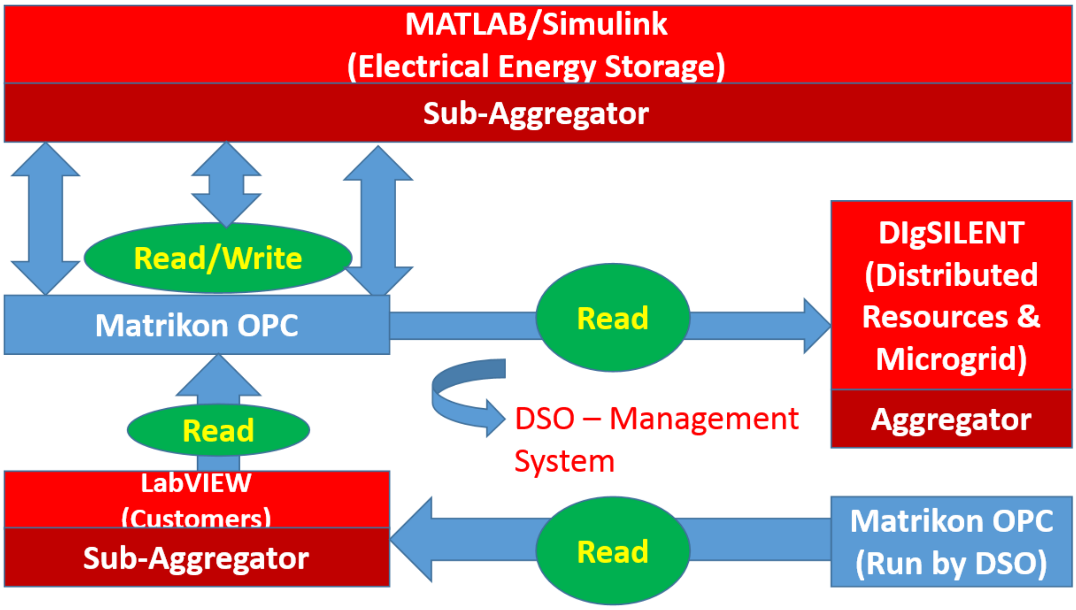

Figure 1: Proposed Architecture for Virtual Power Plant

SECTION 2: PROPOSED ARCHITECTURE

The architecture provides a platform for DSO; so that customers, distributed resources, microgrids, and energy storage systems can provide the ancillary services. It is divided into aggregator and sub-aggregator units; where the sub-aggregators can only follow read/write commands. Aggregator also has built-in intelligence to take decisions based on the inputs from these participants. These decisions are dependent on data, cash flow (cost-benefit analysis), availability of energy etc.

There will be optimization tools inside the aggregator to serve this purpose. Aggregator then interacts with DSO where it provides the services upon requirement. The aggregator then generates a flexibility curve in order to provide services to DSO. This flexibility will depend on the remunerating price, capacity, time of requirement, and the place of required service. The architecture offers advantages both in terms of flexibility (to TSO), as well as increase in the hosting capacity. The architecture is shown in Figure 1.

Sub-aggregator 1 is the storage system developed and simulated within MATLAB/Simulink. The storage system complies with the capacity requirements, and the relevant Key Performance Indicators (KPIs). The storage system has the potential of both upward and downward reserves, which is available via the state of the charge for the storage system.

Sub-aggregator 2 is the customers' demand-response system implemented within LabVIEW, which is capable to monitor the metering data of customers via Modbus protocol. It is assumed that the meters support Modbus communication. It also receives commands from DSO, which serves as control (response) to customers. The aggregator unit is developed using DIgSILENT tool, which includes a medium voltage distribution network, and an interface for controller at DSO management system. Market scenarios for the DSO are created using a tool called PLEXOS.

The next step is the interface between the defined sub-systems. The selected interface is OPC (OLE-Object Linking and Embedding for Process Control) [14], as all the software nodes i.e. DIgSILENT, LabVIEW, and MATLAB/Simulink are compatible with the standard. Matrikon OPC server and explorer are used for the communication with the aggregators and sub-aggregators based clients. Basics of Matrikon OPC is followed from [15]; and LabVIEW data socket programming is used for communication with OPC server as in [16].

SECTION 3: ARCHITECTURE AS A PLATFORM TO DSO FOR THE ANCILLARY SERVICES

The distribution network in DIgSILENT mimics the distribution system; where different medium-voltage feeders, low-voltage feeders, and laterals are investigated using power flow and state estimation. Within the feeder, the mixed distributed generation resources are added to experiment the penetration of distributed energy resources. The fact of low visibility of these resources to the DSO remains the same. The selected OPC feeder nodes, for the distribution system, are monitored via the DSO management system. Moreover, these nodes can take OPC read inputs from the OPC server (under the influence of both the sub-aggregators).

With the penetration of distributed resources at the distribution system; the DSO management system becomes aware of any change in power flow and/or state-estimation results (for example; penetration of PV panel varies the reactive power, which ultimately changes the node voltage and line loading) through the OPC alarm. The OPC, run by DSO at PLEXOS, becomes active, and gives OPC commands to the customers' demand-response based sub-aggregator for the possibility of provision of ancillary service. The customers offer the provision according to their capabilities.

The next OPC server reads the commands from the previous sub-aggregator, and gives commands to the micro-grid and storage based sub-aggregator, simulated inside MATLAB/Simulink. The energy storage system manages its state of charge value, depending on the particular ancillary service provision. After adjustment, the MATLAB/Simulink gives read signals to the OPC server, which gives the signals back to the aggregator and DSO management system.

After receiving the signals from OPC, DIgSILENT re-performs the power flow calculations, and checks for all the parameters limits. The DSO is aware of the results, and in case of any needs for services, the cycle is repeated. The cases where the architecture does not resolve the issues (like congestion etc.); the DSO interacts with TSO for the necessary provisions. Table 1 elaborates the TSO-DSO interactions, and the benefits of the architecture.

From the table, it is clear that the different sectors, i.e. the aggregators, sub-aggregators, DSO, TSO, and the generators resolve the ancillary issues in an elegant manner. Local issues at the distribution level are managed locally under the control of DSO. The responsibility goes to TSO (with the aid of conventional generators) only when the DSO is not able to manage the issues, when the issue is outside of the distribution boundary, or at the point of interconnection.

SECTION 4: CONCLUSION

Detailed architecture is already explained, however in brief: the Matrikon OPC server serves as communication interface between the different power system actors (that are implemented through different software). The architecture provides flexibility in terms of provision of services, interactivity in terms of involvement of different actors of power system, novelty in terms of a new simulation platform tool, and feasibility in terms of parameters defined through software simulations in the paper.

The paper presents the way distributed energy resources cause issues to the power system as a whole, the way these issues are resolves in a conventional manner along with the potential proposals for better techniques, and the way the proposed architecture is beneficial for such utilizations.

CONGESTION AND OTHER ISSUES RELATED TO ANCILLARY SERVICES (LOCATION)	ISSUES RESOLVED BY:	OPC SERVER INVOLVED VISIBILITY & OBSERV-ABILITY
LV LATERAL **LV FEEDER**	Customers demand-response	OPC(under DSO) Sub-aggregator(Lab-VIEW), Aggregator, and DSO
LV LATERAL **LV FEEDER**	Micro-grid and/or energy storage system	OPC(both) Sub-aggregators, Aggregator, and DSO
MV **FEEDER**	Any sub-aggregator	OPC(relevant) Sub-aggregators (relevant), Aggregator, and DSO
MV FEEDER	Micro-grid	None Aggregator
ANY	TSO	None DSO
POI*	Conventional power plants (generators)	None TSO

TABLE 1: ELABORATION OF ARCHITECTURE FOR ANCILLARY SERVICES

*Point of Interconnection

The future work includes two major components:

1- Elaboration of test cases with the involved actors and software interfaces, which will serve as a theoretical and experimental validation for the architecture.

2- The future work will also include the commercial aggregators (i.e. the transmission level distributed generators, and storage providers) at the TSO level, for inclusion into this architecture. The expanded architecture will give added flexibility to TSO.

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