NETWORK ACTIVE MANAGEMENT FOR LOAD BALACING BASED IN A INTELLIGENT MULTI AGENT SYSTEM

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ABSTRACT

More than 1/3 of the EU's power will need to be generated from Renewable Energy Sources (RES) in 2020. This implies a profound transformation of Europe's energy system, grid and markets.

The integration of distributed and micro generation in the electricity grid will provide more options for Distribution System Operators (DSOs) to balance their grid areas on the Medium Voltage (MV) and Low Voltage (LV) levels, thereby reducing stress at the Transmission System Operator (TSO) level. At the same time, this will place new requirements on TSOs and DSOs, particularly in terms of operational security.

This paper describes the impact of intermittent distributed generation (DG) on distribution grid operation and how load balancing can be used to reduce that impact and to take advantage of it.

INTRODUCTION

At Low Voltage (LV) level, the Distribution System Operator (DSO) must manage storage, micro generation and loads by means of micro grids. Small changes in a micro grid are quickly balanced through storage capabilities and/or defining new levels of injection from Renewable Energy Sources (RES).

DSOs will have to become much more involved in relation to innovative voltage control, power flow management and dynamic circuit ratings in order to ensure more sophisticated legal provisions for system security management under increased uncertainty.

The MV structure needs to have frequent updates regarding the various micro grids and the DSO must manage not only these different micro grids but also the storage units, tap-change transformers, DG, capacitor bank and loads connected to MV level based on a hierarchical multiagent system (MAS). It follows that a set-point control strategy is needed in order to manage the grid at different levels (Fig. 1).

The DSO and TSO must therefore integrate their Supervisory Control and Data Acquisition (SCADA) systems with an interface that handles data and information exchange in real-time, without losses and compliant with privacy and security requirements. Ultimately, the overall system must be resilient against a wide range of failures (e.g. malfunctioning devices), passive attacks (e.g. leakage of consumer or provider information) and active attacks (aimed at disrupting the normal operation of the underlying communications and control infrastructure).

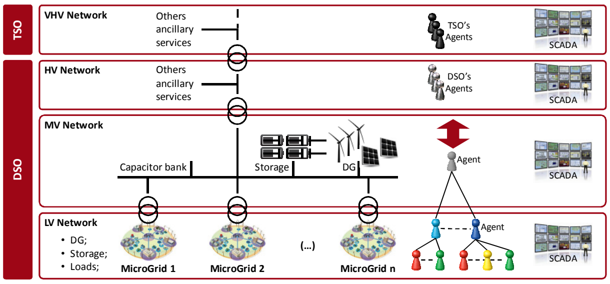

Figure 1. Conceptual architecture integrating MAS and SCADA

The solution proposed adds decision nodes to defined locations of the SCADA infrastructure that interact with one another to satisfy the needs of the micro grid they represent and to help other decision nodes accomplish similar tasks for their own micro grids. This is achieved by means of a blackboard type of interface, which is made available in each decision node and on which other nodes are able to post their individual needs and give updates on the current situation.

Micro grids can be altered after a decision when a part of the micro grid represented by one node becomes represented by another node. A micro grid is a section of the distribution grid that goes from a secondary substation/ primary substation/ power plant to a group of consumers.

At LV level, the development of Advanced Metering Infrastructure (AMI) is expected to increase both the quantity and the quality of data retrieved, while enhancing the scope of control commands.

Our main contributions are (a) a comprehensive set of requirements, (b) technical specifications for the required building blocks, and (c) a complete system architecture that applies Multi-Agent Systems (MAS) to deliver optimized and robust load balancing solutions for distributed grids.

RELATED WORK

M. Huang et al. (2010) [1] describe a hierarchical MAS based control strategy for migrogrid with some similarities to the one presented in this paper.

F. Brazier et al. (2002) [2] describe a multiagent system performing negotiation between an utility agent and many client agents for load balancing of electricity use.

HIGH LEVEL REQUIREMENTS

A DMS must give a good and quick response to clients' demands in spite of where and how energy is produced and consumed. Intermittent renewable energy generators such as wind and solar generators and micro generators together with the raising of electrical vehicles are posing as the most difficult to manage. Managing these assets requires the smart grid of the future to be easily and quickly reconfigurable.

Functioning modes

The proposed reconfiguration features can work automatically or as decision support systems for the grid operator. In automatic functioning, the DMS decides and acts without user interaction, whereas functioning as an advisor requires the operator to validate the DMS's decisions and apply them. The first approach is faster but decisions are taken solely based on system data. The second approach is slower but decisions take into account users' knowledge and expertise. However, in both cases the DMS makes the decision for the user in a first step.

Decision making process (using current grid examples)

Decisions can affect different parts of the grid, based on involved grid components. To understand what a decision is and how it is made, let's analyze the work of a classic grid operator. All its actions can be summarized in opening and closing switches, may they be scheduled actions or emergency actions. These switches are placed in specific parts of the grid with the purpose of connecting or disconnecting these parts from one-another, enabling energy flow from the producers to the consumers. Now, let's analyze some examples of switches.

Busbar connection

In a substation (see Figure 2) we have three switches. Switch 1 connects the feeder to the first bus bar, switch 2 connects the feeder to the second bus bar and switch 3 connects the two bus bars. If there is a problem in TP2 and it stops functioning, bus bar 2 will be disconnected. However, if TP1 has enough power, the grid operator closes switch 3 and bus bar 2 is connected by TP1.

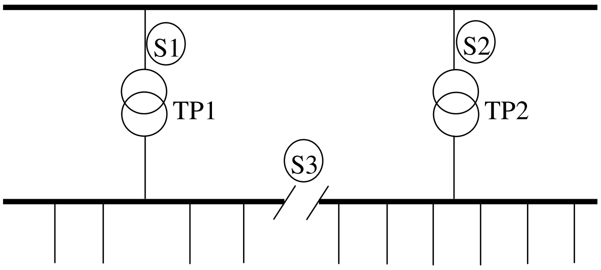

Figure 2. Simplified model of a primary substation

Connection of capacitor bank

Other example is the connection of a capacitor battery (see Figure 3) when reactive energy rises above stipulated levels. The grid operator closes switch 1 when reactive energy is too high and opens it when reactive energy is too low.

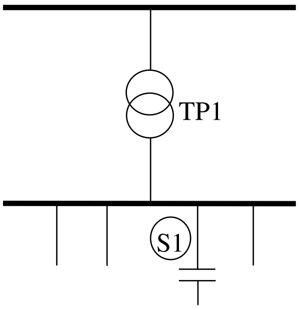

Figure 3. Power factor correction capacitors

Load balancing by transferring loads

A third example is when a whole SE fails and the operator connects the clients affected with another SE or, if this is not possible, it tries to connect them through the MT grid. In Figure 4, if SE1 failed, its clients would be disconnected. If SE2 had enough power, the operator would close switch 1, connecting all the clients. These three emergency decision examples are given to illustrate the kind of decision making the DMS must be able to accomplish.

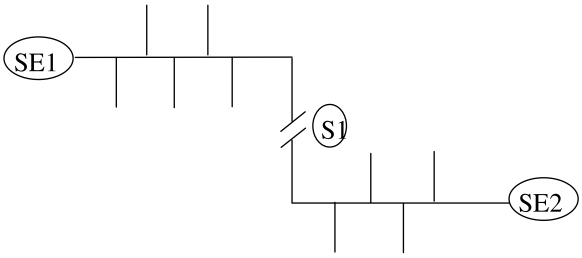

Figure 4. Simplified model of two connected feeders

The process is similar in the case of feeder overload. If a primary substation detects that one of its feeders is close to overload the system must evaluate the possibility of transferring some of the load (and possible DG) aggregated in secondary substations from this primary substation to another one.

Automating scheduled grid interventions

Scheduled actions would require the schedule to be inserted in the system. And everything has to be controlled remotely. The DMS can only decide based on the system's knowledge and act on what it can control. The proposed DMS shortens response times, which results in shorter blackouts, when there is a solution.

Decision making in future smart grids

In the case of the future grid, the distribution system would be acting constantly by reacting to the changes in signals and measures taken from several parts of the grid. In the case of micro generators, if they are producing more energy than required in a part of the grid, their generation is be reduced (equally affecting the ones involved), which has to be considered in the contract established between the clients and the DSO. Regarding electrical vehicles, increased demand due to simultaneous charging of a great number of vehicles would have a quick response with a reconfiguration of the grid or by performing smart charging (shifting charges to off-peak hours).

TECHNICAL CONTROL STRATEGY

A modern electric grid can be viewed as a large complex and distributed system which contains many subsystems. In a conventional electric grid, control strategies are accomplished by Distributed Management System (DMS - SCADA). However, with DMS, as a centralized control strategy, it is hard to achieve a platform-independent control for distributed generation and microgrids.

Therefore, besides DMS, it's suggested to introduce two more control levels: i) Central Autonomous Management System (CAMS) and ii) MicroGrid Control Center (MGCC).

The next three points describe the technical features of DMS, CAMS and MGCC, using a hierarchical multiagent approach. These systems communicate hierarchically to exchange information related to DG current state and to make the required adjustments/ tuning, based on a setpoint strategy (see Figure 5).

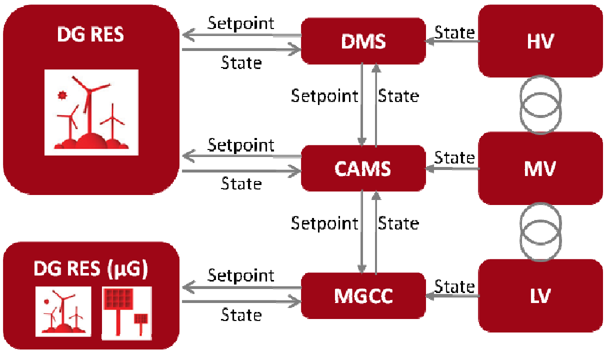

Figure 5. Setpoint strategy scheme

DMS: Distributed Management System

The future DMS is crucial to coordinate energy flow between DSO and TSO grid. The biggest difference to the future DMS is the fact that it does not need to have direct access to the data relative to the (possibly innumerous) microsources in every microgrid connected to the MV or LV network.

The DMS is represented by the DMS Agent that stands alone at the top level of the multiagent hierarchy. Its purpose is to guarantee system robustness by serving as a negotiator based on data received from the agents positioned at the hierarchical level immediately below (primary substation HV/MV). It also enforces the actions resulted from the negotiation.

CAMS: Central Autonomous Management System

The CAMS answers to the DMS, under the responsibility of the DSO. Each primary substation HV/MV is represented by a CAMS Agent, who is responsible for controlling and monitoring the running operations of each feeder from the primary substation and to report the overall status to the DMS Agent and other CAMS Agents.

At this level it's essential to have an overall schedule formed and the decision-making process includes the management of Distributed Generation (DG). CAMS is responsible for:

(i) Critical but not so time-sensitive decisions;
(ii) Handle a large amount of data communication;
(iii) Coordinate with secondary substation level (MGCC) to achieve specific functions for a common goal;
(iv) Coordinate with DMS in order to control the amount of DG DER injected that can is necessary to maintain grid stability;

The decisions taken in CAMS level can give rise to a series of effects to sub-level (MGCC).

MGCC: Micro Grid Control Center

MGCC controls and monitorizes all the microgrids (LV feeder) connected to a common secondary substation. A centralized control (MGCC) is represented by a MGCC Agent who is responsible for evaluating the data received from agents at the bottom level (DG Agents and Load Agents). MGCC Agents analyze the current status of microgrids and take actions in order to guarantee grid connection. Additionally, they report their overall status to the CAMS Agent at the upper level.

There are two major agent types for monitoring and controlling:

(i) DG Agent: Collects information, as well as monitoring and controlling DG DER power levels and its connect/disconnect status;
(ii) Load Agent: Aggregates all the resistive and inductive loads. It can also act over specific loads.

For example, a MGCC Agent monitors the operation state of secondary substation and sends control instructions to open or close secondary substation breakers for switching between island-mode and grid-connected mode.

The decisions taken in MGCC level need the most time-sensitive operations to achieve real time control of the micrograms and enhance the robustness of the power supply.

SECURITY CONCERNS

The security concerns of industrial networks are numerous. Implementing agents on such a critical infrastructure increases the risk that a cyber-attack can compromise an extremely large network that touches many private networks, including SCADA and supervision systems, industrial automation, control systems and business and information systems. Bearing in mind that industrial networks are important and vulnerable, and there are potentially devastating consequences of a cyber incident several security measures and consideration must be addressed, therefore, by evaluating the agents network, identifying and isolating its systems into functional groups or enclaves, and applying a structured methodology of defense in depth and strong access control, the security of the network as a whole will be greatly improved.

In this scenario, confidentiality, integrity and availability represent a formidable challenge that must be addressed in order to prevent unauthorized disclosure by protecting information, computing and communication services from the eyes of intruders, to protected from illegitimate and undetected modification and to protect from personification or forgery. To achieve this goal, it is vital that data packets be encrypted to ensure that the communication between agents is unintelligible. It must also be authenticated by secure signatures to avoid or detect the modification of the communication between agents with malicious intent. Other potential attacks that must be accounted for are traffic analysis attacks (which can be countered through anonymization techniques), replay attacks (requiring the use of time stamps) and denial of service attacks (which must be mitigated by detecting the sources and eliminating them from the network).

Privacy issues are raised in the DSO-TSO link when exchanging client related information. The key is to separate identity and network location, thereby increasing the level of anonymity. Clients' privacy must be protected also through efficient regulation.

CONCLUSIONS

By acting locally and being sensible to minor changes DSOs are more capable to ensure security on the supply side and to increase system reliability and robustness.

DSOs will be able to use several ancillary services for balancing purposes, either in normal or emergency modes of operation (e.g. islanding operation) and also to allow a larger integration of renewable power sources providing storage capacity to store surplus of local energy generation or to shave peak loads.

Hierarchical MAS strategy control provides a flexible and cost effective way to efficiently control networks with multiple microgrids and high penetration levels of DG RES.

In order to make a demonstration, some aspects must still be defined, such as agents' internal structure, communication protocols and interfaces.

REFERENCES

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