AGENT-BASED GRID AUTOMATION IN DISTRIBUTION GRIDS: EXPERIENCES UNDER REAL FIELD CONDITIONS

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ABSTRACT

In this contribution, the experiences and results from the tests under real field conditions are described, which are concerned with grid automation systems in the research project Agent.HyGrid. Furthermore, the deployment of the grid automation system in a real-world distribution grid is discussed.

INTRODUCTION

Energy infrastructures face major challenges. With the increasing awareness about the environmental impact of fossil fuels, the share of power generation from renewable energy sources is on the rise globally, making electrical power supply more decentralized, but also more volatile. The rising penetration of conventional electricity grids with such distributed energy resources (DER) is one of these challenges [1]. To tackle these challenges, grid automation systems (GAS) are often an economically superior alternative to the conventional grid enhancement in distribution grids [2]. These GAS can determine the grid state based on a very limited number of sensors installed in the field. In case of critical grid states, the GAS automatically executes a control strategy to resolve the occurring issues. The further development of new concepts for grid automation is focus in numerous research efforts [3]. An example of this trend is the research project Agent.HyGrid [4]. Within this project an agent-based GAS is being developed to investigate the interaction of physically distributed software agents. A software agent in this context is an autonomous software unit, which is able to communicate with its environment. Due the distributed design and intelligence of such a GAS, high levels of reliability and resilience are ensured [5]. Another research topic of Agent.HyGrid is the development of distributed control strategies. This is motivated by a considerable increase of controllable actuators in future grids, which will in turn lead vastly bigger solution spaces and thus result in higher complexity [6]. At this point, centralized GAS architectures will not be able to make control decisions with a level of detail as a distributed system is able to. Dealing with these research questions, Agent.HyGrid has now begun the last phase, where the implemented GAS is examined in laboratory and field tests. The test under real field conditions are discussed in this paper.

Section 2 describes the foundations and the implementation of the agent-based GAS. The third section shows the basic principle and evaluation results of an approach for a grid state detection. In the fourth section, communication-related aspects of the system are investigated. In section 5, the robustness and resilience of the GAS are examined. Section six summarizes the results of the tests under real field conditions.

AGENT-BASED GRID AUTOMATION

For the implementation of a GAS, it is necessary to install different kinds of assets, like sensors, industrial personal computers (PC), communication infrastructures and actuators. In the agent-based system, software agents with different tasks and objectives are deployed on PCs, to control the corresponding assets.

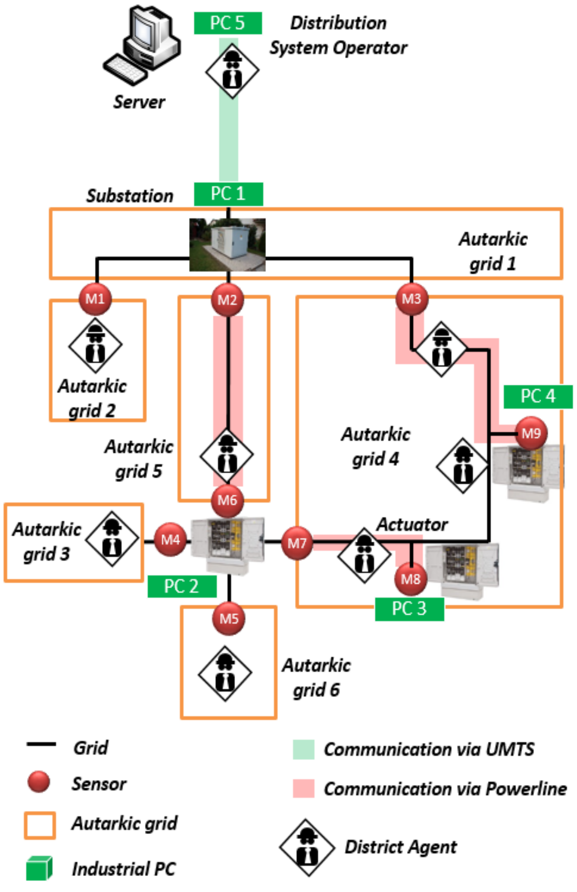

Figure 1: Structure of the agent-based grid automation system

Figure 1 shows the structure of the agent-based GAS, which will be installed in a real low voltage distribution grid. As shown in this figure the distribution grid is divided into six districts. Every district is bounded by one or more sensors and is able to determine the grid state based on these sensors (depicted in red). Based on the sensor measurements the grid state of each district can be determined independently. Thus the district are called autarkic grid in the sense of the grid state detection.

The sensors are located either in cable cabinets or in transformer substations. Additionally, industrial PCs are installed in these locations to host the software agents. For communication within the GAS and to the DSO, different technologies, like Powerline, Ethernet or UMTS are used. The software agents are configured and tested by the DSO on its server. Afterwards they are remotely deployed to the industrial PCs in the field [7]. These software agents can then determine the grid state of their corresponding autarkic grids. In the case of critical grid states, each agent can autonomously make control decisions based on its own actuators. For this reason, these software agent are called “District Agents”.

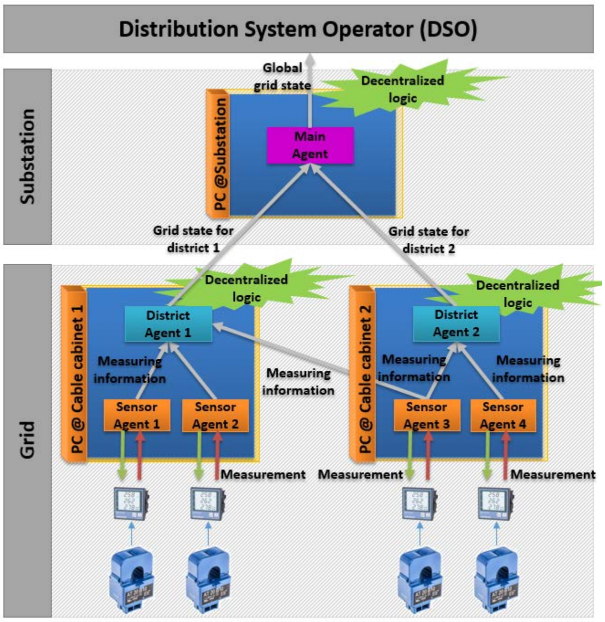

Figure 2: Deployment and tasks of the agents

Besides the mentioned District Agents, further agents are used in the system. Figure 2 shows the information aggregation from the transducer to the DSO, enabled by different types of agents. On the lowest level, Sensor Agents take measurements from the measuring devices via Modbus TCP/IP. The obtained measurements are validated, checked for plausibility, pre-processed and serve as measuring information for the District Agents. As previously mentioned, the District Agent aggregate the district states to the global grid state and forwards this to the DSO. This structure decentralizes the competence to several deployed agents. Simplified, each agent transforms its input data into a more valuable information in order to aggregate to the next higher level. Therefore the robustness and reliability of the system are greatly enhanced, because there is no single point of failure. For a better comprehension of the District Agent, the next section describes the approach of the grid state detection.

APPROACH AND QUALITIY OF THE AGENT-BASED GRID STATE DETECTION

The task of the grid state detection (GSD) is the determination of the actual grid state based on few sensors as illustrated in Figures 1 and 2. The core of the GSD is an algorithm for power and voltage estimation of unmeasured nodes. For explaining the idea of this estimation, a simplified grid is depicted in Figure 3.

Figure 3: Autarkic grid with different load assignments

In this example, the autarkic grid is bounded by two sensors at the beginning and the end of the considered area. This sensor positioning allows the determination of the total consumed load in the autarkic grid. The resulting challenge is question, how this load is distributed over the unmeasured nodes. The simplest variant is a linear distribution.

However, there is also the possibility of a best or worst case distribution. In the best case variant, the entire load is placed on the first node (node 2) in the grid. Correspondingly, the entire load is placed on the last node (node 7) in the worst case scenario. Neither of these methods represent a realistic load situation, but they can help to identify the real load distribution. More specifically, this method can be used to identify the spatial position of the center of the consumed load.

As an illustration, an autarkic grid consisting of single-family houses can be imagined: During the day, the residents are at work and only the base loads are active in the households. Here, the system would detect a homogenous (linear) load distribution. In the evening, the residents are back at home and might use multimedia or entertainment systems, kitchen appliances and load their electric vehicles. This will change the assumed homogenous load distribution into a heterogenic load distribution, because not every resident has an electric vehicle. In addition, the DSO does not know, which household has a charging station and an electric vehicle. The challenge of the algorithm lies in the identification a more suitable load distribution. As basis data, the algorithm use the measured total load and the measured voltage drop within the autarkic grid. With the measured total load, the algorithm calculates the voltage drop of the three scenarios. As a result three different values for the voltage drop can be calculated. Figure 4 shows the voltage drops, depending on the three possible load scenarios (best, worst and linear case).

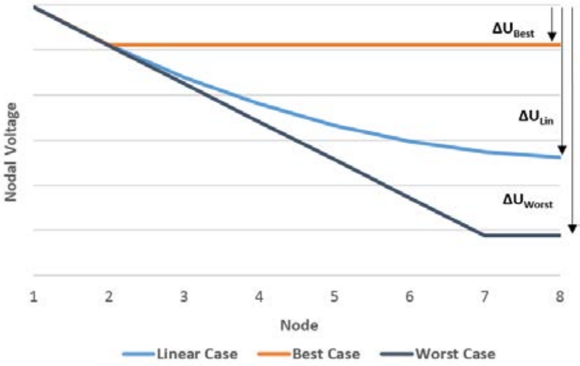

Figure 4: Voltage drop depending on load scenario

As shown in Figure 4 shows, the best case load distribution causes a small voltage drop, whereas the worst case scenario causes the largest possible voltage drop. The voltage drop of the linear scenario is approximately in the middle of the other two scenarios. As the sensors not only measure the power flow, but also the voltage at the perspective node, a voltage drop can be determined with only two sensors. This measured voltage drop can be set in relation to the three previously calculated scenarios. Conversely, a large voltage drop reveals a load center at the end.

If the measured voltage drop corresponds with the voltage drop of the best case scenario, the load must most probably be focused at the beginning of the grid. In the case of an equally high probability of the linear and worst case scenario, the entire load is more likely to be distributed linear at the end of the grid. In addition to this load distribution, the method can also be used to validate incorrect sensor measurements or static GIS-data. If the measured voltage drop does not match to the measured power, the agent detects an error.

To validate and evaluate the GSD algorithm, synthetic generated time series were applied in laboratory tests. In the next step, already monitored time series from the field were considered as data basis. The evaluations of the quality of the grid state detection were carried out for a period of 3 months. Table 1 shows the quality of the agent-based grid state detection's field vs. laboratory results.

Table 1: Quality of the grid state detection

Input data set	Max. error in %	Relative error in %
Real field data	1.5	0.56
Synthetic data	2	0.7

Table 1 shows the maximum error and the relative error of the grid state detection for the entire time series. The errors of the laboratory test are higher, because the synthetically generated data has more inhomogeneous load distributions, which do not occur in reality. Furthermore, the synthetically generated data is more likely to be used to detect large loads and different load distributions. In comparison to the laboratory test, the field scenario is more homogenous and the changes are smoother. Therefore, the results of the field are more precise. In the field, there are rarely any strong changes in the load distribution. Therefore, the determination of different load distributions was performed in the laboratory test. Here, we could detect up to 70% of intensive loads and have assumed a correct load distribution.

AGENT COMMUNICATION

The communication between all PC-units, sensors and actuators is an important part of a smart grid system, as inter-agent communication is for a multi-agent system. For communication between software agents, a standardized message format called Agent Communication Language (ACL) has been specified by the Foundation for Intelligent, Physical Agents (FIPA). To establish an efficient information exchange based on ACL message exchange, Agent.HyGrid uses a subscriber mechanism that implements the FIPA Subscribe Interaction Protocol. This ensures that relevant information like new sensor measurements is provided to all agents that need it in an event-based manner, without unnecessary communication overhead like cyclic broadcasts or requests. One example for this subscription mechanism is the communication between a District Agent and its Sensor Agents, which is illustrated in figure 5 and described in the following. The agent communication was monitored with build-in tools of the Java Development Framework (JADE) [8].

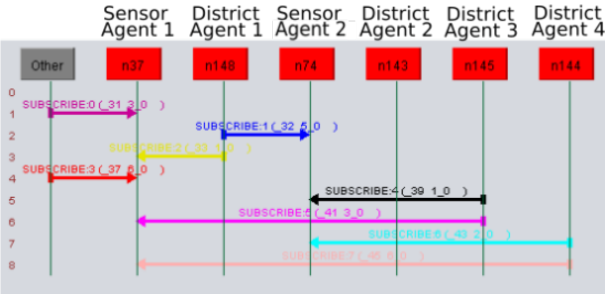

Figure 5: Communication snapshot with JADE

The District Agent initially sends a subscription request to all sensor agents in its district. The Sensor Agents accepts the request and adds the District Agent to their subscriber list. Now every time a new measurement occurs, the Sensor Agent will provide all subscribers with the new values. In the early stages of the implementation, it was realized that sensors would take the measurement very high frequently and therefore send messages continuously.

For solving this problem, each Sensor Agent collects the measurements over an adjustable period and calculates the median of these data series. Only if the median value has changed by a certain threshold, the information is sent to the District Agent (subscriber). The median filtering of the measured values over a certain period enables the suppression of measurement noise, transients and statistical measurement errors and increases the reliability of the measurement. During the long-term test, it was noticed that the Sensor Agents send no measurement updates at night. At first, it was assumed that the Sensor Agents are out of order after a long-term. But the evaluation pointed out that the Sensor Agents were still operating and just didn’t detect any significant measurement changes.

So, a mechanism to recognize a failure of the agents was needed. The solution was quite simple. If the measurement value does not change significantly, the agent sends a measurement update with the same values as an “alive signal” after a determined time. If the subscribed agent does not receive a new message after that time, it can be assumed that the sending agent is not available. In summary, the subscription mechanism provides an efficient, event-based way to exchange information between agents, while the described time-out mechanism allows to detect failure of agents.

ROBUSTNESS OF THE AGENT-BASED GRID AUTOMATION SYSTEM

A GAS must fulfil its tasks in the event of partial failures, which could result from different causes. For satisfying this requirement, the presented decentral, agent-based GAS was developed. This investigation shows how the agent system, especially the grid state determination, behaves in different cases of failure.

The biggest identified problem is the failure of at least one PC. For centralized grid automation architectures this would cause a failure of the entire system. With the decentralized agent system, it was investigated, how the system reacts, when one PC is disconnected from the power supply during the system operation.

As expected, the remaining PCs continue determining the grid state. The District Agents, hosted on the failed PC, don’t provide a new grid state to the main agent. By the time-out mechanism described above, the Main Agent recognizes that the District Agent stopped sending updates and probably out of operation. Overall, this failure did not lead to the failure of the entire system.

The second most serious error that could be identified, is a communication failure between a PC in the field and the PC in the substation. This error was caused by breaking the connection between both PCs. In this test, it could be proved that the disconnect District Agents continue performing their grid state detection. As District and Sensor Agents are located in the same cable cabinet, they can perform their tasks independently of the rest of the system.

In summary, due to the decentralized structure of the system, failures of the hardware as well as the communication could not cause the entire grid automation system to fail. It has been proven that he agent-based GAS is characterized by a high robustness and reliability.

CONCLUSION

Characteristic for this agent-based GAS is the distribution of the intelligence among several PCs in the grid. On the distributed PCs different agents are deployed, which pursue different tasks and local objectives. This decentralized structure of the distributed intelligence represents a new approach, compared to centrally organized GAS. For the fields of investigation: Grid state detection, communication and robustness of the entire system several experiences from the tests were collected. It could be shown that the quality of the grid state detection is more precise in the field than in the laboratory. In the subject of communication, the event-based message transport has shown to be efficient. In general, it has been proven by various tests that the agent-based GAS is robust and a failure of the entire system could not be provoked.

In Summary, this paper represents the essential experiences of an agent-based GAS in the practical application under real conditions.

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