MULTI-LEVEL DISTRIBUTION GRID PLANNING PROCESS BY MEANS OF A MULTI-AGENT-SYSTEM

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ABSTRACT

With the integration of distributed generation and controllable loads in the distribution grid, the provision of system services by these units has to be accounted for in the distribution grid planning process. Since these units are often installed on a low or medium voltage level, they have an impact on all overlaying grid sections. Additionally, complex control algorithms of distribution grid participants demand for a time series based distribution grid planning process.

In this work, a multi agent system for time series generation in the planning process is extended. It takes interdependencies of multiple voltage levels into account and enables an integral analysis of the distribution system. Multiple levels of interaction within the system are introduced and the embedding of the implemented grid–agent in the agent environment is defined. Furthermore, the detailed implementation of two behaviours for the agent is described. The paper closes with an evaluation of the developed approach and an outlook on further research.

INTRODUCTION

The allocation of system services for the transmission grid on a distribution grid level is analysed and suggested in a recent German grid study [1]. This suggestion is based on the assumption that simple node models can represent the lower voltage levels. Occurring congestion in the distribution grid is usually neglected. However, with the increasing integration of distributed renewable generation in recent years, many network areas of the distribution grid are already congested for certain scenarios and need to be extended [2]. Additionally, balancing and compensation effects between the distribution grid voltage levels are not considered either. For example, automated voltage control in the low voltage grid has a significant impact on the medium voltage profile. However, innovative and coordinated control algorithms for distributed generation are difficult to be considered in conventional distribution grid planning tools. An integral, coherent network analysis of all distribution grid voltage levels as a whole is not carried out in the distribution grid planning process. Every voltage level is planned separately and the subjacent feed-in or load is usually accounted for with an aggregated peak value. [3] The utilisation of peak values is common practise in the distribution grid planning process. But recent reports like [4] show, that this practise is becoming unviable for the increasing amount of flexibility in the distribution grid planning process. Volatile distributed generation based on renewable energy sources, high power electric loads like electric vehicles and storage systems are installed into the grid. Additionally, these new grid users often implement complex control algorithms to react on financial incentives or, in the context of storage systems, determine the optimal loading strategy. These different objectives are difficult to incorporate in the conventional network planning process based on a single or two extreme scenarios. The authors of [4] state, that a time series based planning process will be the only option to correctly consider these interdependencies and innovative grid users in general.

To face these challenges, a multi-agent-system planning tool is developed to generate time series for multiple distribution grid voltage levels and sub-networks. This enables the evaluation of different control algorithms for distributed generation units or load flexibility potential in the planning process. Even complex negotiation processes can be represented in the multi-agent simulation environment.

In [5] the approach of creating time series of individual network participants based on a multi agent system (MAS) was holistically presented. The work focussed on the processes in an isolated voltage level. In this paper, a multi-level network calculation method is embedded in the simulation environment. To achieve this objective, the network data is separated at the transformer level for all partial networks. Every network participant in a network is represented by a single agent in the multi-agent framework and calculates the electric feed-in or load, in dependency of the environmental conditions, for every time step of the simulation. An individual partial net agent (PNA) calculates the network-loading situation for every partial network.

This contribution focuses on the addition and embedding of the PNA in the existing agent environment. Furthermore, the finite state machine (FSM) behaviour of the PNA and the transfer of important environment information for multiple PNA is defined. The paper closes with an evaluation of the developed approach and an outlook on future research.

THE MULTI AGENT SYSTEM

In order to generate time series for the distribution grid, every network participant is represented by a single agent in the developed (MAS). The structure of the system for an exemplary distribution grid with the medium voltage level as well as the subjacent low voltage grid is depicted in Figure 1. External influencing factors that are not part of the grid topology, like the system time (1), the local weather (2) and the global market price (3), are also represented by individual agents.

The medium- and low voltage load agents (4) with individual parameter sets represent either a standard load profile or a probabilistic load model. In addition, an agent

(5) represents every distributed generation unit (DGU), especially those based on renewable energy sources. These agents calculate the feed-in based on local weather information. In order to estimate the impact of innovative distribution grid participants, electric vehicles (6) and storage systems (7) are also represented by individual agents.

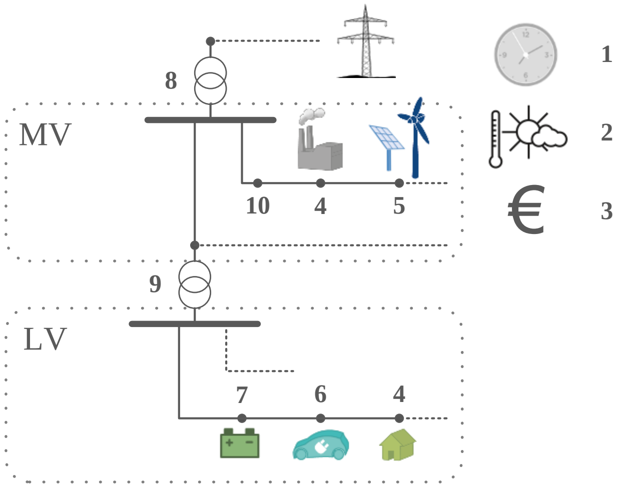

Figure 1 General design concept of the MAS

The focus of this work is on the description of the PNA (8 and 9) that perform the complex power flow calculation for each partial net in the system. The node agents (10) provide input data for the PNA. They aggregate the apparent power values of all connected elements at their network node and send it to the corresponding PNA. In dependency of the voltage level the PNA represents, either the main net agent (MNA) or the subnet agent (SNA). For a unique MNA (8) in the system multiple subnets can exist, that are represented by an individual instance of SNA (9). The network utilisation in the exemplary grid can be calculated separately for each partial net and the system variables of the connecting node are communicated between the PNA. In contrast to an integral power flow calculation, the topology and nodal powers do not have to be available in a central instance. This offers a distributed power flow calculation with minimal local knowledge for each PNA that can be calculated on several distributed computation platforms.

CONCEPT OF INTERACTION IN THE MAS

The developed MAS implements multiple levels of interaction, which follow the structural diagram depicted in Figure 2. Each simulation of a certain period in the system starts with the initialisation phase where all integral parts are created and determine their initial parameters. In the following stage, the environment parameters of the system are determined. This includes the simulated time step, the predominant weather for the area of the distribution grid as well as the global market conditions. Based on these environmental conditions, the agents determine their feed-in or load. If the modelled distribution grid includes network participants that are capable of negotiating their behaviour on a nodal level, this negotiation is carried out subsequently. With the negotiations reaching a steady state, the network control algorithms and negotiations on a network level are carried out. When reaching a steady state, the nodal negotiations are executed again and can react on changes on a network level. The last level of interaction is defined by an influence of the network participants on a global level. If all negotiations within the system have reached a steady state after multiple instances of iteration, the effect of all system participants on the environment can be identified. An impact on the initial defined environment entails another iteration of the network and nodal loops.

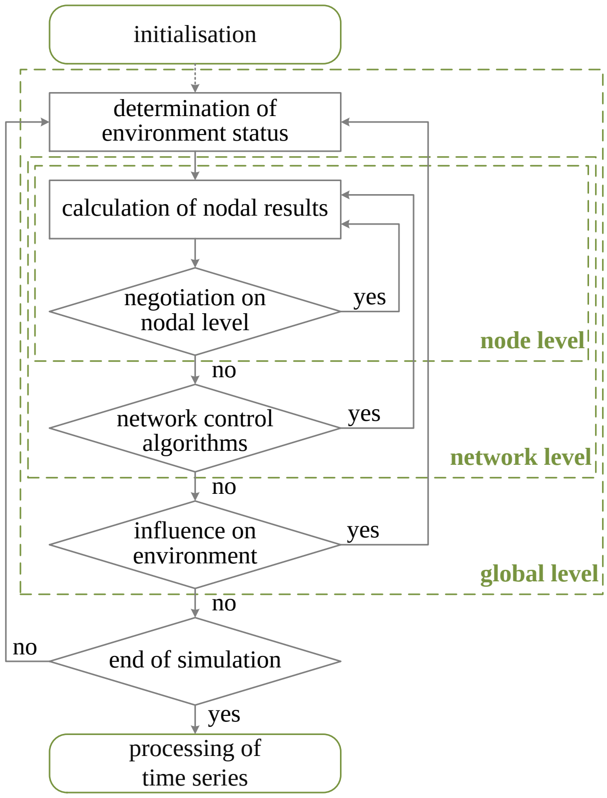

Figure 2 Concept of interaction in the MAS [5]

When the impact of the system participants on a global level is can be neglected, it is checked whether the end of the simulation period is reached. If this is false, the overall process is carried out for the next time step in the period. For every completed time step the resulting time series of the system are processed, stored in a result database and can be evaluated subsequently.

GRID AGENT DESIGN

Since many agents within the system require a local perspective on the grid status, the nodal voltage for example, an adequate representation of local measurements is required in the system. Due to the

modular structure of the agent system, a central power flow calculation with general knowledge of the whole system entails a high communication effort. Therefore, the PNA, which represent individual network segments, are introduced to the system. The connection node between the main net and the subnet is the high voltage node of the connecting transformers. This means, that the implementation of the grid agent is a link between the individual network segments for the calculation process.
In the following, a simplified distribution grid with a main net a and a single subnet b is used to describe the interaction of the MNA and the SNA. Since the agents implement the same basic behaviour, variables are defined for all partial networks i. The connection node for this example grid is named a_b. Additionally, the embedding in the agent environment as well as the transferred variables are defined according to Figure 3.

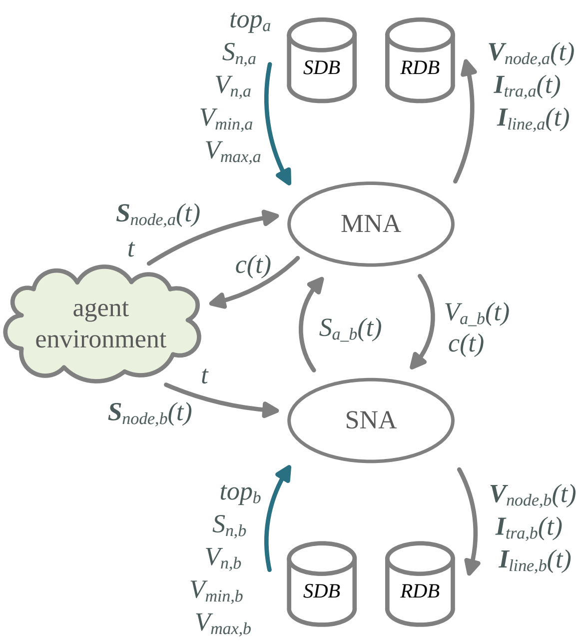

Figure 3 Embedding of the PNA in the agent environment

The MNA is unique and represents the grid with the highest nominal voltage level in the analysed system. However, multiple SNA can exist in the system. Any of these SNA represents a subjacent network segment to the grid represented by the MNA. All PNA get their initialisation parameters from a setup database (SDB). For all PN, this dataset includes the grid topology information top_i, the nominal power $S_{n,i}$ and nominal voltage $V_{n,i}$ as well as the corresponding voltage limits $V_{min,i}$ and $V_{max,i}$. The agent environment provides the current system time step t as well as the time dependent nodal power elements of all nodes in a partial network. These elements are combined to the nodal power vector $\boldsymbol{S}_{node,i}(t)$ in the PNA. The agents process the information on the current loading situation for the partial network. The MNA calculates the voltage for the connection node of the subnet $V_{a\_b}(t)$ and sends it to the SNA. With $V_{a\_b}(t)$, the SNA can determine the network status in dependency of the voltage conditions in the overlaying main net. The resulting apparent power value at the connection node $S_{a\_b}(t)$ is sent to the MNA subsequently. This iterative process is repeated until the MNA determines the steady state of the system. A steady system state is indicated by the parameter $c(t)$, which is sent to the SNA and the agent environment. For a stationary time step, the PNA store the final network loading status in a result database (RDB). The result dataset for a partial network consists of the nodal voltage vector $\boldsymbol{V}_{node,i}(t)$, the transformer loading vector $\boldsymbol{I}_{tra,i}(t)$ and line loading vector $\boldsymbol{I}_{line,i}(t)$.

IMPLEMENTED BEHAVIOUR

In the following section, the implementation of the FSM-behaviour for the MNA and SNA is described and the general proceeding is depicted in Figure 4. As defined in the previous section the MNA represents the main net a, the SNA represents subnet b the connection node is defined as a_b. If an action is described for a network i, the proceeding is identical for both agent implementations and the agents are referred to as PNA.

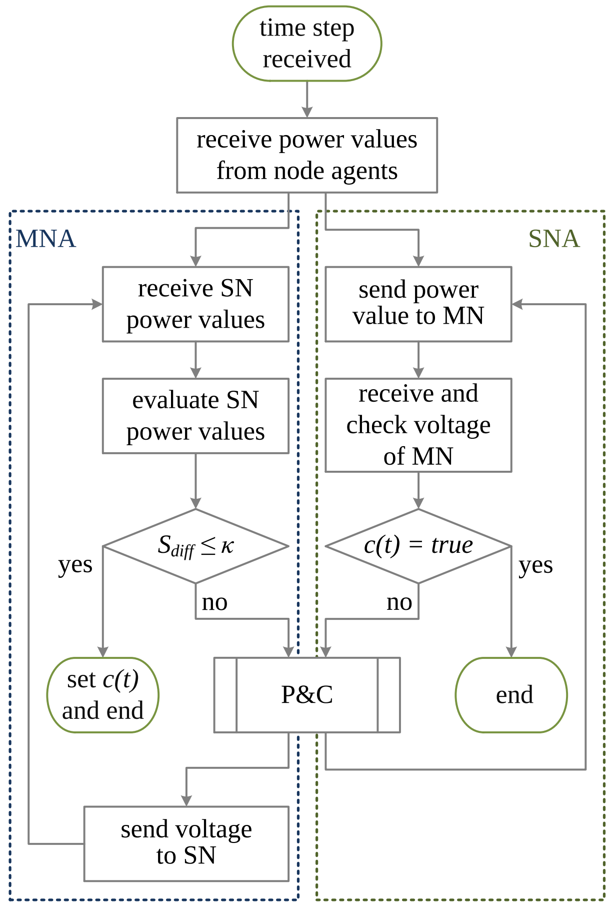

Figure 4 FSM-behaviour for the MNA and the SNA

The defined behaviour is executed in every time step t of the simulation period and starts, when the agents receive updated time step information from the agent environment. Next, the MNA and SNA request the apparent nodal power balances from the node agents of their corresponding partial net. These aggregate the apparent power values of all connected node elements, the individual agents, which represent the network participants like loads, storage systems or DGU.

The SNA initiates the interaction with the MNA and sends the apparent power balance $S_{a\_b}(t)$ at the connection node, which has an impact on the loading situation in the main net, to the MNA. When the MNA receives $S_{a\_b}(t)$, it checks, whether a connection node power value was already received in the time step t. In this case, the differential power S_{diff} is determined. If S_{diff} is smaller than a predefined boundary κ, the grid status is assumed to be stationary for t. In this case, the SNA receives a message from the MNA with the confirm variable $c(t)$. Otherwise, the network loading situation changed within t and the MNA executes the subroutine *Power flow & Control* (P&C) to determine the grid loading situation for the main net as well as control parameters for all agents in main net a.

P&C is embedded as a subroutine of the actual grid agent behaviour to take into account DGU with local control algorithms or tap changing transformers. Within the subroutine the PNA determine the control requirements for these assets from a network operation standpoint. The subroutine is described in the following separate subsection. When the subroutine P&C is completed, the control algorithms in the main net are completed and the voltage value at the connection node $V_{a\_b}(t)$ can be sent to the SNA.

With this updated connection node voltage, the SNA can determine the grid loading situation in dependency of adjustments in the main net. The SNA exports the final network status for b to the result database. If the time step is not complete, the SNA continues with the subroutine P&C and determines necessary control actions for the subnet as described for the MNA. After this task is finished, the SNA sends the updated apparent power at the connection node $S_{a\_b}(t)$ to the MNA. This iterative interaction between the two agents is carried out until the MNA identifies a steady network status in the grid a. In this case the MNA also writes the results of the power flow calculation for main net a to the result database.

Consideration of control mechanisms in the P&C subroutine

The process of the subroutine P&C is depicted in Figure 5 and starts with the power flow calculation for the grid topology of the PNA that calls the subroutine. If all nodal voltages of the network $\boldsymbol{V}_{node,i}(t)$ in the time step are within the interval $[V_{min,i}, V_{max,i}]$, no control action is required and the behaviour is ended. For a voltage boundary violation, it is checked, whether DGU are available that have apparent power control capabilities. The implementation of multiple control schemes for DGU in the MAS was developed in [6]. As an example, one implemented algorithm models a reactive power control of DGU units in dependency of the local voltage (Q(U)-control). For this control, the PNA provides the local voltage at the connection node of the DGU. The corresponding DGU-agent analyses the voltage and adjusts the reactive power output or consumption accordingly. If controllable DGU are available in the partial net, the agent waits for the reaction of the DGU-agent on the current network status. In the subsequent power flow calculation, the impact of the performed control action can be determined by the PNA and in the case of a denied request other measures can be taken. Based on the available number of DGU and the implemented control mechanisms, this process varies in complexity and is repeated until the voltage boundary violation in the grid is resolved or all DGU-agents in the system reach the limit of the control capabilities of their units.

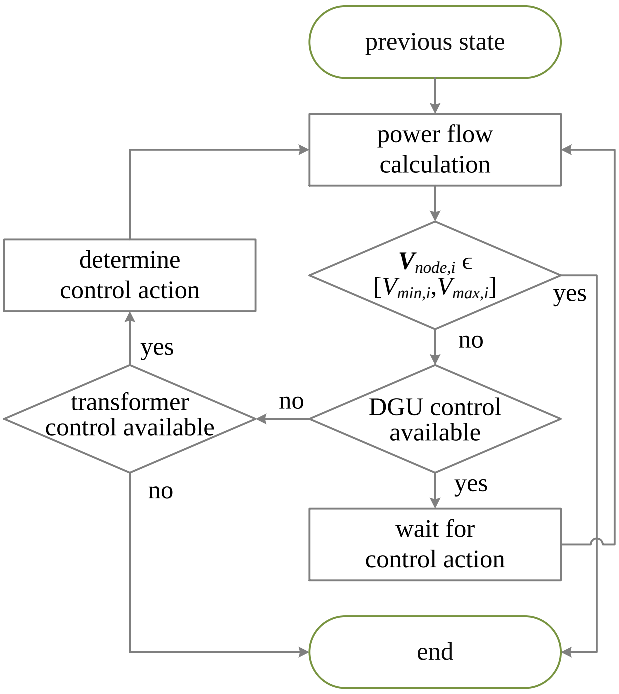

Figure 5 Implementation of the subroutine P&C

After the DGU control reaction, the PNA determines whether the tap position of the local transformer in the partial net can be adjusted from the current point of operation, as another method to eliminate the voltage boundary violations in the network. If the tap position of the transformer can be changed, the PNA determines the control adjustment with a beneficial impact on the voltage profile of the PN. Then, the tap position of the transformer is changed incrementally. Subsequently, the impact of the control actions is evaluated by a power flow calculation. If the control potential of the transformer and DGU is depleted, or no element of $\boldsymbol{V}_{node,i}(t)$ violates the defined voltage boundaries, the subroutine P&C is completed.

CONCLUSION AND OUTLOOK

In this work, an existing multi agent system for time series generation was extended to enable an integral and coherent analysis of multiple voltage levels in the distribution grid. When system services are requested from a subjacent subnet, occurring congestion in this network can be detected. Additionally, balancing effects between distribution grid voltage levels can now be evaluated. This includes the impact of local control algorithms for DGU in the low voltage grids, which can have a significant influence on the medium voltage profile. Even the effect of automated local grid transformers can be evaluated for both voltage levels. Due to the agent-based structure of the system, complex coordinated control algorithms can be implemented and analysed in the simulation framework. On this basis, the DSO can evaluate the impact of multi-level control algorithms as well as the influence of controllable DGU on an overlaying network. This can support the development and planning of demand oriented distribution grids with reduced operational reserves and reduced total system costs.

The presented approach allows for the consideration of an arbitrary number of subnets for a unique main net. Due to the structure, with only the connection node parameters being exchanged, multiple parallel iterations for the control behaviour can be carried out. Additionally, the approach enables the distribution of the calculation on multiple agent platforms. In contrast to a central power flow calculation within a central instance, the necessary amount of exchanged messages in the agent system is reduced. On the downside, additional iterations for the interaction of the MNA and multiple SNA may be required.

In future work the validity of the implementation will be evaluated in detail by a comparison of the power flow results in the Cigré distribution grid benchmark system, published in [7]. It will be evaluated, if distributed control systems have significant impact on overlaying networks on a time series base. Additionally, the implementation of the partial network agent has to be extended to be applicable for the complete distribution grid, covering all voltage levels. Then, the agent has to detect the network topology of the environment to act in dependency of the represented voltage level. Apart from a representation of the highest and lowest voltage level in the modelled distribution grid, a representation of intermediate levels is required. Therefore, the agent will implement a combination of the described behaviours in future work.

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