LOCAL REACTIVE POWER SUPPORT FOR GRIDS WITH A LARGE SHARE OF DECENTRALISED GENERATION CAPACITY

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ABSTRACT

For future grids it is foreseen that a large share of decentralised generation capacity will exist at the distribution level. As decentralised generation depends on variable power sources like air flow (wind turbines), solar irradiation (PV-cells) and space heating equipment (temperature switched micro CHP), power generation may change dramatically from minute to minute. As these power sources in general are devised to supply only real power, reactive power still has to be delivered by the HV- and MV-grid parts.

In this future situation, HV-grid parts may temporarily deliver a relatively low amount of real power to their MV-grid parts whilst the reactive power need in these parts remains the same. To adapt to this situation in a flexible way, a significant part of the central generation capacity temporarily may have to be committed to delivering reactive power mainly. As delivering mainly reactive power is not an economically viable way of operating central generation capacity and HV grids, a solution is sought by generating reactive power at the decentralised generators.

The problem addressed in this paper is how to generate the optimum amount of reactive power at all times for a group of decentralised generators equipped with power converters in one and the same local MV-grid.

INTRODUCTION

Many modern decentralised generators like wind turbines, PV-arrays and micro-CHP units are equipped with electronic power converters connected to the local electricity grid. In presence of an energy storage device (e.g. rotational inertia, capacitance, or inductance), electronic converters can be programmed to also deliver reactive power. This can be implemented for decentralised generators easily, as these often consist of a power production device and an electronic converter that adapts the power source to the sinusoidal grid voltage and current. The problem to be solved then is how to generate the optimum amount of reactive power at all times. “Optimum” in this sense means that the reactive power at the HV feed-in of a local MV-grid is minimised, as well as the energy losses in the MV and LV distribution grid.

One way to solve the problem would be to connect a large reactive power source at the HV feed-in and then minimise reactive power flow. However, as for small decentralised generators it is not known how many there are now and how many there will be connected to the specific MV-grid in the future, this device will not be easy to dimension economically. Further, there will be associated costs for the network operator in installing, maintaining and operating this device.

An alternative way to solve the problem would be to let the decentralised generators act themselves in order to compensate for the total reactive power demand of the loads in the MV-grid segment. To achieve this, a coordination control mechanism and a communication link between generators and the MV sub station are needed.

Coordination control mechanisms vary from simple local measurements of reactive power flow to intelligent software agents that use information and measurements from neighbouring grid nodes. These intelligent agents are embedded in the electronic converters and act to optimise local reactive power flow. This is similar to existing market based coordination schemes for Supply and Demand Matching (SDM) where software agents trade real power on electronic markets with the aim to optimise the utilisation of decentralised power sources[2,3,4,5,6].

The communications link needed between the agents has some small response time for transmitting data. This limits the update frequency from the current system situation to the next one. As the update frequency depends on the communication technology chosen, we do not make a definitive choice for it in this paper. Instead, the update frequency is considered to be much higher than the grid frequency. In effect, this assumption will yield the best result achievable with the coordination control mechanism under investigation. This best result will be approximated in reality when the update frequency is chosen high enough.

PROBLEM APPROACH

The main questions to be answered for coordination control mechanisms for generation of reactive power with power converters of decentralised generators are:

- By which control mechanism(s) can the reactive power at the feed-in of an MV-grid be minimised?
- How can be achieved that the energy losses due to reactive power flows in the MV-grid and LV-grid parts are minimised?

In this paper only the first question is addressed. In order to

do so a simulation model of an MV/LV-grid is built with a large share of decentralised generation. The generators are equipped with power converters controlled by software.
Next a coordination control mechanism is devised and implemented. The correct operation of the coordination control mechanism is demonstrated by testing it for a group of 3 generators that is located in the MV-part of the grid.

COORDINATION ALGORITHM SET-UP

For the coordination control mechanism a strategy is adopted that is already used in existing market based coordination schemes for Supply and Demand Matching (SDM) [2,3,4,5,6]. Its main constituents are the concepts "node agent" and "generator agent", that each consist of a set of logical rules implemented in software.
Each generator is equipped with a "generator agent" that has the following tasks:

a) Generate a bid function for reactive power
b) Communicate the bid function and reactive power set point to the node agent.
c) Convert an availability set point received from the node agent into a reactive power set point.

Further, the MV substation is equipped with a "node agent" with the following tasks:

a) Collect bid functions and present reactive power set points from all local generators
b) Aggregate the bid functions into a node bid function.
c) Monitor reactive power flow at the substation, and calculate the amount not caused by the local generators.
d) Calculate a reactive power setpoint that cancels the reactive power flow at the sub station.
e) Communicate the corresponding availability set point to all generator agents.

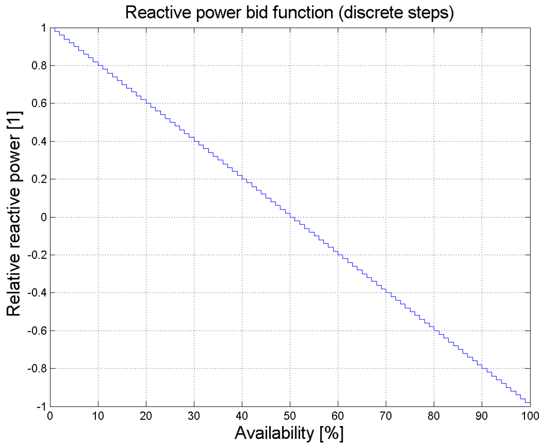

Figure 1 Reactive power bid function

A linear bid function as shown in Figure 1 is used. It consists of the available reactive power as a function of an integer value varying from 0 to 100. The latter parameter is called the "availability" in this paper.
In the figure the reactive power is designated with a fraction varying from 1 to -1 in 101 discrete steps. To get the reactive power scale for a specific generator, this relative reactive power has to be multiplied by the available reactive power, which in turn equals the nominal power (dimension [VA]) of the converter minus the real power (dimension [W]) from its power source.

The node bid function is constructed by adding the bid functions from all participating generators. In order to achieve zero reactive power at the sub station, only the reactive power Q_{load} f the loads must be compensated by the joint generators. As in the situation with the generators switched on this power no longer can be monitored directly at the sub station, it has to be approximated from a reactive power balance at the substation node:

$$Q_{node} = Q_{loads} - Q_{generators} \Rightarrow Q_{loads} = Q_{node} + Q_{generators}$$

The reactive power flow Q_{node} in the sub station is monitored, and $Q_{generators}$ is approximated by adding the present reactive power set points of all generators. From Q_{loads} the corresponding availability set point is found by inverting the node bid function for the value $-Q_{loads}$.

The communication between the agents can be limited in the case under investigation. All software agents can be expected to "know" that the discrete bid function in Figure 1 is generic for each participating generator, and that the maximum allowed response time between agents has a certain value. The basic information to be sent by each generator agent is the time, the maximum power rating of its power converter, and its current reactive power set point. Further, the basic information to be sent by the node agent is the time, and the next availability set point.

SIMULATION IN A LOCAL MV GRID MODEL

For the simulation set-up the well-known Matlab-Simulink simulation software from The MathWorks is used [1].
To test the devised coordination algorithm the MV grid model depicted in Figure 2 is used. It models a rural area (countryside), and has the following specifications:
Sub station:

- 10 kV rms voltage between phases
- 1 measuring (node)
- 1 node agent

Network:

- 2 branches of 6 km length each
- Distance between loads 2 km

Loading:

- 6 inductive loads of each 0.03 MW active power and 0.02 MW inductive power

Generation:

- 3 renewable power generators connected to 0.1, 0.2 and 0.4 MW power sources, and a nominal power (MVA) that is 20% higher than this number.
- 3 ideal inverters capable of generating reactive power
- 3 bid curve agents

The 20% surplus in the nominal power of the generators is

necessary in order to be able to still deliver reactive power at the moment that the power source is switched on.
A time interval of 16 periods of the fundamental grid frequency (50 Hz) is simulated at 50 Hz grid frequency. For accuracy reasons a small simulation time step of 50 micro seconds is used.

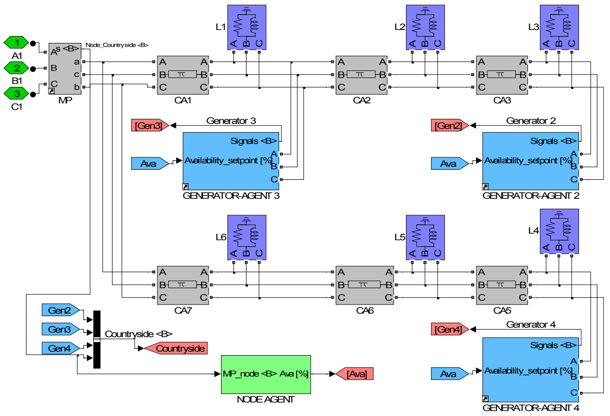

Figure 2 MV (10 kV) grid simulation model

Initially, the generators and the node agent are switched off. After starting the simulation at time zero, the system is converging to its stationary state during the first 2 grid periods. Next the generators are switched on at time 4 periods. The system converges to its next stationary state during 4 periods, and next the software agents are switched on at time 8 periods. In the interval from 8 to 16 periods the actions of the node agent and the 3 generator agents lead the system to its final stationary state, where the reactive power at the sub station approaches zero.

SIMULATION RESULTS

Figure 3 shows the time development of the availability set point calculated by the node agent at the sub station. At the start, the availability is 50%, corresponding to no reactive power generation at all. When the software agents switch on at 8 periods the availability evolves in discrete steps to its stationary value in about 6 grid periods.

In Figure 4 the three phase to neutral voltages and the phase currents are shown for reference. The switching on of the generators at 4 periods is clearly visible. The switching on of the software agents does not show clearly because the reactive power to be compensated is much smaller than the real power flow.

In Figure 5 the evolution of the set points for real and reactive power generation is shown for all three generators. The set points for reactive power appear to be evenly distributed among the generators, in accordance with their individual power rating and generation surplus.
This minimises the extra generation load for each participating generator. It also diminishes the associated decrease of service life time of the power converter of each generator.

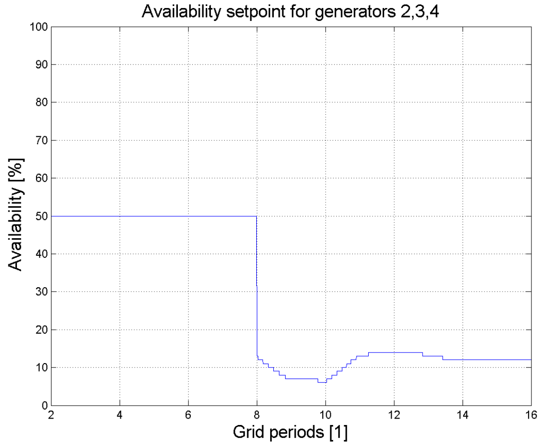

Figure 3 Availability set point for the generators

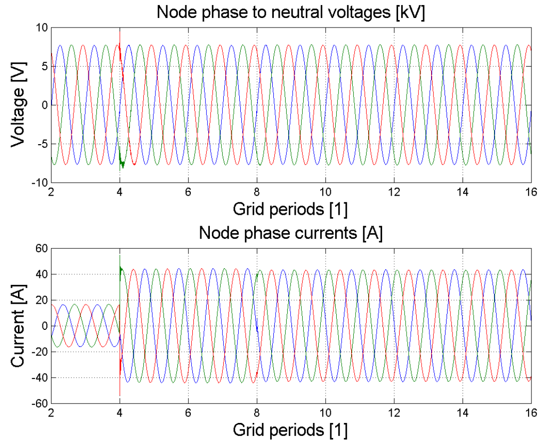

Figure 4 Node phase to neutral voltages and phase currents

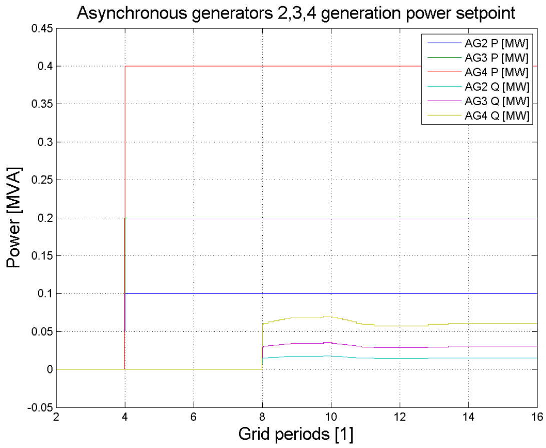

Figure 5 Generation power set points

When assessing plots of reactive and real power one should bear in mind that these are only accurately know at the stationary situation. This is because in the simulation the reactive and real power of the three phases are calculated using running time averages of certain functions, depending on the voltages and currents, over at least one grid period. Therefore, after a switching action in the system there is a time delay of about one period in the correct measurement of the active and reactive power. This is however not a bottleneck for the purpose of assessing the effectiveness of the coordination control mechanism for reactive power, as we are only interested in the response time from the switching on until the stationary situation.

Figure 6 shows the actual real and reactive power generation for all three generators. Some small deviations from the set points in Figure 5 are noticeable.

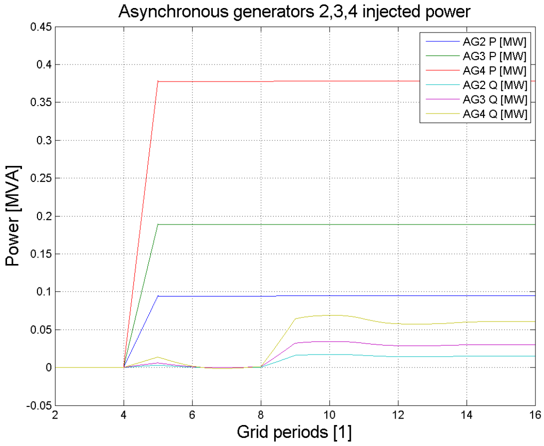

Figure 6 Injected generation power

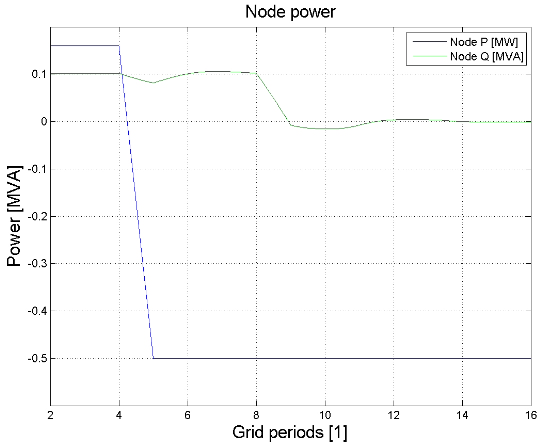

Figure 7 Local node power at the sub station

For reactive power these are due to the switching on and reaching a stable state of the power converters (period 4 through 6), and due to the switching on and reaching a stable state of the software agents (period 8 through 14). From the figure it seems that this deviation is about 15% at the start, but we cannot be sure about this because of the fore mentioned time delay of one period in correct measurement of the reactive power. However, we can conclude that reactive power is decreasing towards a stationary value of zero in about 4 to 6 periods.

For the real power generation the deviation at several grid periods after switching on is in the order of 5% and persistent. This is due to a deviation in the internal control loop model of the power converters. However, this does not influence the observations for the effectiveness of the coordination control mechanism for reactive power generation.

Finally, in Figure 7 the local node power at the substation is plotted. The switching on of the generators at period 4 and that of the software agents at period 8 again are again clearly visible. It demonstrates unambiguously the effectiveness of the coordination control mechanism devised in reducing the reactive power flow at the sub station to virtually zero.

CONCLUSIONS

In this paper a coordination control mechanism for reactive power compensation at an MV substation by a group of decentralised local generators is devised and tested by simulation. The control mechanism devised is similar to existing market based coordination schemes for Supply and Demand Matching (SDM) using software agents.

The simulation results indicate that the coordination mechanism effectively reduces the reactive power flow to zero at the sub station. Further, the necessary reactive power generation is distributed evenly among participating local generators and in accordance with their individual power rating and actual generation surplus. In effect the participating generators work together as a group, minimising the extra generation load and diminishing the associated decrease of service life time of the power converter of each generator.

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