# PROBABILISTIC TOPOLOGY DETECTION FOR EFFICIENT MV-MICRO GRID CONTROL WITH AUTARKIC SMART GRID SYSTEMS

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## ABSTRACT

*Due to political and economic goals, not only the German power grid is in a radical change. The classical top-down energy flow is continuously transforming into a bottom-up energy flow. Intelligent automation systems are increasingly important in this context. The smart grid systems and new developed functions induce an increasing flow of information, so-called micro-grids are supposed to regulate the power flow locally with a reduced data transfer. Such micro-grids can operate independently if it is able to decouple themselves from the power grid. In isolated operation, it is essential to recognize or record the exact breaker states so that the system define the limits of a micro-grid clearly. Although all breaker states are included in the SCADA (Supervisory Control and Data Acquisition), there is usually no connection between the SCADA and the automation system for IT security reasons, therefore the topology detection is essential [1].*
*Together with industrial partners, the University of Wuppertal is developing an automation system that could be operated in such a medium voltage (MV) micro-grid.*
*The main focus of this paper is on the detection of different topology configurations in a MV micro-grid.*

## INTRODUCTION

In the past, various concepts for automation systems have already been developed. Most concepts are based on a classical grid state estimation. The grid state estimation enables the system to reduce the number of measurement sensors. The system needs also a number of grid properties (branch and node information) to estimate the grid state by dynamic measurement data in the grid model. [2]
However, the concept presented here does not include an estimation of the grid status and only monitors or controls measured values of sensors. In comparison the mentioned system increase the number of measurement sensors by the presented concept. This added measurement sensors leads to an increase of dynamic information of the grid state and a decrease of computational effort.
A future smart grid systems includes a topology detection because this function provides a save and reliable grid operation in all situations. On the one hand the normal grid operation depends on the knowledge of the actual grid topology. [3] On the other hand the control algorithm needs the correct topology to locate the right actuators for different control interventions. [4] If the information about the topology is not available a function is needed to get the information. This paper presents a two-step topology detection. The first step of the function is analyze the actual situation and detect situations where a total probabilistic topology detection is needed. The second step is the topology detection itself. The presented smart grid system runs cyclic but only the control algorithm works continuously. The topology detection and other functionalities work if a trigger is available. This structure allows the system to control several micro grids independently in parallel. Figure 1 shows the structure of the system.
The paper focuses on the two-step topology detection and will show the single analyzes and first results of the development. The paper ends with a conclusion and an outlook, to illustrate further research activities.

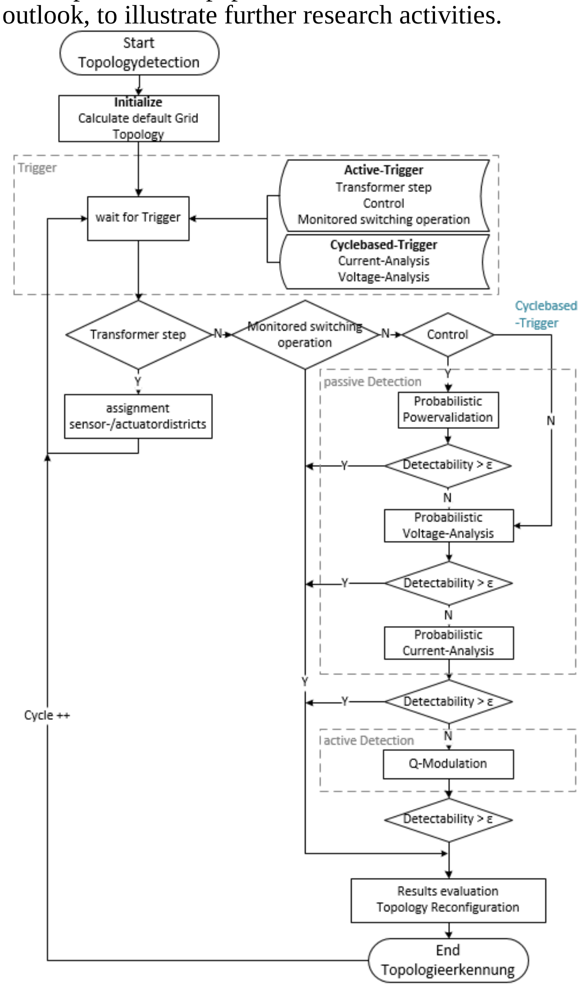


**Figure 1:** Architecture topology model

## Concept Topology Detection

The concept bases on a simple comparison of internal calculation and real measurement data. The smart grid has an internal topology available. The actual measurement data evaluates this internal topology. All information of the sensors are used to test the internal topology. If the analyze presents some contradictions a trigger starts the second step and a probabilistic topology detection assess all breaker states.
The measured values are used for a multiple-level concept, which is a step by step approach.

1. Sensor assignment and district formation
2. Current assessment
    a. Comparison of internal and calculation results
    b. Probabilistic topology detection based on the measured current
3. Voltage assessment
    a. Comparison of internal and calculation results
    b. Probabilistic topology detection based on the measured voltage
4. Q-modulation

### 1 Sensor assignment and district formation

Sensor districts are formed in the initialization for the investigation of breaker changes in the grid. A sensor at the beginning and at the end defines such a district. No information is available within the district, except the apparent nominal power of the consumers or feeders. A district current can be determined, which is required for the current and voltage assessment.
In addition to the formation of the sensor districts, the assignment of the sensors is of importance here. This is determined via a transformer step. A voltage modification on the transformer also means the same voltage modification on the connected sensors. This ensures that the sensors belong to the respective transformer and establishes autonomous network areas.

### 2 Current assessment

The current assessment is used on the one hand as a trigger and on the other hand as probabilistic breaker change detection. In both cases, cyclic current measurements are compared with the following measurement.

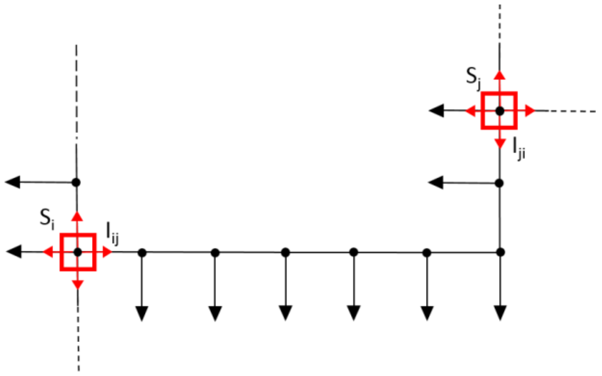


**Figure 2:** Exemplary grid area MV – 2 sensors

The analysis is performed separately for each sensor.
In order to set the trigger, there has to be a significant current difference between both cycles (Equation 1).

$$\Delta I_{ij} = I_{ij}(t) - I_{ij}(t-1) > \varepsilon_{Trigger} \qquad (1)$$

The Epsilon limit is particularly important. Power fluctuations shall not exceed the limit value, but switching changes do. The current deviation at transformer-related sensors is usually greater than at grid boundary areas. Therefore Epsilon is defined as relative change current instead of absolute value.

If the limit value ε is exceeded, detection of the breaker change is initiated.
In probabilistic current assignment (Fig. 1), the trigger sensor j is analyzed again. The proximate sensors of trigger sensor j are examined (Fig. 2). In static state, the current change at an adjacent sensor can be measured exactly, because the power balance remains unchanged.
However, due to grid fluctuations, the current change agreement is not exactly satisfied, wherefore deviations are assessed probabilistically. The more accurate the match on an adjacent sensor, the greater the probability of a breaker change in this network area. Figure 3 shows the switching change probability p [%] in relation to the current change equivalence [A].

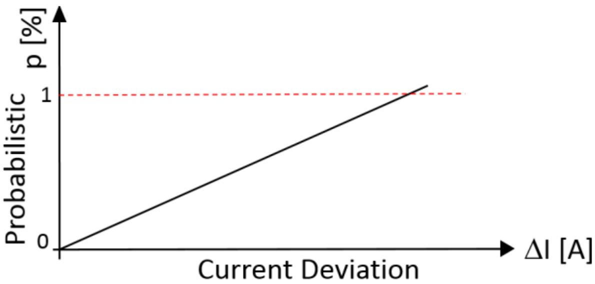


**Figure 3:** Probability diagram of current conformity

For example, this could represent the grid section in Figure 2:

**Table 1:** exemplary current measurements of two sensors measurement

| | | |
|---|---|---|
| Sensor j for t1 | 127 A | |
| Sensor j for t2 | 158 A | |
| | ΔI = 31 A | Trigger |
| Sensor i for t1 | 64 A | |
| Sensor i for t2 | 41 A | |
| | ΔI = 23 A | |
| calculated agreement | p = 75 % | |

The table above shows the measured values of two sensors for two time cycles. Sensor j calculates a current deviation of 31 A and triggers. Accordingly, all adjacent sensors are compared to the current deviation. Sensor i measures a change of 23 A, which equals a match of 75 %.

## 3 Voltage assessment

The voltage assessment examines the minimum and maximum voltage drop in a grid district from a district current and compares it with voltage measurement values. If the voltage measurement value is not within the expected voltage range, a breaker interruption in the grid area must be assumed.

First, the district current is calculated from sensors i and j. As the exact power consumption of the consumers in the grid area is not known, the entire district current is rejected on the one hand at the nodes closest to the transformer and on the other hand most far away from the transformer. This worst- and best-case analysis allows the maximum and minimum expected voltage at the end of the district to be determined (Fig. 2) [5]. If the measured voltage at the sensor is not within the expected voltage range, the grid area is interrupted.
Otherwise, an interruption in the district cannot be safely assumed. However, the voltage level can be evaluated probabilistically in order to determine a probability of interruption.

In addition to the maximum and minimum voltage limits, a third point is calculated to determine the most expected voltage level (Fig. 4). A load or feed-in center of power is determined from the apparent nominal powers.
The calculated voltage for the load center is located between maximum and minimum. Based on these voltage values, interruption probabilities are modulated (right diagram on Fig. 4). If the voltage measurement almost matches the voltage for the load center, the probability of an interruption is low.

An aggregated detection probability is formed from the voltage and current probabilities, which represents a switch change to the internal topology model. If the detection probability exceeds a defined limit value, Epsilon is assumed to have a secured switch change and the internal model is updated. However, if the detection probability is below that of Epsilon, no reliable statement can be obtained about the breaker status in the grid area. Instead, active detection is started, in which actuators are actively controlled in their reactive power ratios in order to be able to detect the switch state.

## 4 Q-Modulation

In Q modulation, actuators are selected which are sensitive to the grid area. The change in reactive power leads to a voltage deviation which can be measured at adjacent sensors. The reactive power changes must not lead to a limit value violation. For this reason, topology detection is only started in an uncritical state.
The expected state changes in voltage and reactive power can be calculated using the sensitivity matrix and the following correlation: [6]

$$\Delta \underline{I}_{Act} = \frac{\Delta P + j\Delta Q}{\overline{\underline{U}_{1,2}}} \tag{2}$$

$$\Delta \underline{U}_1 = \underline{S}_{1,Act} \cdot \Delta \underline{I}_{Act} \qquad \Delta \underline{U}_2 = \underline{S}_{2,Act} \cdot \Delta \underline{I}_{Act} \tag{3}$$

$$\Delta \underline{U}_{1,Act} = \Delta \underline{U}_1 - \Delta \underline{U}_{Act} \qquad \Delta \underline{U}_{2,Act} = \Delta \underline{U}_2 - \Delta \underline{U}_{Act} \tag{4}$$

$$\Delta \underline{I}_1 = \Delta \underline{U}_{1,Act} \cdot \underline{Y}_{1,Act} \qquad \Delta \underline{I}_2 = \Delta \underline{U}_{2,Act} \cdot \underline{Y}_{2,Act} \tag{5}$$

$$\underline{S}_1 + \Delta \underline{S}_1 = \left(\underline{I}_1 + \Delta \underline{I}_1\right) + \left(\underline{U}_1 + \Delta \underline{U}_1\right) \tag{6}$$

$$\Delta \underline{S}_1 = \underline{I}_1 \cdot \Delta \underline{U}_1 + \Delta \underline{I}_1 \cdot \underline{U}_1 + \Delta \underline{I}_1 \cdot \Delta \underline{U}_1 \tag{7}$$

For a evaluable voltage change to occur at the sensor, there must be a minimum sensitivity between actuator and sensor. (Fig. 5). The capacitive and inductive reactive power characteristics of actuators are used.
As a capacitive reactive power feed-in has a voltage-increasing effect and an inductive reactive power feed-in has a voltage-reducing effect, this results in a large controllable voltage range.
Figure 5 depicts the relationship described above. Modifications to the actuator have the greatest effect on the voltage, because the sensitivity is greatest here. Sensitivity decreases towards the transformer, however, and the voltage is not affected as strongly.

Similar to the current and voltage assessment, probability indices are also defined during Q modulation. If the expected voltage changes correspond to the measured values, the internal topology is correct and there are no switching changes.

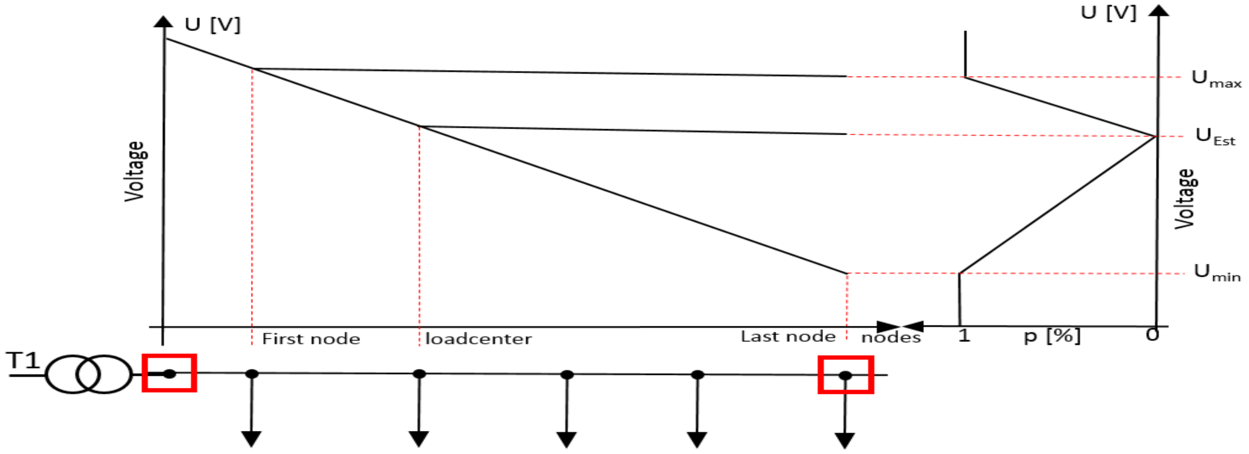


**Figure 4:** Calculated voltage limits and probability diagram

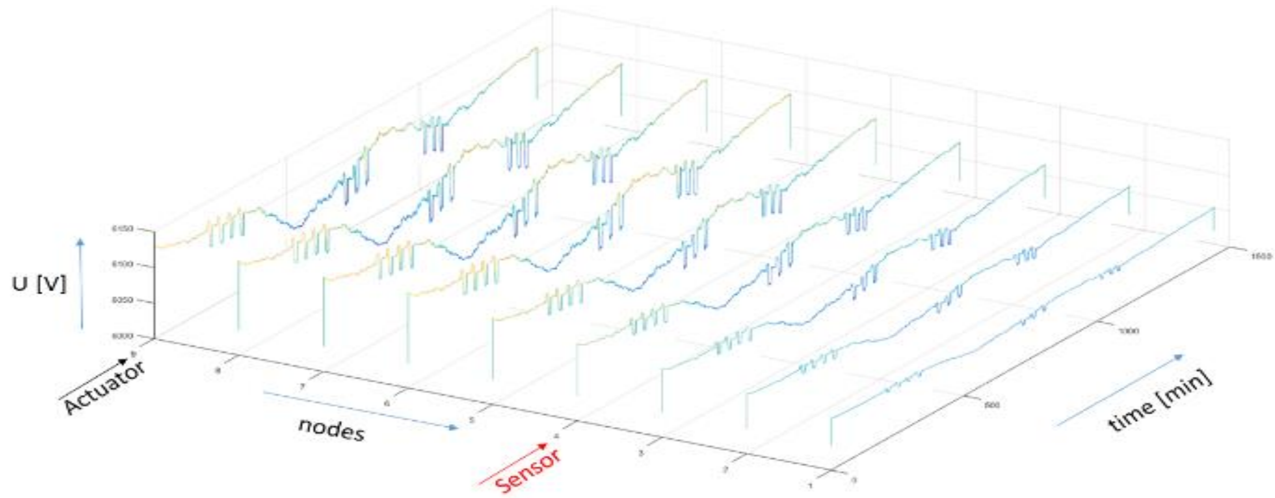


**Figure 5:** Voltage level after Q Modulation

Finally, to make a comprehensive statement about the examined switch position, all three probability ratios are evaluated together and a detection probability is determined. It must exceed a defined Epsilon so that a reliable statement can be assumed. However, if the limit is not reached, no valid statement can be made about the investigated network district.
In such cases, districts that are difficult to detect must be located in advance and equipped with an increased degree of sensor configuration.

## Results & Conclusion

The presented topology detection method uses new concepts for the detection of breaker changes. It is particularly interesting if no phase measurements are available.
Due to passive detection, a large part of breaker changes in the grid can already be detected. The advantage here is that no active operations have to be carried out in the grid. With active detection such as Q modulation, switching changes can be detected that were not previously detected by passive detection.
Due to the Q modulation, the operator of the actuator is rarely restricted in its feed-in behavior. No active power needs to be reduced, resulting in no loss of yield.
The variation of an inductive or capacitive power factor also enables a wide assessment range.
In the future, larger industrial customers could also be considered for Q modulation.

Finally, a sufficiently precise topology detection with the appropriate sensor equipment and available actuators is possible.

The presented concept is currently still in the development phase. After successful simulations in a software environment, the entire automation system is set up as a laboratory network and prepared for a final external field test.

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