



# Distribution network monitoring: Interaction between EU legal conditions and state estimation accuracy

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## ABSTRACT

The expected increase in uncertainty regarding energy consumption and production from intermittent distributed energy resources calls for advanced network control capabilities and (household) customer flexibility in the distribution network. Depending on the control applications deployed, grid monitoring capabilities that accurately capture the system operation state are required. In order to establish such monitoring capabilities, several technical and legal challenges relating to monitoring accuracy, user privacy, and cost efficiency need to be tackled. As these aspects have complex mutual interdependencies, a universal approach for realising distribution network monitoring is not straightforward. Therefore, this article highlights these issues and proposes a method to evaluate monitoring accuracy and the proportionality of personal data processing, and to illustrate the interdependencies between finding the legal grounds for data processing and the monitoring accuracy the processed data produces. To illustrate the method, several test cases are presented, in which the accuracy of network monitoring is assessed for different measurement configurations, followed by an analysis on the legality of the configurations.

## 1. Introduction

The energy landscape is changing. Renewables are being integrated at an ever-increasing pace into our energy systems, and much of the current energy demand is electrifying due to e.g. heat pumps and electric vehicles. Because of the intermittent character of electricity produced from renewable energy sources (RES), the production of electricity becomes less predictable and controllable. Both the electrification and the integration of RES increase the peaks that exist on the electricity networks. As current electricity network capacity is based on the maximum power peak, an increase in peak power is always translated into additional investments in the current electricity networks' capacity. These additional investments are expected to be extremely significant (Verbong et al., 2016).

A more cost-efficient solution for dealing with the increasing uncertainties on the distribution networks would be to utilize the current electricity system in a more flexible way. This could be realized by developing advanced network operation strategies, i.e. active distribution networks, to keep the network within efficient, stable and safe operation conditions. Examples of such strategies are power flow control algorithms for optimising the network states using local controllers

for reactive power and voltage, or demand side management programs and market mechanisms for using flexibility from both active power production and consumption (Blaauwbroek and Nguyen, 2015; Gungor et al., 2013; Torbaghan et al., 2016). However, in order to realise these future network operation strategies, advanced monitoring capabilities for the distribution network to accurately capture its actual system states are required (Angioni et al., 2016; Pérez-Arriaga, 2013). The information gained from network monitoring will serve as input for various network operation strategies to operate the network more efficiently and within secure boundaries. However, these monitoring applications will rely on various data sources, such as network measurements, pseudo-measurements, weather forecasts and end user data. The accuracy requirements for this data depend on the goals and functionalities the advanced network operation strategies are supposed to realise. In any case, data collection is costly, as investments have to be made in monitoring equipment, communication infrastructure, etc. Therefore, hardly any measurement equipment is installed in the current distribution network, preventing Distribution System Operators (DSOs) from gaining insight in their system states. Usually, the investments that have to be made for gaining this insight can be related to the degree of accuracy (quality): the higher the accuracy (e.g. shorter

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timeframe of measurements, more detail, and reliability), the higher the investments costs (Singh et al., 2009). In addition, currently a high level of legal ambiguity with regard to data processing in distribution networks exists, which is a hurdle for realising network monitoring (EDSO for Smart Grids, 2015; European Energy Regulators, 2015). Most of this ambiguity can be ascribed to lack of a clear framework for assessing the legality of data processing for network monitoring purposes. Also the lack of clear and measurable goals makes it difficult to assess whether, how, and which data should be processed. Without a clear and justifiable framework for data processing, it is impossible to process personal data for network monitoring purposes. Therefore, next to making investments in measuring equipment, the legal conditions regarding the measuring, processing, and estimation of information in relation to system operation need to be clarified. These legal conditions mainly relate to two aspects.

Firstly, European Union (EU) law requires that DSOs provide for secure, reliable and (cost-)efficient electricity networks. In practice this means that within their framework of (legal) requirements, DSOs should strive for optimal efficiency of their electricity networks. In this context network monitoring is also subject to the requirements of keeping networks secure and reliable in a (cost-)efficient manner. Consequently, the costs of monitoring and control applications used for network operation should be proportionate (cost-efficient) in relation to the benefits (security, reliability or efficiency) they create.

Secondly, while monitoring their network, DSOs have to respect the privacy of their (household) customers as much as possible, especially taking into account that household customers generally become more vulnerable to (unlawful) privacy breaches if the network is equipped with advanced monitoring capabilities (Milaj and Mifsud Bonnici, 2016). Although network monitoring might contribute to more secure, reliable and efficient networks, they might also reduce household customer privacy. Therefore, a balance has to be struck between both interests.

Considering both the technical and legal aspects involved in network monitoring as discussed above, it is clear that the complex interactions amongst these aspects complicate the question on how the monitoring functionality can be realized for a specific case. Therefore, the aim of this article is to discuss these issues and introduce a method that is able to strike a balance between the interests of the DSO and household customers, resulting in a legally feasible outcome with the lowest monitoring error margin (highest data quality) and reasonable costs for installing measurement equipment.

The article is structured as follows. To begin with, Section 2 introduces the technical aspects and goals of the distribution system monitoring and the functions it should serve. Section 3 provides the legal framework for data capturing in distribution networks (including a short introduction to the newly adopted EU General Data Protection Regulation – GDPR). Section 4 introduces the method to evaluate monitoring accuracy and the proportionality of processing personal data. Section 5 discusses a number of test-cases, for which the performance of monitoring applications is assessed and the legal feasibility of the test-cases is analysed. Finally, the article concludes in Section 6.

## 2. Technical aspects in distribution system monitoring

As aforementioned, due to the current lack of monitoring capabilities in distribution networks, newly developed monitoring applications are required in order to establish adequate control capabilities in distribution networks. These monitoring applications will give insight in the system states of the network. The system states form a data set that defines the operation state of the network uniquely. In order to acquire the system states, they can be measured directly (e.g. voltage magnitude levels and phases) at each node of the grid with high measurement frequencies. However, the installation of measurement and communication equipment for the large number of nodes in distribution networks will be a costly exercise (especially for phasor measurements).

Besides, this measurement data might not always be as accurate as required (e.g. because of failing measurement equipment or communication delays/losses). Therefore, as commonly applied in transmission systems, state estimation of distribution systems has been proposed (Della Giustina et al., 2014) in order to enhance the accuracy and reliability of the monitoring in distribution systems. The next paragraphs further explain the background of state estimation, network observability and the possible types of measurement equipment and data.

### 2.1. Power system state estimation

State estimation is a process to obtain the maximum likelihood estimate of the system states, based on measurements, pseudo-measurements (e.g. historical data from other sources) and a model of the network. The model of the network and the system states together uniquely define the full operation state of the network. Estimation of the system states is applied because usually not all the system states can be measured directly, or the measurements values might be inaccurate. Instead of relying on inaccurate measurements or pseudo-measurements, a more accurate estimate of the true system states can be obtained by using a model of the network and a state estimation algorithm. This way, less measurements are required or a less expensive metering infrastructure can be used. Algorithms for bad data detection can identify faulted sensors or data that is arriving late, such that the data can be excluded from the state estimation process and eventually be replaced by pseudo-measurements to retain observability of the network. For a fully observable network, typically the system states are defined as the set of all nodal voltages and corresponding angles, but also the set of all branch currents and angles can be used, together with a reference voltage. The last option is gaining more attention in recent research, because of its computational performance (Pau et al., 2013; Wang and Schulz, 2004). Before state estimation can be carried out, first the observability criteria of the network need to be satisfied.

### 2.2. Network observability

In order to make the network fully observable, a minimum number of measurements is required. This minimum number is related to the number of nodes or branches in the network. A branch is formed by a line or cable of the network, whereas a node is defined as a point where multiple branches come together. Suppose the radial network consists of  $n$  nodes and therefore  $b = n - 1$  branches. The number of system states that now uniquely defines the network is  $2n - 1$ . In case of nodal voltage state estimation, this number is made up by  $n$  voltage amplitudes of all the nodes and  $n - 1$  voltage angles of all the nodes except the reference node (slack node). In case of branch current state estimation, this number is made up by  $b$  current amplitudes of all the branches,  $b$  current angles of all the branches and 1 reference voltage amplitude of the slack node. Now, for a fully observable network, at least  $2n - 1$  measurements are required that can be mapped independently to the  $2n - 1$  system states. Therefore, if insufficient measurement equipment is installed to provide this data, the measurements have to be complemented with pseudo-measurements. In the test cases presented in Section 5, the data set that is input to the state estimation at least contains  $2n - 1$  measurements and pseudo-measurements.

### 2.3. Network measurements

In practice, the (pseudo) measurements themselves can be obtained from various sources. These sources can include data from measurement equipment installed in the distribution network, as well as all kinds of pseudo information in case real measurement data is missing (because of a lack of measurement equipment, bad data connections etc.).

Real measurement data can be obtained from measurement

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