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Time Synchronized Low-Voltage Measurements for Smart Grids

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Abstract

This paper analyzes possible future development of Smart Grids based on more detailed monitoring of grids. The authors propose measurement methods for the low-voltage level of Smart Grids, and for this purpose they exploit approaches known from the corresponding high-voltage level. Using time synchronization and intelligent end-point devices enables us to collect essential data for faster detection of illegal consumers, branch overload detection, power-quality verification, and other processes. Such information can improve the overall stability and reliability of a grid by covering the low-voltage level that is characterized by the dynamic change of topology or different disturbance sources and has gained the status of being the primary source for the majority of customers.

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Keywords: Smart Grid; measurement; utilization of time; time synchronization; IEEE 1588

1. Introduction

The current population growth is closely connected with an increased demand for energies. The process can be vividly illustrated in the example of electrical energy, which is essential for the correct functioning of almost every complex device in the world. With this trend, infrastructures transferring the given type of energy from the producer to the customer are becoming more and more important for humankind. In this context, Smart Grids were introduced as a response to the existing status of electrical infrastructures, enabling us to outline future progress in this area.

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The following chapters contain a closer analysis of the Smart Grid field, define the purpose of the approach and provide a brief discussion of the IEEE 1588, a most popular time synchronization guideline for computers and various devices across different branches of industry.

1.1. The Smart Grid

The Smart Grid constitutes a modernized electrical grid that utilizes communication technologies to gather and behave according to information from consumers and producers. This procedure should be carried out automatically to improve the stability, effectivity, and robustness of energy distribution, bringing substantial economic benefits.

In the past, roles of the producer and the consumer were clear and strictly prescribed. The producer (a large power plant) generated electrical energy, which travelled through extra high voltage, high-voltage, and low-voltage grids to the customer (house/factory). The flow of energy was regulated unidirectionally, from the power plant to the home or premises; however, with alternative power sources, such as solar or wind power plants, the flow in the grid was not clearly traceable.

The Smart Grid covers different producers and consumers of energy. Thus, the concept includes not only alternative power sources, electric cars, and other intelligent consumers [1] but also the necessary cooperation between all members within the grid to achieve a common goal: stable and effective energy distribution.

The method to reach this goal is based on employing measurement and control for the distribution grid. However, if we intend to implement this process at a large scale, it is important to interpret the Smart Grid as a large distributed system. Every node of this system then needs to possess some kind of intelligence to be able to cooperate with its counterparts. But such cooperation requires also other elements, namely the awareness of time and certain time synchronization, to facilitate the timestamping of events and action planning as a whole system.

At present, time synchronization is used almost exclusively in high-voltage grids. Precise time is utilized for synchrophasor measurements and other wide area measurement systems. Time synchronization can be useful in low-voltage grids too: It allows better measurement and control of the entire distribution network, and these operations are based on information from not only high-voltage but also low-voltage grids, where the primary consumption is performed. The area measurements in low-voltage grids that are proposed in this research report introduce faster detection of illegal consumers, branch overload detection, power-quality verification, and other features.

1.2. The IEEE 1588 standard

The IEEE 1588 standard, also known as PTP, exists in two versions: an older one from 2002, and a newer one released in 2008. The latter variant is also known as the IEEE 1588-2008 [2] or PTPv2. This packet-oriented synchronization method is suitable for systems requiring high accuracy of the synchronized time with an error of less than 1 us. It is nevertheless also possible to achieve an error of less than 100 ns with proper implementation of PTPv2 [3]. The IEEE 1588 uses hardware timestamping to obtain the precise time of the received/transmitted packet and the subsequent calculation of the time offset and delay on line [4]. The basic principle of the IEEE 1588 synchronization is presented in Fig. 1.

The IEEE 1588 has gained popularity in many disciplines and also found wide application in industry. Originally, its evolution was pushed forward predominantly by the five following areas: measurement and testing; telecommunications; industrial automation; energetics; and armed forces. These fields, however, are characterized by different requirements for synchronization, and therefore it is not possible to create a single, universal set of rules to cover each and every of the said domains. To alleviate the problem, the concept of the IEEE 1588 profiles was introduced together with the IEEE 1588-2008 (PTPv2), (National Institute of Standards and Technology). The profiles define sets of mandatory, optional, and forbidden parameters and features in such a way as to guarantee the interoperability of devices from one area, (Brunner & Antonova) (Ingram, Schaub, Campbell, & Taylor, Evaluation of Precision Time synchronisation methods for substation applications) (McGhee & Goraj)

1.2.1. IEEE 1588 profiles

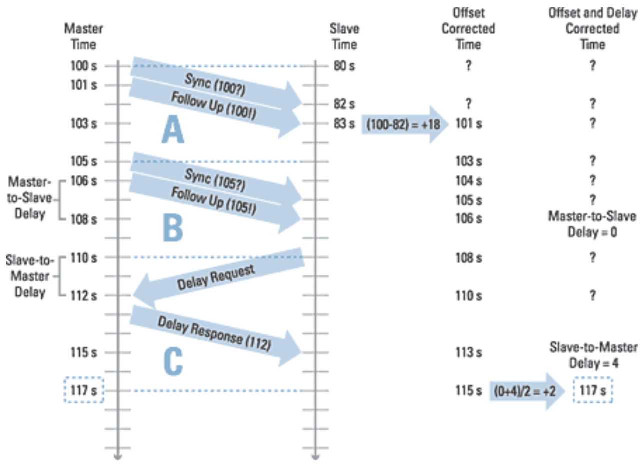

Fig. 1. The basic principle of the IEEE 1588 [12].

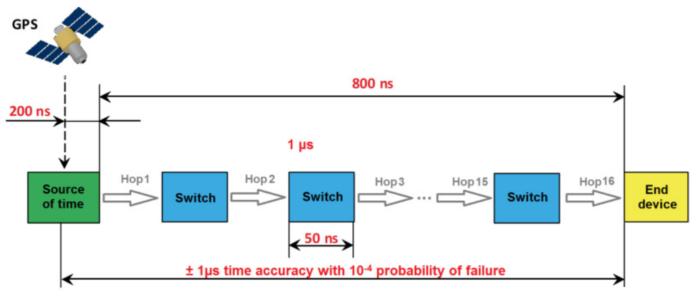

Fig. 2. An example of the IEEE C37.238-11 performance.

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The use of the IEEE 1588 standard within Smart Grids was promoted by the "Power profile", which is declared in the standard profile IEEE C37.238-11 (Fig. 2). The main purpose of this profile is to define the methods and parameters of the applied time transfer from a UTC-synchronized device (e.g., by GPS) to devices that use this time for their functionality (synchrophasor measurements; event logging; protection; …), [8].

2. State of art

As already mentioned, Smart Grids are distributed systems comprising different producers and consumers of electrical energy and a mandatory transferring infrastructure. The older grid model with a strict and clean flow of energy from the power plants to the consumers, though used mainly in past, has persisted till the present day. Considering this fact, we should note that almost all measurement and control related to the grid is performed on the high-voltage level, and the required number of devices for the measurement and control is small compared to the count of devices necessary in the low-voltage case. Thus, the equipment can be more expensive and sophisticated

(IEEE 1588; GPS receivers). Thanks to such devices, different measurements and tests can be completed; however, time synchronization is most important for WAMS (Wide Area Measurements System). The following chapters present the most widely used types of equipment.

2.1.1. Synchrophasor

The synchrophasor, also known as the PMU (Phasor Measurement Unit), is a device enabling the precise measurement of electric waves on a grid. It is used for high voltage measurements and came to be regarded as one of the most important instruments in the given context. Its main function consists in monitoring the grid "health", improving the stability and robustness, connecting island networks, and interconnecting two different networks.

As the PMUs are placed in different locations, time synchronization is essential to provide the reference point for the measurements. Every PMU produces accurately timestamped values that are sent to a server for processing. The measurements from different PMUs are combined together and provide a comprehensive overview of the entire interconnection and grid stress; alternatively, they are used to trigger corrective actions to maintain stability, [4] [9] [5].

2.1.2. Traveling-wave fault detection

This system is utilized for accurate location of faults to facilitate quick maintenance and repair of high-voltage lines. At the moment of a fault, there occurs a traveling wave of voltage and a current surge propagating along the power line. These effects can arise from disturbances such as actual faults, switching operations, or a lightning. The distance to the fault location is calculated from the time needed by the wave to travel to the measuring point. There are different realizations of this method, but they all utilize precise time. This time is acquired from a GPS receiver or by the IEEE 1588 standard and used to accurately timestamp the event of surge detection or a breaker/switch action. To evaluate the position of the fault, it is necessary to gather results from different locations on the power line and to compare the times [10].

2.1.3. End-to-end relay testing

Precise time is also used for testing purposes. To verify the protective relaying scheme generally used to protect power lines, we have to secure appropriate coordination of the relays at both ends of the line. The settings for these relays are calculated using a model of the transmission line, but they need to be verified in real conditions. The relays at both ends are supplied with the precise time to provide a common reference for test scenarios. With the common reference, the tests can produce appropriate results to prove the concept and verify proper functionality of the protection, [4].

2.1.4. Event timing and reconstruction

As stated before, Smart Grid is a typical example of a decentralized system. The awareness of the common time base is essential for its proper operation. Time is included in almost every area of its operation: control, planning, safety, security, debugging, and timestamping. It is widely used in the various phases, from the measuring to the recording of the processed results. Without timestamps, it is not possible to find correlation between the actions and reactions of the system in normal or faulty conditions. Furthermore, time information is also used by almost every security and authentication algorithm. Generally, the accuracy of 1ms is sufficient for recording the events and actions of SCADA systems, and therefore the IEEE 1588 can handle this, [8].

3. Proposed solution

It has become evident that the simple, older model with the monitoring/controlling of only the high-voltage (HV) level of the grid is not sufficient for a modern Smart Grid. The HV level can be considered consistent because the topology is almost constant, and only special, well-defined devices are allowed to be connected directly to this level.

Conversely, the low-voltage (LV) level is full of changes, dynamic connecting/disconnecting of bigger consumers (factories, electric cars) and possible producers (alternative sources of energy). The LV level is apparently becoming more and more important within the concept of the stability and effectivity of the whole grid, and distribution companies have started to realize this.

The rising intelligence of LV devices [11] will enable us to implement time synchronization (IEEE 1588 or other, as discussed in chapter 4) and to materialize features ensuring the monitoring and control also on the LV level. The following chapters describe some of the possible features and improvements that can be realized with a common time base.

3.1. Current maps

This instrument is a variant of the large number of measurement systems rooted in Kirchhoff's laws. The existence of current/voltage maps based on the synergy of data from different measuring points (electric meters or LV substations) would bring several advantages:

- Fast detection of non-technical losses or illegal consumption
- Overload or low capacity of branch detection
- Verification of the power quality required by the standard

Any improvement of the effectivity of a grid depends on the ability to measure non-technical losses. These losses can indicate possible malfunction of a device or illegal consumption, which is a recurrent and much feared phenomenon in some countries. These measurements allow distributors to reveal, locate, and deal with sources of ineffectiveness.

3.2. Localization of disturbance sources

The LV level of a grid is the spot where virtually all types of devices are connected, including the problematic ones. For example, almost every modern electrical device is equipped with a switching power supply that can be the source of disturbance in the case of malfunction or a wrong/cheap design. The cleanest solution to prevent such disturbances from traveling over the grid and influencing other devices is to eliminate their source or sources.

Power quality measuring is no longer a privilege ensured by expensive, dedicated devices. Today's electricity meters resemble network analyzers rather than simple meters. With the DFT (the discrete Fourier transform) and measuring ability of up to the 100th harmonic of the current/voltage, they open new possibilities for monitoring grids closer to the sources of disturbances.

3.3. Emergency situations

One of the hardest tasks in power grid controlling is to restore the grid operation after a blackout. The reasons of a blackout may differ and comprise causes as diverse as malfunctions, natural disasters, and military conflicts; the aim, however, is invariably the same: to restore the power grid operation as quickly as possible. In addition, if the amount of power available is limited, institutions such as hospitals have to be prioritized.

Synchronized time in devices allows us to pre-load instruments like electricity meters with start-up scenarios for gradual loading of the grid. With the increased demand for energy after a blackout, only gradual loading of the grid can enable power plants to reach their maximum power and protect the grid against another blackout caused by extreme load.

4. Future work

Firstly, it is important to analyze time synchronization for LV devices to be able to implement the improvements proposed in Chapter 3. This is a difficult task due to the large volume of devices and, therefore, a substantial pressure on the final price of a device. Generally, the GPS solution is not suitable for these devices because of the "need to see sky", but there still remain two possible solutions:

1. Internet of Things – be a part of a network supported by the IEEE 1588; extra cables or a wireless structure are required.
2. A synchronization method for a slow communication channel such as the PLC (Power Line Communication).

Most LV devices already use the PLC, exploiting its two main benefits: No extra cable is necessary for the communication, and a low price of the communication interface is guaranteed. Therefore, future research activities will focus on developing a synchronization method suitable for the PLC.

Conclusion

This paper discusses the importance of time synchronization within the Smart Grid concept and proposes better control of the entire grid through low-voltage level monitoring. Currently, grid control is based only on the high-voltage grid level, but practical experience shows that the low-voltage level is becoming increasingly more important due to alternative energy sources, electric cars, and the Smart Grid concept as such.

Dealing with grids on the low-voltage level can result in faster detection of non-technical losses or illegal consumption and may facilitate improved localization of disturbance sources or better grid start-up after emergency situations. But, above all, it is important to resolve the problem of time synchronization for the related devices, where the pressure on the final price is very intensive.

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