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IDEA OF MONITORING INTERNAL PROCESSES OF DISTRIBUTED SOLAR INVERTERS

The paper presents a study aiming at analyzing the means to monitor the internal state of the parallel connected inverters and to investigate the indirect interactions between these inverters. Features of the monitoring system and integration with the control system were presented. These means can be then used to improve the reliability and resilience of the microgrids and will be investigated further in our energy grid emulator.

IDEA MONITOROWANIA WEWNĘTRZNYCH PROCESÓW ROZPROSZONYCH INWERTERÓW SOLARNYCH

Artykuł prezentuje studium, którego celem jest analiza sposobów monitorowania wewnętrznego stanu równolegle połączonych falowników oraz zbadanie pośrednich interakcji pomiędzy tymi falownikami. Przedstawiono cechy systemu monitorowania i integracji z systemem sterowania. Środki te mogą być następnie wykorzystane do poprawy niezawodności i odporności mikrosieci i będą dalej badane w naszym emulatorze sieci energetycznej.

1. INTRODUCTION

The growing demand for Distributed Energy Resources (DER) is forcing the development of more intelligence in solar inverters. Every inverter that joins the grid injects interference that can affect other inverters. To rapidly detect possible faults or conflicts, real-time internal monitoring is necessary. The smart inverters should be aware of the state they operate in, what are their capabilities and what is the condition of the grid.

There are many publications in the literature about monitoring the internal process of converters, focused mostly on DC/DC converters. Studies that deal with inverters are usually limited to transistor module monitoring, not taking into consideration the integration with the control system. A significant number of the industrial inverters provides variety of measurements; however, they are not equipped with a complex monitoring systems. The monitoring in the inverters should meet certain requirements such as detecting and remembering relevant events, making autonomous decisions based on measurements, and process collected data.

Connecting an inverter to the grid entails challenges to the distribution network, including voltage deviations, power quality (PQ) decrease, fault levels, and reverse power flow [1]. The newest standards are putting more responsibility on solar inverter module, meaning they gain flexibility for their behavior in abnormal conditions. They are able to provide current during voltage and frequency ride-through or voltage support (Volt/VAr, Volt/Watt), which requires advanced metering and awareness of grid conditions [6]. The research goes beyond current standards and some trends that are expected to happen are dynamic voltage support during abnormal voltage conditions, learning the best setting for optimal PQ and resolving grid-DER incompatibilities [2].

The objective of the paper is to investigate the process of monitoring the internal state of the parallel-connected inverters and the indirect interactions between these inverters. The result can be then used to improve the reliability and resilience of the microgrids and will be researched further in our energy grid emulator. The task of the emulator is to mimic a full-scale smart power grid to test and evaluate power management algorithms.

2. MONITORING INTERNAL PROCESSES

2.1 Self-monitoring

For the purpose of monitoring processes between inverters, first, it is critical for an inverter to provide correct data about itself. Necessary measurements for control of the inverter such as input and output voltage and current are important but not sufficient to provide a comprehensive view of the inverter's condition.

One of the key feature of the modern generation of inverters is self-awareness. This term covers various functions. One of them is knowing the detailed state in which it operates. The state includes information about the mode of connection (islanded or grid-connected) and detection of possible faults. The measurements could be extended to obtain more information about the health of the inverter. The weak link in the construction of the inverter is the input capacitor, which causes short lifespan when exposed to high temperatures. The monitoring of DC link capacitor can be done by integration of current measurement directly in series with capacitor, or the extracted ripple current from existing input current measurement. It is an example of measurement that could be used by the inverter to forecast future behaviors with knowledge of component aging. In this case, real-time measurement and processing are not necessary. This is different from transistors monitoring, which are another weak link in inverters. A factor that influences the performance of the transistors is the temperature, caused by switching with high frequency, which generates heat that may lead to overheating. The micro-inverters are mounted on the rooftop where the highest ambient temperature occurs when the inverter performance is the most important, therefore monitoring the temperature can detect early faults and provide knowledge of inverter behavior in high temperatures. A temperature sensor in the case of transistors is worth considering. Another possible fault in transistors can be detected with current measurements used for control loops.

The monitoring module should take full advantage of measurements that already exist in inverters for controlling purposes. Measurement of currents flowing in and out of the inverter can inform of possible conflicts, for example when amount of current is close to the expected boundaries in that state. That information might be transferred to the upper Energy Management System (EMS) controller to help with decision about the working state. It can be improved, if the inverter has information about the period of the day, or day of the week. In more advanced system processed by EMS, history and forecasting data could be also advantageous. Under unfavorable conditions for photovoltaics, the solar inverters might start to slowly power down, if it is needed, and shift energy production to high inertia synchronous generators. When the inverter is not connected to the load, it should not be inactive. The voltage measurement loops should be turned on to be prepared for the possible connection to the grid. In many countries the metering infrastructure is still underdeveloped, thus measuring devices in inverter could enable the implementation of EMS.

2.2 Microgrid monitoring

The case in which a single inverter will power the load is unlikely. Typically, multiple inverters cooperate in parallel with or without connection to the grid. In the case of low penetration of DERs, which is below 2% of load served by DER, the grid is stiff and only the trip limits for voltage and frequency are required [2]. When the load served by DER increases up to 30%, then the grid is softer and requires voltage regulation, to meet the demand and PQ. The weak grid is more vulnerable to voltage sags and surges. This condition cannot switch off the inverter; other inverters have to provide support instead. The inverter should detect such condition and react by manipulating individually active and reactive power to stabilize the voltage [4]. Fully and part-time islanded grids require advanced power sharing and load following techniques. In hierarchical decentralized control, primary control is responsible for controlling voltage and frequency in normal operation. It enables the implementation of droop control and more advanced power-sharing concepts [6]. Output voltages and currents used as control variables can also be used in grid monitoring system to estimate its parameters. It helps to gain relevant information about grid condition and to support possible decisions to be made by the inverter and influence the behavior of the system.

To fulfill the plug-and-play feature of the inverters, the connection of the inverter to a grid should happen seamlessly. Different inverters with different impedances might be connected to the grid. When the grid is driven mostly by DERs, then the soft start of the inverter should be implemented. It helps avoiding potential over-voltages or even sharp frequency increases due to the electric current inrush during restarting [2, 6].

A major challenge of distributed inverters is cybersecurity. Lots of vulnerable information is exchanged with inverter module, such as pricing information or demand data [5]. Therefore, self-security should be assured at the device level. Cyber-attacks can result in manipulation of measured data or control set points and commands, that could lead to abnormal operation, price increase, blackouts or damage of equipment. In order to protect measurement data, a good approach is to sense electrical quantities with built-in sensors. This data should not be exchanged by communication link with other modules if it is not necessary. Nevertheless, set point for reactive and active power and mode of operation commands must be exchanged between superior controller and inverter, thus they are weak points vulnerable to cyberattacks. The protection against attacks has been a trending research area within recent years. Examples of the techniques used to create systems resilient to cyber-attacks are advanced communication protocols, cryptography, and device-level and system-level security layers [5].

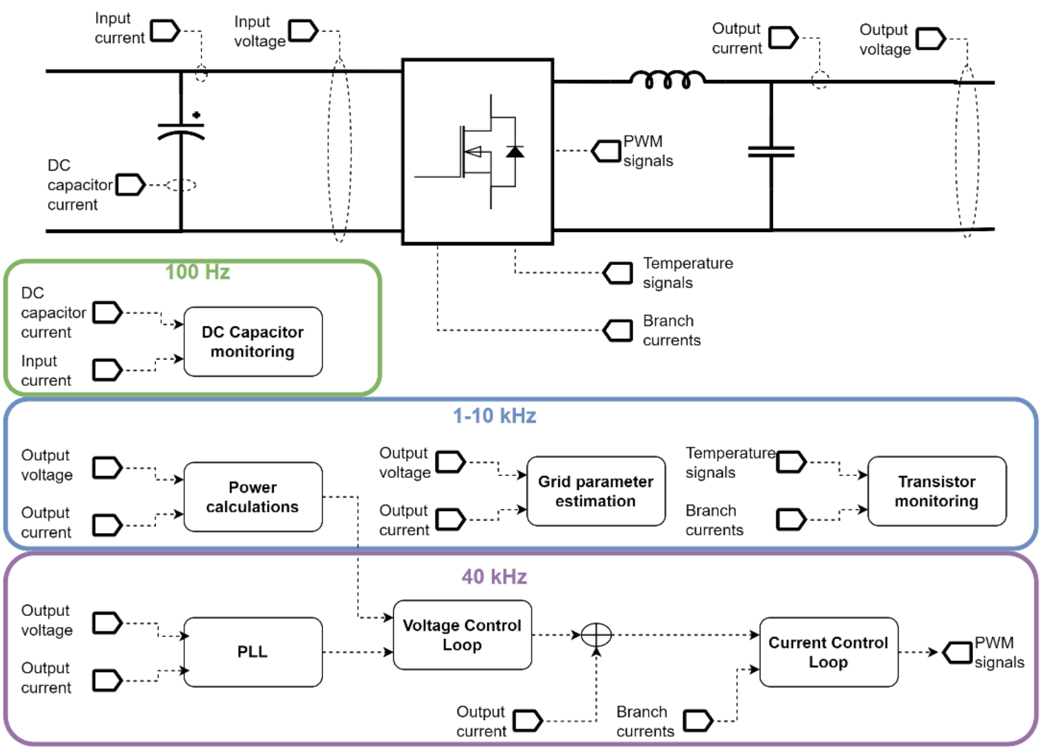

Fig. 1. Inverter with control loops
Rys. 1. Falownik z pętlami sterowania

3. INTEGRATION MONITORING WITH CONTROL SYSTEM

Integration of monitoring processes with the control system is the crucial point in smart inverter design. The monitoring system senses lots of data, nevertheless it should not harm the control loops. In our test system, we are using a digital signal processor equipped with a co-processor with independent code execution, separated from the main core, specialized in math operations [7]. An overview of the system and control loops is presented in Fig 1.

The two main control loops (inner current and outer voltage) and Phase-Locked-Loop (PLL) for synchronization purpose, execute at 40 kHz. The reference for voltage loop is the power set point, calculated with the use of one of the methods mentioned in Section 2.2 with execution frequency that might be between 1 kHz and 10 kHz. The transistor monitoring and grid estimation loops should be executed at approximately 1-10 kHz. DC capacitor does not need fast feedback so a frequency of hundreds of Hertz is sufficient.

With development of additional sensors, the price of the design increases. Nevertheless, early detection of faults and continuous information on the inverter condition can limit maintenance and repair costs. The increase in the board size is not relevant due to small size of sensors. However, more sensors can lead to power losses, therefore it is important to choose non-invasive and low-powered sensors.

4. CONCLUSIONS AND FURTHER STEPS

The work presented in this paper deals with functions that are needed for monitoring internal processes in distributed solar inverters. Functions for self-monitoring, as well as grid-monitoring, require additional sensing technologies with appropriate implementation. Integration of monitoring system with control system needs to be carefully managed. Presented functions will be implemented in the IHP smart grid emulator.

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