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An experimental study for the islanding detection by the harmonic distortion method and protection system of the inverter

***Abstract**. In this paper is analyzed is the passive technique of the voltage Harmonic Distortion (HD) for the protection and distribution of PV systems connected to the utility grid. We have made the measurement of the HD voltage in the PCC and the measured value is compared with a certain threshold if this threshold is exceeded inverter will be disconnected. During normal operation, the voltage at the PCC is the grid voltage, so distortion in most cases can be considered as negligible. However, when islanding condition happens, the current harmonics produced by the inverter are transmitted to the load and presents higher impedance than the grid. The interaction of the harmonic currents and the grid impedance generates voltage harmonics which can be measured. Therefore, the voltage HD variations beyond a certain threshold can be used to detect islanding. The technique in question is analyzed based on the non-detection area and based on the possibility of degradation of the output power quality, which is a known weak point of this method. The analysis focuses on the worst case of detecting when the energy produced by the photovoltaic system is the same energy that takes the load when there is no change to the parameters at the common point of connection to the utility grid. Results are obtained by monitoring a grid connected to the photovoltaic system with a power of 3.9 kWp installed on a flat roof of a laboratory building of FECE in Pristina. Simulations for the respective topology were made with Matlab Simulink.*

Streszczenie.** W artykule analizowany jest system fotowoltaiczny podłączony do sieci z pasywnym układem poprawy zawartości harmonicznych. W układzie moerzona jest zawartość harmonicznych I układ jest odłączany gdy ta wartość przekroczy dopuszczalny poziom. Jednocześnie przekraczanie zawartości harmonicznych może być sygnałem zjawiska wyspowania. **Eksperymentalne badania możliwości wykrywania wyspowania przez pomiar zawartości harmonicznych w systemie fotowoltaicznym

Keywords: photovoltaic module, utility grid, islanding detection, passive methods, voltage total harmonic distortion
Słowa kluczowe: system fotowoltaiczny, efekt wyspowania, zawartość harmonicznych

Introduction

The problem of islanding of photovoltaic systems interconnected with utility grid has been the main challenge in implementing distributed generation of electricity. Islanding is a condition in which a portion of the utility system, which contains both load and operating generation. The distributed generation of electricity is an option that is being considered seriously around the world, especially in countries where the centralized power generation system is very old and causes large environmental pollution. Distributed generation, as defined by Karlsson is "…an electrical power generation source connected directly to the distribution grid or on the customer side of the meter". One of the main problems encountered in distributed generation is the possible formation of isolation conditions (areas called the island) that can continue to work normally even if the electrical grid is disconnected. For applications without detection and correction, it is better to combine more methods for detection of islanding detection based on other work processes [1, 2]. This unity power factor condition combined with passive parameters of parallel RLC load and frequency is considered the worst case for islanding detection when the active power of load matches to the output power of distributed generation [3, 4]. Is describes an anti-islanding control technique for use in utility-interconnected photovoltaic systems. The technique can be used to prevent islanding in any distributed generation resource that uses a static inverter as the interface device [5]. The ability to protect from the creation of islanding circumstances is an important request for distributed generation. It is necessary to detect when the system works under insulation conditions and disconnect from the network as soon as possible [6]. Detecting the islanding is important for all DG systems. In the last decade, many algorithms have been developed for such detection. This paper is focused only on the passive method for detecting voltage harmonics of the photovoltaic system when it is under isolation conditions.

Most of the circumstances of isolation can be easily avoided by monitoring the AC voltage and frequency at the inverter terminals, and/or by allowing the inverter to work only when these parameters are within acceptable limits. In the case of creating isolation circumstances, there will be an imbalance between the isolated load and the isolated generation, either in frequency or voltage (or both), wandering out of their operating boundaries and causing FV invertor disconnection. However, it is possible, however, that power demand requirements adapt very close to the PV output moment so that the voltage and frequency limits will not be passed even if the system is under isolation. The existence of this "non-detecting" area in the case of balancing load and generation means that an inverter used only for voltage and frequency detection can continue to operate [7].

System description and characteristics

In order evaluate the performance of such technique, a PV system, with capacity 3.9 kWp, was installed on the roof of Laboratory buildings at the Faculty of Electrical and Computer Engineering in Pristina, Kosovo, and connected to the grid system (figure 1). This system consists of two types of photovoltaic modules, monocrystalline and polycrystalline, batteries, inverter, battery chargers and devices for measurement and monitoring. The grid-connected systems consist of 18 modules, with an active surface area of 26.26 m^2. Specifically, the system comprises PolySol 240 VM (IBC Solar, STC Power 240 Wp, module efficiency 14.7%) polycrystalline silicon modules, and 9 MonoSol 195 DS (IBC Solar, STC Power 195 Wp, module efficiency 15.3%) monocrystalline silicon modules. The PV modules [8] are arranged in 2 branches with 9 modules each connected to a Sunny Boy SB 2000 inverter, irradiance and temperature measurement instrumentation and data logging systems (Sunny Sensorbox and Sunny WebBox). The roof is approximately 8 m high and the modules were fixed mounted at an angle of 450, facing south [1].

Such a tilt angle was chosen to maximize yearly energy production, taking into account the geographical position of Prishtina. The grid-connected PV system was monitored to assess the performance of this system in the local climate conditions. The data acquisition systems consist of a Sunny

Boy 2000 inverter, Sunny SensorBox, and Sunny WebBox. Sunny SensorBox was used to measure in-plane total solar radiation on the PV modules. There are also additional sensors for measuring ambient temperature and module temperature at the back of one module and wind speed. Data recorded on 15 min intervals is collected by WebBox extracted via SD card and read directly into a computer.

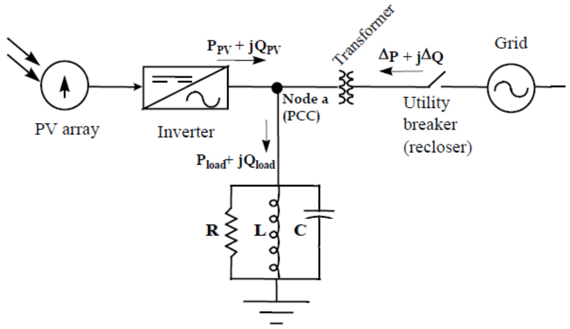

Fig.1. PV system/utility feeder configuration showing power flows [4]

The inverter is equipped with Bluetooth, which can communicate with other devices or can be remotely controlled, and is also equipped with the SMA standard that is a basic type of Ethernet communication standard. This enables optimization of inverter work for 10-100 Mbit speed data transmission from the PV system to Sunny Explorer inverter software. The installation of the photovoltaic system and Sunny Boy inverter, which is located in the FECE laboratory, looks like in Figure 3. There are two inverters connected to each branch, of photovoltaic panels, so there are two independent systems (one for the monocrystalline modules and the other for the polycrystalline modules).

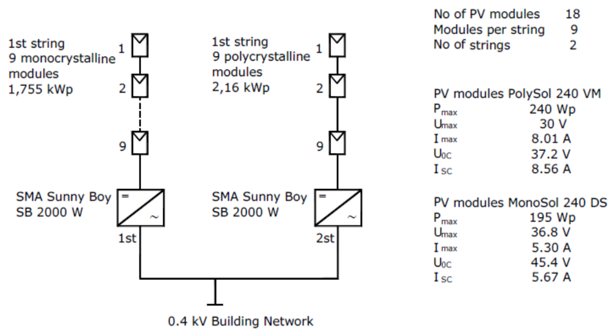

Fig. 2. Schematic block circuit diagram of the PV system [3]

The schematic block circuit of the PV system is shown in Figure 2. Sunny Boy is a PV inverter without a transformer that converts the DC power supply to a suitable AC power supply and transmits it to the service network [9]. From the collected measurements it is noted that, for the same radiation and at the same time, solar panels produced from monocrystalline silicon produce 171 W power, while the solar panels produced by polycrystalline silicon produce 218 W power.

Research Method

The method of detection of voltage harmonics or simply detecting harmonics in another literature can be found also as impedance detection in the frequency specification. In this method, the PV inverter monitors the harmonic distortion (THD) of the node **"a"** voltage v_a and shuts down if this THD exceeds some threshold. Under normal operation, the utility, being a "stiff" voltage source, forces a low-distortion sinusoidal voltage (THD ≈ 0) across the load terminals, causing the (linear) load to draw an undistorted sinusoidal current [10]. Summing at node **a**, when the utility is connected to the harmonic currents produced by the inverter will flow out into the low-impedance grid. Because these harmonic currents are kept small and the impedance of the utility is generally low, these harmonic currents interact with the very small utility impedance to produce only a very small amount of distortion in the node-**"a"** voltage. Typically, when the inverter is connected to the utility grid, the THD of the voltage *va* is below the detection point. When an island occurs, there are two mechanisms that can cause the harmonics in *va* to increase.

Fig.3. PV modules mounted in the roof

One of these is the PV inverter itself. A PV inverter will produce some current harmonics in its AC output current, as all switching power converters do. A typical requirement for a grid-connected PV inverter is that it produces no more than 5% THD of its full rated current [11, 12]. When the utility disconnects, the harmonic currents produced by the inverter will flow into the load, which in general has much higher impedance than the utility. The harmonic currents interacting with the larger load impedance will produce larger harmonics in v_a [13, 14]. These voltage harmonics, or the change in the level of voltage harmonics, can be detected by the inverter, which can then assume that the PV inverter is islanding and discontinue operation. The second mechanism that may cause the harmonics to increase is the voltage response of the transformer shown in Figure 1. This second mechanism is currently not tested for using today's testing standards but deserves mention at this time. When current-source inverters are used, and when the switch that disconnects the utility voltage source from the island is on the primary side of the transformer, as shown in Figure 1, the secondary of the transformer will be excited by the output current of the PV inverter. However, because of the magnetic hysteresis and other non-linearity of the transformer, its voltage response is highly distorted and will increase the THD in v_a. There can also be non-linearity in the local load, such as rectifiers, which would similarly produce distortion in v_a [15]. This non-linearity tend to produce significant third harmonics in general. Thus, when this method is used in practice it is frequently the third harmonic that is monitored [16]. In theory, the voltage harmonic monitoring method promises to be highly successful in detecting islanding under a wide range of conditions [17], and its effectiveness should not change significantly in the multiple-inverter case.

Harmonic detection suffers from the same serious implementation difficulty: it is not always possible to select a trip threshold that provides reliable islanding protection but does not lead to nuisance tripping of the PV inverter. It is clear that a threshold must be selected that is: a) higher than the THD that can be expected in the grid voltage; but b) lower than the THD that will be produced during islanding by either of the two mechanisms described above. Let us assume that the PV inverter produces 5% THD in its output current, the maximum allowable limit. For a resistive load fed by this current, in the absence of the utility voltage source, the THD of *va* will also be 5%. However, for RLC loads, it is possible for the THD of v_a to be less than 5% because the parallel RLC circuit can exhibit low-pass characteristics that attenuate the higher frequencies. It is therefore clear that the THD threshold will have to be set lower than 5% [18]. In reality, the utility voltage distortion that we assumed to be ≈0 in the foregoing discussion can actually be expected to be 1-2% under normal conditions (because of the interaction of harmonic currents drawn or supplied by loads with the utility source impedance), but there are many conditions, such as the presence of power electronic converters that produce current harmonics at frequencies at which the utility system has resonance, which can cause this value to increase significantly [19]. Also, transient voltage disturbances, particularly large ones such as those that accompany the switching of capacitor banks, could be interpreted by PV inverter controls as a momentary increase in THD, depending on the measurement technique used. It is clear that in some cases it is not possible to select a threshold that meets the criteria.

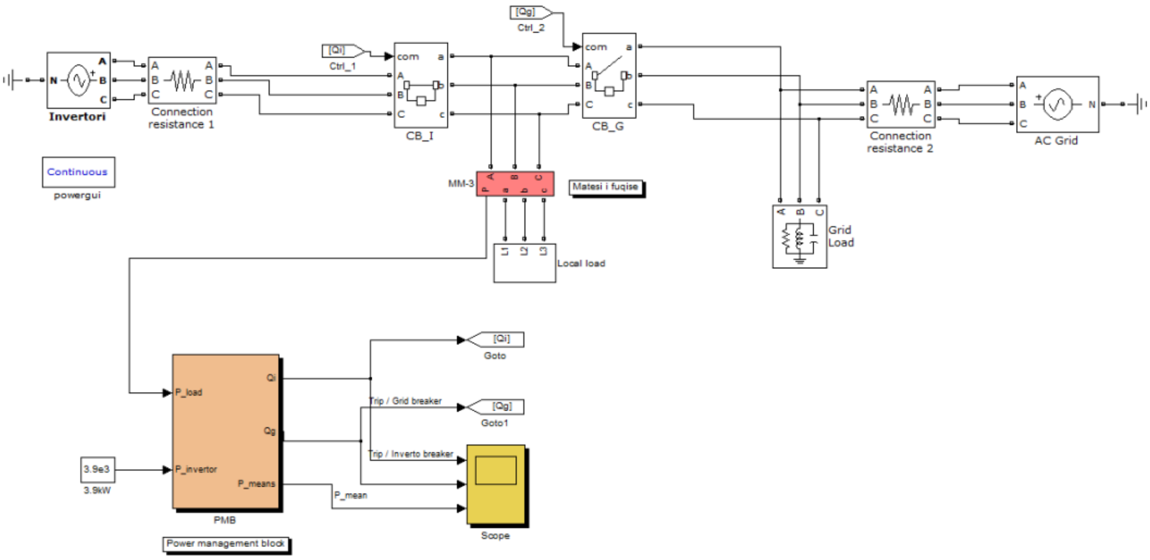

Fig. 4. The topology of the Active Power Utilization Circuit

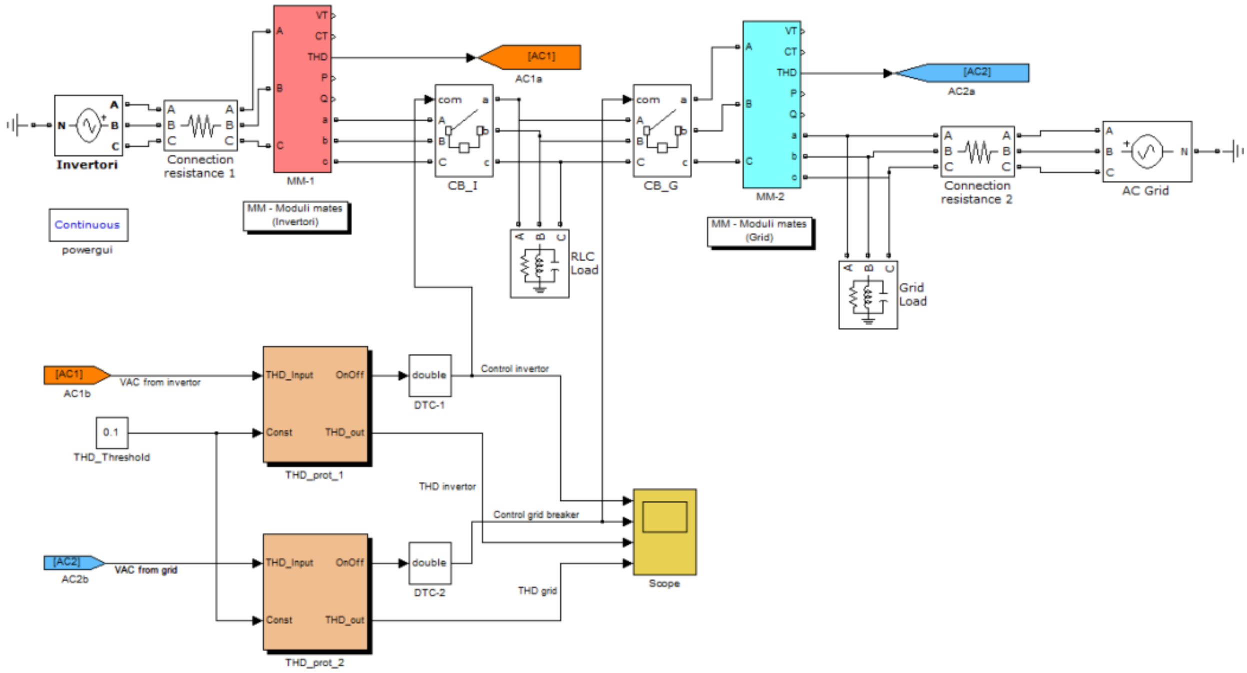

Fig. 5. The topology detection of harmonic distortion

It may be possible to overcome this problem using digital signal processing and harmonic signature recognition, but these techniques have not been implemented cost-effectively in small PV inverters. For these reasons, the harmonic monitoring technique has not been used commercially. This method can be made to fail if the load has strong low-pass characteristics, which occurs for loads with a high value of the quality factor *Q*, and for loads that may occur with a service entrance disconnect that does not include a transformer inside the island. It is also possible that a nonlinear load might exist that would require an input current with a harmonic spectrum matching that of the output current of the inverter, but in all likelihood, this load is purely a theoretical abstraction. This method may fail when inverters have high quality, low distortion outputs.

Results and Analysis

Figure 4 shows the topology of the active power utilization automaton and the inverter disconnection. PCC voltage can only change when the grid is disconnected and DC and load power are not the same. The topology of the circuit for the detection of harmonic distortions will be shown in Fig. 5.

The results are achieved by the technique: ode15s (stiff/ NDF) and are shown in Figure 5. The measurements are made for the constant C = 0.1. From the diagram we can conclude that: If the THD of the inverter or the THD of the electrical grid exceeds the threshold of C = 0.1, then disconnects the source by switch off and have harmonics distortions. We are based on the monitoring of all the harmonics by the total harmonic distortion (THD) of the PCC voltage or on the monitoring of only the greater harmonics, generally the 2nd, and 3rd, through the harmonic synchronization PLL. Considering a grid model in which the harmonic distortion is very low and a PV a system that produces only the fundamental voltage at its terminals, in the islanding condition the THD does not change. All the harmonics amplitudes present an oscillatory behavior during the transient with a large variation from normal operation to islanding condition. Harmonics the 2nd and the 3rd do not change a lot. This is illustrated in Fig. 6. It is worth noting that the 3rd is very small when the grid is still connected and it is difficult to set the thresholds to realize a reliable method. Many measurements have been made and based on the results achieved we can conclude that: In normal operation, the voltage at PCC is controlled by the grid; in islanding condition, DG controls the PCC voltage and its harmonics.

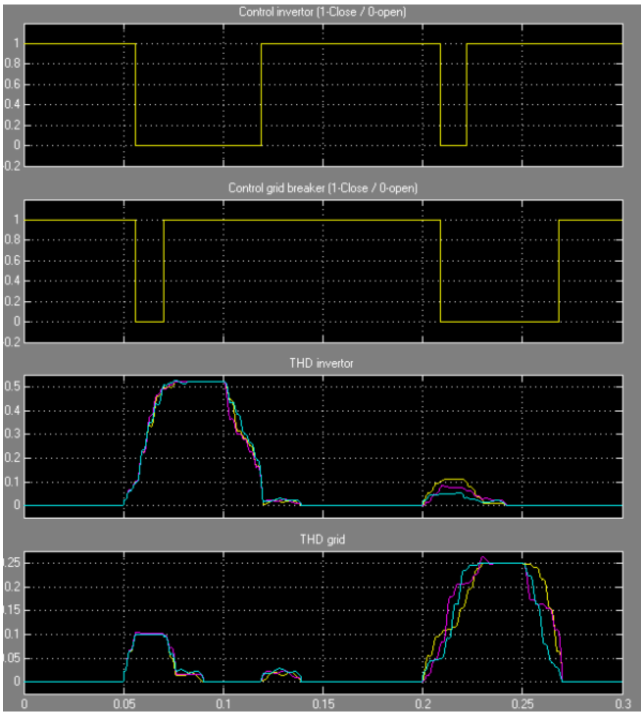

Fig. 6. Simulations for the topology detection of harmonic distortion

It is possible to consider all the harmonics using the THD of the PCC voltage or only the main harmonics: the 3rd and 2nd. It is possible to use a Phase Looked Loop (PLL) to provide the values of the monitored harmonics. It is very hard to detect islanding if the grid voltage harmonic distortion is not high or low enough such as the THID changes when islanding occurs. The maximum amplitude of the grid voltage harmonics is reported in fig 6. The grid voltage harmonic distortion can change in the time depending on the grid impedance; moreover, the inverter system can present a harmonic distortion in DC bus with a consequent harmonic distortion generated on the grid side. Generally, a PV system is connected to the grid through a transformer that can affect the harmonic distortion especially in the case of Electric Island. For this reason, it is not always possible to select a trip threshold that provides reliable islanding protection. The NDZ of the harmonic-based methods is strongly tied to the load. RLC parallel resonant load present a low pass characteristic in frequency that can filter low order harmonics more than other and influence the detection of islanding. In case of a huge variation of harmonics amplitude, these methods have a small NDZ.

Conclusions

In this paper, we analyze the passive method for detection of islanding of distributed generators, and especially for applications based on inverters. Photovoltaic (PV) power grid-connected systems have the advantages of being prompt and reliable supplies of electrical power. Nevertheless, the installation and operation requirements from the grid side have to be fulfilled in order to guarantee the security of the PV system technicians and the efficiency of the power system. Particularly, the potential for "islanding" is one of the dreads that are brought about by PV grid-connected systems. The harmonics detection method is based on monitoring the Total Harmonic Distortion of the PCC voltage to determine whether islanding occurs. In normal operation the impedance of the power grid is small, the inverter current harmonic component mainly flows into the grid. The PCC voltage is decided by the utility-grid voltage and the voltage harmonic content is small. When the power supply is disconnected the nonlinear load harmonic current flowing into the inverter will also have large harmonics. The islanding conditions can be decided by detecting the harmonic distortion of the output voltage. This method has several advantages: it is simple, has a high detection accuracy and is viable.

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