Power Quality Analysis in Off-Grid Power Platform

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Abstract. *Research projects in the field of electrical distribution systems are moving to a new philosophy of Smart Grids, where the effort is to use the maximum possible share of power from renewable energy potential. Under this philosophy the emphasis is on energy independence, reliability and safety of operation of energy distribution system. Research in this area leads for example to developing of autonomous local microgrids with the several specific requirements. However, the problem of parameters keeping of quality of electric energy can arise together with increased penetration of distributed generation in microgrids. This problem is caused by decreased short-circuit power of local renewable energy sources, stochastic supply of electric energy from renewable energy sources and operating of active distribution grid in autonomous mode without connection to the external distribution system. General introduction to the power quality evaluation in off-grid power system is introduced in this paper. Initial results from power quality analysis from small off-grids system is presented in this text too.*

Keywords

Battery tank, off-grid system, power quality, renewable energy sources.

1. Introduction

This paper introduces the initial evaluation of power quality (PQ) of off-grid power system, which was built as research platform for renewable energy sources (RES) testing. Off-grid system was sized as a model for usual residential supply [1].

The main idea of this concept is to find links or relations between environmental (solar irradiance and wind speed) and PQ variables associated with solar and wind energy. Based on these links prediction of PQ for off-grid power system will be introduced to optimizing PQ level in off-grid power system.

In particular, this contribution concentrates on the relationships between environmental (solar irradiance and wind speed) and power quality (PQ) quantities.

The paper is organized in four main sections. Section 2 provides a brief introduction to issues of power quality in general and problems specific to RES power quality. It also brings an overview of relevant technical standards. Section 3 provides a review of work on the PQ evaluation related to off-grid power systems. Section 4 describes the overall structure of off-grid power system and also describes individual components. Section 5 describes the PQ evaluation and some of the partial results made from this data. Conclusions are presented in Section 6.

2. Background

Power quality can be explained as the fitness of consumed electrical power to user appliances and devices. Good power quality allows electrical systems to function in their intended manner without significant loss of performance or life. Without the proper power quality, an appliances (or load) may result in appliance damage or operate stoppages at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power.

With the RES installation for off-grid power system supply, their impact on the power quality should be significant. Voltage fluctuation caused by variability of photovoltaic (PV) and wind power generation is one of the most important issues. Another significant problem is harmonic distortion, since both types of generation plants are usually connected to the power system through inverters. Wiring diagram of described off-grid power system together with individual system components are described in section 4. More detailed characterization and overall off-grid power system description is widely introduced in [1], [2].

2.1. Power Quality

It is not necessary to reach power quality levels defined by several international standards in off-grid power systems, but only good power quality allows electrical devices to function in their given manner without loss of performance or possible damage.

2.2. Standards and Rules for PQ

Usually in grid-connected power system are PQ levels defined and maintained by several international technical standard organizations. The well known are as follows IEC (Int. Electrotechnical Commission) and the IEEE (Institute of Electrical and Electronics Engineers). In off-grid applications where PQ limits are not defined by common standards we can use for the PQ evaluation limits defined for grid-connected power systems.

1) European Standards

IEC61000-4-30 (2008) "Testing and measurement techniques – Power quality measurement methods" is part of the series IEC61000 "Electromagnetic compatibility". It defines the methods of measurement and interpretation of results for power quality parameters in 50/6 0Hz AC power supply systems. The measurement methods describe, for each type of parameter, how to obtain reliable, repeatable and comparable results regardless the compliant instrument used for measurement and its environmental conditions. The standard defines three measurement classes A, S, B. Class A is used where precise measurement are necessary, e.g. for contractual application to resolve disputes. The processing requirements and instrument prices for class S are lower. Class B is obsolete. It has the weakest requirements, and it is not recommended for new designs. The standard also contains links to two other standards: IEC61000-4-7 for measurement of voltage harmonics and IEC61000-4-15 for measurement of flicker.

PQ analyzers with functionality defined in IEC61000-4-30 provide periodical data that has to be statistically processed. European standard EN 50160 describes how should be the measured data processed. It describes how to determine the main voltage characteristics of electricity supplied by public networks. It defines the "electrical product" for high, medium and low voltage systems in terms of the characteristics at the supply terminals.

2) IEEE Standards

IEEE Std 1159 (2009) "Recommended Practice for Monitoring Electric Power Quality" is maintained by the Working Group for Power Quality Monitoring, which was formed in response to the need for standardizing the rapidly expanding power quality monitoring manufacturing industry and the field use of their products by utilities and end-users. The standard introduces consistent terminology and definitions, and discusses power quality monitoring devices, application techniques, and the interpretation of monitoring results. It includes descriptions of conducted electromagnetic phenomena occurring in single and poly-phase AC power systems, and encompasses the monitoring of electrical characteristics of these systems. The standard describes nominal conditions and deviations from these conditions that may originate within the source of supply, load equipment, or from the interactions between the source and the load.

2.3. Enforcement of Standards

Both the IEEE1159 and IEC61000 series of standards cover issues of power quality. They agree on compatibility, the basic concepts and terminology. However, IEEE 1599 is not enforced; it is an informative and instructive tutorial developed by volunteers and approved by consensus. Conversely, the IEC 61000 series of standards has been developed by a group of assigned national experts through careful drafting before being approved by national voting. It is enforced at the national level by many countries.

3. Related Work

Guidelines for the measurement and assessment of power quality characteristics for the photovoltaic system are described in [10]. Harmonics, flicker, unbalance and slow voltage variations were included in these guidelines [10]. Power quality analyses for grid-connected photovoltaic plants were introduced in various papers [5], [6], [7]; also general PQ issues associated with grid-connected PV systems are discussed, for example, in [3], [10].

Power quality analyses for off-grid-connected power system were discussed only in a few papers. In [9] there were analyzed the main factors of the impact of fluctuations of wind power from the off-grid wind power systems and energy storage technology to mitigate the off-grid wind turbine power fluctuations. Smart control system for standalone and grid-connected PV systems were introduced in [4]. Also, fluctuation of total harmonics distortion (THD) in islanding mode was shortly evaluated. The THD during islanding mode of operation was around 6 % [4].

Combined photovoltaic and unified power quality controller was described in [8]. The main issue of the controller is to eliminate grid-end current harmonics caused by the distorted-unbalanced load-terminal voltages.

However, none of these papers provides overall PQ analysis of whole hybrid power system with RES. In this paper we try to find a relationship between environmental, electrical and PQ variables. The main goal is to find interconnections between environmental variables like solar irradiance or wind speed and PQ variables and arrange the basis for the PQ variables prediction for off-grid power systems.

4. System Configuration

The developed off-grid power system was designed according requirements of usual consumption of family house, whereas the mentioned system has to satisfy features of smart grid system. Basic features of developed smart grid system are:

- independence on the delivering of energy from external power grids,
- operation of the grid system with well-balanced between production and consumption of electric energy,
- energy storage possibility,
- using mainly renewable energy sources of electric energy,
- non-traditional character of load,
- new conception of protection with bi-directional power flow,
- active energy management system with supporting of methods of artificial intelligence.

The off-grid power system is created by three basic parts. The first part, part of sources, contains two types of renewable energy sources, namely wind power plant and photovoltaic system. These types of renewable energy sources were selected purposely, because mutual combination of their running ensures energy supply during all year. It is given by character of individual sources, where the electric energy is mainly supplied by wind power plant for the season of spring and winter and by photovoltaic system for the season of summer and autumn.

Only one of these sources is not applicable for specific meteorological condition of Czech Republic, where the system is installed. The block scheme of off-grid power system is introduced in Fig. 1.

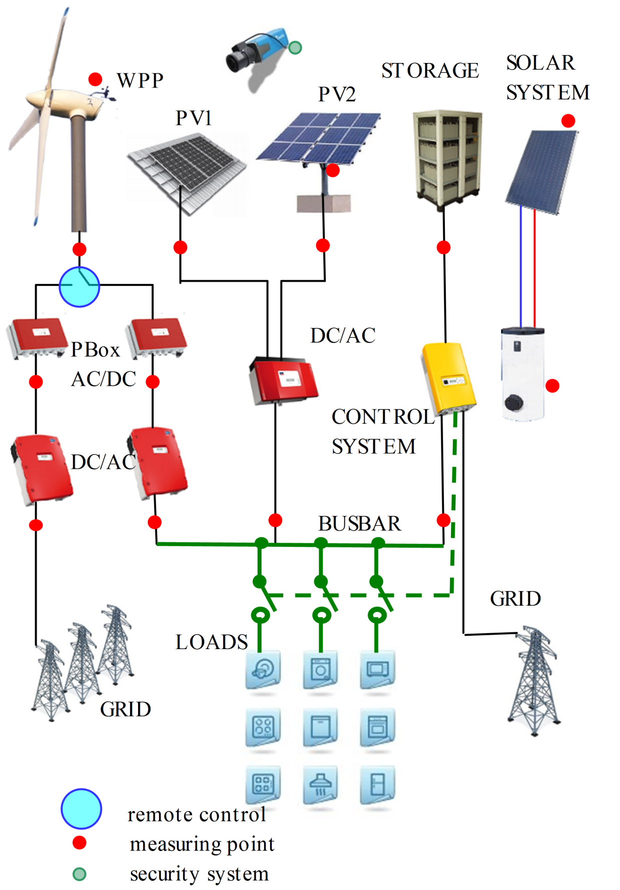

Fig. 1: The block scheme of off-grid power system.

The first source of electric energy is formed by the wind power plant (WPP) equipped with a synchronous generator with permanent magnets and the total installed capacity of 12 kVA. The synchronous generator is connected through a protection box (PBox) with controlled (AC/DC) converter and frequency converter (DC/AC) with a recuperative unit to a 1 phase AC (BUSBAR) with 230 V level and 50 Hz frequency. The photovoltaic power plant (PV1) with polycrystalline technology and the total installed output of 2 kWp is used as another renewable electric power source. The electric output from the photovoltaic system is also connected through a frequency converter (DC/AC) to the common 1 phase AC BUSBAR as a part of the transmission. The PV1 with polycrystalline technology has placed in the stable construction. The second photovoltaic system (PV2) has monocrystalline technology, identical installed output as PV1, but individual photovoltaic panels are placed on the tracker for its better using and higher efficiency of energy conversion.

Individual (LOADS) are supplied from BUSBAR, and their individual connections are controlled according to the condition of the actual state of storage device, connection priorities, character of the current surge of load and the predicted value of available power from the wind and photovoltaic power plants.

Connecting of the loads according to the requirements mentioned above is done using the smart control system (CONTROL SYSTEM), which also controls charging of the storage device (STORAGE) with the total capacity of 840 Ah and voltage 48 V DC (third part of off-grid power system). This storage unit with lead batteries balances the power and thus accumulates electric power in the case of surplus of electric power from the photovoltaic and wind power plants. This storage unit works as a backup source for synchronization of individuals power components in the case of direct supply of individual loads from the 1phase BUSBAR. The weather station is part of off-grid power system conception for definition relations between meteorological, electrical and mechanical values. Wind velocity, wind direction, temperature, relative humidity, pressure or UV radiation is possible to measure with implemented weather unit. The power flow between individual components, actual values of required parameters and total efficiency of off-grid power system is monitored by monitoring system in individual measuring points. The (SOLAR SYSTEM) is used for supply of heat energy in the off-grid power system, but detail description of heat energy power flow is not purpose of this paper.

5. Exploratory of Off-Grid PQ Data

The PQ evaluation was processed due to European standard EN 50160 and database of monitored variables (meteorological and electrical) were used. In this survey, we use positive values of variables (marked "+") for power consumption and negative values of variables (marked "-") for power production. Day with changeable solar irradiance (March 20^{th}, 2013) was selected for presentation of the PQ evaluation in this text. We try to find the interconnection between meteorological and electrical variables, so we switch off WPP and only PV1 and PV2 were switched on. During this evaluation period there was some of the possible operation modes (on-grid and off-grid) used. Characteristic variables for selected time period are shown on Fig. 2. Selected time period should be divided on three operation modes. Time period from 0:00 to 8:00 present on-grid mode (mode 1). Since about 8:00 solar irradiance G is increasing and also PV1 and PV2 production is increasing too. For the detail see G, PV1 and PV2 on Fig. 2. At about 8:00 hybrid power system is switched to off-grid mode (mode 2), and load (P on Fig. 2) rise according to usual day consumption of typical dwelling. When total amount of PV1 and PV2 is sufficient to supply actual load, then there is used "by-pass" and load is directly supplied by PV1 and PV2. In the case that solar irradiance fluctuate and partially there is not enough power to supply load directly from PV1 and PV2 storage device is connected, and load is supplied from storage device. For details see SD on Fig. 2. After 4:00 PM load is supplied entirely from storage device (mode 3).

For power quality evaluation there were selected fundamental variables, frequency f, total harmonic distortion of the voltage (THDu), total harmonic distortion of current (THDi) and short (P_{ST}) and long (P_{LT}) time Severity. Soft fluctuation of frequency should be seen at Fig. 3 while hybrid power system is in on-grid mode (mode 1). Fluctuation of frequency is caused by back influence of external distribution grid in on-grid mode. Fluctuation of THDimax is more significant in this mode, and it is caused by cyclical fluctuation of load of connected appliances (refrigerator and TV and PC in stand-by mode). Load P is on Fig. 3 rated with total installed power 2500 W for comfortable description of discussed problems. The value of THDu is in limits set by CSN EN 50160, and it is of course related with short-circuit power of external distribution grid.

In off-grid mode, PQ variables are held by control system of SMA Sunny Island. These PQ variables are in off-grid mode more dependent on the character of load and value of short-circuit power. This situation is shown on Fig. 3 where rapid change of load cause change of frequency and THDu out of limits.

Harmonic voltage analysis is shown on Fig. 4. Harmonic voltage with frequency 150 Hz (U_{HARM3}) is 17.4 %. UHARM3 limit set by CSN EN 50160 is only 5 %, it is caused by connected device with semiconductor technology, e.g. laptop's charger, LCD screen, TV, etc.

Long and short time severity is shown on Fig. 5. When system is in mode 1 the values of long and short time severity reach values of around 0.15. Long and short time severity start to fluctuate according to increased current and reach values higher than limits set by CSN EN 50160. The value of long and short time severity is related with dynamic changes of load current.

Control system of SMA Sunny Island is not so fast to hold frequency and THDu in limits according to normative values. After finishing of rapid changes of load; control system of SMA Sunny Island is again able to stabilize frequency and THDu in off-grid mode. As it was described above, THDi is load dependent variable with direct impact of load changes. Rapid changes of THDi are usually produced by appliances with huge application of semiconductors. Details of these rapid changes of THDi are shown in Fig. 3 from about 10:00 am till 2:00 pm.

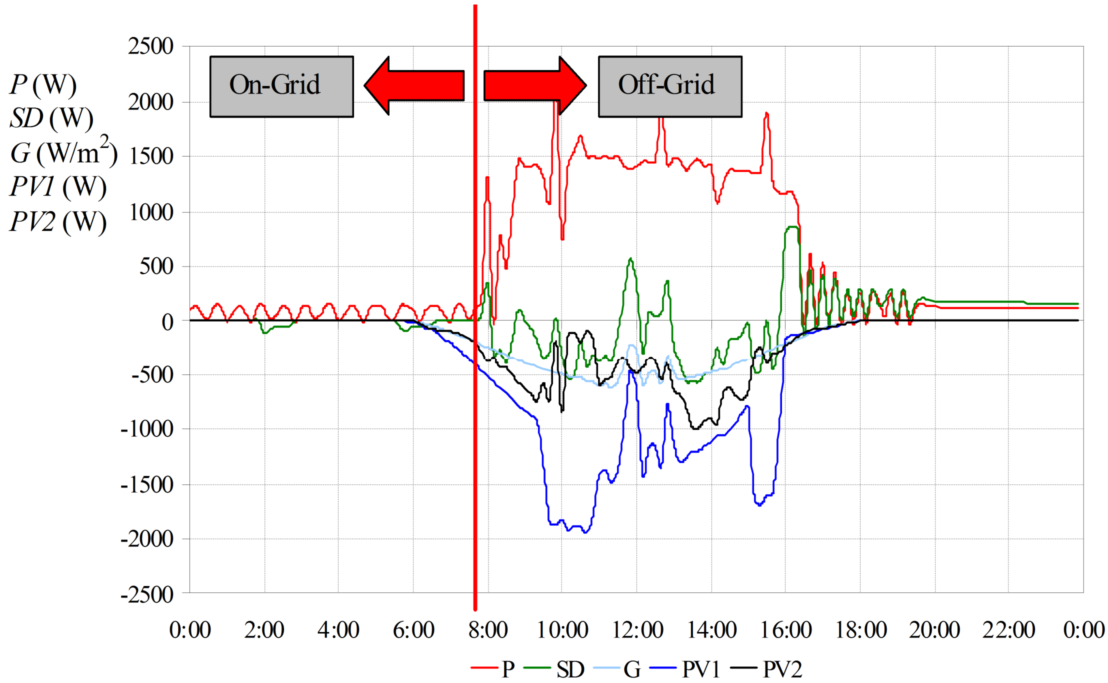

Fig. 2: Example of power variables.

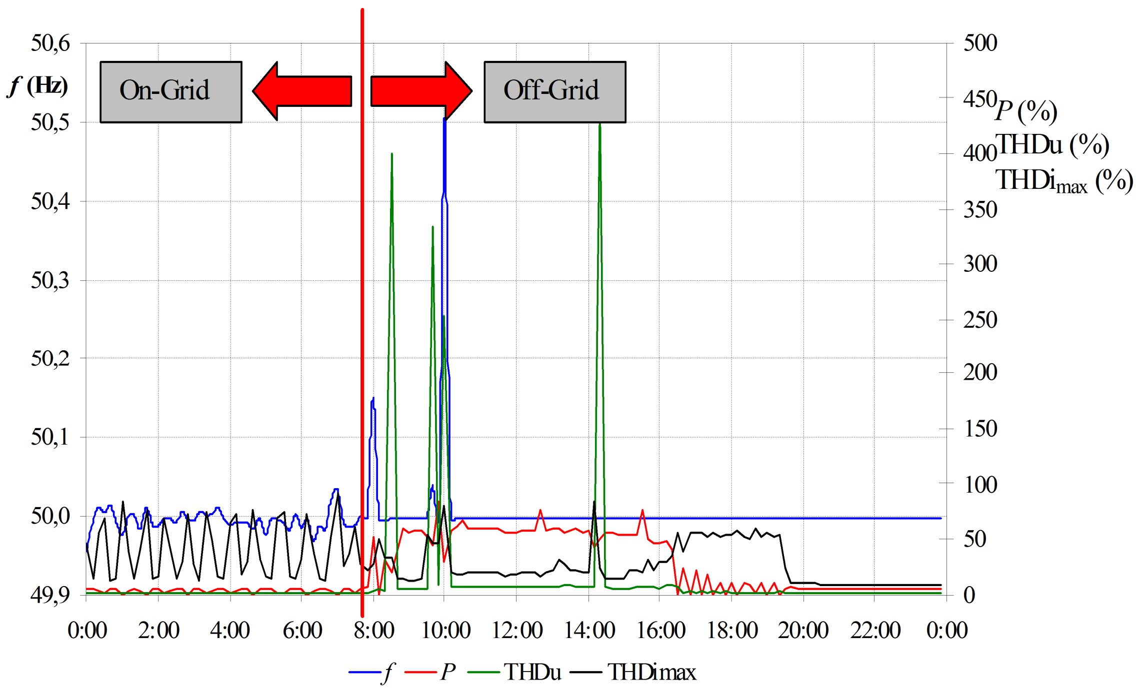

Fig. 3: Example of power quality variables.

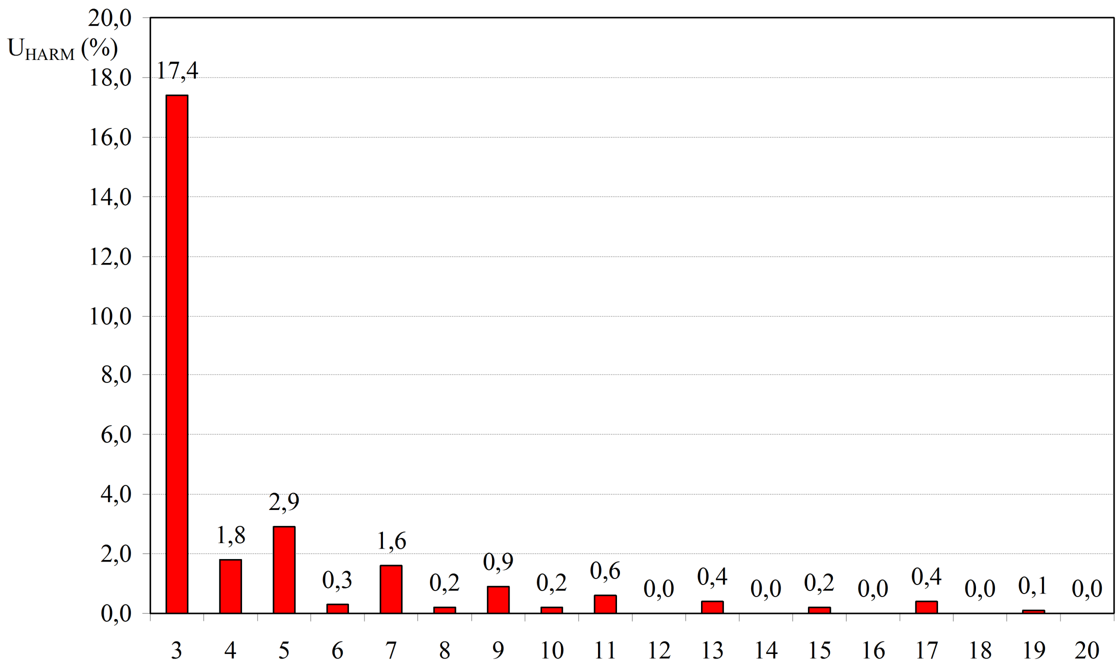

Fig. 4: Harmonic voltage analysis.

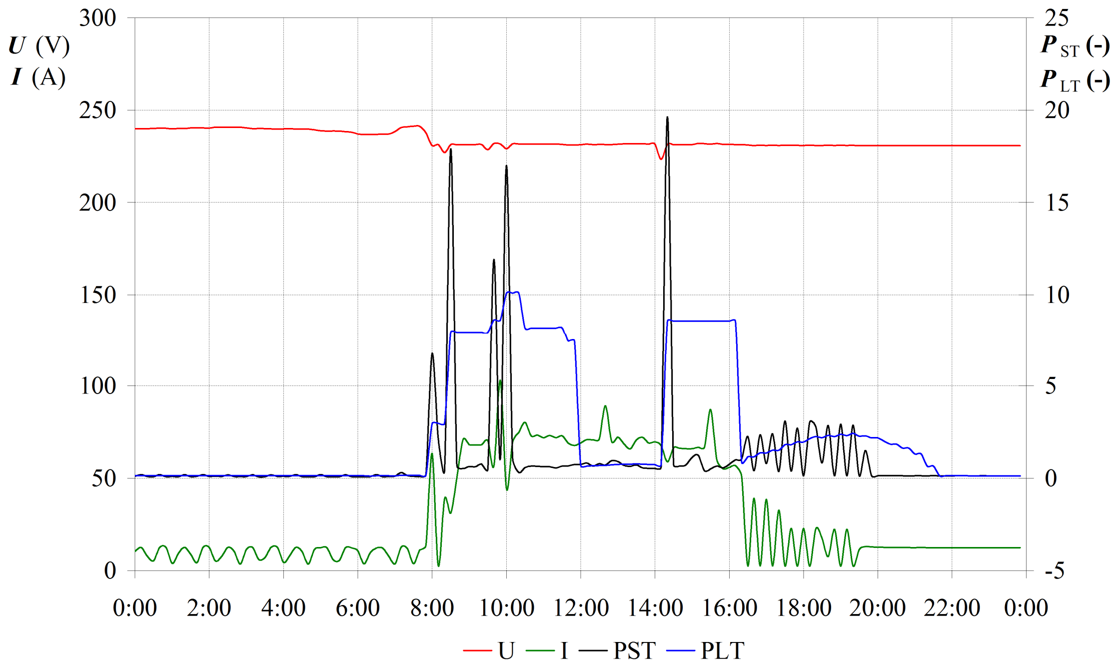

Fig. 5: Short and long time severity.

6. Conclusion and Future Work

Utilization of solar and wind power in off-grid power system for residential supply is in contradiction with the increasing PQ sensitivity of equipment and devices being connected to the off-grid power system. Definition of links and relations between the solar irradiance and wind speed and direction, it may be possible to reduce the negative effects of solar and wind power and allow their use while keeping acceptable level of PQ. In this paper, we try to introduce initial outlook on power quality evaluation in hybrid power system where on-grid and off-grid operation mode are possible.

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