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A novel approach to adaptive active relay protection system in single phase AC coupling Off-Grid systems

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ABSTRACT

This research paper presents an Adaptive Active Relay Protection (AARP) system for the failure state and abnormal operation states, such as short-circuits and overloads, in single phase Off-Grid systems. This proposed AARP system is intended for an Off-Grid system which contains several independent sources of short-circuit power and is able to change and configure itself for various operation states in the Off-Grid system. Moreover, the proposed AARP system is based on central control and real-time analysis of data acquired from electronic measuring devices. Presented paper includes a theoretical analysis and the experimental work is confirmed in practice.

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1. Introduction

A research team from the Department of Electrical Power Engineering, VSB-Technical University of Ostrava, Czech Republic, has developed a smart household platform operated in the Off-Grid mode (Off-Grid system) based on a hybrid energy system where Smart-Grid requirements are implemented. In order to deserve the attribute "Smart", the system must meet a specific set of requirements, namely: (i) autonomous operation independent of external power grids, (ii) operation with an equable generation-consumption balance, (iii) possibility of energy storage, (iv) predominant use of renewable energy sources (RES), (v) capability to serve non-traditional loads, (vi) operation under a sophisticated control system, and finally (vii) use of a new type of grid protection respecting the dynamic changes of short-circuit power [1–12].

An Off-Grid system is a system that is able to operate independently of the external distribution grid to feed power to the installed loads. Renewable energy sources, such as Wind Power Plants (WPP), Photovoltaic (PV) systems, storing energy in battery banks are predominately used as sources and the entire power system is operated under a sophisticated energy management system. The energy sources and energy storage systems are selected to match the power consumption of a conventional household and the investment cost.

In order to be able to analyze the operations of the entire power system, we developed a monitoring and control system to provide sufficient information for the final evaluation of all the elements in the Off-Grid system, such as the electric power quality, power flows, short-circuit conditions in the Off-Grid system, etc., see [1] for an on-line visualization of the given system. The design and implementation of the AARP system to limit the effects of short-circuit and overload is an important task in the Off-Grid system for smart household operation. The short-circuit current in the Off-Grid system is determined by the Off-Grid inverter with a battery bank, WPP and PV along with the power converters. The electric power generation from RES is stochastic in nature and this consequently has a negative impact on variations in the short-circuit current in the Off-Grid system as compared to a conventional low voltage distribution system (On-Grid) [2]. In addition, the short-circuit current in the Off-Grid system is usually several times lower than conventional On-Grid systems [3–6]. In order to ensure a selective and hundred-percent relay protection against short-circuits and overloads in the Off-Grid system, it is vital to modify the standard relay protection concept used in the conventional low-voltage networks with a considerably higher short-circuit current than in the Off-Grid system [7].

To protect the Off-Grid system operated in AC coupling topology from short-circuits and overloads, there are multi-agent protective systems, [8–10], along with digital relay protection and

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third-generation circuit breakers [11,12], able to ensure selective and hundred-percent protection against short-circuit and overload in the Off-Grid system [13–15]. The protection methods presented in [16–19] introduce a new approach for whole Smart-Grids. The most recent sophisticated protective systems are intended for higher voltage and power levels and they are not suitable to ensure low-voltage electric systems, such as an Off-Grid system against short-circuit and overload [20,21].

For this reason, we developed an AARP system which uses information about the current operation states in the Off-Grid system. Based on the proposed algorithm, it evaluates the current values in the different current circuits and makes further decisions based on the power values. This relay protection concept uses conventional protection elements, such as a circuit breaker with an under-voltage trigger. With the dynamically adjustable threshold values in the AARP system concept, the system may be applied on various power levels, from households to administrative buildings. The AARP concept is based on the regulations and standards intended for the basic protective measure requirements to be implemented in electrical wiring and installations with a voltage level of up to 1000 V AC [22,23]. The proposed AARP system is additionally based on central control and real-time analysis of data acquired from electronic measuring devices. The following chapters describe the sources of the short-circuit current, provide an analysis of failure states and continue with experiment measurements.

2. Description of the hybrid energy source in the Off-Grid system

The experimental platform of the Off-Grid system with the installed hybrid energy system (by hybrid we mean the cooperation of the WPP and PV system) was built on the campus of VSB-Technical University of Ostrava, Czech Republic, in 2011 and is operated in AC coupling topology. One of the advantages of the proposed power topology is that the WPP and PV system with their DC/AC inverters are connected directly to the single phase AC power system (the main connection bus-bar of the Off-Grid inverter −230 V/50 Hz, see Fig. 1) created by the Off-Grid inverter. The Off-Grid inverter is capable of making a bidirectional power flow with the help of battery energy storage, inverter and charger, allowing for stable operation of connected loads and power generation devices on the AC side. The output power of PV and WPP may be self-sufficient to meet the dependent load power without the need to load the Off-Grid inverter and it can charge the battery bank with the surplus amount of energy. The Off-Grid inverter can also cover the peak load demand. The Off-Grid inverters often use the frequency shift power control (FSPC) [24]. An FSPC controls the power frequency in the Off-Grid system. The Off-Grid inverter must be able to limit the output power if PV and WPP DC/AC inverters are connected on the AC side. This situation may occur when, for example, the battery bank of the Off-Grid inverter is fully charged and the PV and WPP power available from the PV and WPP system exceeds the power requirement of the connected loads. To prevent the excess energy from overcharging the battery, the Off-Grid inverter recognizes this situation and changes the frequency at the AC output. This frequency change is monitored by the PV and the WPP inverter and the inverters limit their power output accordingly [25]. This can cause frequency fluctuations within the electric power system up to 50 ± 5 Hz.

In this research paper the experimental platform of the Off-Grid system is used as a generic model in order to develop the proposed AARP system. The source with the highest rated output power is 3-phase WPP, with an installed power of 8 kW using a permanent magnet synchronous generator (PMSG) [26]. The generator's AC output voltage (3 × 425 V, 0–35 Hz) is rectified using a rectifier and the rectified power output is subsequently led through the WPP DC/AC inverter (with a maximum power output of 5.5 kW AC) to the single phase AC power system, see Fig. 1 for detail. The installed PV system is divided in this power system into two strings (PV_1, PV_2). The maximum power output of each PV is 2.1 kW p. PV1 uses polycrystalline solar cells technology. PV_1 is installed on the roof of a building. PV_2 uses monocrystalline solar cells. PV_2 is located on a 2-axis pointing device – the so-called tracker. Thanks to the positioning unit, the output is higher when compared with conventional fixed roof installations. The control unit allows for a maximum use of sunlight even in cloudy weather. The PV_1 and PV_2 power output is led into the PV DC/AC inverter, with a maximum AC output power of 4.2 kW with 2 × 2.1 kW Maximum Power Point Tracking input (MPPT).

For the purpose of testing the AARP system in the experimental Off-Grid platform, we define the following current circuits:

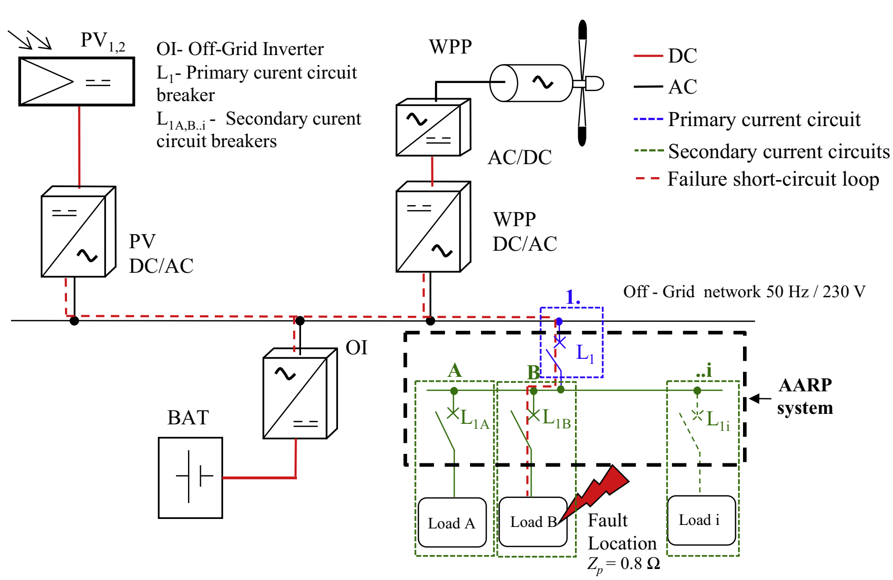

Fig. 1. Wiring diagram of the Off-Grid system using AC coupling topology.

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