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A service interruption free testing methodology for IEDs in IEC 61850-based substation automation systems

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ABSTRACT

This paper presents a methodology for the testing of intelligent electronic devices (IEDs) in IEC 61850-based substation automation systems (SAS), without any service interruption to the end users, during the testing process. IEC 61850-based SAS provides opportunities for a new level of substation operation, enhancing operating efficiency, and protection reliability based on Ethernet-based communication networks. Due to these changes to the conventional substations, importance and dependency on IEDs is increasing rapidly. Frequency of faults occurring in the power systems is random in nature and is unpredictable. It is necessary to test and maintain the IEDs to ensure their proper operation at crucial times. This paper presents a novel methodology for testing the IEDs, without compromising the service reliability during the testing process. The proposed methodology exploits the inherit characteristics of IEC 61850 standard i.e. Network - based communication, interchangeability between multivendor IEDs, and engineering based on substation configuration language (SCL) files. The feasibility and robustness of the proposed method has been verified by performing several performance verification tests with different performance metrics.

1. Introduction

The purpose of SAS is to enhance the operational capability of the substation through exchanging of information between different protective equipment in the network. The challenge with communicating between different IEDs is that they are developed by different vendors with their own exclusive technologies [1–3]. The research on the substation automation standardization emerged, from both the U.S.A and Europe at the same time in the beginning of the 1990s. EPRI in the U.S.A introduced the UCA 2.0 and IEC in Europe introduced the IEC 61850. Subsequently, both were merged into the IEC 61850, based on the data model and services of the UCA 2.0 [4]. IEC 61850 has led to a new era in power automation systems. It defines the layers, methods and protocols for communication between IEDs. It also defines data objects, formats, and configuration language for substation engineering [5–7].

Proper operation of the protective IEDs is a key step in achieving reliability and reducing service outages when a fault occurs in the power system. The effect of the fault could be propagated to the healthy regions if the fault on the power system is not cleared in time. In order to enhance the reliability of the protective IEDs, a dual and/or backup system is adopted for the power system protection. However, such applications using redundancy might result in an increase of incorrect operations in the system, although it can prevent the interruptions in the system [8]. Several researches have been carried out to overcome the faults occurred on the power systems. NVP is widely used to overcome the software-based faults [9]. In this method, mal-operations are removed by comparing the results from duplicative implementations of N programs by applying different algorithms [10]. The voting system is widely used to detect and eliminate faults in the hardware [11]. This determines the possibility of the mal-operation by comparing the results from the implementation of three duplicative systems. If one of the three systems shows a different result from the other two systems and the other two results are same, the system with the different result is considered to be a faulty system.

Occurrence of faults in power systems is random by nature and is unpredictable. Faults may occur once in a month, once in several months, or even once every several years. Therefore, it is necessary to test the health of IEDs and maintain them. Only associated IEDs need to operate promptly in faulty cases and avoid mal-operation during normal operation. Periodic testing of IEDs can ensure the desired operation. Service reliability may be affected during testing of IEDs. Various researches have been carried out to improve the reliability of service in power systems.

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Nomenclature

AIED	acting IED
CB	control block
CID	configured IED description
CM	configuration manager
CT	current transformer
DA	data attributes
DFT	discrete Fourier transform
EPRI	Electric Power Research Institute
TD	trouble detector
GOOSE	generic object oriented substation event
ICD	IED capability description
IC	IED configurator
IEC	International Electrotechnical Commission
IED	intelligent electronic device
LAN	local area network
LN	logical node
MMS	manufacturing message specification
MSF	manufacturer specific function
MSVCB	multicast sampled values control block
MU	merging unit
NVP	N-version programming
OCR	over-current relay
OPNET	optimized network engineering tool
OS	operational status
PRM	probabilistic relational model
PT	potential transformer
RTU	remote terminal unit
RTS	real-time simulator
SAS	substation automation system
SC	system configurator
SCD	system configuration description
SCL	substation configuration language
SMV	sampled measured values
SR	system recovery
SSD	system specification description
SV	sampled values
TIED	test IED
UCA	utility communications architecture
WAN	wide area network

The performance evaluation of data transmission in single and double bus networks in IEC 61850-based utility substations was evaluated by Kumar et al. [12] and the reliability analysis of the substation automation system functions using PRMs was proposed by König et al. [13]. A research based on OPNET for the performance analysis of a SAS architecture based on IEC 61850 was carried out in [14]. A protection system, which can overcome hidden failures in power systems, has been suggested by Gao and Thorp [15], while a simulation model of a typical power system substation communication infrastructure deployment of IEC 61850 for WAN applications was investigated by Golshani et al. [16]. Different issues, which arose during the design and implementation of IEC 61850 substations, were discussed in [17]. Different interoperability issues were discussed in [18,19]. A flexible IED that can support the free allocation of functions to IEDs by means of software reconfiguration only was proposed by Zhu et al. [20], while a backup IED, which can be remotely converted into any type of protective IED without IED exchange, firmware update, or field control, has been designed in [21]. Multi-agent smart grid automation architecture based on IEC 61850 and IEC 61499 with intelligent logical nodes has been proposed by Zhabelova and Vyatkin [22]. A multilevel management system for operation testing of a utility connected micro grid has been proposed in [23]. An ANN-based forecast for management of IED network using IEC 61850 has been proposed by Chemin et al. [24]. Protection schemes based on IEC 61850 and faults in relays have been analyzed by [25,26]. Several tests have been carried out for practical implementation of smart grid by using IEC 61850 by [27–30]. A lot of research has been done on reliability analysis [31] and the enhancement of the reliability of power systems by utilizing IEC 61850 [32–35]. Periodic testing of IEDs is also necessary to ensure the proper operation of IEDs during faulty scenarios. Continuation of service to the end users during these tests is also necessary to increase the overall reliability of the power network.

2. Testing of IEDs and novelty of proposed method

Several types of tests are required against the specifications, from the product development through installation to the disposal (end of life) of IEDs [36]. The general tests for an IED are

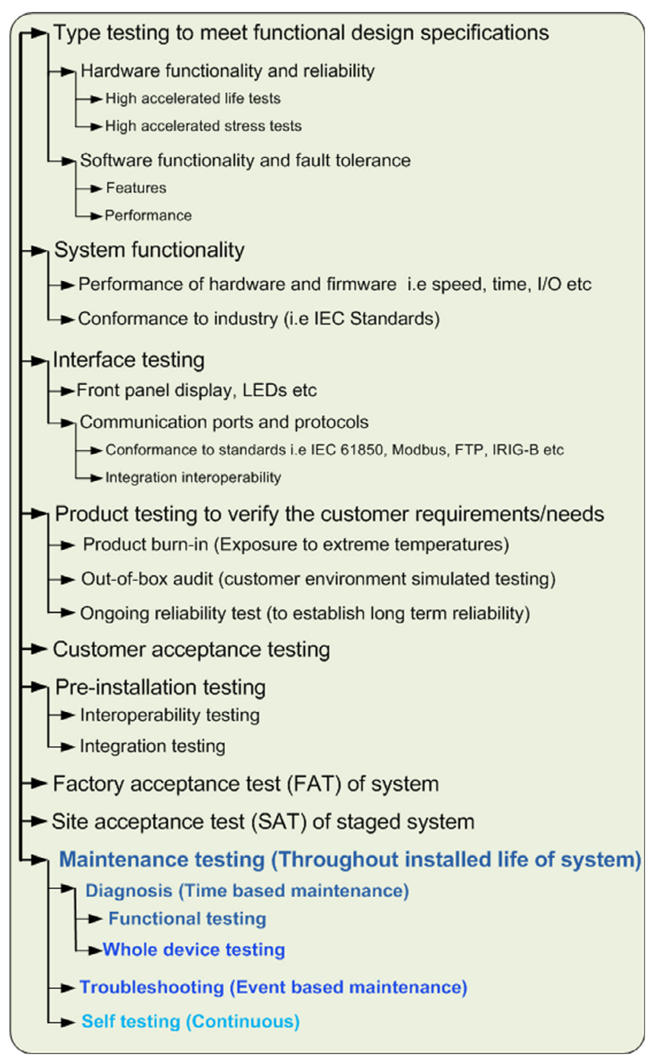

Fig. 1. General tests for an IED development.