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Maintenance and Repair Guidelines for DCS Substation Automation Systems

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***Abstract*— This paper outlines the professional qualification assessment for maintenance and repair personnel specifically focused on DCS (Digital Control System) substations. It emphasizes the significance of maintaining and ensuring the reliability of both active and passive components within the automation system.**

Keywords-component DCS Substations; Substation Automation Systems; Power Grid Reliability; Equipment Stability; Automation Brand Diversity; Maintenance Cycle Frequency

I. Introduction

Ensuring the reliable operation of power transmission and distribution automation systems heavily relies on the stability and high reliability of the associated equipment. The diverse range of automation brands within the national power grid, coupled with limitations in maintenance personnel, presents ongoing concerns for the effective operation of these systems.

To standardize maintenance practices and mitigate subjective behaviors, the "Guidelines for Maintenance and Repair of Substation Automation Systems" were developed based on the power transmission price list items provided by the Organization of Budget and Planning.

In the domain of distributed control systems (DCS) applied in Smart Grid technology, several key facets have been explored and implemented [1]-[2]. For instance, the development of real-time simulators conforming to IEC 61860 standards has proved instrumental in modeling various control system components, communication protocols, and Human-

Machine Interfaces (HMIs) [1]. This simulator, utilizing platforms like OMNeT++ and MATLAB/Simulink, not only aids in evaluating IEC standards but also serves as an educational tool for operators in high voltage substations.

Another significant area of exploration involves safety assessments of substation earthing systems, crucial for maintaining safety standards [2]. Studies like the one conducted on a 132kV substation assessed soil resistivity variations' impact on earthing system safety. Utilizing CDEGS™ software, the study evaluated actual resistances and soil values, highlighting instances where safety limits were exceeded according to IEEE standards.

Further research delves into practical implementations of modern DCS in the energy sector, especially in power transmission and distribution substations [3]. The shift toward modern automation solutions presents benefits like increased productivity, cost savings, and enhanced safety operations, adapting efficiently to the evolving IT landscape. The emphasis lies in presenting optimal DCS designs aligning with customer requirements, international norms, and cybersecurity aspects.

Moreover, the adoption of Process Bus Solutions in substations has transformed traditional approaches [4]. This shift, as exemplified by Araz Energy's projects in Azerbaijan, emphasizes the pivotal role of the Process Bus System in shaping the design, operation, and maintenance of substations. Lessons learned from such projects underscore the changing landscape toward Digital Substations.

Exploration into the static stability analysis of HVDC systems [5] demonstrates the assessment of system performance using novel indices like Multi-send Short Circuit Ratio (MSSCR). Research on Yunnan Power Grid's 7-point DC output highlights the efficacy of MSSCR in evaluating the mutual coupling relationship between multiple DCs.

The evolution of automation in distribution systems [6] signifies a pivotal advancement, enhancing control flexibility and improving reliability. Leveraging advancements in information and communication technologies, automation plays a crucial role in fault isolation, load transfer, and energy consumption display, ultimately enhancing service efficiency.

Application-based discussions [7,8] underscore the benefits of IEC61850 in various industrial sectors, including Oil & Gas and urban rail transit. These applications utilize IEC61850's capabilities in fast load shedding and data optimization between substations, paving the way for efficient communication protocols and innovative applications.

Continuing the trend, endeavors toward the integration of IEC61850 in industrial power distribution systems [9,10]emphasize the transformative impact on legacy grids, steering them toward a smarter grid framework. These approaches aid in achieving real-time data acquisition, communication, and automatic control while ensuring interoperability among diverse IEDs.

Additionally, discussions on high-voltage AC/DC power supplies for urban rail transit [8] highlight comparisons between traditional and proposed power supply systems, focusing on energy utilization and mitigation of rail potential and stray current issues.

Lastly, advancements in process control systems for hydroelectric power plants [13] demonstrate the integration of control systems based on IEC 61850 standards, emphasizing the transmission of consolidated data for effective decision-making.

Power system facese to some challenges and it can be consider such as: The ever-evolving landscape of power systems has seen a surge in research aiming to enhance stability, protection mechanisms, and the integration of renewable energy sources. This literature review explores significant advancements and challenges in this domain, encompassing studies on under-frequency load shedding, wind power integration, grid protection, innovative solutions in HVDC systems, maintenance strategies for automated substations, optimization methods for system reliability, and adaptations in protection schemes due to distributed resources.

Enhancing Grid Stability :Under-frequency load shedding (UFLS) remains a crucial operation to avert power system collapses during disturbances. Recent studies have delved into novel methods of UFLS, emphasizing decentralized approaches that efficiently identify load disconnections and restore system frequencies. Simulation results on IEEE standard systems highlight the superiority of these approaches compared to conventional methods[14]&[23,24].

Challenges in Wind Power Integration: Integration of wind energy introduces unique challenges, notably concerning Low Voltage Ride-Through (LVRT) for Wind Energy Conversion Systems (WECS). Reactive power support during faults and issues with series capacitors in high-voltage lines have prompted research focusing on solutions for wind power plant contingencies[15].

Adapting Protection Mechanisms: Traditional protection methods face adaptations due to the influx of distributed resources. Efforts to ensure the coordination of recloser fuse protection schemes under varying fault currents from distributed sources have been examined. Similarly, challenges in transmission line protection, especially in the presence of series capacitors, have been identified and addressed in recent studies[16,20].

Innovative Solutions in HVDC Systems: The utilization of Plug-in Hybrid Electric Vehicles (PHEVs) as an alternative to active filters in High Voltage Direct Current (HVDC) lines showcases a forward-thinking approach. The potential of leveraging PHEV battery state of charge for grid applications presents a cost-effective and environmentally friendly alternative[17].

Substation Automation and Maintenance: Maintenance strategies for automated substations have been reimagined to accommodate cyber-physical information modeling and panoramic views of substation components. Leveraging IEC61850 standards, studies advocate for enhanced data attribute definitions for both analogue and digital equipment, highlighting the benefits of server virtualization in reducing reliance on protocol converters[18,22].

Optimizing System Reliability: Efforts to optimize power system reliability through smart grids, distributed generation, and PHEV integration have emerged. The utilization of genetic algorithms to determine optimal parking lot sizes for cost-effective reliability improvements showcases a promising avenue for future research[19,21].

The reviewed literature highlights the ongoing endeavors to fortify power systems against disruptions, integrating renewable sources, and redefining maintenance and protection paradigms. Embracing decentralized approaches, innovative technology applications, and adaptive protection mechanisms are pivotal in shaping the future of stable, resilient, and sustainable power grids.

II. Objectives

Establishing maintenance and repair protocols for transmission and distribution automation equipment based on the Organization of Budget and Planning's transmission price list items.

Creating uniform procedures for the maintenance and repair of substation automation equipment.

III. Operational Methods and Regulations

Conduct maintenance and repair processes according to the service codes outlined in the transmission power price list items.

This guideline supersedes all previous directives and notifications concerning the maintenance and repair of substation automation systems.

IV. Maintenance Cycle

The maximum frequency for executing each service code in the DCS system maintenance and repair program is twice a year.

V. Test Results for Maintenance and Repair

Completed and confirmed: The item was correctly performed, and the test result fell within acceptable parameters.Completed but not confirmed: The item was performed, but the test result was inaccurate or outside the acceptable range.Not executed: The specified test was not performed within the maintenance and repair schedule.Not required: The test was unnecessary within the maintenance and repair program.

Definitions

System: A collection of various components that interact to perform a common function.

Automation System: Comprising numeric and computerized equipment responsible for controlling and monitoring a process using digital and analog information.

Substation Automation System: A system responsible for control, monitoring, and protection operations in a high-voltage substation using numeric technology and communication systems.

Intelligent Electronic Devices (IED): Devices containing one or more processors capable of exchanging information and performing processing tasks.

Human-Machine Interface (HMI): Categorized into equipment panel-based and station-level interfaces for configuration, local control, and workstation use.

Active Equipment: Includes server computer systems, HMI computer systems, engineering computer systems, IEDs, industrial switches, serial to Ethernet converters, and time servers.

Passive Equipment: Comprises accessories for computer systems (mouse, keyboard, monitor, and speaker).

Access Levels

Operator Access Level: Restricted to DCS substation operators for operational activities such as monitoring statuses, alarms, sending control commands, and displaying/archiving measurement values.

Engineering Access Level: Reserved for technical personnel to modify configurations, settings of IEDs, active network equipment, and automation software.

Management Access Level (Admin): The highest access level covering both operator and engineering levels, allowing changes to IED configurations and automation system settings.

V. Maintenance and Repair Team for Substation Automation System

The minimum personnel requirement for a substation automation system maintenance and repair team and the maximum number of supported substations by a DCS team are detailed in Table 1.

Table 1 - Minimum Required Personnel for a Maintenance and Repair Group

	Expert	Technician	worker
The DCS Maintenance and Repair Group	2	0	0
The maximum number of substations supported by one DCS group is 30 substations.			

Equipment of the Maintenance and Repair Group

The required equipment for a DCS group is determined according to Table 2. Please note that these are samples.

Table 2 - List of Hardware and Software Equipment Required for Each DCS Substation Maintenance and Repair Group.

Row	Device Name	Quantity	Description
1	Power Tester	1	To test the power supply of computer systems, as required by the client
2	Optical pen for testing the optical fibers of the automation system (multi-mode fibers).	1	
3	Network cable tester	1	
4	Industrial blower and vacuum cleaner	1	
5	Protocol analyzer comprising at least the following protocols: Modbus IEC61850 IEC60870-5-101,103,104	1	
6	A computer network analyzer software similar to Wireshark	1	the software will be acquired in accordance with the client's preferences.
7	A hardware examination software for computer systems, similar to CPU-Z,	1	the software will be acquired in accordance with the client's preferences.

Periodic Maintenance Service and Testing Codes for DCS Substation Equipment

row	Item Description	unit
1	Monitoring the Status of Required Documents for the High-Pressure DCS System (As per the Relevant Test Sheet).	station
2	Inspection and Cleaning of DCS System Panels at the Station	Tablo
3	Control of Archive and Validation of Event Logging	station
4	Inverter Inspection, Control, and Servicing	Device
5	DCS Station Computer Inspection and Cleaning	Device
6	Verification of Peripheral Equipment Functionality (Monitor, Printer, Speaker, Mouse, Keyboard, etc.)	station
7	Review and Control of Version Recording and Specifications of All Software, Examination of Licenses, and Hardware Locks.	station

Description of Maintenance and Repair Service Code Activities for DCS System

Following this, some of the maintenance service codes will be elaborated upon.

The service code 50101 entails "Monitoring the status of the required documentation for the high-pressure DCS system (in accordance with the relevant test sheet)."

A complete list of all DCS system equipment, along with technical specifications, IP addresses, Modbus addresses, serial numbers, Order Codes, connector types, panel names, relay-to-relay communication lists, equipment work credentials, DCS operating procedures, interlock logic diagrams, firmware versions for measuring devices and network active equipment, DCS signal lists, gateways, and communication diagrams must be prepared, controlled, and updated during each maintenance and repair cycle. These equipment items include:

- Relays
- Switches
- Transducers and converters
- Measurement units
- Servers, HMI, gateways, and engineering systems
- Inverters

Service codes 50102 and 50105 respectively denote the following activities: "Inspection and cleaning of DCS station panels" and "Inspection and cleaning of DCS station computers."

Computer system hardware should be cleaned using a blower in a suitable method, preferably in an area outside the control room.

The rotational speed of the fans should be visually inspected. If any faults are detected, replacing the fans is recommended.

Pay attention to server output sounds and identify any unwanted or additional sounds.

The status of alarms in the server hardware case needs to be checked.

Electronic components on motherboards, including capacitors or peripheral cards, should undergo visual inspection and be replaced if necessary.

All panels related to switches, servers, and patch panel boxes should be cleaned by the DCS maintenance and repair team. Cleaning should be done using cleaning cloths, nano wipes, and a specialized cleaning spray. Note: The cleaning spray must meet the standard requirements and not cause damage to electronic equipment, casing, components, or the visual appearance of the case.

The performance of the heater, panel fan, signal lamps, panel illumination, locks, handles, panel sealing, etc., must be examined and controlled by the maintenance and repair team.

The set temperature for the control room panel heaters and BCR room panels is 15 degrees Celsius.

The set temperature for the control room panel fans and BCR room panels is 25 degrees Celsius.

The integrity of the grounding connections for the automation system panel and panel equipment should be checked. If absent, all panel equipment in a panel should be grounded by a bar within the same panel, and each equipment should be individually connected to this bar.

Recording the temperature and motherboard voltage via computer system biasing must be performed.

Service Code 50103 pertains to controlling the archive and validating event registrations. The accuracy of the following items should be examined in this service code at each stage of maintenance and repair activities:

The event list must be stored and archived daily with timestamp details.

Archives should be stored on a drive separate from the operating system drive.

Old archives should be deleted, while archives from up to 3 years ago should remain accessible.

Control over Acknowledge and Reset processes for alarms should be executed.

The possibility of generating reports with the option to select specific time frames, regions, event sources, and priority of occurrence should be examined.

Service Code 50503 involves creating an archive from the protective and control relay configuration software. The relay configuration software's archive should be generated during each maintenance or repair procedure or whenever changes in configurations and settings occur. These archives should be stored not only on the hard drives of the station's systems but also on an external hard drive. Before archiving the engineering system's relay configuration, ensure that the IEC61850 file for the relays is up-to-date, and then proceed with archiving.

The required files for relays from various brands are as follows:

Siemens scheme: Digsi software archive file

GE scheme: UR and F650 relay files and F650 relay logic file with *.pep extension

ABB scheme: PCM software archive file or Series 500 relay software

Sprecher scheme: E-tools software archive file related to the entire project (including control relays labeled SPRECON E-C and protective-control relays labeled SPRECON E-P if present in the station)

For other brands, file extraction should be performed according to the client's preferences. Update the IEC61850 file of the relays and reload it onto the relays. Note down the firmware version, relay model, protocol, and relevant name in the test sheet for any relays that have discrepancies in their IEC61850 files.

Service Code 50504 aims to verify the accuracy of the display and archive of measurement device values. The following aspects need to be examined in this service code:

The accuracy of sending measured values to the automation system by comparing the device-measured values with the values displayed on the HMI pages should be checked. (All defined parameters on the HMI pages need verification.)

Ensure the correct polarity alignment of numbers and check for values not being frozen.

In this item, the accuracy of Daily Report pages and hourly value registrations will be scrutinized. One of the aspects to be examined is the complete recording of values in all hours of the day and ensuring the absence of frozen values in the recorded data. This is important because a constant value might be recorded for consecutive hours.

Validate the trend of measurement values.

Record the firmware version, device model, protocol, and any relevant name in the test sheet.

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