Development of Software Applications to Enhance Demonstration Site Efficiency

Abstract

The DC-grid protection scheme developed for both medium voltage (MV) and low voltage (LV) levels, addressing the lack of standardized global approaches, is enhanced with a **WAMPAC** (Wide Area Monitoring, Protection, and Control) system to monitor AC/DC connection points in real time, providing grid status updates and control instructions to active grid assets, including disconnecting elements during anomalies. The high level of digitalization within TIGON grids includes a robust **cybersecurity defence system**. To ensure secure and optimized energy flow management at each demonstration site, a smart **energy management system** (EMS) is be developed to centrally control the microgrids, leveraging the enhanced capabilities of new converters and transformers. TIGON also uses the project's results to develop a **Decision Support System (DSS)**, providing guidelines for grid expansions and the development of new hybrid grids across the EU.

WAMPAC System Development

The main protection challenges faced in DC networks are:

- Standardisation
- Interrupting DC faults
- High-speed requirements
- Lack of expertise

In order to address these challenges, WAMPAC system for hybrid grids developed has two main components. First, it involves proposing a novel **protection algorithm for DC microgrids**. Second, it includes the **creation of the TIGON platform**, which can manage sampled values and GOOSE messages at 96 kHz and 12.8 kHz. This platform also facilitates the implementation and execution of the proposed protection algorithm. By using the TIGON platform, preliminary tests of the algorithm can be conducted more efficiently, significantly reducing the testing time required before final implementation.

DC Protection Algorithms

A protection algorithm has been developed to be applied in DC microgrids based on the differential current magnitudes and the calculation of the current derivatives.
The DC microgrid shown in Figure 1 is used to check prosed algorithm performance. As shown in the figure, the DC microgrid is composed of three feeders (Feeder 1, Feeder 2 and Feeder 3). Each feeder contains a power converter, two contactors (Cont) and two current transducers (TI+ and TI-).
The protection algorithm must selectively isolate faults on DC busbar (VDC+ and VDC-) and on each feeder. With this aim, the proposed algorithm considers 4 Protection Zones for its operation: Protection Zone 1, Protection Zone 2, Protection Zone 3 and Protection Zone 4.

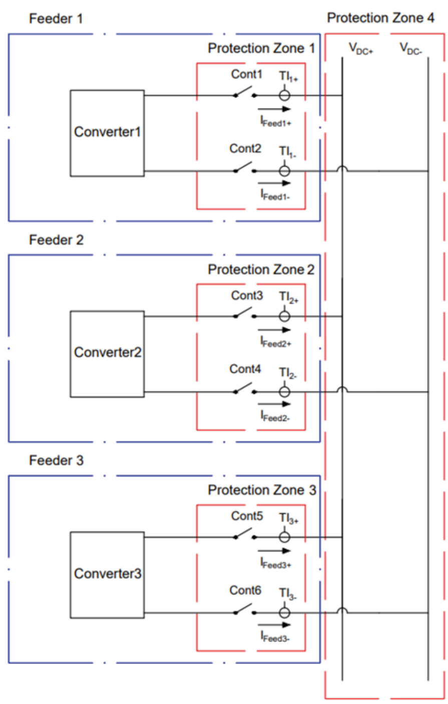

Fig. 1: *DC microgrid used to check algorithm performance.*

The grid model is used to verify the suggested protection algorithm. Initially, offline simulations are used to model it in RTDS. After the algorithm has been debugged, the C++ programming language is used to implement it in the TIGON platform. A number of experiments have been conducted to assess algorithm performance when operating in hardware-in-the-loop mode.

Platform description

The software runs on a Lenovo ThinkSystem SE350 with 16 Intel Xeon D-2183IT processors (32 cores) at 2.2 GHz and 64GB of memory. The Xeon processors have TDP ratings of up to 100W. The server's "Edge Computing" design, with smaller dimensions than traditional servers, allows for wall mounting, shelf stacking, or rack installation, offering flexibility for integration into existing data center grids.
The operating system installed is Rocky Linux 9.2 (Blue Onyx) with a minimal installation. The software stack includes C++ libraries developed for receiving and subscribing to IEC 61850 Sampled Values (SVs) and GOOSE messages. These user-friendly and high-performance libraries, created and tested within this project, can handle high sample rates like 96 kHz.
The libraries' main input is IEC 61850 XML files (e.g., CID files), which define network settings, communication parameters, and datasets for publishers and subscribers. Upon reading the CID file, the library can be instantiated in either publisher or subscriber mode. In publisher mode, it emits data based on the CID configuration. In subscriber mode, it receives ethernet frames, decodes the information, and allows users to set a callback triggered by the arrival of new data frames (SV ASDU or GOOSE PDU).
The algorithms proposed in this work are also developed in C++ using these libraries.

Implementation and Results

A laboratory testbench was implemented for validation tests, comprising a real-time digital simulator (RTDS), the TIGON platform, and various communication devices. The DC microgrids from the project's demo sites were modeled in the RTDS, enabling hardware-in-the-loop testing.
Validation tests included solid and resistive faults in each protection zone of the grids, energization transients of power converters, and load variations. The test results demonstrated that the proposed protection algorithm operated correctly in all scenarios, acting selectively by generating trip signals for contactors on the faulted feeder and opening all contactors in the event of busbar faults. During laboratory tests, the protection algorithm achieved operation times ranging from 1.1 to 2.3 milliseconds.
The solution proposed in this study serves as a recommendation for both CEA and CIEMAT demo sites, with CEA and CIEMAT making modifications based on their specific facility requirements.

Primary Target: Energy distribution

Energy Management System Development

The EMS was implemented in the TIGON CEA pilot. It was designed to be flexible enough to suit different types of microgrids or TIGON pilots, such as the CIEMAT one.

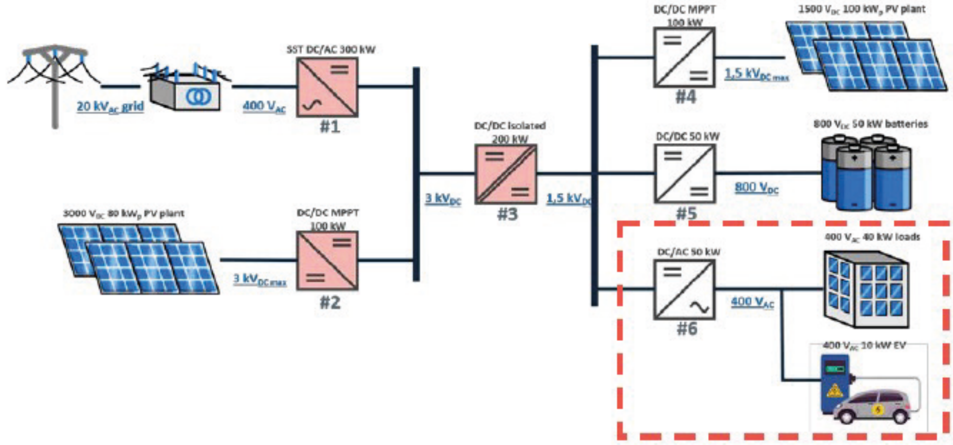

Fig. 2: *Architecture of the EMS*

The initial work, which focused on defining the logical blocks and simulating an optimization approach, specified the cloud service based on a centralized optimization problem and the PMS, which hosts the local power and hazard management functions. Given a non-complex objective function and a single location, the distributed method was deemed unsuitable due to latency issues arising from the search for a common plan among device groups.
Subsequently, the EMS and centralized optimization algorithm were tested with real data profiles. Special effort was made to separate the power management layer, embedded in the demonstrator, from the optimization layer running on a remote server. Particular attention was given to securing data exchanges between these two layers, with the overarching goal of enabling easy PMS deployment across multiple sites while sharing a single optimization service.

Advantages of using the EMS

- Ability to control generation and consumption
- Ability to optimize energy production
- Ability to reduce the energy bill by minimizing spare energy and, consequently, energy costs
- Ability to reduce environmental impact

Primary Target: Energy distribution

DSS tool for hybrid grid planning, operation and cost-efficiency

The Decision Support System (DSS) tool is used to design and operate the hybrid AC/DC grids of the demo sites in a cost-effective manner. This tool can also be applied to other hybrid AC/DC grids beyond those in the demo sites.
The DSS tool has been implemented as a web-based service, enabling users to simulate their own hybrid AC/DC networks and test various configurations before actual deployment. Additionally, the DSS can conduct cost-benefit analyses to evaluate the profits and costs associated with different AC/DC grid configurations, assisting users in selecting the most optimal hybrid grid setup and asset combinations. Furthermore, the DSS provides recommendations for emergency situations, including blackout recovery strategies.
The DSS is accessible at https://dss-tool.cartif.es/auth/login. Users must register to use the tool. No relevant information is stored, and the DSS does not retain any memory of the evaluated AC/DC grids. Users describe their hybrid grid through a self-explanatory Excel-based form. Results are provided in a PDF report that users can use to assess their AC/DC grid design.
The DSS's AC/DC load flow computation capability has been validated by comparing its results with those ob-

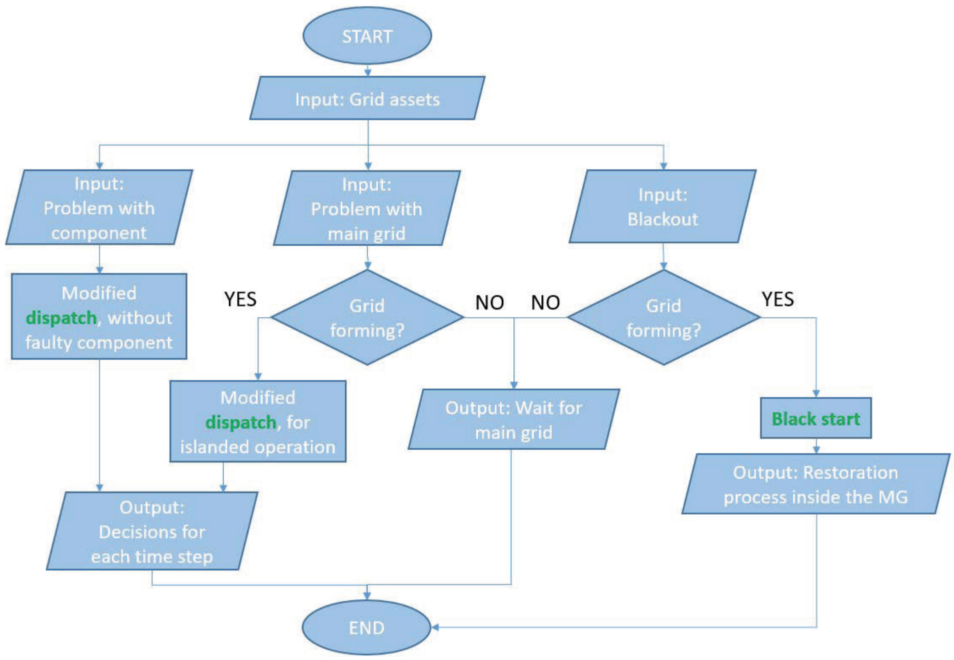

Fig. 3: *Emergencies and grid restoration in a distribution network.*

tained using DIgSILENT PowerFactory, with satisfactory outcomes. It has also been validated using the descriptions of TIGON's demo sites. Load flows were computed successfully, and various emergency scenarios, including blackout with direct reconnection to the main grid, were simulated. Techno-economic indicators were computed for both demo sites.

Cybersecurity defence measures

The cyber-security plan customized for TIGON, encompasses Vulnerability Assessment, Security Behavior analysis, Anomaly Detection, and Security Information and Event Management processes and thus provide a complete set of defence measures to address the challenges of attack scenarios on the grid network.

After conducting a comprehensive study on the regulatory landscape concerning data protection and cybersecurity, the focus was on:

- Network and Information Security Directives (NISD)
- Cybersecurity Standards in the power industry chain
- Documents from regulatory authorities
- Collection of legal instruments
- Review of Commission recommendations on cybersecurity in the energy sector dated 3.4.2019 (C(2019) 2400 final), relating it to the TIGON project
- EU Regulatory Framework in the Energy Sector

Following this, the Security Operations Center (SOC) component is introduced.

The SOC utilizes the Wazuh platform and employs advanced techniques to automate the translation of policy requirements into implemented mitigation measures, overcoming the drawbacks associated with using monolithic or complex security functions. When applying mitigation measures, the SOC considers both SOC agent logs and generated threat-based alerts. The main components of the SOC include SOC agents and SOC manager.

Primary Target: Energy distribution

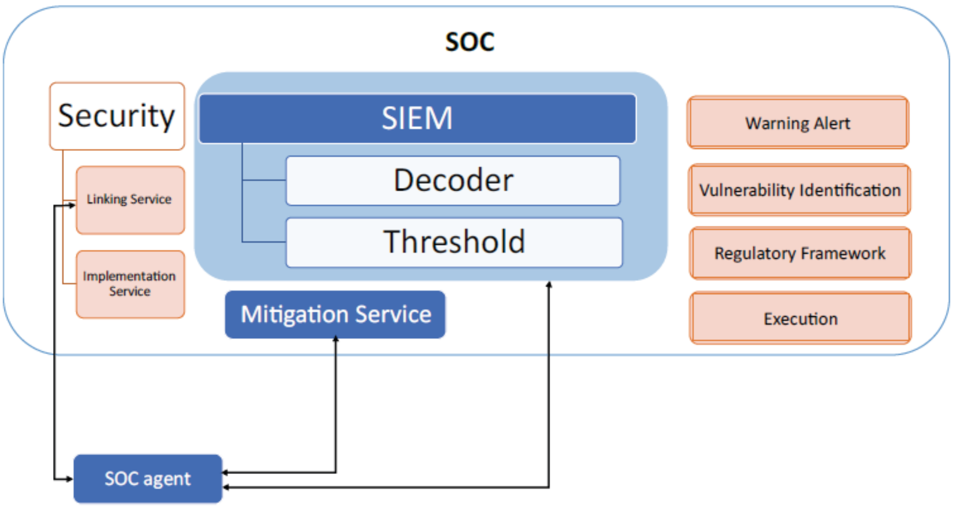

Fig.4: *High Level Architecture of SOC.*

Keep in touch:

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