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The Design and Implementation of IEC61850 SBUS Server Island Detection Using a New Algorithm and Futuristic Interface Communication

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Abstract

The boost insertion of DERs, large-scale PV, and wind energy are included in the power distribution grid network, while fixed series (FSC), static var (SVC) compensation, shunt capacitors, and reactors in the transmission grid network stabilize the power system. The smooth-running system requires secured and reliable island operation to avoid blackouts and brownouts. The unpredictable grid abnormalities such as DC supply failure, BCU faulty, server redundancy failure, mal-operation of the line protection, CBF protection, BB protection operation, and lack of redundancy or mal-operated controller logics/hardwired contacts or causes of human errors in some cases could cause unintentional remote islanding. This paper proposes a new algorithm with the unique design of adoptive logic developed first time at station level IEC61850 grid controller in SBUS Server EcoSUI Engineering software to enhance the reliability and system redundancy which manipulates real-time grid variables instead of measuring only the PCC voltage, therefore there is no NDZ issue and power quality problem hence detects export power failure (demand) at the grid and intimate plant controllers remotely to de-synchronize the generation (supply) for overall island operation, then proposed best-standardized communication interfacing topology between grid controller to plant controllers.

Disciplinary: Electrical Engineering and Technology.

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1 Introduction

The stable power network should adhere to the rate of increasing DERs insertion into the system is a challenging demand for power utilities, require transmission system enforcement as power consumption expected to be double by 2050 [1]. Recently, Distributed Generation (DG), large scale PV as well as wind plants have been developed rapidly [2, 3], however, it involves complex challenges. Where the most crucial requirement is the islanding scenarios to be detected due to loss of main Utilities.

There are two islanding operations, the intentional islanding is a general planned operation for scheduled maintenance that is safe for the system, however, unintentional islanding occurs due to an unexpected fault incident that immediately requires to de-synchronize the grid at PCC [4] and directly impacts network stability. As a result, frequency and voltage become out of desired ranges w.r.t grid, and this hazard could cause electrical devices and system equipment damages. Therefore, such unintentional & uncontrolled islanding should distinguish the fault and island condition, The IEC 62116 and IEEE 1547 standard [5] conclude that the PV system requires to be isolated from the grid within 2 seconds after islanding conditions attained.

The selectivity of the island detection method must realize the following factor such as reliability and NDZ limits, operating time, Impact on the grid power quality and transient response, installation and running cost, grid topology, grid BB scheme, grid variables V, I & P, and type of faults [6, 7].

The islanding detection methods are divided into local and remote methods. The local methods and their sub-categories can be overviewed [8] in detail. The remote island method is based on communication detects islanding situation from grid variables and send a signal to DGs or power plant by sort of communication such as PLCC that transmits a continuous signal via the power line to the DG [9], Signal extended by disconnect at grid requires unique transmission. while SAS/SCADA uses grid IEC61850 controller to detect the island condition [6] which is most efficient and reliable.

The smart remote islanding detection method is categorized into operating principles and the Internet of things (IoT). The operating principle island detection based on synchro-phasor [10],[11] which further categorized in PMU based which detects islanding by angle difference method and slip acceleration method while distributed controlled island detection uses 87L line difference communication for transfer trip [12]. Also, the centralized islanding detection method utilizes the loss of mains (LOM) protection algorithm [13].

In the Internet island detection method, the export power failure indication by circuit breaker status is broadcasted over a virtual private network (VPN) among the stations. A VPN is implemented between stations. Control signals such as circuit-breaker status are broadcasted through the Internet. This broadcast status is encapsulated in a message data ‘ping’ payload[14].

The computational intelligence techniques methodology has been described in [15].Islanding protection using Neuro-fuzzy system and wavelet analysis in distributed generation inverter-based researched into [16, 17]. An adaptive artificial neural network controller was proposed [18] to reduce the NDZ. The droop control and Variable Impedance insertion [19] methods also offer different solutions to the subject. The islanding detection based on FPGA is elaborated in [20].

The regional island detection method proposed in [21] implemented a load change method to detect islanding by regional control devices.

The remote islanding is cost-effective but reliable and provides better performance over conventional method to detect island time to be analyzed, The processing delay in island detection algorithm such as 100ms in CID and 1.25 sec in PMU based [6] to be considered.

The main grid where PV or conventional power plants are connected could have multiple bus bar schemes, In Saudi Arabia normally EHV substation has a ½ Circuit Breaker scheme, HV Substation has a double bus bar configuration while the LV grid has a single Bus Bar scheme. The existing island detection in the grid controller is not enough to decide whether the grid is fully dead or its export energy failed. The only software-dependent island signal is extended to power plants for islanding operation therefore it is necessary to verify all possible scenario to identify that the grid is really dead or its export MW has failed to avoid island mal-operation, hence software and hardware interlocks along-with 2oo3 redundancy technique must be ensured for operational system reliability.

Most researchers have worked on IEC61850 bay level island detection engineering [1, 22, 23, 24, 25] by GOOSE, Data Object modeling, and report through data module methods, which are lack of redundancy issues. The proposed method first time is introduced at station level engineering which superscript and provides multi-level redundancy for island detection and its successful operation.

2 Proposed System: Engineering and Design

2.1 IEC61850 Grid Controller Island Detection Engineering

The Substation automation system is comprised of three-level such as process level, Bay level, and station level. The island command can be configured at station level and bay levels, There are three ways to detect loss of grid or export power failure in IEC61850 SAS Engineering such as, at Station level, In Common BCU by GOOSE and Report through data module Method forming BCU network as open system interconnection (OIC) or IEC-IEC gateway in which all concerned desired feeder BCU will report to common BCU which will work Server for them, This IEC-IEC gateway interconnects to station level and report to main controller and gateways. The disadvantage of both bay level engineering is as all concerned BCU signaling in a network will not report to station level in case of common BCU failure.

The engineering process for an IEC 61850 project, starts with collecting each BCU/IED's ICD/CID/MCL files at bay level, these files are merged into an SCD that is unique for the entire grid. The signals are mapped to station level by defining the data sets, logic, MMS, GSE, GSSE, and

GOOSE messages containing information (Analog/Digital, SPC, DPS, regulating step CMD, set-point and T/F step indication) for engineering operation.

2.2 EcoSystem User Interface (EcoSUI) Island Detection Engineering and Redundancy

EcoSUI is the operating interface (HMI) that provides the user with an interface for all operational and engineering functions which facilitates both HMI and server engineering and allows supervisory and controlling a grid. It communicates with other EcoSUI modules such as the central DataBase (DB), and Station BUS (SBUS) Server, see Figure 1.

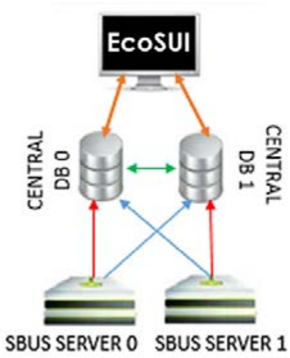

Figure 1: Island Detection Redundant communication

The central DB gets the configuration that is stored locally on each computer while the SBUS server gets live values from SBUS equipment and retrieves data from BCU. There are two central DB (DB0 is main and DB1 is redundant) and get an update in parallel which provides the redundancy for configuration, Alarms, Events, Measurement, and Live Values which are real-time variables to be used in island command configuration. If the Main Central DB is absent during EcoSUI or SBUS Server startup, they will retrieve their configuration from the Backup Central DB, and If One Main SBUS Server fails, status and values on EcoSUI keep updated to its backup SBUS Server, therefore there are rare chances to fail island initial in a dual redundant system. The EcoSUI HMI allows the operator to supervise, control and maintain the substations in a very quick and intuitive manner.

2.3 The Proposed Island Detection Algorithm

The proposed logic is prepared at station level in EcoSUI SBUS server engineering application because it has the advantage to collect all data point of station level as well as bay level simultaneously which provide easy access for island configuration.

The proposed method is unique from other conventional methods reported as it detects loss of grid by substation real-time variables. The proposed island detection logic and coding were designed for a 132KV substation where a double BB single circuit breaker scheme was used. This logic will verify that substation export energy is failed (called dead grid) and the power plant must go in islanding to keep a balance between generation and load. As per designed logic in Figure 3 and algorithm in Figure 2, the substation is said to be a dead grid or consider as export energy failed when exported power feeders or line circuit breaker DPS/SPS Open status achieved due to its concerned protection operated or planned operation, grid export MW is less than -1, dead pole detection <30% or no voltage archived and concerned BCU is valid or healthy. This same logic of each exported feeder to be multiplied as per requirement and exported feeder status to be checked by the intelligent controller from HMI/Servers measurement. The two Circuits A and B are considered as exporting power for testing purposes.

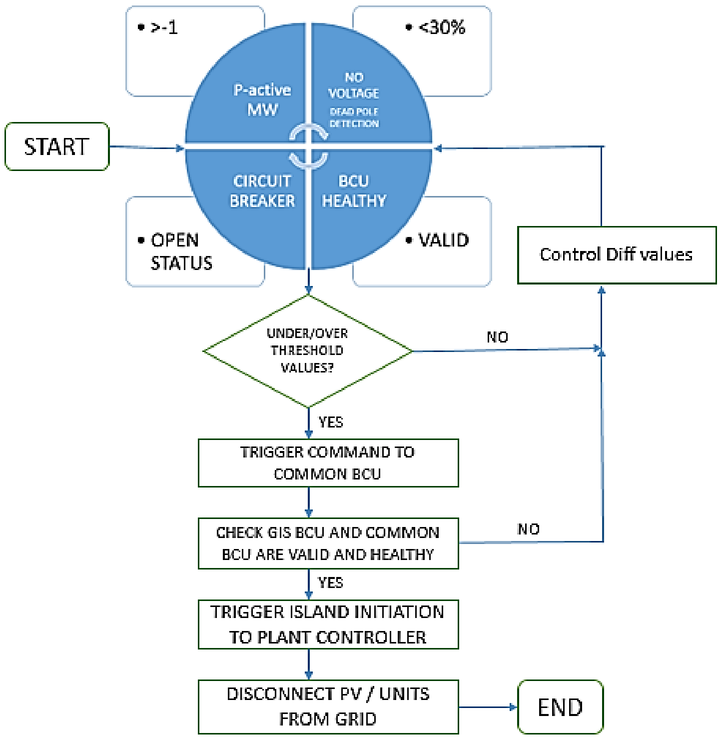

Figure 2: Proposed Island detection algorithm.

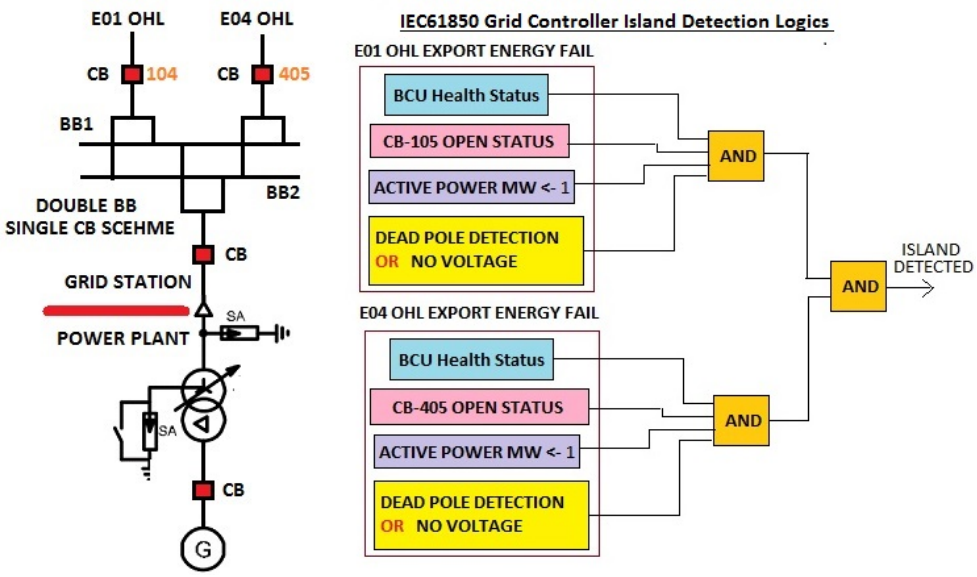

Figure 3: Grid Station SLD and proposed logics for island detection for ECoSUI SBUS Server.

For double and Single Bus Bar scheme suggested the same logics because of single controlling CB but ½ CB scheme requires two-controller CBs of each line so BB CB will have same logics while additional Middle CB open status and validity or a healthy status of their controlling CB are to be considered.

2.4 Proposed Island Logic Implementation in EcoSUI SBUS Server

The replica of proposed logic in Figure 3 described in algorithm Figure 2 has been implemented in EcoSUI SBUS Server presented in Figure 4 which will validate all assigned variables Figure 5 and then it triggers the command to Common BCU where it will operate output contacts of common BCU. The Common BCU configuration forming 2oo3 voting is represented in Figure 7. The complete system architecture and scheme can be seen in Figure 11.

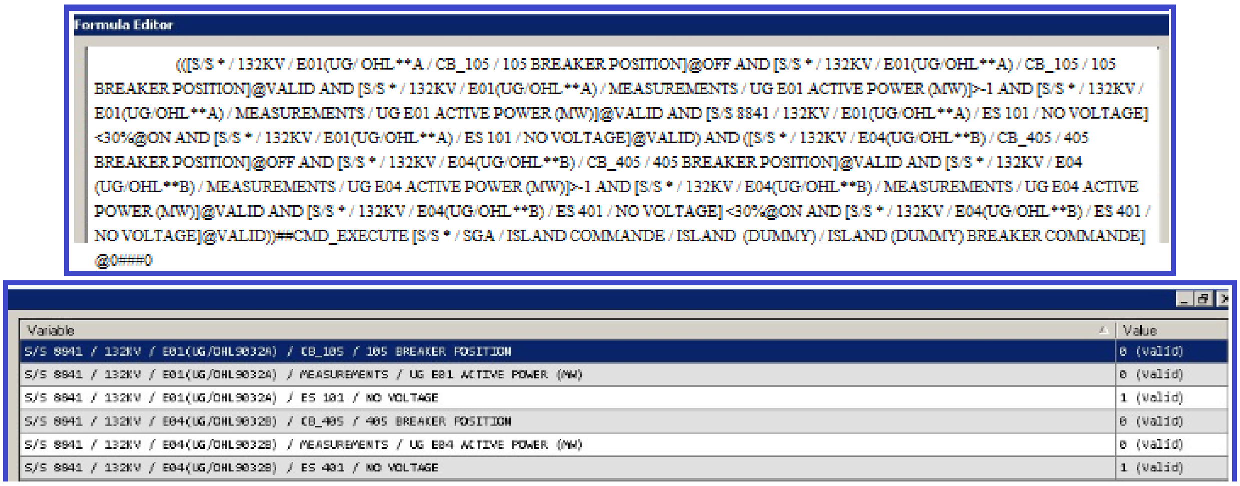

Figure 4: Island command and configuration in EcoSUI SBUS Server V2.4.

Figure 4 shows the encoding of logic formulated and implemented in EcoSUI SBUS Server for detail visualization, where * = substation name or code, ** = Circuit Name, E01 is Bay 01, E04 is Bay 04, and SGA is substation general alarm. In IEC standard +VE MW means the import and -VE MW the export. The variable used in this logic is shown in Figure 3 and its validity status is illustrated in Figure 5 while the possible action of this logic has been described in Figure 6.

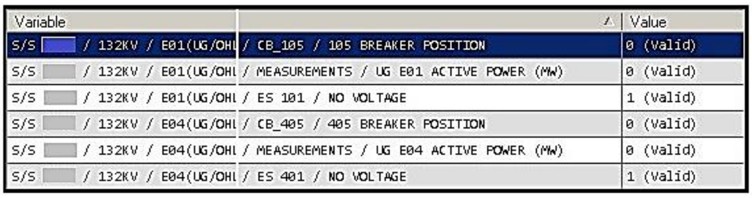

Figure 5: EcoSUI SBUS Server Formula Editor variables.

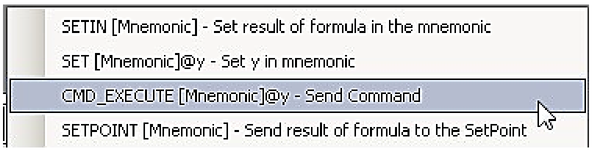

Figure 6: EcoSUI Possible Action of proposed logic.

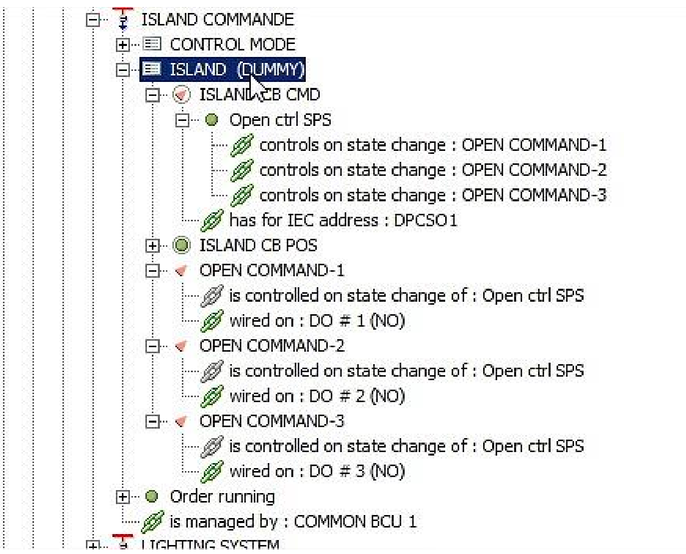

Figure 7: Common BCU configuration forming 2oo3 voting.

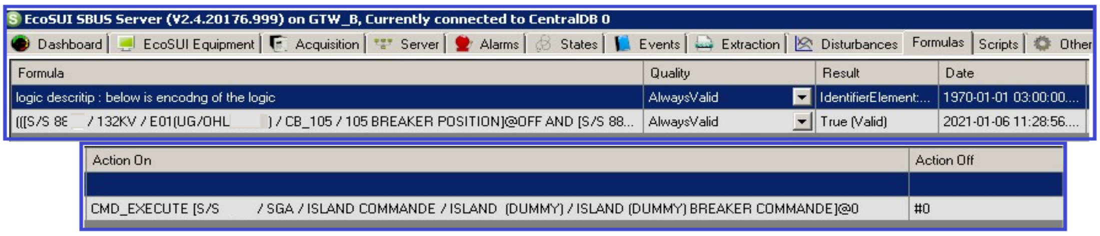

Figure 8: Island dummy command SBUS server logic mapping.

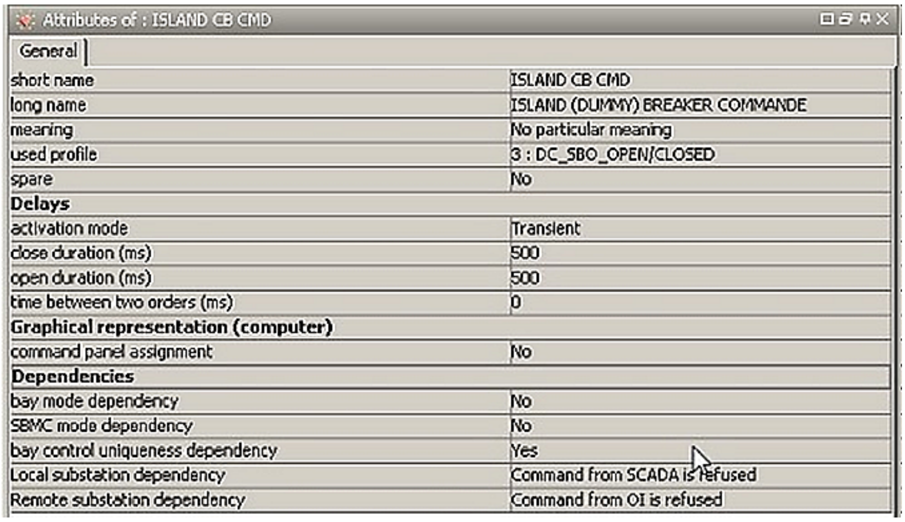

Figure 9: Island dummy command configuration in PACis

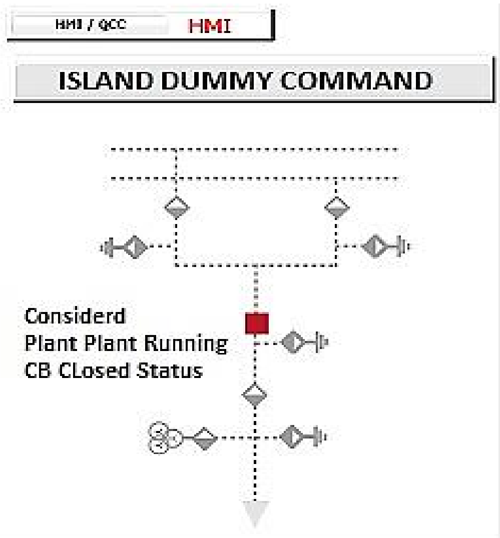

Figure 10: Dummy command for the island operation.

3 Proposed Islanded Communication Scheme

Figure 11 describes the complete island detected alarm to be extended in power plant's unit control panels from the grid, the grid controller has to decide the when power plant leads to island operation and trigger to Common BCUs through SAS network. The controller island detection logic has been proposed in Figure 3. The island detection initiation could be transmitted to the power plant by both reliable proposals. The proposal-1 requires software and hardware verification by using three I/O Boxes or common BCUs. The inputs/outputs of the system which can't be integrated directly from IED functional block in IEC61850 or standalone equipment sources such DSM, FDR, HVAC, and auxiliary system, etc., are required to terminate to I/O boxes or common BCU. The two output contacts of each box designed in 2oo3 voting architecture are required to be operated by the same controller logics described in Figure 4, this software detected island signal should verify the used common BCUs and concerned GIS BCUs are valid and healthy by their watchdog hardwired NC contacts. This verified island signal (L52Loss_Grid) is further extended through interface panels to the power plant where it operates a bi-stable relay and its contacts initiate a command to all plant unit controllers simultaneously for overall island operation, while in Proposal-2 in Figure 12, The island detected software initiation is directly sent via fiber optics redundant communication network to the power plant to trigger additional installed I/O box. The number of output contacts of this I/O Box can be configured depending upon the requirement for desired units to be islanding. Proposal#2 requires additional BCU or I/O Module, however, Proposal#1 is made by existing BCUs which require hardwiring modification only, therefore this paper focuses on proposal-2 which has high software and hardware redundancy along with reliability and cost-effective.

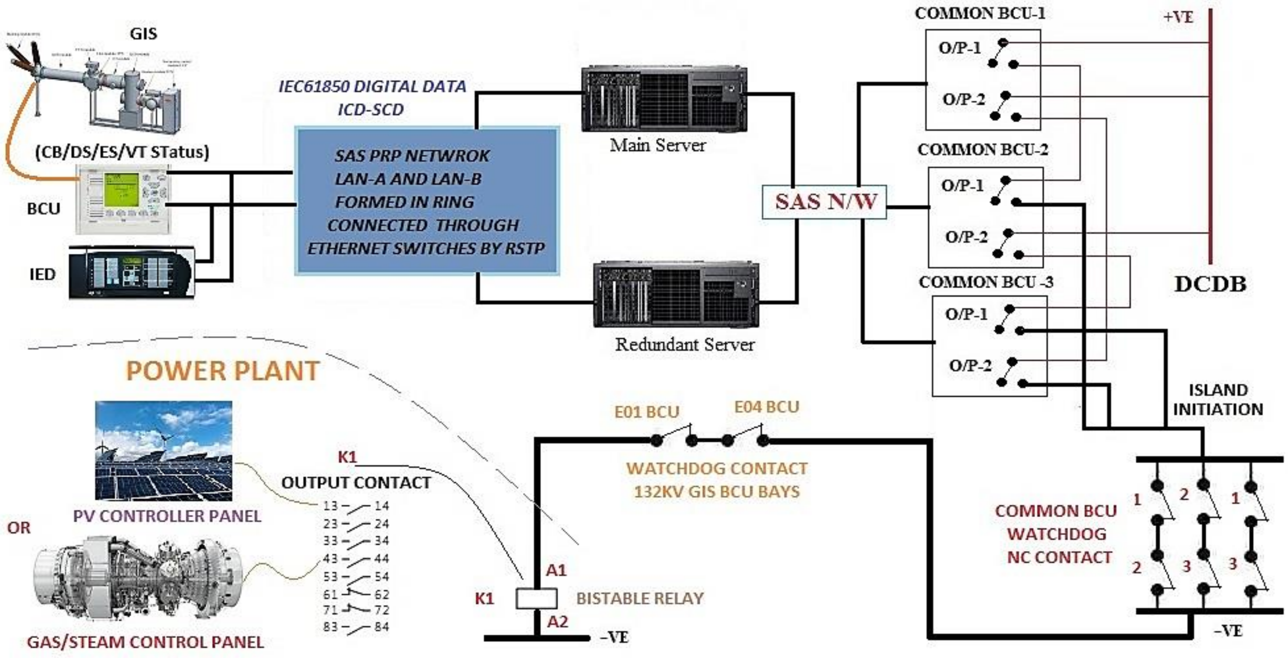

Figure 11: Proposal-1 entire the island communication and DC hardwire schematics diagram.

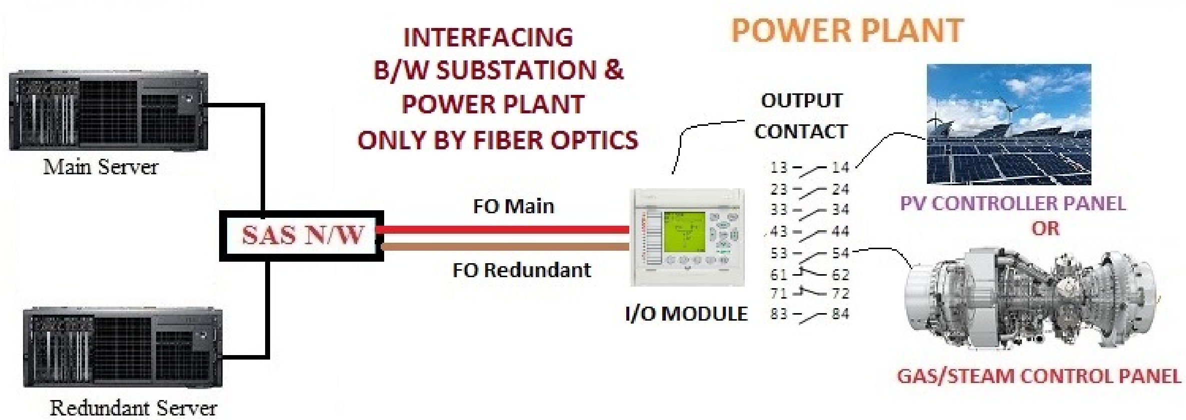

Figure 12: Proposed-2 entire Island scheme with fibre optic communication.

4 Developed Real-Time Island Commissioning

The validation of configured Island Command initiation in EcoSUI V2.4 SBUS server software can be tested by two commissioning procedures in both cases when the grid is live or energized and dead grid.

4.1 Actual Simulation by Secondary Injection FREJA 546 Megger by using a Bi-stable Relay as Power Plant CB

The entire island simulation test was carried out presented in Figures 14 & 15 by arranging Line E01 set as transmitting export power and its line CB and Dummy CB(Additional configuration done to simulate as Power Plant in Figures 8, 9 & 10) were closed, used two sets of secondary injection kit shown in Figure 13, one for IED fault simulation and other for injection measurement voltage, current and MW to BCU while auto-reclosure of lines kept out of service. The one additional output contact of protection IED 7SD522 configured to stop the second freja300 used for BCU measurement to set sequence as both kits will stop together when injected Zone-1 fault in Line protection IED 7SD522 so that IEC61850 controller detect dead grid or export energy failure by proposed logic. The Controller logic trigger command to Common BCU, it operated the one bi-stable relay (Considered as a plant) will give feedback to SAS HMI and open island dummy CB (Considered PP CB Open) as shown in Figure 16 HMI event list which concludes successful island operation by simulation.

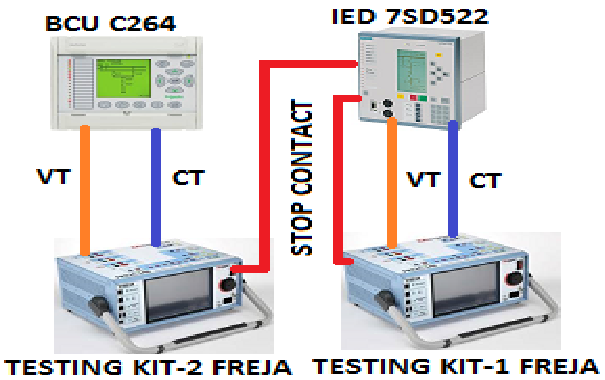

Figure 13: Test Connection for fault simulation.

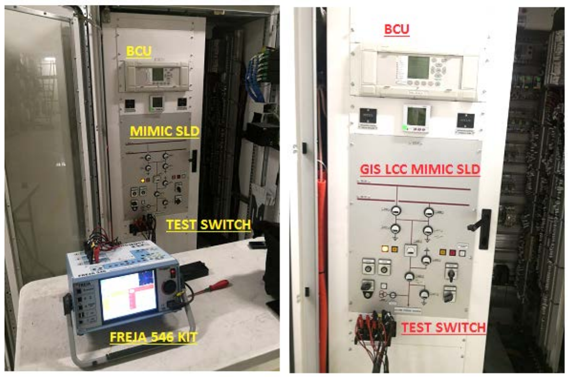

Figure 14: Test platform connection with BCU for island operation

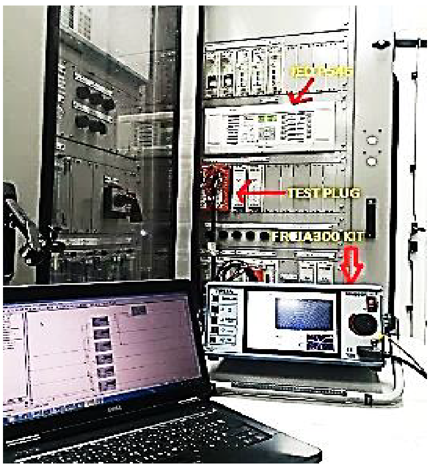

Figure 15: Testbed connection with IED 7SD522.

Date	Description	Message
2021-01-06 12:00:52.495	ISLAND (DUMMY) BREAKER COMMAND	OPEN
2021-01-06 12:00:52.495	105 BREAKER POSITION	OPEN
2021-01-06 12:00:52.337	105 BREAKER COMMANDE	OPEN
2021-01-06 12:00:52.202	105 BREAKER COMMANDE	ORDER SENT OPEN
2021-01-06 12:00:51.524	105 BREAKER COMMANDE	ORDER SELECTED OPEN
2021-01-06 12:00:21.746	105 BREAKER POSITION	CLOSED

Figure 16: HMI Events for island dummy command.

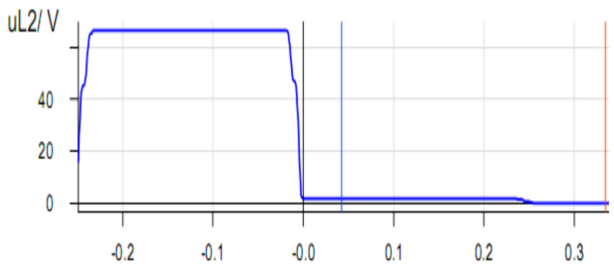

Figure 17: 7SD522 IED line voltage pre-fault and after a fault.

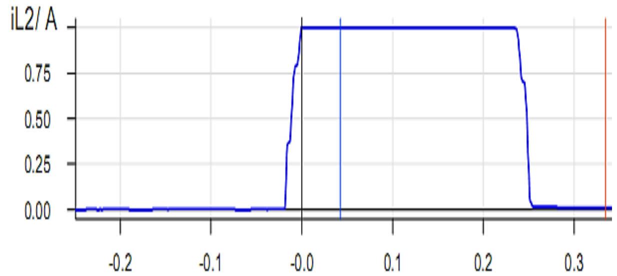

Figure 18: 7SD522 IED line current pre-fault and after the fault

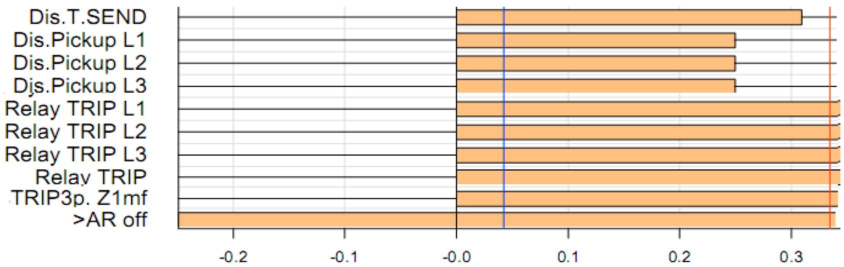

Figure 19: 7SD522 IED 21 Zone-1 start and trip with AR OFF.

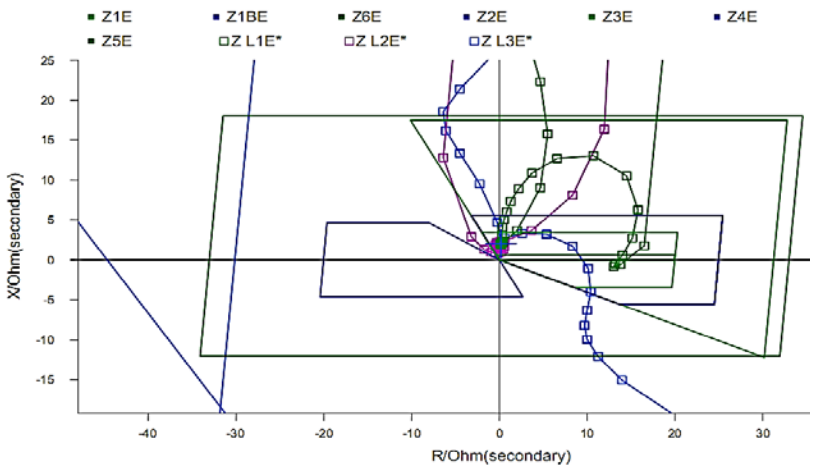

Figure 20: 7SD522 IED Impedance Diagram X-R showing zone reach at the fault simulation.

Figures 17, 18, 19 & 20 show fault simulation summary extracted from SAS EWS in Comtrade file from Sigra 4.55 software.

4.2 IIT Substation Automation Synthesizer Software and IED SCOUT Software for Both Cases Either the Grid is Dead or Live

The IIT synthesizer and IED scout are simulation software to simulate all grid station signals/ status without initiating actual sources from the field in the real system except SNMP sources. It helps to validate all IEC61850 substation automation controller engineering as well as gateway 101/104 Ports configuration, even these procedures do not require partial or full grid station outage. The standalone laptop is required to connect with SAS network at station level to Ethernet switch, but bay level all switches either power to be switched-off or keep disconnected from station level as represented in Figure 21, final SCD file is to be imported in IIT synthesizer or IED scout, then any IED/BCU can be viewed to simulate its Alarm, indication, commands and measurement, each source select the value “True or False” and set time, then verify the changes reported in HMI, Thus each grid variables assigned for island command in IEC61850 grid controller logics can easily be simulated and validated step by step.

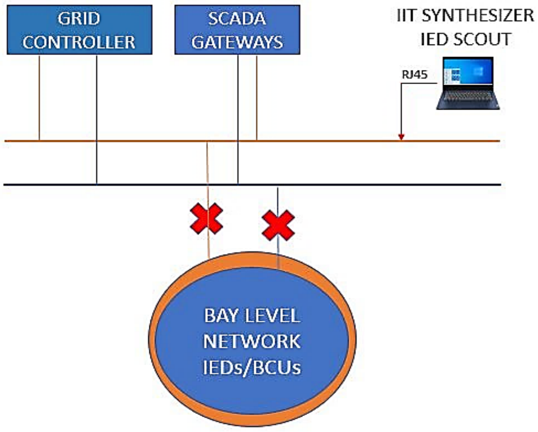

Figure 21: IIT Synthesizer and IED Scout connection

5 Simulation Test Result and Discussion

Figure 16 predicts the controller itself island detection time by the proposed method that is instantaneous due to the trigger feature but varies depending on the type of communication used. The overall islanding time was calculated 299ms with proposed communication in Figure 11, while 100ms is expected by proposed communication in Figure 12 due to reason as there is no hardwires or bistable relay between interfacing. The results express that the proposed method has less detection time than earlier reported methods.

6 Conclusion

This paper provides a comprehensive summary of the latest remote islanding methods, describe design factor to select, a possible cause of mal-operation of island detection and its impact, and explained three best way to do island detection engineering in IEC61850 substation automation system. A new remote islanding detection technique is proposed and designed first time at station level IEC61850 SAS controller in ECOsui SBUS software which detects island situation based on real-time grid variables to increase the reliability and availability after Root Cause Analysis (RCA) in-depth of the reported incident caused 1669MW lost due to mal-operated controller island detection logic and, then proposed two futuristic communication concept designed interfacing for between IEC61850 grid controller to plant controllers keeping in view the latest issues, was aimed at the re-validating various design and technical parameters of the islanding situation. The island detection time itself in the controller is instantaneous and observed faster with proposed fiber optics communication than hardwired interfacing. The Application of the proposed method can easily be implemented and flexible in wide ranges of DGs, large scale PV tide grids, wind-power plant, and conventional gas turbine and steam turbine power plants. This paper also proposed two unique commissioning test procedures for island operation detection time in live system as well as when the grid is dead. Actual simulation of grid variables in real-time by secondary injection FREJA 546 Megger to detect an export power failure. The procedure uses IEC61850 simulation software such as IIT Substation Automation Synthesizer and IED SCOUT software to test each individual grid variables used in controller logic. The test-bed platform validates that the designed remote islanding detection algorithm and proposed communication are easily implemented in DERs and large-scale PV and wind energy systems to avoid blackouts and brownouts.

7 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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