Island Detection Communication in IEC61850 Grid Controller by Utilizing 2oo3 Architecture to Improve Redundancy and Reliability

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Abstract— After large-scale photovoltaic (PV) and wind power integration with the national grid, the island grid detection is a crucial technique that identifies when a grid should be considered as dead. This logic is built in an IEC61850 grid controller which mainly depends on the bus bar scheme and fault type. It becomes more complex when the ½ circuit breaker scheme is utilized. The lack of communication redundancy causes island mal-operation due to the substation's DC supply failure. In order to avoid such mal-operation discrepancies, this paper investigates the conventional islanding detection method. Then, an advanced IEC61850 grid controller 2oo3 architecture is proposed for islanding detection, based on SAS redundant communication which improves reliability. However, even if there is an interface communication failure, the power plant control center can still detect the islanding through the proposed IEC61850 grid controller and SCADA IEC60870-5-101/104 gateways integration. This method has the tendency of full supervision of the entire grid and perfect logical judgment by plant operation staff. This feasible and the proposed redundant communication architecture can play a decisive role for power system network stability in order to avoid system blackout.

Keywords-IEC61850 Substation Automation System (SAS) grid controller; 2oo3 (2-out-of-3 voting); SCADA IEC60870-5-101/104 gateway; stability; blackout

I. Introduction

Globally, higher PV insertion is being injected into national transmission systems in consideration of climate change [1] and in order to avoid energy insecurity. Large scale grid connected PV plants consist a revolutionary plan of Saudi Arabia for modernized energy boost as the Vision 2030 of Saudi Arabia is to inject 50% of its electricity to the transmission system from renewable sources due to the natural potential for wind and PV energy. Large scale PV power integration may affect system stability and reliability due to the islanding problems which have impact on power quality and could be harmful for the electrical equipment and personal safety. Consequently, it is essential to evaluate and select a suitable island detection method for small and large distributed power connectivity with grid [2, 3]. The islanding detection methods are mainly classified as local and remote. The local islanding detection methods are further categorized into active

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(AID), passive (PID), and hybrid methods (HID) while remote methods detect export energy failure of the grid. Detailed descriptions of each method can be found in [4, 5]. The PID methods detect the islanding by passive parameters (P_{MW}, Q_{VAR}, frequency, voltage, phase angle, etc.) at PCC [6]. The discrepancies of large non detection zones in PID and power quality issues in AID are rectified by HID which combines both AID and PID methods. The communication-based methods utilize the communication between DG or the power plant and the utility grid such as PLCC which transmits continuous signals via the power line to the DG [7]. Signals produced by disconnections require unique transmission such as telephone link, microwave, etc., while SAS/SCADA uses the grid IEC61850 controller to detect the islanded condition [8] and is most efficient and reliable [9].

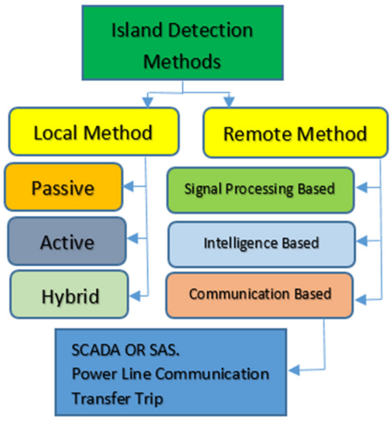


Fig. 1. Classification of island detection methods.

In IEC61850 Substation Automation System (SAS), the redundant grid controller/servers detect the island condition (basically depending on bus bar scheme and type of faults). Forming dead grid/L52_Loss of grid/export energy failure initiation is complex. Island detection from the grid is normally taken by the Circuit Breaker (CB) status (the CB status is hardwired to GIS BCU inputs to report grid controller) in most substations. The single output of the controller is only software depended, which could lead to islanding mal-operation in case of substation DC supply failure or due to any accident, hence software and hardware interlocks along-with 2oo3 redundancy technique must be ensured for reliability. This paper focuses on SCADA and SAS communication-based island detection methods. The contribution of this paper is the improvement of the communication-based island signaling redundancy and reliability by using 2oo3 architecture in IEC61850 grid controllers/servers. Furthermore, there are two new outstanding and feasible implementations of communication solution from the IEC61850 grid controllers by using the KVM extender and the IEC60870-5-101/104 SCADA gateway ports monitoring the access to the power plant by using an RS232 extender in serial to the FO convertor. The performance of the proposed 2oo3 scheme is validated favorably by an actual commissioning test. The fault is simulated in P546 IED on the experimental test bed while the sequence of events and the behavior of GT/ST after islanding are presented. The measured results show that the proposed 2oo3 technique can confidently enhance redundancy and reliability of island signaling. The result of the proposed method is compared with the results of other methods. It is shown that island detection time is reduced from 734ms to 299ms which is under the limit specified in IEC 62116 [4] and IEEE 1547 [10] which is 2s.

II. PROPOSED COMMUNICATION BASED ISLAND DETECTION

The summarized architecture of IEC61850 substation automation system is illustrated in Figure 4 and it is comprised of three levels: station level, bay level, and process level. Grid protection, control, metering, and SAS supervision monitoring data (analogue, digital, single point and double point status, regulatory command, and set points) are integrated through ICD, CID, and MCL to SCD files to be reported in servers and gateways as per IEC61850 standardization. This IELC61850 digital data time-stamped by GPS SNTP IEC61108 protocol are also being reported or utilized for the island signal to the power plant from grid and are converted in signal addressing IEC60870-5-101/104 protocol by gateways and are transmitted through the OLS system DVM/SDH via the OPGW (fiber optic) network within specific interoperability settings (DATA link address size, common address size, object address size, cause of transmission size, balance/unbalance mode, communication baud rate, link address) to the power control center and power plant as recommended in this paper. The whole protection signalling, controlling, metering, and SAS network supervision are tested in open loop test and in close loop test.

A. Proposed Island Detection Communication in IEC61850 Grid Controller by Utilizing 2oo3 Technique

Three widespread configurations, namely 1oo1, 1oo2, and 2oo3 can be used in redundant automation control systems. The 2oo3 architecture provides slightly higher reliability and better availability compared to loo2 as measured by the probability indices of failure on demand (availability, MTTF, MTTFDangerous, and MTTFSafe [11]). Usually, the indices used to measure the programmable electronic controller's performance are MTTF and availability. Each programmable controller's architecture can fail, either dangerously or safely. In dangerous failures, the intelligent controller is unable to shut down the plant if a shutdown is needed and in safe failures undesired shutdowns of well operating plants occur [11]. The architecture in which both dangerous and safe failures are taken care is known as 2oo3 which identifies that 2 units out of 3 are required to operate the system. The IEC61850 reports data to both redundant controllers which work in Hot-Standby configuration, therefore I/O boxes or common BCUs are considered as controller outputs (in Figure 2). The two outputs from each common BCU unit are configured and all the wired outputs are considered in the voting scheme to confirm the actual signal. This common output signal is named as the island initiation from the grid controller and is extended via the interface communication panel to the power plant for island operation.

Figure 2 illustrates the entire island signal flow chart initiation from grid process level to power plant island operation. The export energy failure of the grid is detected by the IEC61850 grid controllers which identify the exported OHL/UG tripped by the concerned protection IEDs on fault. Besides, the CB trip stata are reported through the Bay Control Unit (BCU) and thus the grid controller sends the island detection trigger to common BCUs via SAS redundant IEC61850 network. A typical EHV transmission substation in Saudi Arabia has multiple voltage levels (380KV/132KV/13.8KV). Each level may have many I/O box and common BCUs (for ACDB, DCDB, battery chargers, etc.) depending on hardwire source requirements, therefore three common BCUs are recommended for the proposed 2oo3 logic. Afterwards, two output contacts of each common BCU are to be configured and multiplied hardwiring in the voting circuit to extend the alarm for case-1 while one output contact is required in case-2 of each common BCU as proposed in Figure 2. The proposed 2oo3 logic verifies that the actual signal is authentic in order to avoid false initiation or mal-operation. This actual island signal (L52Loss_Grid) is further extended through interface panels to the power plant where it energizes a multiplication relay and its contacts send a command to all GT and ST controllers simultaneously for overall island operation. The probability of the controller continuously staying in operation is defined as a reliability function. The reliability functions for base systems are measured through solving Markov models of four configurations 1oo1, 1oo2, and 2oo3 without and with partial recovery (2oo3 and 2oo3-PR) are depicted in Figure 3.

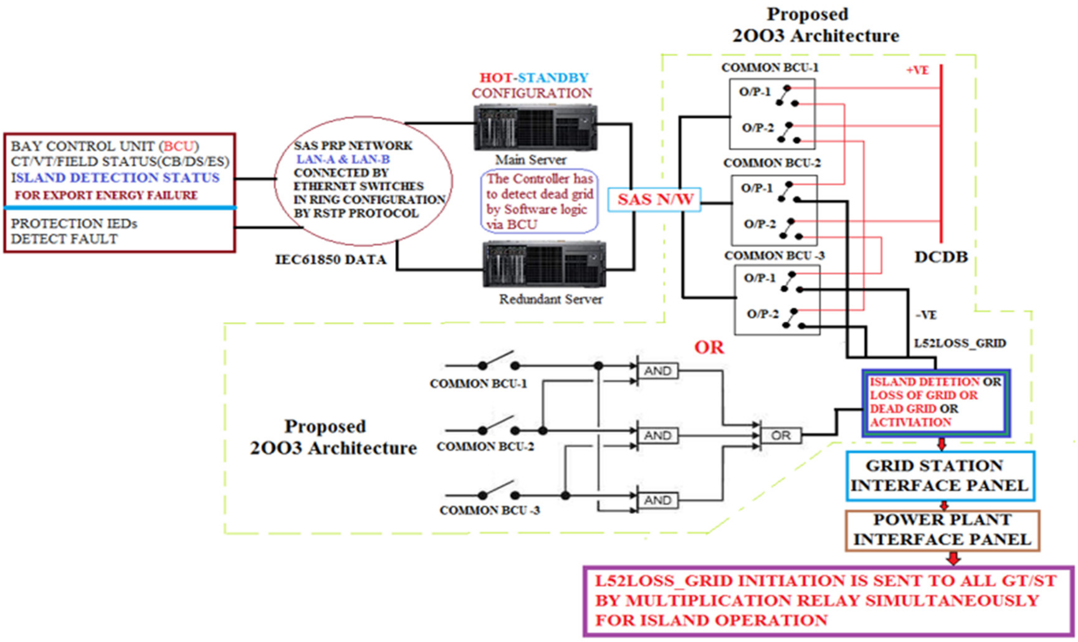


Fig. 2. The proposed 2oo3 communication architecture.

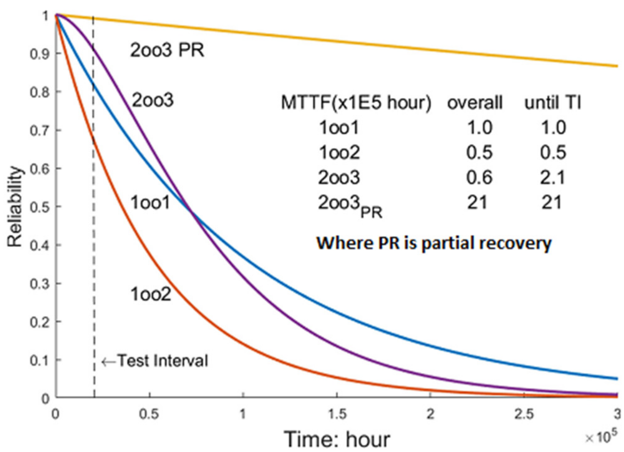


Fig. 3. Reliability functions for 1oo1, 1oo2, and 2oo3 without/with partial recovery (2oo3 and 2oo3-PR).

B. Proposed Island Detection Communication through SAS Server and Gateway

Figure 4 shows the proposed architecture which depicts the 380KV/132KV/13.8KV/440V general transmission substation and describes the real time application of Ethernet protocols such as the Parallel Redundancy Protocol (PRP) IEC 62439-3 Clause 4, Non PRP, and High-availability Seamless Redundancy (HSR) Protocol. The EHV 380KV and HV 132KV is an important and huge network so the Dual Attached Nodes (DANs) have been used whereas in the LV side (13.8KV) both Singly Attached Nodes (SANs) and Virtual DANs (VDANs) may be used depending upon client requirements [9]. There are two additional possibilities (other than 2oo3 voting island command interface communication) to detect islanding in consideration of continuous monitoring of the complete grid in order to take prompt actions to avoid any emergency situations. This proposed communication network can be more secured by utilizing a firewall router in compliance with cyber security.

1) Case 1: Grid Controller Access to the Power Plant

In the proposed architecture in Figure 4, the grid server connection to the power plant is shown. The DVI cable of the grid server/controller is connected to the KVM extender which converts it to fiber optics and extends DVI or USB console up to 20km away and could be extended more by the communication system. The advantage of this proposal is the plug and play to HMI as shown in the architecture to monitor the complete substation SLD status, alarm page, event page, etc. and does not require any engineering at the power plant besides cybersecurity concerns. The power plant will have only viewer authority to access the grid controller due to the operational safety concern.

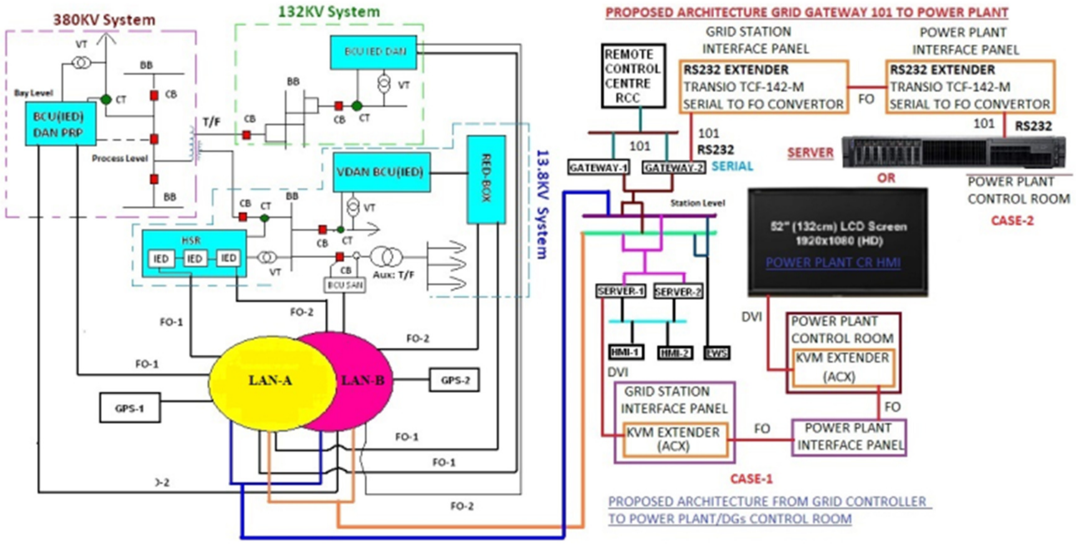


Fig. 4. SAS architecture with SLD using PRP, Non-PRP, and HSR for the proposed communication of the grid controller with the power plant.

2) Case 2: SCADA Gateways 101/104 Communication Integration with the Power plant

In the proposed architecture in Figure 4, the grid gateway IEC60870-5-101/104 port connection to the power plant is shown. The serial RS232 port 101 cable of grid gateway is connected to the RS232 extender which converts it to fiber optics and extends the gateway 101/104 communication up to 40km with single mode FO and 5km with multi-mode FO. However, it can be extended more, up to 400km by single mode OLS.

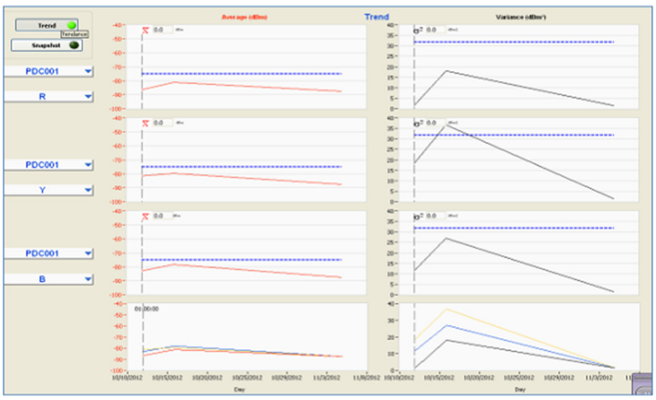


Fig. 5. Graphical data of the selected sensor.

By the proposed solution the power plant will have complete substation monitoring access and can take any emergency action accordingly, but a Protocol Convertor (PC) and 101/104 protocol engineering shall be required in the power plant. Another advantage of the proposed communication is that the power plant may watch online Partial Discharge (PD) of GIS, SF6 overview, and GT/SGT online gas monitoring The ftp data allow performing the monitoring of UHF sensors defined in a specific configuration for the of GIS to monitor [9] as shown in Figure 5. The real spectra acquired on the selected sensor and their associated sensors are shown in Figure 6. The plant control center can even detect the islanding condition by this method in case of interface island command communication failure, as suggested in [2].

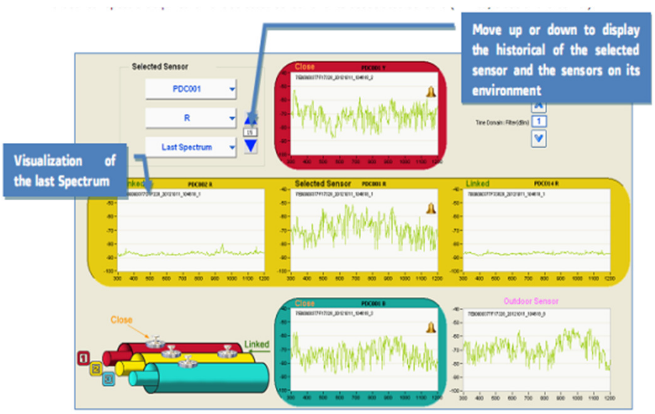


Fig. 6. Spectra acquired on the selected sensor.

III. DEVELOPED REAL TIME TEST BED OF ISLANDED DETECTION

Commissioning simulation test was carried out to validate the islanding operation time and behavior of the GT/ST. All concerned circuit breakers of OHL-1 were arranged as they are exporting MW to the load while OHL-2 is OFF and Gas Turbine/Steam Turbine CB were closed as per the Single Line Diagram (SLD) shown in Figure 7 while the testing set-up is shown in Figure 8.

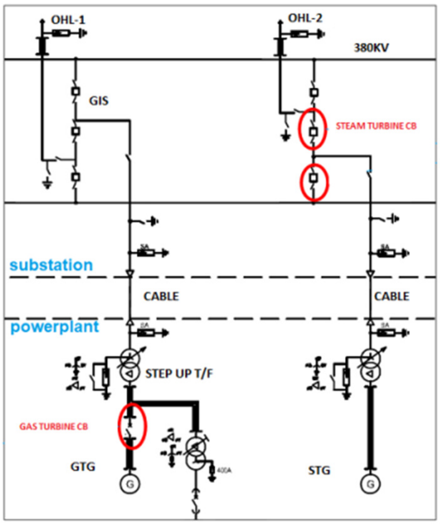


Fig. 7. Single line diagram.

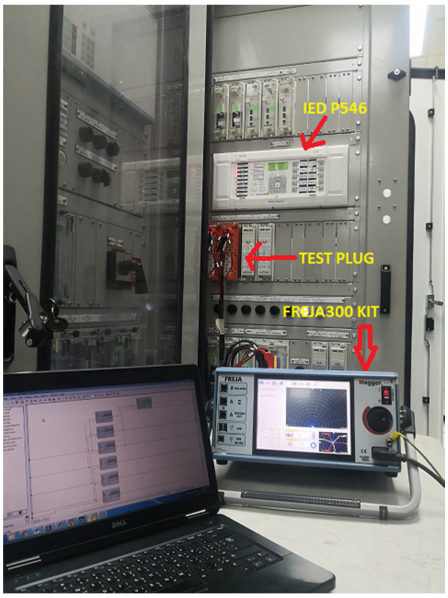


Fig. 8. Real-time experimental test bed for island fault simulation.

Zone-2 fault was simulated on OHL protection IED Micom P546 by the secondary injection of FREJA300 testing kit in sequence order which tripped the associated line CBs. In addition, the station controller/server detected export power failure and triggered to common BCU which further extended the island signal to multiplication relays in the power plant, hence signal was sent simultaneously to both GT and ST. The "loss of grid" signal triggers the gas turbine unit to trip and take automatic fired shutdown while a tripping signal is also sent to the HV breakers (located in the substation) of the steam turbine. The steam valves of these turbines close, hence the island operation was successful. Figures 9, 10, and 11 show the fault simulation summary extracted from the SAS engineering work station in comtrade file from Sigra 4.55.

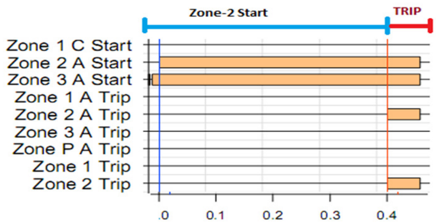


Fig. 9. P546 IED zone-2 start and trip time.

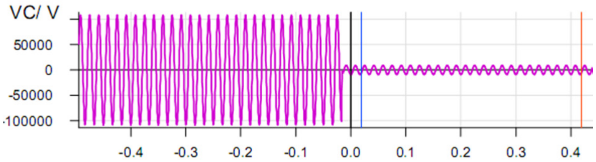


Fig. 10. P546 IED line voltage before and after fault.

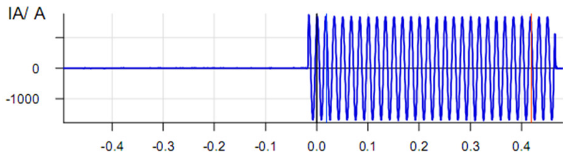


Fig. 11. P546 IED line current before and after fault.

A. Sequence of Events

The sequence of events in Figure 12 offers a chronological overview of the fault simulation in OHL to successful island operation. All the recorded events are in sequence and time stamped.

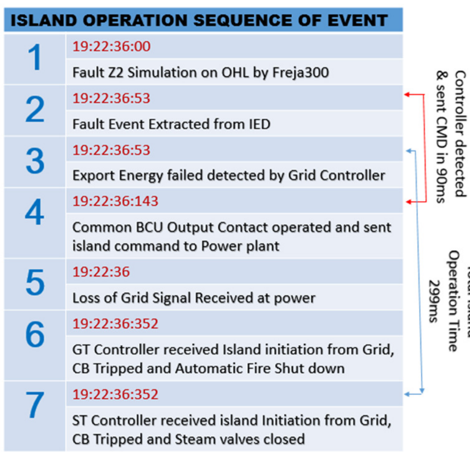


Fig. 12. Island operation chronological overview.

B. GAS Turbine (GT) Behavior Analysis during its Islanding Operation

When the GT controller receives the island initiation, the load is immediately decreased as shown in Figure 13. The extraction of the alarm list in Figure 14 confirms that at 19:22:36 the loss of grid logic is activated. The GTs in service are tripped (opening of GT breaker) as preselected for island operation.

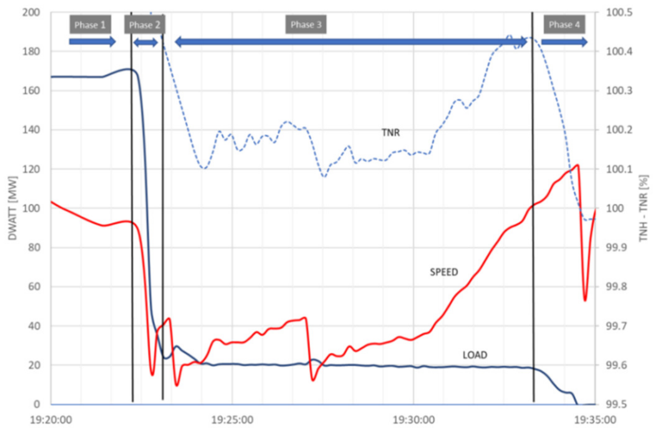
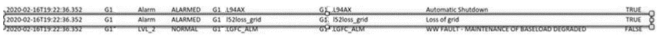


Fig. 13. GT load and speed profiles.



2020-02-16T19:22:36.352	G1	Alarm	ALARMED	G1 L94AX	G1 L94AX	Automatic Shutdown	TRUE
2020-02-16T19:22:36.352	G1	Alarm	ALARMED	G1 l52loss_grid	G1 l52loss_grid	Loss of grid	TRUE
2020-02-16T19:22:36.352	G1	LVL_2	NORMAL	G1 LGFC_ALM	G1 LGFC_ALM	WW FAULT - MAINTENANCE OF BASELOAD DEGRADED	FALSE

Fig. 14. GT controller alarm list.

C. Steam Turbine (ST) behavior Analysis during its Islanding Operation

The island operation signal generated by the substation caused the trip of the ST at 19:22:36 (recorded at GT control system time) as shown in Figure 15.

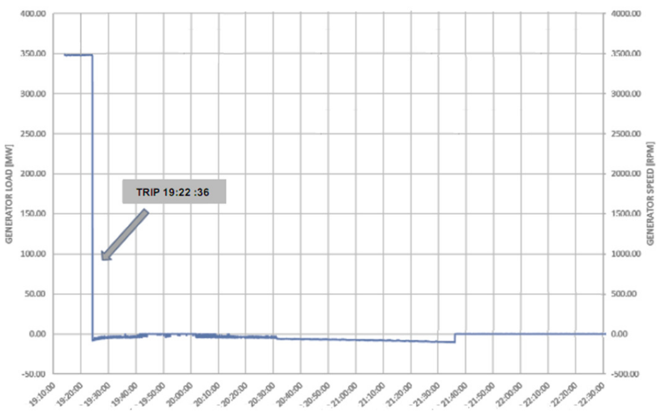


Fig. 15. Steam turbine trip profile.

IV. SIMULATION RESULTS AND DISCUSSION

The comparison of the obtained island detection time with the results of other reported methods [13, 14] is presented in Table I. The results are obtained from the corresponding tables. The corresponding results are compared only by time detection. The results show that the proposed scheme has less detection time than earlier reported methods. The island detection by the controller is 90ms while total island operation time is 299ms as shown in Figure 12.

TABLE I. RESULT COMPARISON

Method	[13]	[14]	Proposed
Detection time	500msec	734msec	299ms

V. CONCLUSION

To overcome the detriments of the traditional local islanding detection methods such as large NDZ and poor quality issues, the SCADA communication-based island detection method is most effective with respect to fast island detection time. To avoid mal-operated islanding, this paper proposes an advanced IEC61850 grid controller redundancy communication by using 2oo3 technique making islanding detection faster while improving reliability, consequently reducing island detection time to 299ms from 734ms which is under the limit specified by IEC 62116 and IEEE 1547 standards. Additionally, this paper also proposes IEC61850 grid controller access to the power plant by using KVM extender and IEC60870-5-101/104 gateways communication link by using the RS232 extender. The implementation steps are introduced in detail and enable the plant operator to have full monitoring and supervision of the entire grid with limited user authority in compliance with the cybersecurity feature. The communication redundancy concept introduced in this paper will help designing unified grid architectures on future digital substations, SAS, DGs, and ISCADA. The commissioning test has been validated and the experimental test results have effectively proven that the proposed scheme can be applied to a practical large scale power plant like PV and gas/steam turbine plants.

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