The Need for Speed - Why Fast Track Digital Substation Deployment?

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Abstract

IEC 61850 standard has been widely accepted and used in the transmission and distribution substations. Many utilities had built the IEC61850 digital substation and demonstrated many benefits including massive reduction of copper wirings and footprint. Vietnam Electricity Northern Power Corporation (EVNNPC) have been using IEC 61850 at station bus for years and started to look into the first IEC 61850 process bus digital substation 110kV Que Vo 110kV pilot project in 2019. Application of IEC 61850-9-2LE process bus introduces merging units, fiber optic network replacing copper wiring, network traffic bandwidth, Ethernet switches and process bus protection relays. EVNNPC considered them as a protection and control (PAC) scheme and the reliability and redundancy of PAC in digital substation must be equivalent or better as compared to a conventional substation. EVN's first digital substation, Que Vo 110kV digital substation project was constructed, commissioned and energized in 2020 successfully. The success of Que Vo 110kV digital substation project marked a significant milestone, proving the concept and benefits of digitalization. By mirroring the success of 110kV Que Vo digital substation, EVNNPC subsequently deployed another 4 greenfield and brownfield 110kV digital substations and a 220kV digital substation project. The standardization of digital substation optimised the manpower and cost of operation, maintenance service as well as reducing execution time of these projects. All 5 subsequent projects were successfully constructed, commissioned, and energized by 2021. This paper describes the design principles, architecture adopted, reliability analysis of protection and control (PAC) scheme in digital substation, benefit of digital substation standardization, proven benefit of IEC 61850 process bus and the return of experience of deploying these six digital substations.

Introduction

Electricity Vietnam (EVN) is the authorized Transmission Service Operator (TSO) which manages the electrical network in Vietnam. EVN has released IEC 61850 station bus technical requirements for protection relays, SCADA and computerized control systems for years. However, IEC 61850 process bus is relatively new to EVN. EVN started to look into the IEC 61850 process bus in 2019 by inviting local Engineering, Procurement and Construction (EPC) players and international vendor partnership. Various discussions, testing and technology demonstrations were done for proof of concept and drafting the new requirements.

Figure 1: DSS proof of concept at Northern Power Company (CPC), a subsidiary of EVN

EVN Digital Substation design principles and architecture

Application of IEC 61850-9-2LE [1] process bus introduces merging units (MU), fiber optic network replacing copper wiring, network traffic bandwidth, Ethernet switches and process bus protection relays. EVNNPC considered them as a protection and control (PAC) scheme and the reliability and redundancy of PAC in digital substation must be equivalent or better as compared to a conventional substation. EVNNPC requires the protection system to maintain the mandatory requirement of n-1 concept for all 110KV and higher voltage level substations. EVNNPC also considers MU as a part of the protection system. Therefore, each bay in the digital substation must have 2 units of MU and 2 units of protection relays as the Main 1 and

Main 2 system. Having replaced copper wires with fiber optic cables, EVN requested a redundant scheme on the fiber optics network to maintain the highest reliability of the process bus communication. EVN adopted IEC 62439-3 Parallel Redundancy Protocol (PRP) in both the station bus and process bus network.

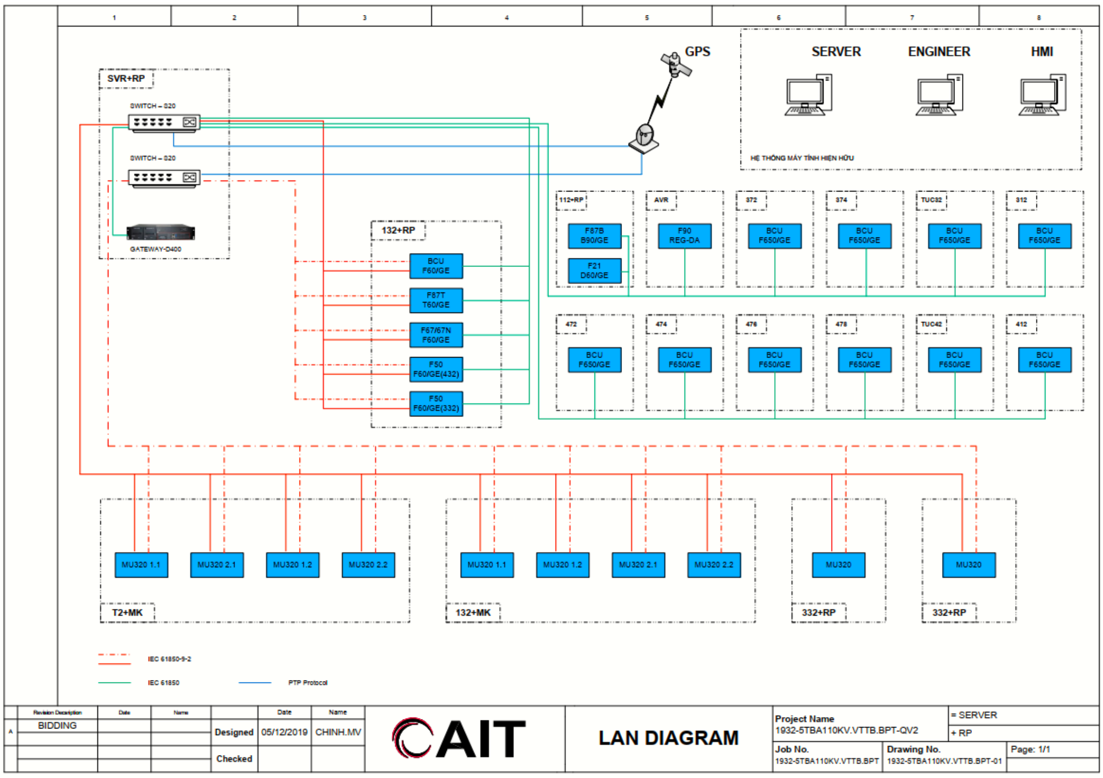

Figure 2: Typical network architecture used in EVN

EVN 6 Digital Substations deployment in 2020-2021

EVN adopted the first digital substation at 110KV Que Vo 2 which is located in northern Vietnam. The Que Vo 110kV digital substation project was constructed, commissioned and energized in 2020 successfully. The success of Que Vo 110kV digital substation project marked a significant milestone, proving the concept and benefits of digitalization. By mirroring the success of 110kV Que Vo digital substation in 2020, EVNNPC subsequently deployed another 4 greenfield and brownfield 110kV digital substations and a 220kV digital substation project. The standardization of digital substation optimised the manpower and cost of operation, maintenance service as well as reducing execution time of these projects. All 5 subsequent projects were successfully constructed, commissioned, and energized by 2021.

1) 110kV Que Vo substation

This substation is located in Bac Ninh province, Northern Vietnam. This is a brown field project with extension of the second transformer T2 110KV/22KV capacity to 40MVA to supply power to new industrial customers in Que Vo industrial zone.

2) 110KV Nghi Son substation

This substation is located at Nghi Son city, Thanh Hoa province in Vietnam. This is the first green field digital substation in Vietnam, including two 110KV bays, one transformer capacity 40MVA supplying power to Nghi Son 1 Industrial zone, Nghi Son Cement factory, and the citizens in the area.

3) T2 TBA 110KV Hung Nguyen

This substation is located in Nghe An province, North Central Vietnam. This is a brown field project with extension of the second transformer T2 110KV/35KV/22KV capacity to 40MVA to supply power to new industrial customers in Que Vo industrial zone.

4) 220KV IALE Windfarm Substation
This substation is located in Gia Lai province at the highland area in Central Vietnam. This is a green field project, including two 220KV outgoing bays, one bus coupler and one transformer bay to transmit power of IA LE 1 windfarm capacity 100MW to the national network.

5) 110KV Cai Lan Substation
This substation is located in Quang Ninh province, Northern Vietnam. This is a brown field project with extension of the second transformer T2 110KV/22KV capacity to 25MVA to strengthen power supply to Cai Lan industrial zone.

6) 110KV Phung Xa Substation
This substation is located in Ha Noi city, capital of Vietnam. This is a retrofit project of the secondary system, including two 110KV outgoing bays, one bus coupler and two transformer bays to supply power to the citizens in Ha Noi city.

EVN Protection and control (PAC) scheme requirement in a digital substation

EVNNPC requirement is that a digital substation must be equivalent or better as compared to a conventional substation. The use of redundant systems is mandatory for 110kV and above voltage level. In this paper, protection relay performance (operating time) is assessed, and the reliability of protection and control (PAC) scheme is analyzed.

Protection relay performance

	Total clearance time including primary breaker trip time (EVN requirement <100ms)	
	Conventional substation (copper wires + protection relay)	Digital substation (merging unit + protection relay)
Transformer protection	<100ms	<100ms
Distance protection	<100ms	<100ms

Table 1: commissioning testing test result

Based on the commissioning testing results, process bus protection relay scheme in a digital substation provides equivalent performance and trip operating time.

Reliability of protection and control (PAC) scheme

Reliability is that it is the probability of a device performing its function properly, for a certain period of time, under given operating conditions [2]. In this study, the reliability level of the protection system is based on the creation of reliability models that relates the individual reliability of all the units that compose it. Conventional substation model and digital substation model are compared and quantitative levels of reliability of the whole system is obtained.

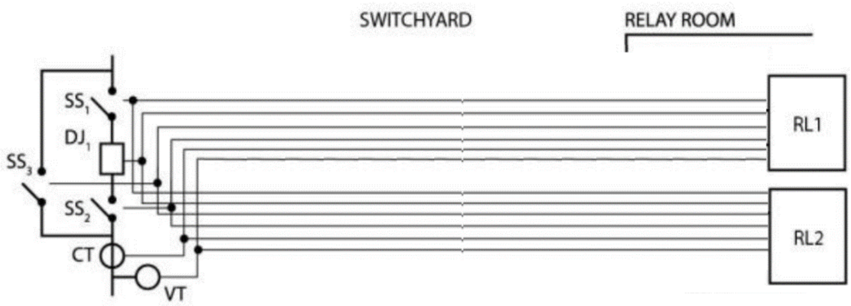

Figure 3: Typical conventional substation PAC scheme architecture

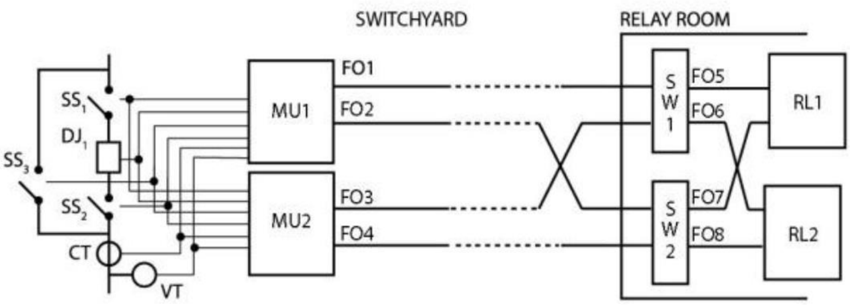

Figure 4: EVN Digital substation PAC scheme architecture

As shown in Figure 3, the conventional protection systems, from the point of view of interconnection between switchyard equipment and IEDs, are simple structures that are composed of the protection relay which is installed in the control room and the cables that connect it with the switchyard elements. Regarding the level of reliability, the protection system is related to the level of reliability of the wiring, instrument transformers, and protection relays. In the conventional system, two independent sets of cables from the CTs and the VTs are taken to the relay room to be connected to each protective relay.

As shown in Figure 4, digital substation uses IEC 61850 process bus network to replace the copper wirings with fiber optics. Regarding the level of reliability, the protection system is related to the level of reliability of the wiring, instrument transformers, merging units, Ethernet switches and process bus protection relays. An equivalent process bus topology considers the use of two MUs with redundant network ports connected to the switches by fiber optic cables. Protection relays with redundant network ports are also connected to the switches and execute the protection functions. However, digital substations have additional digital flexibility. For example, IEC 61850 Process Bus Digital architecture allows automatically switching over in the event of failure as shown in Figure 5. This flexibility increases the system availability. [6]

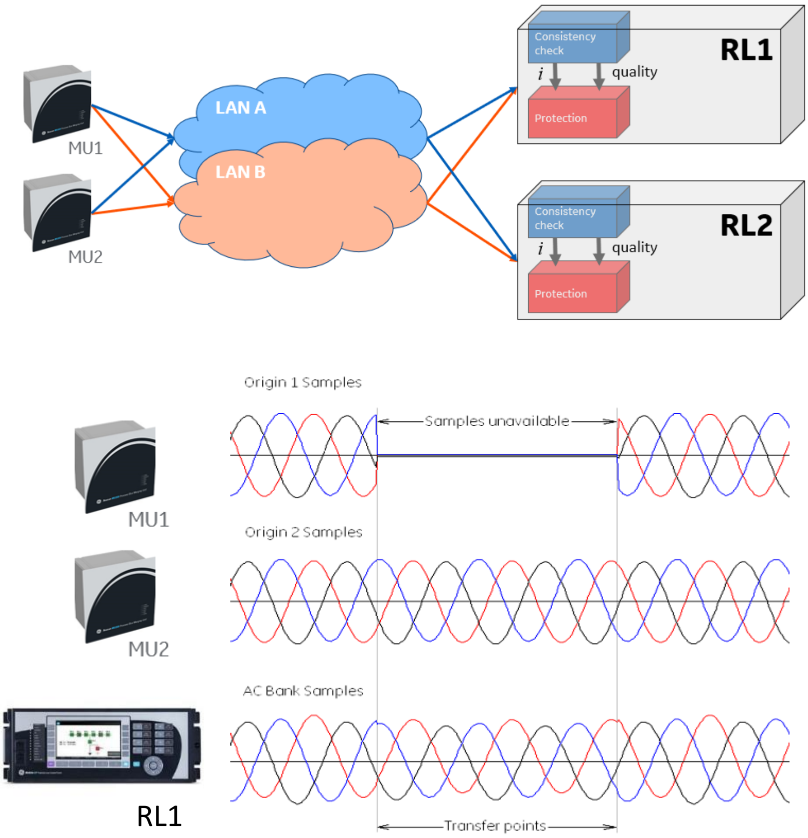

Figure 5: Digital architecture allows automatically switch over on the event of failure and increases system availability

Reliability of conventional substation can be deduced to below. All terms used are referred in Figure 3 and Figure 4.

$R_{conventional} = [1 - (1 - R_{CC1} * R_{RL1})*(1 - R_{CC2} * R_{RL2})]$

$R_{digitalsubstation} = [1 - [1 - [[1 - ((1 - R_{FO1})*(1 - R_{FO3}))]*[1 - ((1 - R_{FO5})*(1 - R_{FO7}))]*R_{SW1}]] *$
$[1 - [[1 - ((1 - R_{FO2})*(1 - R_{FO4}))]*[1 - ((1 - R_{FO6})*(1 - R_{FO8}))]*R_{SW2}]]] *$
$[1 - [(1 - R_{MU1})*(1 - R_{MU2})]] * [1 - [(1 - R_{RL1})*(1 - R_{RL2})]]*$
$[1 - [(1 - R_{FO1})*(1 - R_{FO2})*(1 - R_{MU2})]] *[1 - [(1 - R_{FO3})*(1 - R_{FO4})*(1 - R_{MU1})]]$

The reliability of each element (component and product) is closely related to the MTBF (Mean Time Between Failure). This value depends on the number of units analyzed and the time when these devices are in operation. Based on this information, it is possible to estimate the rate of failures of a piece of equipment within a given period of time and, therefore, the probability of failure or, in other words, its reliability level [3]. The reliability of some electronic equipment can be estimated below.

$R = e^{(-t/MTBF)}$

Where, R, t and MTBF are the reliability level of the equipment, the time interval for the analysis and the mean time between failures for the equipment, respectively. For a comparison of the reliability between different architectures, the MTBF of each network element was obtained in [4] and by surveying the manufacturers. In this study, the reliability level of each element was established (at typical values) as shown in Table 1.

Element:	MTBF (yrs)	Reliability
Protection relay	300	0.9967
Merging unit	300	0.9967
Ethernet switch	100	0.9900
Copper cables	100	0.9900
Fiber optic cables	100	0.9900

Table 2 Reliability for each element of the protection system

Based on this, the reliability of the system can be compared.

	Reliability
Conventional substation	0.9998
Digital substation	0.9999

Table 3 Reliability comparison for conventional substation and digital substation

Based on above, PAC scheme in digital substation has advantage and higher reliability compared to PAC scheme in a typical conventional.

Engineering, installation and footprint reduction

In a conventional substation, all primary equipment statuses are gathered in the outdoor panel, then they are connected to the protection indoor cubicles by hundreds if not thousands of copper wirings. Prior to the adoption of process bus, protective relays and bay control units (BCUs) have to be hardwired directly to the primary equipment. Also, in many cases, hardwired required for interlocking and for signalling between other relays and BCUs. Every panel has different design and require careful engineering and installation. The design must be modelled and controlled for testing are therefore every electrical signal. The engineering efforts focus massively on physical wirings design and how to test the signals. For example, multiple test blocks are wired into circuits to isolate devices from the system, as a point to inject secondary currents and voltages, and as a place to observe the status of physical outputs.

In a digital substation, all primary equipment statuses are gathered to the Merging units in the outdoor panel, then they are converted to IEC 61850 digital signals and then transmitted to the protection indoor cubicles by two fiber optic cables. This builds the SLD with yard-to-MU connectivity that promotes standardization. AC 3-line and DC elementaries will also then enjoy standard designs as shown in Figure 6. [5] The interlocking for control the equipment are done by software logic on the bay control unit.

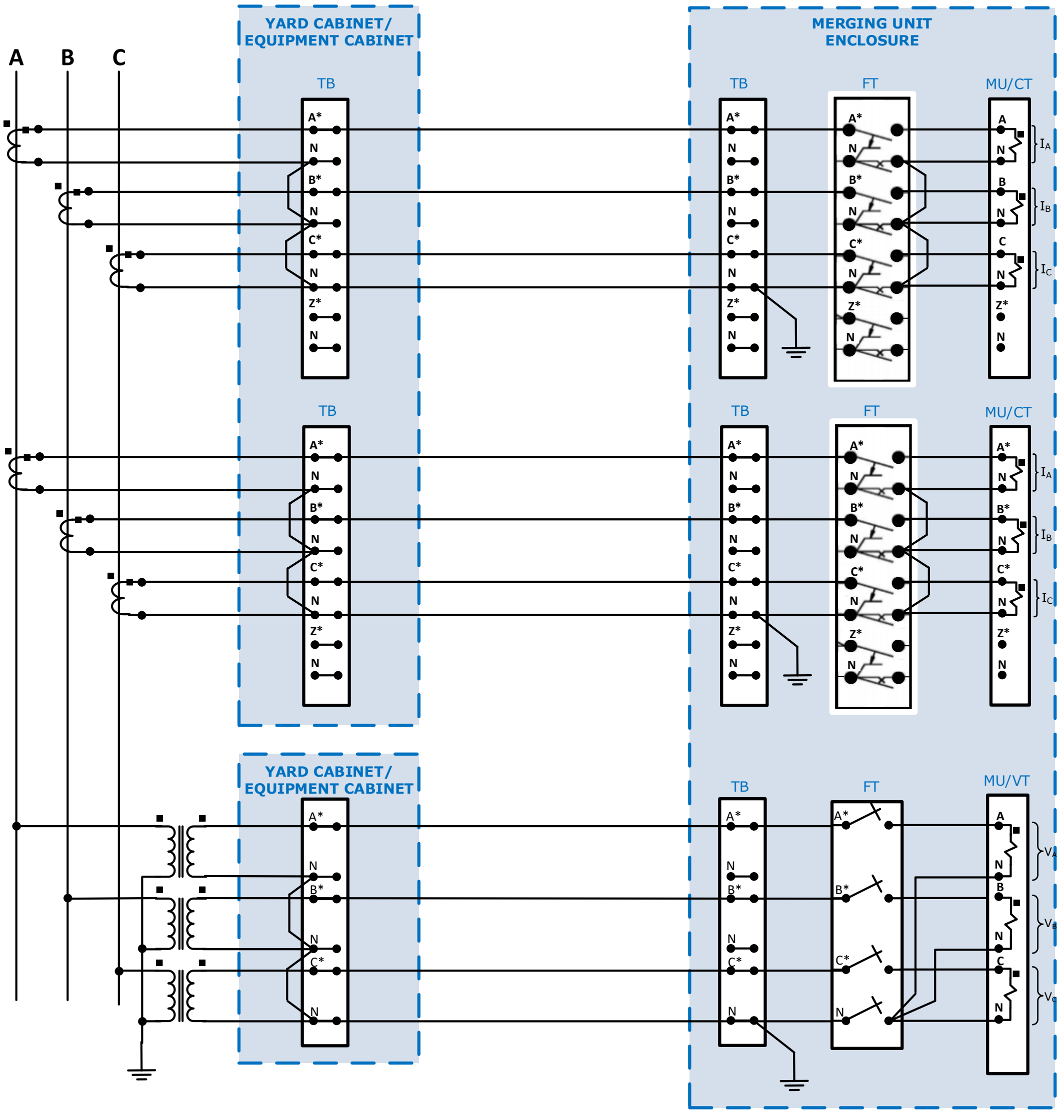

Figure 6: Standard wiring to merging units at a digital substation

In term of testing, for a conventional substation, test equipment is used to provide controlled test values of currents and voltages injection to simulate primary equipment status, and to capture the operation of physical output contacts.

As comparison, digital substations using IEC 61850, can do IEC 61850 test mode and simulation for test object isolation, simulate test data, and gather feedback without tripping, affecting the system. [7] For example, Simulation mode (LPHD.Sim) and TEST mode (LLN0.Mod) helps expedite the testing without having to remove the wirings. LGOS and LSVS helps verifying a GOOSE or Sampled Values message is being published. IEC 61850 Edition 2 provides robust virtual and physical testing capabilities to accomplish testing reliably and safely.

Figure 7: The MU units in the outdoor cubicle at 110KV Nghi Son

Figure 8: Outdoor cable at a typical conventional substation vs outdoor cable at 110KV Nghi Son digital substation

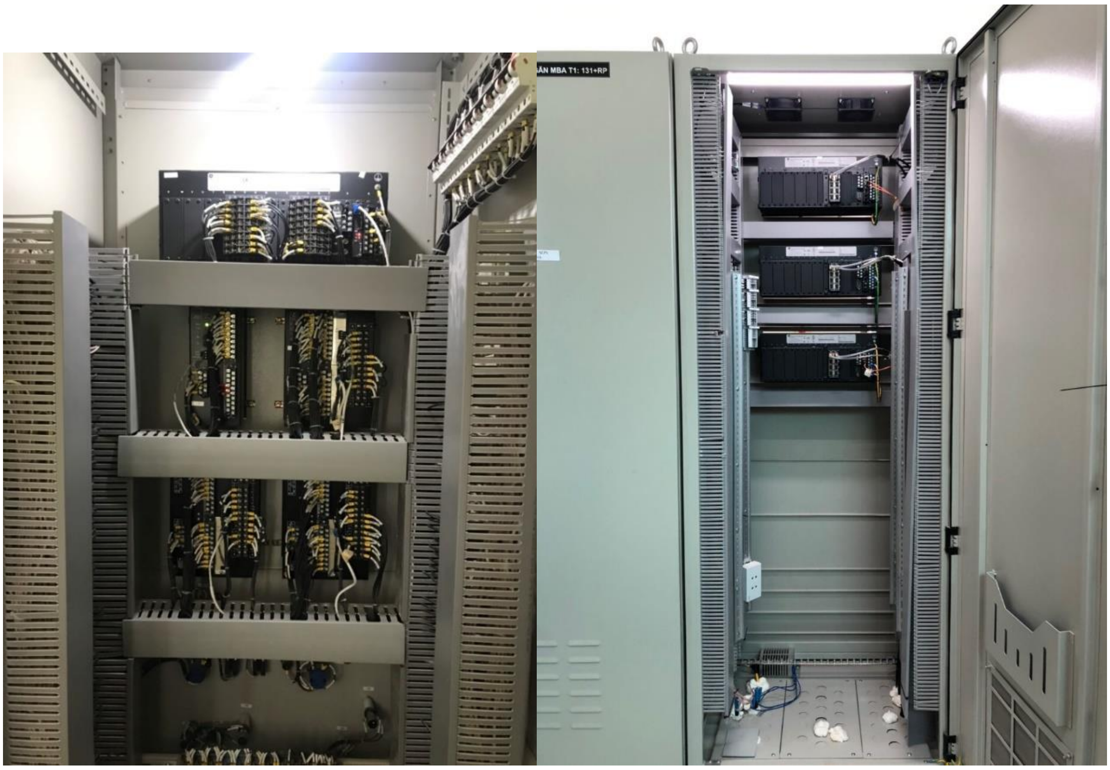

Figure 9: Protection panel at a typical conventional substation vs protection panel at 110KV Nghi Son digital substation

Digital substation also delivery additional benefits such as massive copper wiring reduction, cable termination reduction, space footprint reduction, cubicle reduction. These offer obvious benefits in terms of CAPEX, optimiced manpower and installation time. This is aligned and proven by other utility pilot projects. For example, first digital substation in TransGrid Australia project demonstrated the same simplification on testing, 90% reduction in engineering drawing, 93% cable trench reduction, 47% cabinets footprint reduction. [9]

Standardization on wirings and interlocking

EVN deployment of 6 digital substations also demonstrated digital substation standardization can reduce the substation build and installation time. A digitally enabled substation is necessary to enable substation systems to adapt to remote monitoring and flexible system [8]. It has been EVN's strategy to migrate the operation of substation from a manned station to an unmanned substation. With massive hardwiring reduction and software logic interlocking, many operations could be centrally monitored and reduce human operation mistakes. Digital substation technology provided a solution to realise EVN strategy.

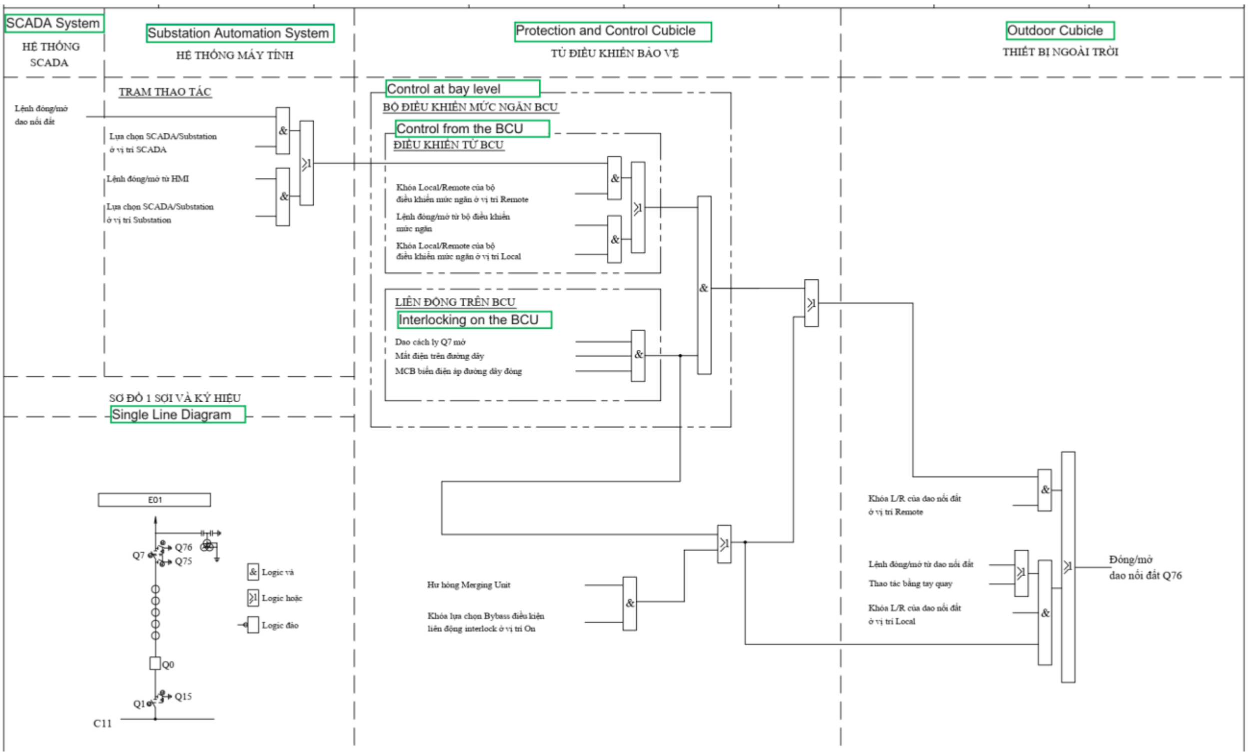

Figure 10: Logic design with interlocking on the BCU at 110KV Nghi Son

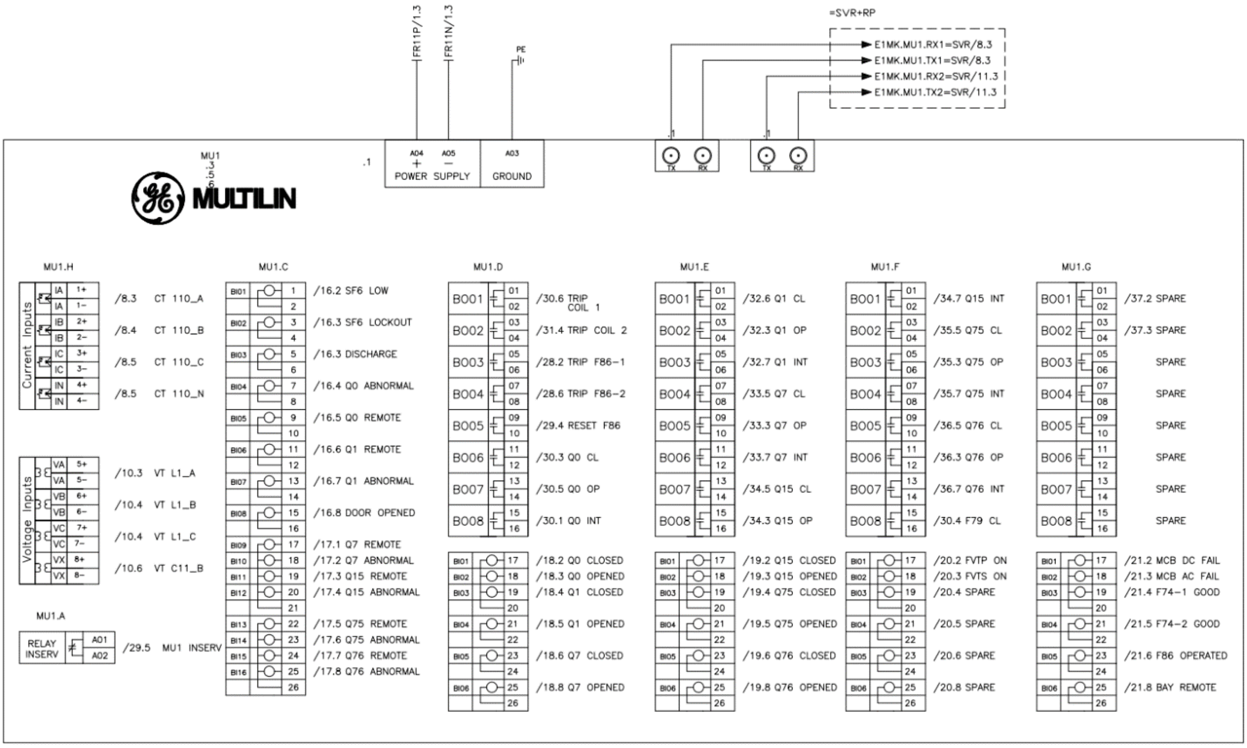

Figure 11: All primary equipment statuses were gathered to the MU unit and protection and control command from the BCU transmitted to the MU through communication at 110KV Nghi Son

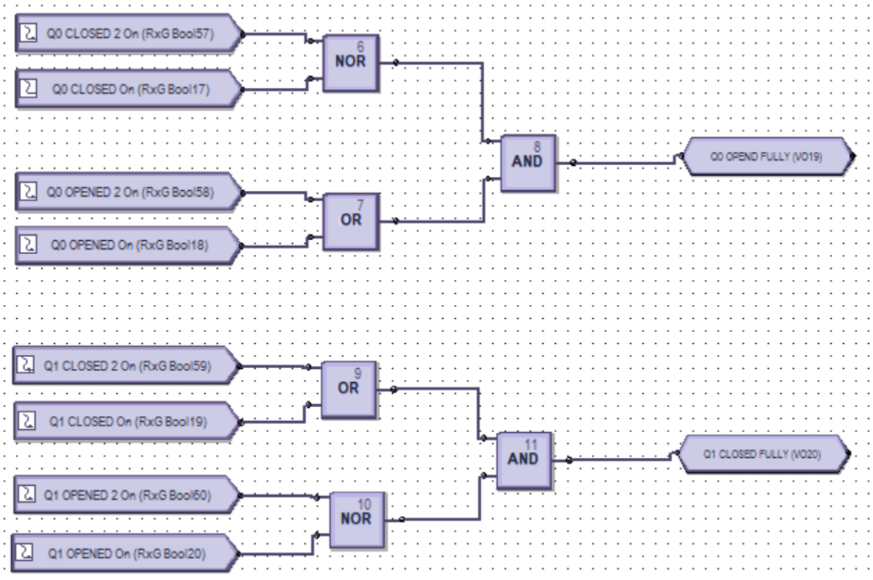

Figure 12: Software logic for interlocking on the BCU at 110KV Nghi Son

Engineering duration	Conventional substation	Digital substation
110KV Nghi Son	3 months (outdoor cubicle -1month, Cabling -1 month, and etc)	2 weeks

Table 4: Engineering duration comparison for a conventional substation and digital substation

Conclusions

Digital substation has been widely tested by many utilities in the world today, but the majority of utilities focus on lab testing and deploy pilot projects for proof of concept and monitor the performance. EVN is steps ahead and successfully deployed and commissioned 6 digital substations in 2 years, especially during the challenging COVID time. Based on the 6 digital substations' mass deployment experience, conventional substation and digital substation reliability analysis was conducted. The digital substation shows that it has advantage and higher reliability in protection and control (PAC) scheme compared to a conventional substation. Also, based on 6 projects, digital substation standardized engineering was proven to reduce the deployment time. These are on top of many well proven digital substation benefits for example, massive copper wiring reduction, cable termination reduction, space footprint reduction, optimised manpower, cubicle reduction offers obvious benefits in terms of CAPEX and installation, simplification on testing, reduction in engineering drawing, cable trench reduction, cabinets footprint reduction. The mass deployment of digital substation is feasible and bring benefits to the network operator.

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