Introduction of 132/11 kV Digitally Optimized Substation for Protection, Control and SCADA System in DEWA Transmission Network

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Abstract- Dubai's transmission power system plays a vital role in delivering optimum reliability and uninterrupted power. We therefore need to maintain the highest levels of technology, operational and cyber security best practices for all digital systems.

This paper aims to provide the conceptual overview and benefits of a digitally optimized substation design. The new design includes control, protection and cyber security systems supplied from different vendors from across the globe which are engineered, configured and extensively laboratory tested to ensure perfect functionality of these highly complex and challenging digital technologies. Identifying the latest technologies available and implementing these in innovative new ways has produced new designs that enhance functionality and reliability whilst reducing large quantities of discreet components and circuitry.

At station level, virtual technologies are introduced and are embedded in two servers each of which includes all SCMS, cyber security, engineering workstation and data storage with seamless redundancy similar to cloud computing server centers. Servers are configured in a cluster configuration with the remote OT data center as witness server. All applications run in a dedicated virtual machine and virtual security scans and records all traffic with artificial intelligence monitoring performed at the cyber security operations center (CSOC).

At 132kV bay level, duplicate and integrated control and protection is introduced through two multifunction intelligent electronic devices (IED's) per bay, each from a different manufacturer. All inter-bay connections are digitized through

IEC61850 process bus, which are engineered to be interoperable and interchangeable between different manufacturers without the need for reconfiguration. The latest IEC61850-9-2 compliant IED's provide enhanced digital fault recording capability which automatically transmits fault records through the IEC61850 network in the common Comtrade file format. Fault records are automatically available at the station HMI and at the central data center. Remote access to all IED's is provided through a secure virtual desktop application. Role based access, centralized user and password management is managed by a specialist OT security team.

The unique new designs were developed in house by DEWA specialists in conjunction with specialists from the original equipment manufacturers and software developers. The digitally optimized substation (DOSS) is a completely new design focused on digitization and optimization of all control, protection, data acquisition communications and cyber security systems.

The digitization of thousands of components and reduction of over 100km of copper wiring delivers significant reduction in carbon footprint, reduction in building size, energy saving, cost reduction while improving the functionality and reliability of the transmission power system. This innovative initiative will ensure that DEWA will have arguably the most advanced substations both regionally and globally by introducing the latest digital technologies, optimized designs in line with the industry leading best practices.

I.INTRODUCTION

Dubai Electricity & Water Authority (DEWA) was established in 1992 by His Excellency Sheikh Maktoum bin Rashid Al Maktoum with the objective to provide reliable power to residents of the Emirate of Dubai. Since its inception, DEWA has continuously invested in maintaining and upgrading the power delivery infrastructure to meet the increasing demands of the growing Emirate of Dubai.

Dubai Electricity & Water Authority (DEWA) Power System includes Generation, Transmission and Distribution networks. The transmission network operates at 400kV and 132kV voltage levels with over 350 transmission substations consisting of 400/132kV, 132/33kV and 132/11kV sites.

The new substation designs take the latest equipment and technologies, applies them to substations in new and innovative ways that benefit the environment, DEWA and the community.

II.DIGITAL SUBSTATIONS: FACTS VS MYTHS

A full digital substation by definition includes low power instrument transformers (LPIT's) also known as non-conventional instrument transformers (NCIT's). These NCIT's are connected to merging units, which perform analogue to digital conversion, applies a time stamp in order for the sampled values to be transmitted over an ethernet network.

However, looking carefully at the concept of a digital substation, it is evident that since the NCIT's are analogue devices that produce an analogue sinusoidal output, these systems are no more digital than conventional instrument transformers. The fact remains that substations transport power which is the product of voltage and current which are analog quantities both at primary and at secondary levels. We can therefore conclude that the term full digital substation is somewhat misleading.

A. Comparison of NCIT Vs. Conventional CT

In full digital substations non-conventional instrument transformers for measuring current are either a rogowski coil or optic sensor both of which are analog systems as shown in Figure1. These NCIT's transfer analog quantities in proportion to the measured primary quantities to merging units (MU) which perform analog to digital (A to D) conversion much the same as conventional IED's which already have built in A to D converters based on 1 amp input rating. The significant different appears at the output of the merging unit which transmits the measured data through ethernet. This is where the system becomes complex since ethernet does not have a definite or a fixed data transmission time. This is unacceptable for protection systems, which will become unstable due to measurement misalignment.

The merging units therefore need to time tag each sample before transmitting. Since the IED's are sampling at about 8kHz this amounts to a very large amount of data being transmitted for the 3phases plus neutral for currents and voltages from each merging unit. This data is transmitted through the process bus which in turn has the effect of slowing the ethernet speed. The additional cost, complexity, additional components with the obvious adverse impact on reliability would logically be implemented if there were some significant benefits. The claimed benefit is that NCIT's produce a more linear and accurate measurement, which may be true if there was an identified reason why the conventional system was not adequate. Since protection IED's have very advanced filtering and algorithms capable of maintaining optimum performance even with significant nonlinearity or saturation during faults – this advantage is negligible in almost all applications.

For most applications it therefore becomes evident that the use of merging units is unwarranted and are an additional equipment required to be used that reduces overall reliability and availability of the power system.

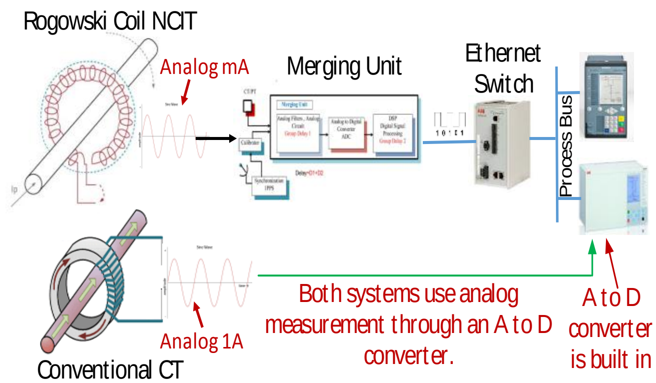

Fig1: Comparison of conventional CT vs Rogowski coil NCIT

Non-conventional instrument transformers for all substation equipment such as bushing CT, Reactor internal CT and transformer neutral CT are not available especially for applications which are immersed in oil. This makes a full digital substation using all NCITs not possible.

In DEWA a typical 132/11KV substation has 71 x 11kV bays which would result in a large number of merging units and a large amount of data on the process bus. The additional cost, complexity and the fact that OEM's are unable to provide a consistent solution makes this option impractical considering that there is no benefit to the power system.

B. Reliability of NCIT Vs. Conventional CT

A quick comparison of NCIT with conventional CTs is as shown in table below. A NCITI requires a matching merging unit which needs to be considered as part of the measuring system when compared to a conventional CT which does not require additional components in order to connect to IED's. It is evident that NCIT does have several disadvantages over conventional CTs in terms of mean time between failure (MTBF), performance, life expectancy etc. This is a separate subject and the details are not covered in this paper; however, it is evident that use of NCIT/sensors with merging units does not offer any great advantages towards substation digitization as shown in Table-1.

Table-1 Conventional CT Vs NCIT

Description	Conventional CT	Sensor + Merging Unit (NCIT)
Life expectancy	> 40 years	20 years
Mean time between failures (MTBF)	1,506,939	500
Replacement strategy	Not required	May require new GIS
Consequence of failure	1 x protection out	Feeder + Busbar prot. + Control out
Probability of interruption	Low	High
Performance	Medium	High
Advantage	Reliability	Claim of full digital

III. DIGITALLY OPTIMIZED SUBSTATION DESIGN

DEWA took the initiative to review the digital substation concept and developed an innovative digitally optimized substation (DOSS) design. The new design retains the proven reliable conventional instrument transformers and utilizes the most practical and beneficial digital substation concepts of process & station bus. The DOSS design utilizes the latest smart technology available in intelligent electronic devices (IED's) which allows customizing and optimizing the configuration of the control and protection systems in substations while reducing the number of auxiliary relays and components. This approach ultimately achieves the best-engineered solution whilst achieving higher reliability, cost reduction and lower carbon footprint.

The key features of the DOSS design are:

- Consistent substation design irrespective of the contractors/ OEMs.
- More efficient design approval process for new substation projects.
- Reduction in time required for project design approvals, testing & commissioning.
- Additional benefits such as reduction of maintenance cost, ease of operation and simplification of the substation design.
- Using conventional instrument transformers ensures that protection and control systems can be refurbished in future without the risk of needing to replace instrument transformers or possibly switchgear.

The digitally optimized substation simplified architecture is shown in Figure-2.

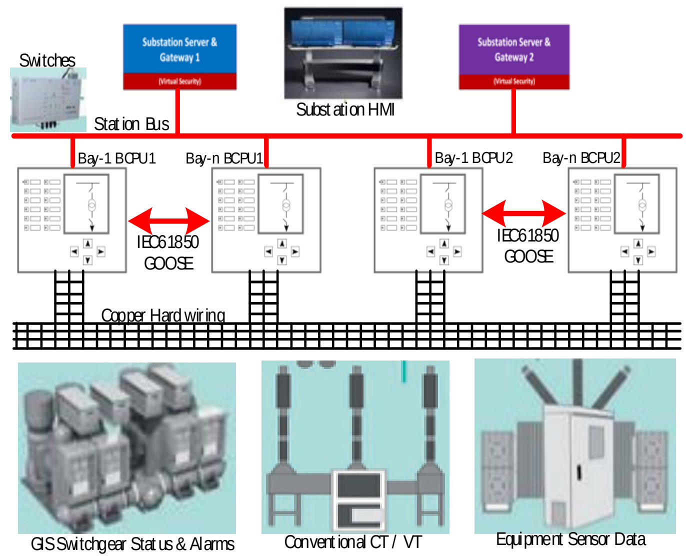

Figure-2: Simplified DOSS Architecture

A. The Basis of Design Optimization

Optimization of control and protection system considered the following main aspects:

- Protection & Control functions are integrated in single Intelligent Electronic Device (IED)
- Hard-wired interlocks replaced with digital signals (IEC61850 GOOSE signals over process bus).
- Electromechanical relays replaced with digital functions.
- Reduction or elimination of CTs.
- Integrated busbar and feeder backup protections for 11kV network.
- Integrated Tap Change Controller (AVR).
- Removal of 24 x metering units on 11kV.
- Elimination of external DFR devices by utilizing the inbuilt fault recorder capabilities in IEDs.

- Each bay shall have two independent and redundant protection and control systems.
- Two independent auxiliary DC systems for BCPU-1 & BCPU-2, to avoid common mode failure.
- Protection schemes engineered to produce efficient designs with minimum number of auxiliary components.
- Standardization of SCADA alarm lists with reduced number of alarms to the master control station.

B. Details of Design Optimization for a Typical 132kV Feeder Bay

For a typical 132kV feeder bay the existing conventional SS design and new digitally optimized SS design are as shown in Figure-3.

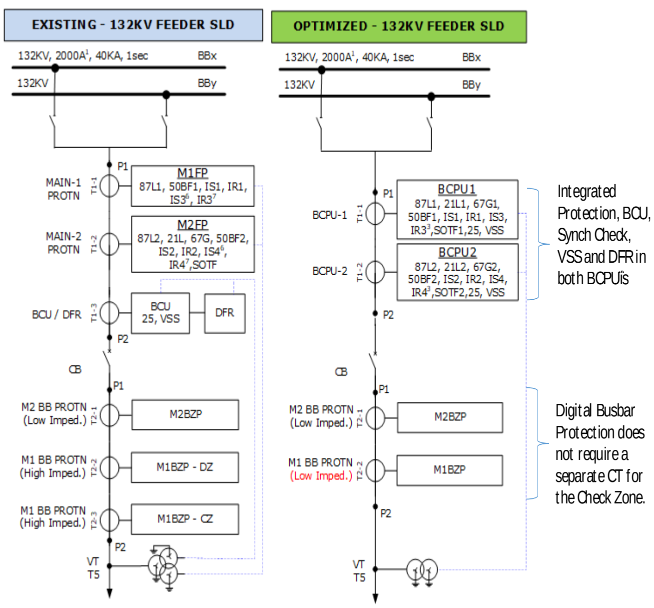

Figure-3: Feeder bay design in conventional & DOSS design

The protection and control designs for a typical feeder bay in conventional and new DOSS designs are compared in Table-2.

Table-2: Comparison of Feeder bay design in conventional & DOSS design

Application	Existing Conventional SS Design	Digitally Optimized SS Design
Bay Protection	Main-1 Protection (M1FP)	Bay Control & Protection Unit-1 (BCPU1)
	Main-2 Protection (M2FP)	Bay Control & Protection Unit-2 (BCPU2)
Bay Control	Bay Control Unit (BCU)	Not Applicable (Integrated to BCPU1, 2 and Respective CT core eliminated)
Fault recorder	DFR	
Busbar protection	High Impedance Main-1 Protection (M1BZP)	Low Impedance Main-1 Protection (M1BZP)
	Low Impedance Main-2 Protection (M2BZP)	Low Impedance Main-2 Protection (M2BZP)

DOSS designs include integrated control & protection panels (CPP) instead of separate protection and control LCC panels. A comparison of existing and new panels are as shown in Figure-4.

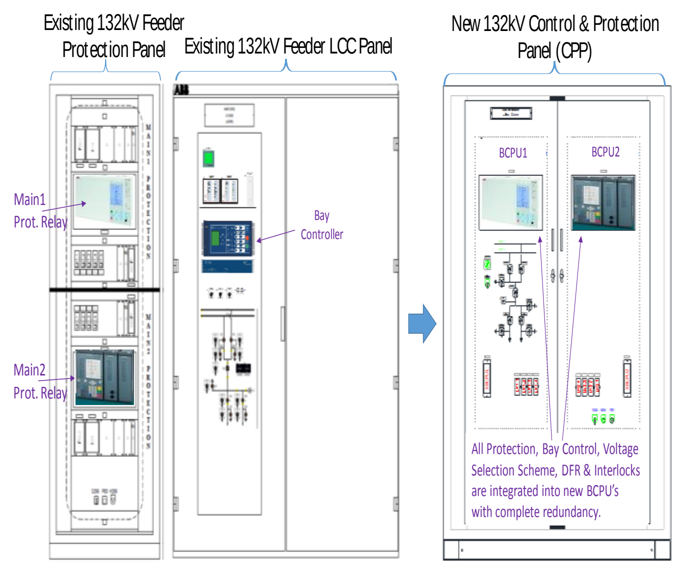

Figure-4: Feeder bay panels between conventional and DOSS design

Accordingly, similar optimizations are done for all 132kV and 11kV bays in the new DOSS design. As per the new BCPU and BMP functionality, the protection & control IED's are prequalified and approved after successful laboratory testing.

The approved BCPU, BMP IEDs for some of the applications are as shown in below Table-3.

Table-3: Prequalified BCPU, BMP IEDs for DOSS SS

Voltage Level	Typical Bay	Application	IED Make	IED Type
132kV	Feeder	BCPU1 / BCPU2	Siemens	7SL87
			SEL	411L
			Hitachi	RED670
132kV	Bus Coupler	BCPU1 / BCPU2	Siemens	7SJ85
			SEL	451
			Hitachi	REC670
132kV	IDT Transformer	BCPU1 / BCPU2	Siemens	7UT85
			SEL	487E
			Hitachi	RET670
11kV	Feeder, Incomer & Capacitor Feeder	BMP	Siemens	7SJ85
			SEL	451
			Hitachi	REC670

C. SCMS Architecture in new DOSS Design

In the new DOSS design, the SCMS is completely redesigned and introduces virtual technologies. The number of SCMS components are greatly reduced whilst increasing reliability and redundancy. The SCMS architecture utilized in new DOSS design is as shown in Figure-5.

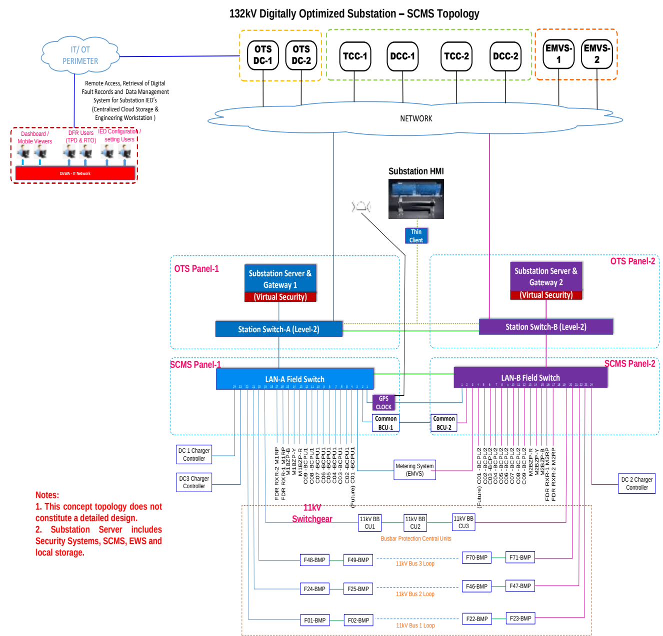

Figure-5: SCMS architecture in DOSS design

D. Standardization of DOSS Design

Standardization in DOSS design achieved by preparing standard design documents by DEWA and including them as part of tender documents for contractor's strict compliance. The following are the standard design documents:

- Control and Protection specification.
- SCMS technical specification.
- DC technical specification.
- Metering technical specification.
- Conceptual protection single line diagrams, trip logics and control & interlock logics for all the typical bays.
- Control and protection panel schematic and general arrangements drawings.
- Substation DC system single line diagrams.
- Substation DC chargers schematic and general arrangement drawings.
- Test terminal block standard terminal arrangements.
- Master station SCMS signal list with standard IEC61850 signal address.
- Standard CT & VT parameters for all bays and all applications.
- BCPU/ BMP IEDs specific wiring templates for each make and application.

In addition to above mentioned standard design documents, pre-qualified manufacturers were also provided to the contractors to select the approved vendors.

- Approved IEDs list.
- Approved protection and control component list.
- Approved energy meters list.
- Approved CT and VT manufacturers list.
- Approved panel manufacturers list.
- Approved DC system manufacturers list.

E. Digitally Optimized SS Design – Benefits

The new innovative digitally optimized substation design provides significant benefits to DEWA as a utility. The new design for 132/11kV substations includes the following advantages:

- Protection & control functions are integrated into a single IED (BCPU1/2): Reduction of 15 IEDs, redundancy in control functions and 18 x control and protection panels removed.
- Hard wired interlocks are replaced with peer-peer GOOSE digital signals: Over 100km of copper cabling eliminated.
- All electromechanical relays replaced with digital systems: Over 8000 devices removed.
- Reduction in the number of current transformers: Total 258 units removed.
- Integrated busbar and feeder backup protection for 11kV network.
- Integrated tap change controller (AVR) into BMP IEDs: Panel with 3 x controllers removed (digitized).
- Removal of 24 x metering units on 11kV.
- Integrated digital fault recorders (DFR's): 3 x DFR panels removed.
- Optimized SCMS system: 4 x SCMS panels, 5 x computers, 2 x monitors, 20 x network switches, 196 fiber optic cables, 4 x fiber optic patch panels, 1 x GPS clock removed.
- Virtual security, role based remote engineering access through virtual machine is achieved.

The summary of removed equipment as part of the 132/11kV design optimized SS are as shown in Table-4.

Table-4: Summary of removed equipment in DOSS SS

S.No.	Equipment	Description of Change	Quantity of Removed equipment
1	132kV GIS	Reduce 13 x Sets = 39 CT's	39
2	132kV Feeders	Remove 3 x 132kV Protection Panels	3
3	132kV IDT's	Remove 3 x 132kV Protection Panels	3
4	132kV Bus Coupler	Remove 1 x 132kV Protection Panel	1
5	132kV LCC	Reduce 6,707 x components (Aux relays, timers, terminals, mcb's, switches etc.)	6707
6	11kV Feeder with Metering	Meters removed and CT's for metering are retained.	255
7	11kV Feeder without Metering	Optimized with reduced CT's and components	672
8	11kV Cap Bank	Reduced Capacitor Bank Protection relay and integrated into BMP.	102
9	11kV Incomer	Check Zone relay removed, AVR function integrated into BMP.	81
10	11kV Bus Sections	Reduced CT's and several components digitized	59
11	11kV Busbar	Remove High Impedance scheme and implement Low Impedance BBP with integrated 11kV Feeder Backup protection. Reduce 73 x sets of CT's	3
12	LVAC	Remove 34 components including High Impedance REF & CT's	34
13	SCMS	SCMS panels & components	232
14	AVR	Remove 1 x AVR panels and equipment's	4
15	Digital Fault Recorder (DFR)	Remove 3 x DFR panels and equipment's	3
		Total	**8198**

Additionally, the new design will support DEWA's vision and environmental goals.

- The reduction in carbon emissions approximately 37 tons per year for 132/11kV substation due to annual energy saving of 53MWH.
- Reduction in substation building size by $133m^2$.
- Savings of 7 million AED per substation due to reduced equipment.
- The new design utilizes, control and protection panels (CPP) developed in the UAE along with local manufacturers.

IV. CONCLUSION

The DOSS design selects the best technologies available, combines it with best design practices to achieve the industry leading optimized substation design.

The innovative DOSS design concept can be implemented in other organizations globally, which have the same business portfolio (electricity supply), and this will positively influence our responsibility to support the sustainable development goals and protect the environment.

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