SMART DISTRIBUTION SUBSTATION DESIGN FOR A SUSTAINABLE AND EFFICIENT DSO MODEL

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ABSTRACT

Electricity networks have rapidly evolved in the last two decades to respond to the new social, political and technological landscape. It is important for DNOs to provide quality, efficient and reliable energy supply to customers. As an aspiring DSO, is it vital to consider the latest innovation technologies and therefore drive the change, maximizing the benefits on sustainability, digitalization, environment and safety aspects of the future network.

Distribution substation equipment is part of this growing digital era. In addition, as increased awareness of the importance of environmentally friendly technologies grows, so does innovative thinking on how to tackle this problem.

This paper intends to outline the key features and benefits of the future sustainable digital distribution substation.

INTRODUCTION

Current 33/11 kV distribution assets have limited capability to respond to the new needs of the dynamic energy sector. Future technologies offer greater levels of control, monitoring, safety and fault reduction than existing distribution substations and will light the way to a DSO model. Consequently, future distribution substation designs should consider the latest available technologies.

Analogue technology is not fully effective at processing data to the required accuracy and precision of the newest existing substation protection and control standards. Also, it doesn't allow for easy and cost-beneficial data and command sharing, which therefore hinders development of the global system autonomy needed to create a smart network.

In addition, distribution substations use SF_6 and mineral oil as insulation materials; both environmentally harmful and with potential risks to human life in case of failure. Current environmental policies are advocating for greener and safer solutions to be implemented, which is driving the need for new insulation mediums to be integrated in future substation designs.

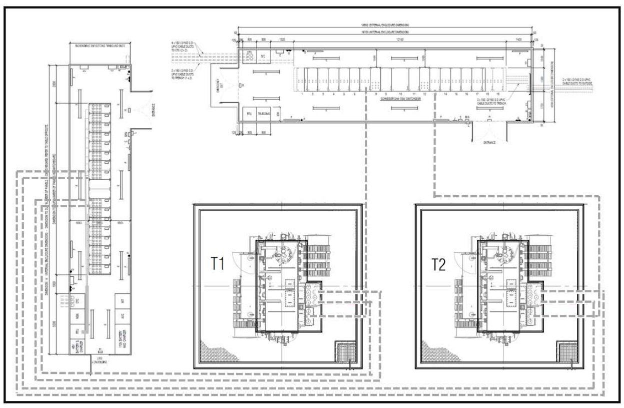
As a DNO, it is critical to move away from reactive and time-based maintenance and investment strategies to an online monitoring based system that manages asset reliability, prioritizing maintenance operations, reducing operating costs and improving network safety.

Moreover, sustainability and energy efficiency has to be better reflected in the new substation designs in order to maximize footprint usage and heat wastage.

This paper will aim to solve the concerns stated above by proposing a future substation model aiming to incorporate new technologies.

EXISTING SUBSTATION

The following diagram shows a typical 33/11kV substation layout, showing the most relevant network components.



The following list summarises the key points that, unless evolved towards new technologies and innovative approaches, can hinder the full development of a smart sustainable distribution network:

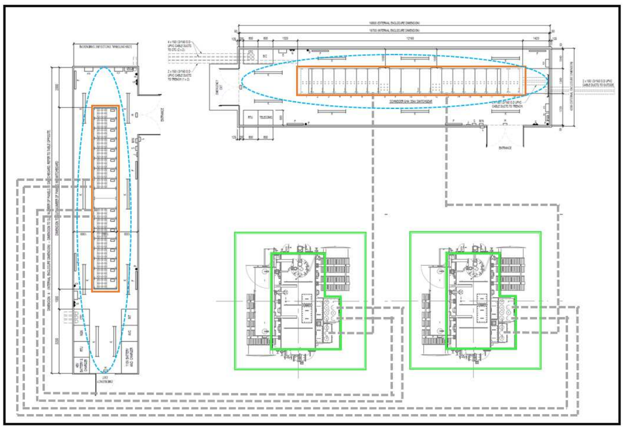
- **Transformer:** Historically, these have always used mineral oil as their insulation and dielectric fluid, which has a big impact on safety and environmental objectives.

- **Control & Protection:** The digitization of the Protection, Automation and Control system occurred over twenty years ago; however, the vast majority of protection and control devices found in substitutions are analogue based.

- **Asset management:** Currently established asset management processes mostly rely on a reactive and time-based maintenance and investment strategy, which leads to low asset reliability and impacts on safety and customer service.

- **Switchgear:** Sulphur-hexafluoride (SF_6) is widely used in electricity transmission and distribution as an insulator and switching gas due to its high dielectric strength, good thermal conductivity, non-flammability and non-toxicity. However, SF_6 has a large global warming potential (GWP) – 23,500 times more than CO_2- and a lifetime in the atmosphere of 3,200 years, placing it amongst the gases with the most potent greenhouse effect and thus, as one of the F-gases included in the Kyoto Protocol.

PROPOSED FUTURE SUBSTATION



Transformer

The transformers installed in this substation are ester-insulated.

One of the main advantages of esters is that these dielectrics are classified as type K fluids, which means that they have much higher flash and fire points. This enhances fire safety, especially critical in populated or sensitive areas, and can result in big cost reductions when avoiding the installation of fire extinguishing systems or firewalls.

In addition, in the case of installing more than one transformer in the same location, the distance required between transformers to ensure interaction safety in case of failure of one of the units is not required due to the non-flammability of the esters, therefore reducing cost of land needed and allowing more equipment in a smaller area.

The ester used is synthetic due to the improved oxidation stability and high pour point in comparison with natural ester.

Switchgear

The switchgear in the proposed substation is SF_6-free, helping to reduce human-based greenhouse gas emissions and therefore control climate change.

The current marketplace offers various options for SF_6-free 11kV metal-enclosed switchgear, usually using vacuum interrupters and air insulation.

The research is less advanced at medium-voltage level than for transmission voltages, due to the lower quantity of SF_6 and sealed systems. However, the market is starting to develop medium voltage switchgear using alternative gases. The 33kV switchgear proposed for this substation includes one of the recently developed SF_6-free gases as insulating medium, with vacuum as the interrupting technology.

Control & Protection

For the future substation design the proposal uses IEC61850 MMS (Manufacturing Message Specification) protocol within the 33kV protection and control panels, along with IEC60870-101 as the preferred protocol to the central system. In order to reduce costs and production time, a very high degree of standardisation is introduced to the build.

The system level comprises of a single combined backup protection and control unit per bay; connected together via a fibre ring utilising RSTP and SNTP along with a standard switch and gateway device.

The system shall be designed with a top down engineering process that also levers the use of standardised ICD template files rather than a bottom up engineering process. This is because a top down process facilitates the use of one data origin, i.e., design, draw or modify things only in one place. These changes will be automatically implemented elsewhere when needed. As all the information is stored in the Company Systems this data origin shall also be part of it.

Together with the top-down approach, the following points are crucial for a proper engineering process:

- Strong standardization at all levels, from the Company Systems to the bay and process bus levels, as it will reduce engineering expenses and times.
- Automatisation: together with a good standardisation and the one data origin concept, atomatisation of engineering process shall help reduce human errors when designing and configuring. It shall also facilitate that non-specialist staff can design and configure the substation.

Introduction of this system leads to:

- A large substation cost reduction (removal of separate control and protection panels, removal of multicore cables between protection panels and switchgear, reduced civil footprint, reduction in commissioning time);
- Ability to expand the substation without the need for major changes;
- Reduction in maintenance interventions;
- Standardization of projects, schemes and testing;
- Very quick and easy to build using supplier configuration tools (fully repeatable with standard templates);
- Possibility to type test or to fully prove a substation configuration in a factory environment;
- Increased automation, which helps create a smart network;
- Use of IEC61850 will help prevent future problems from obsolescence.

Online monitoring

The proposed substation includes an online monitoring system to measure and communicate the condition of the assets continuously and therefore develop a proactive asset management strategy that prevents failure and allows for early intervention in case of an identified need.

The online monitoring system gathers all the data and communicates it through existing communication lines to a central heat map, accessible remotely through IP addressing. This heat map includes a geographical layout of the entire network and a colour coded condition profile, in order to quickly identify the overall network's condition.

It also sends specific alarms when the parameters reach the established threshold values, in order to highlight urgent intervention needs.

The table bellows summarises the different parameters to monitor for the specific assets in the substation.

Equipment	Parameter
Transformer	Oil Temperature
Transformer	Winding Temperature
Transformer	Direct Winding Temperature measurement with Fibre Optics
Transformer	Fan operating time
Transformer	Fan current
Transformer	Moisture in Oil
Transformer	Dissolved Gas Analysis
Transformer	Hydrogen indicator
Transformer	Partial Discharge
Transformer	Bushings Capacitance
Transformer	Bushings Power Factor
Transformer	OLTC - Time to TAP Changer
Transformer	OLTC - Engine Current during the TAP Changer
Transformer	OLTC - TAP Changer counter
Transformer	OLTC - Inoperative Time
Transformer	OLTC - Oil Temperature - TAP Changer
Switchgear	Operation Counter
Switchgear	Time to Open/Close
Switchgear	TRIP COIL SUPERVISION
Switchgear	Insulating Gas Pressure
Switchgear	Partial Discharge
Batteries	Battery bank Voltage
Building	Temperature
Building	Humidity

Battery monitoring should be carried out by an intelligent battery charger that is capable of Automatic and Programmable Discharge of the battery against the connected load such that it can maintain a cycle of charge and discharge so that the battery is not overheating or generating hydrogen gas.

- Automatic and programmable Impedance testing with the battery disconnected from the charger by connecting a resistive load and the charger directly supplying the substation DC loads in this period and Impedance calculation from voltage drop measurement during Circuit Breaker Tripping or Closing.

- Automatic and programmable Capacity testing against load and against resistance which will include registration of voltages, currents and energy.
- Detection of open circuits and ripple voltages.

CONCLUSION

To keep pace with the expanding complexities of modern network demands, asset improvements within the new sustainable digital substation will be at the cutting edge of both technological advances and design.

Adopting digital communications as standard in distribution substations will provide opportunities for reduced losses, standardised data models, savings in overall life-cycle cost, new and improved functionality and secure and flexible substation design.

The digital distribution substation will have the required level of flexibility and performance to aid the network transition, allowing for greater system automation and control as well as increased levels of safety and security.

Remote online monitoring and predictive analytics will be at the heart of the substation design, in order to maximize asset utilization, improve customer supply and operational and public safety.

The distribution substation design will also reflect the socio-political drive for greener industry solutions and increased sustainability, by replacing environmentally harmful insulating materials, and maximizing the efficient use of the substation through the installation of small-scale renewables and utilization of heat waste for heating purposes.

REFERENCES

[1] J.R. Agüero, E. Takayesu, D. Novosel, and R. Masiello, “Modernizing the grid: Challenges and opportunities for a sustainable future,” *IEEE Power & Energy Magazine*, vol. 14, pp. 74–83, May/June 2017.

[2] D. Tan and D. Novosel, “Energy challenge, power electronics & systems (PEAS) technology and grid modernization,” *CPSS Transactions on Power Electronics and Applications*, vol. 2, no. 1, Mar. 2017. <AU: please supply page numbers>

[3] IEEE Quadrennial Energy Review Report to DOE (2015, Sept.). [Online] Available: http://www.ieee-pes.org/qer

[4] Scanned magazine- PAC IED 62850 in smart grid