May 2024 Technical Information

Power Grids

Green Energy & Mobility

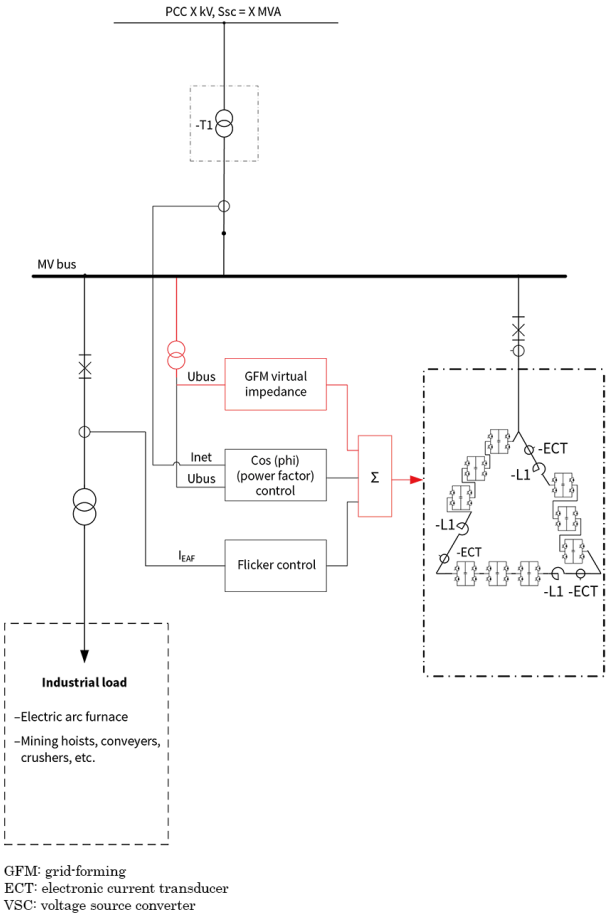
#Carbon Neutral #Disaster Prevention and Resilience #Co-creation and Open Innovation #Sustainability #Generative AI #IoT/Data Utilization #Energy

1. How STATCOM with Grid Forming Control Can Improve Industrial Output

High power, fast dynamic, and intermittency are the key features of industrial loads such as mining facilities and electric arc furnaces. Flicker, harmonics, unbalance, and power factor are common issues in those applications. These issues can result in reduced safety/stability of the power network, diminished production performance, and non-compliance with grid connection requirements. In addition, the sensitive industrial loads can deteriorate due to large disturbances in the local network, especially under weak network conditions. A grid-forming static synchronous compensator (STATCOM), an emerging solution for transmission grid power quality/stability, can also be adopted for industry applications. The grid-forming control loop appears as a supplementary control in parallel with the existing power quality control loops, as shown in Figure 1-1. It can effectively enhance the power quality and maintain grid code compliance, while also contribute to stability thanks to the voltage source behind an impedance characteristic. It reacts instantaneously to counteract voltage changes and becomes a sink for harmonics. Improved power quality and performance are demonstrated in Figure 1-2 in a case study.

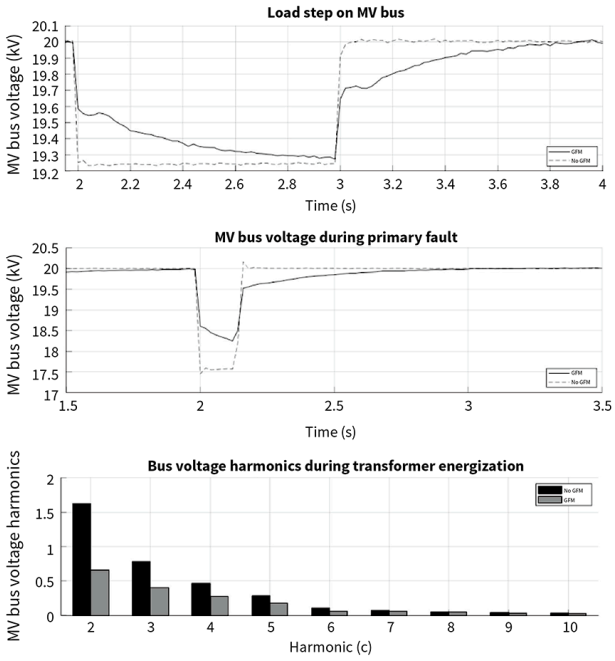
(Hitachi Energy Ltd.)

[01-1] General control block diagram of GFM STATCOM in an industry application



GFM: grid-forming
ECT: electronic current transducer
VSC: voltage source converter

[01-2] Performance enhancement by GFM STATCOM



2. Energy-Storage Enhanced STATCOMs for Wind Power Plants

The world has seen a rapid increase in the deployment of large-scale wind power plants (WPPs) in transmission grids. The dynamic interactions between wind turbines (WTs), power transmission cables, and other electrical infrastructure within WPPs have posed challenges to grid stability and power quality, particularly under diverse operating conditions.

Energy-storage enhanced STATCOM is an all-in-one solution to address the stability and power quality challenges with grid integration of large-scale WPPs. With the energy storage system at the direct current (DC-) link and grid-forming control, the E-STATCOM can effectively support the system by offering:

(1) Adequate damping to system oscillations, featuring reduced power overshoot and desired settling time of step response of WPP active power,

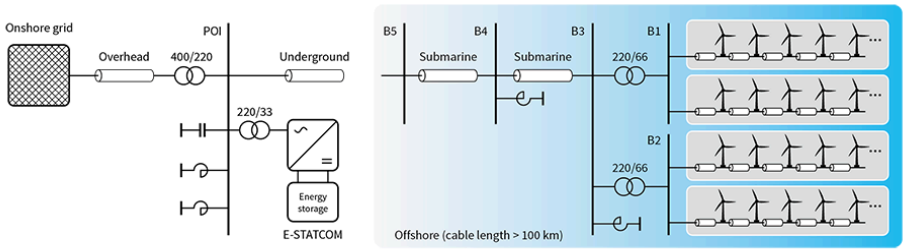
(2) Inertial response with improved rate of change of frequency (RoCoF), and

(3) Active harmonic filtering with enhanced voltage total harmonic distortion (THD).

Building on proven Hitachi Energy converter technology, the E-STATCOM exhibits high scalability, compact design, enhanced efficiency, and ease of maintenance, making it an advantageous solution for grid applications.

(Hitachi Energy Ltd.)

[02] Simplified system diagram of an offshore WPP equipped with E-STATCOM.

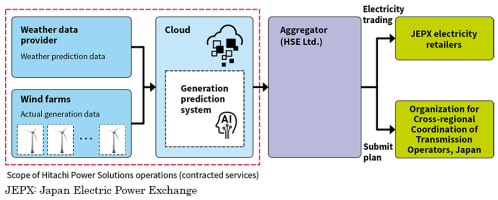


POI: point of interconnection

3. Defining Rated Power of Power Transformers for Solar and Wind Generation Based on Load Profile and Ambient Temperatures

Integrating renewable sources into the electrical system safely and reliably requires complex technical solutions. This article presents a methodology for defining the rated capacity of the step-up transformers used in large renewable power plants focused on optimizing technical and financial parameters. Due to the inherently intermittent characteristic of such energy sources, the traditional definition of the rated capacity based on the peak generation leads to underutilized assets, as the average loading will be significantly lower than their rated power.

[03] Proposed flowchart for the transformer rate definition



JEPX: Japan Electric Power Exchange

An economic analysis combined with full compliance with the technical requirements has been performed aiming to reduce the total installation cost, and thus to promote the expansion of renewable energy generation. On top of the traditional thermal and efficiency evaluations, Hitachi Energy also developed an algorithm that simulates the transformer operation, calculating the operating temperatures, the water content in a discrete number of sections of the coils and the corresponding aging, integrating these parameters to estimate the total lifespan of the equipment. This calculation allows for safely loading above its nameplate and for an accurate assessment of not only aging, but also the parameters that could represent a risk of failure due to the increased loading conditions.

(Hitachi Energy Ltd.)

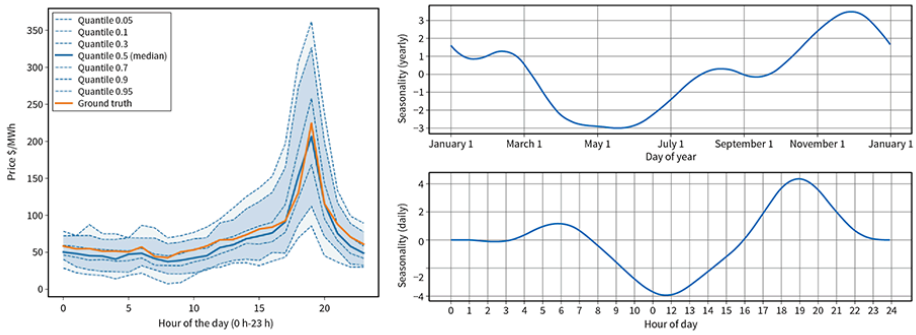
4. Interpretable Probabilistic Price Forecasting for Energy Markets

Electricity market participants use energy price forecasts as a key input to make daily and hourly bidding decisions. While most market price forecasting solutions only generate forecasts of the expected values, algorithms that are interpretable while being able to quantify uncertainty, known as probabilistic forecasts, will add additional benefits to downstream bidding algorithms that aim to optimize profit.

Hitachi Energy Research has developed a machine-learning based probabilistic forecasting model for energy markets that is interpretable and provides probabilities along with price ranges to support better bidding formulation. Acknowledging price curve characteristics, the developed forecasting model is end-to-end trained and is capable of automatically estimating the underlying trends and seasonality patterns and quantifying the effects of external variables and events on energy prices. To provide probabilistic estimates, the model forecasts several quantiles simultaneously with associated probabilities. The model is evaluated on California Independent System Operator (CAISO) and Midcontinent ISO and is shown to outperform other state-of-the-art forecasting models. The explainable seasonality module also reports the learned seasonal patterns and the impact of events on energy prices.

(Hitachi Energy Ltd.)

[04] Probabilistic energy price forecasts and interpretable seasonality pattern learned by the model



5. World's First Compact Cool Dry-type Transformer for Wind Off-Shore

The transition to electricity generation trough clean energy sources has motivated the development of designs for transformers to meet the new demands from the wind industry and to overcome technological challenges.

The main benefits of the enhanced cooling concept integrate a considerable footprint reduction of dry transformers, a reliable asset with proven safety for people and environment due to the minimal quantity of coolant and the possibility to use the existing central cooling system of the turbine to avoid dissipating heat in the surrounding room.

Furthermore, the benefits of this new technology can be easily expanded to other usages: large power dry-transformers, units in confined spaces like marine or urban sub-stations; or applications with high ingress protection (IP) degree which makes the heat extraction complex with the classical air-cooled units.

After a long trial period with a complete set of tests including (but not limited to) heating, vibrations and short-circuit tests that was performed successfully upon the last demonstrator, the first* dry-type transformer with CompactCool technology for the wind off-shore segment was commissioned and energized in September 2023 by Saitec Offshore Technologies.

(Hitachi Energy Ltd.)

[05] Erection of the CompactCool unit inside the tower of Saitec

* Based on research by Hitachi Energy Ltd.

6. Offshore HVDC Grids—The Next Frontier of Renewable Energy Transmission

European offshore wind is experiencing remarkable growth and is critical for net-zero greenhouse gas emissions by 2050, with other regions inevitably following this revolution in the coming years.

High-voltage direct current (HVDC) transmission is a pivotal technology for this, especially voltage source converter (VSC) solutions, pioneered by Hitachi Energy in 1997 and continuously developed toward higher power, compactness and efficiency.

With the growth of HVDC connecting and dispatching renewables, a shift away from point-to-point offshore connections towards offshore hybrid systems and, ultimately, offshore grids will deliver multiple socio-economic benefits. The technologies are available for these goals — now they must be deployed at speed and scale by developing the right frameworks to plan, build, operate and maintain offshore DC grids.

New regulatory approaches and innovative business models will be essential for this, and the expandability of DC grids will drive interoperability of the critical HVDC solutions, as demonstrated through industry-wide innovation projects. The immediate next step needed is a full-scale offshore grid deployment, building the next frontier of renewable energy transmission.

(Hitachi Energy Ltd.)

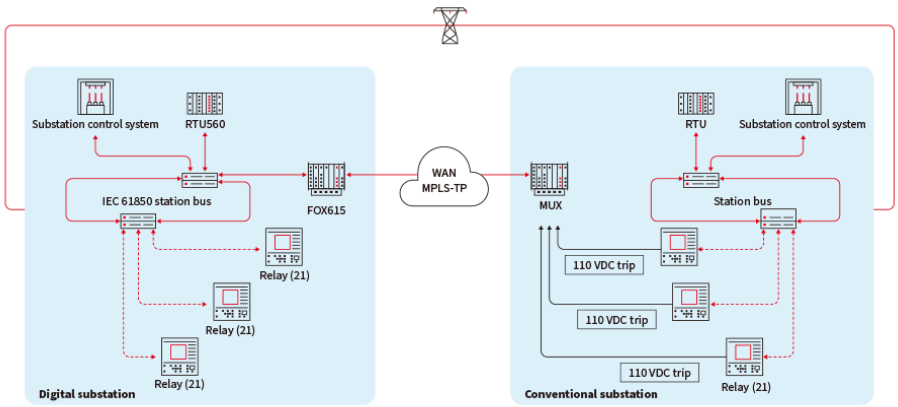
[06] An offshore converter station at Dogger Bank, United Kingdom (Source: Hitachi Energy; Credit: Aibel)

7. Enabling Distance Protection between Fully Digital IEC 61850 and Contact Based Conventional Substations

IEC 61850 adoption is steadily increasing in power grid networks and has evolved to support inter-substation communication over a wide area network (WAN). Implementing IEC 61850-based line protection would require digital concepts on all the connected remote ends of the protected powerlines. This is typically not the case because of the stepwise modernization of existing conventional substations to digital ones. Hitachi Energy developed a solution that provides interoperability between legacy teleprotection solutions with modern IEC 61850 protection systems. This enables a gradual migration to digital concepts, including line protection applications and paves the way for new protection solutions and multivendor deployments. The smart gateway is available as BIGO1 for the multiplexer platform FOX615 or as a standalone solution with the NSD product line. Core functionalities are the participation in a digital substation environment as gateway IED, which provides multiple benefits such as clear responsibility boundaries between involved departments, strong demarcation lines for cyber security aspects, improved protection performance as well as enhanced monitoring and maintenance functionality.

(Hitachi Energy Ltd.)

[07] FOX615 with BIGO1—TEPI2 bridging the gap between conventional and digital substations



RTU: remote terminal unit
MPLS-TP: Multi-protocol Label Switching-Transport Profile
MUX: multiplexer
VDC: voltage, direct current

8. System Modelling and Reliability Study of the Tri-Port SST Featuring Energy Storage and Distributed Redundancy for Datacenters

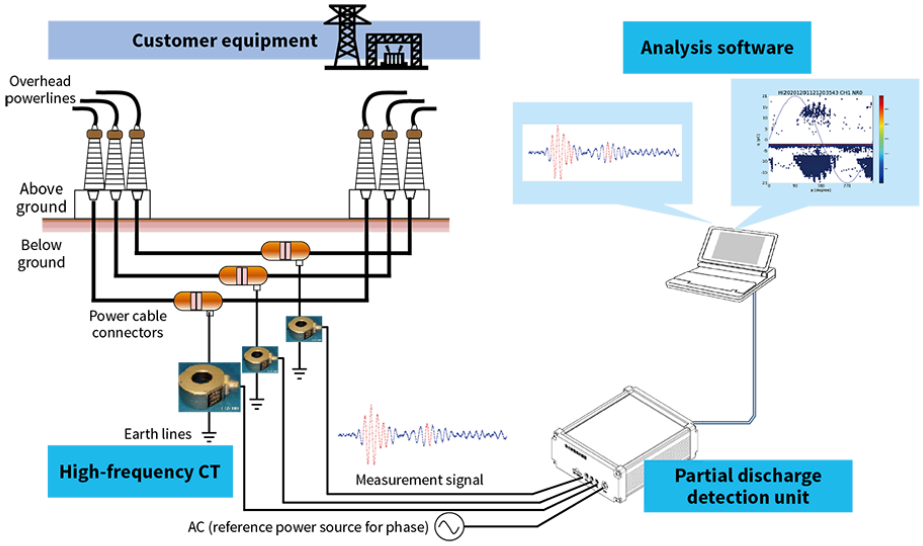
Many of the largest datacenter operators, such as Microsoft, Google and META have committed themselves to a challenging sustainability roadmap that implies 24/7 carbon free energy, by 2025 and 2030, respectively.

This work proposes a DC electric energy distribution scheme for datacenters that is equivalent to state-of-the-art alternating current (AC) distribution systems in terms of specific and very stringent availability and reliability requirements. It features significant benefits in terms of efficiency and controllability and focuses specifically on the integration of solar power, fuel cells, and battery-based uninterruptible power source (UPS), with the medium voltage (MV) solid state transformer (SST) as the enabling technology. Especially, the tri-port SST with UPS for linking MVDC distribution and low voltage DC (LVDC) bus to IT loads is proposed and significant benefits are demonstrated in terms of component count, cost, reliability, and efficiency, due to a reduced number of conversion stages.

The proposed DC distribution scheme provides flexible solutions for future green data centers committed to the 2030 Sustainability Roadmap — 100% supply from renewable energy sources, every hour of every day.

(Hitachi Energy Ltd.)

[08] Improving efficiency, reliability, and availability of DC green datacenters with tri-port SST



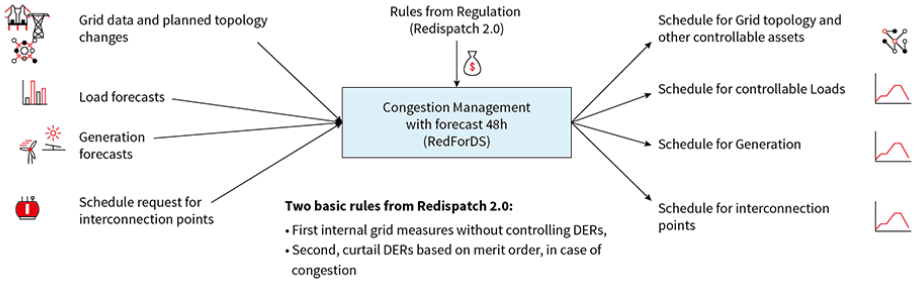
CT: current transformer
AC: alternating current

9. Congestion Anticipation and Preemptive Resolution in Distribution Networks Using Internal Grid and Redispatch Measures

The paradigm shift from a centralized to a more decentralized energy system poses new challenges for the energy system. This work presents a new congestion resolution framework that combines internal grid measures such as topology changes with subsequent redispatch of distributed energy resources. The sequenced strategy ensures that curtailment and corresponding compensation costs only occur after internal grid measures are exhausted. Firstly, a stepwise topology adjustment approach is applied using a modified minimum spanning tree and local search algorithm. This approach requires only two load flow calculations. Secondly, if the suggested topology changes are insufficient, a linear programming model based on the grid sensitivities, i.e. linearized power transfer distribution factor values derived from the last load flow calculation, is proposed. Alternatively, by simultaneously considering all changes, the developed linear programming model can propose an optimal curtailment strategy. Tests on realistic medium voltage grids showed that the sequential algorithm can efficiently find a solution to resolve grid congestion by minimizing both the topology changes and load curtailment.

(Hitachi Energy Ltd.)

［09］ **Input and output for congestion management**



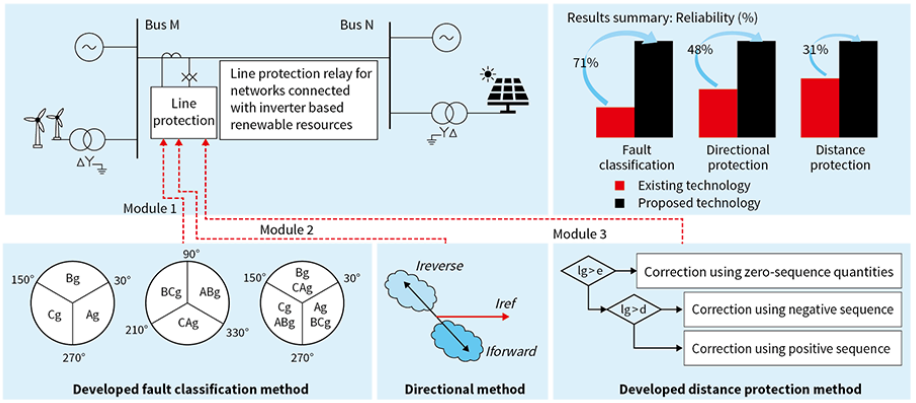
Forecasting data and grid operation planning data are used by the proposed congestion management framework to generate schedules for grid topology, load, and generation as well as interconnection points, considering the relevant regulation schemes (e.g. Redispatch 2.0 in Germany).

10. Innovative Line Protection Technology for Enabling High Penetration of Renewables in Power Grid Systems

The global installed capacity for renewables is expected to increase by up to 85% by 2050. This shift is being driven by climate goals, energy security and economic factors. Unlike fossil fuel-based generation, renewables are integrated to the power grid through power electronic converters. The main challenge posed to line protection is the unique fault response dictated by converter controls and grid codes. Decades-old protection algorithms designed based on conventional understanding are falling inadequate and several practical relay failures from various power utilities have been reported. To futureproof line protection, Hitachi developed an innovative technology based on renewed understanding of renewables' fault characteristics, grid codes, converter controls and years of domain knowledge and expertise in substation protection. The technology is reliable, provides significant improvements over the traditional solutions (71%, 48%, and 31% in the reliability performance of the three key modules: fault classification, directional detection, and distance protection). The technology can be implemented in existing relay platforms without the need for additional hardware and infrastructure upgrades thereby reducing the overall solution cost.

(Hitachi Energy Ltd.)

［10］ **Reliable line protection relay for renewable connected power grids and experimental results summary**

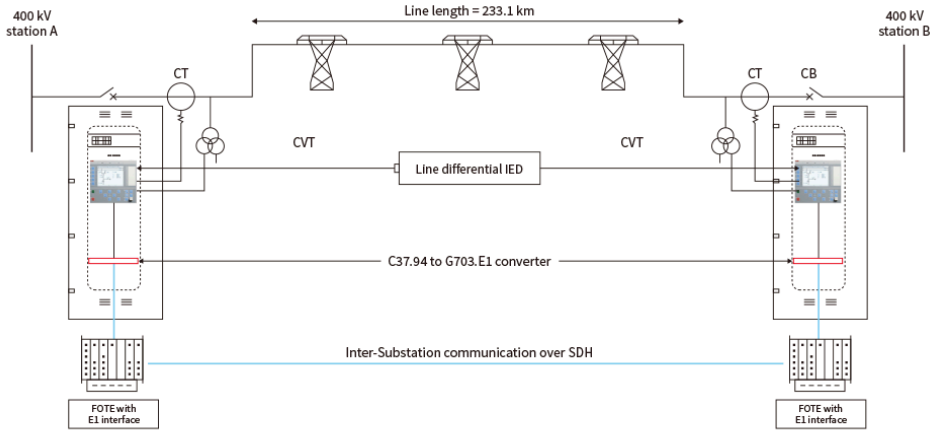


11. Economical Fault Locator Technology for Power Transmission Networks: Experiences from Recent Pilot Installations

Locating a fault precisely on power transmission lines is highly advantageous to power utilities in expediting the repair of faulted components, speeding up the restoration of power supply, thereby reducing outage time and the financial burden on utilities. Hitachi developed an economical, setting-free fault location technology for power networks using advanced communication capabilities at substations and decades of Hitachi Energy experience in power system automation and communication. The method was implemented in relay and installed successfully on a 400-kV, 233.07-km line from Powergrid, India and on a 220-kV, 265.6-km line from Svenska Kraftnat, Sweden. The pilot installation and experimental results from the laboratory confirms that the method can locate the fault within a span of two-towers (up to 300 m) which is comparable with traveling wave-based technology that requires 1,000 times higher sampling rate, high-cost hardware, complex commissioning, and settings. This technology saves on engineering costs, does not require settings or any additional hardware beyond what is required for modern line differential protection solutions, i.e., a 2-Mbps communication link.

(Hitachi Energy Ltd.)

[11] Double-ended fault locator pilot installation setup



SDH: synchronous digital hierarchy

12. Controlled Switching as an Alternative to Pre-insertion Resistors for Overvoltage Mitigation on Transmission Lines

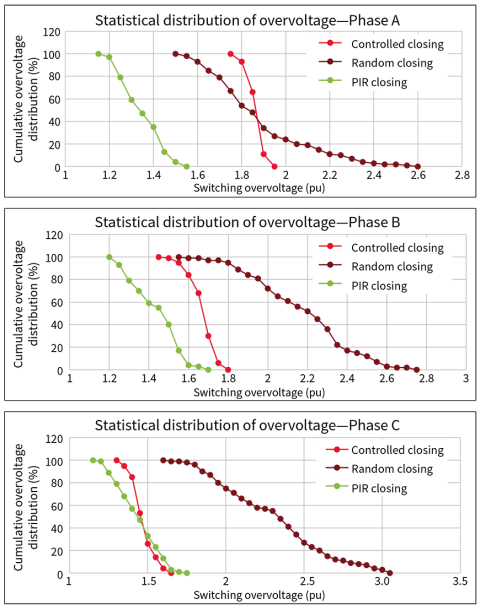
Traditionally, pre-insertion resistors (PIR) on circuit breakers (CBs) have been used for mitigating overvoltages during (re-)energizing of transmission lines. More recently, controlled switching (CS) has also been successfully employed for the same purpose. Hitachi Energy will shortly release a new CS device that will prevent delayed current zeros, which is the biggest concern when applying CS on lines, together with mitigating overvoltages. Novel algorithms for detecting secondary arc extinction and dynamically changing line configurations will further ensure successful reclosure.

Simulation studies show that controlled switching is able to limit the overvoltages within the specified operational limits of a line, leading to results similar to those obtained with PIR, as shown in the figure. Various line configurations (different lengths and compensation levels) and switching scenarios (dead-line charging, auto-reclosing) were covered in the study*.

The figure shows one example of the statistical distribution of the switching overvoltages at the receiving end of a shunt-compensated transmission line equipped with surge arresters at both ends, during auto-reclosure following a single-line-to-ground fault. Both controlled closing and PIR considerably mitigate the overvoltages and bring them within acceptable limits.

(Hitachi Energy Ltd.)

[12] Statistical distribution of switching overvoltages during auto-reclosure on transmission line



* U. Parikh, N. Dubey, M. Stanek, M. Palazzo, “Feasibility of point-on-wave switching as replacement of pre-insertion resistors for switching overvoltage mitigation on long transmission lines,” 2023 CIGRE Canada Conference & Exhibition, Vancouver, BC, Sept. 2023, pp. 25–28, paper no. 663.

13. Electric Local Public Transportation: Operations and Charging Strategies

The containment of carbon dioxide (CO_2) emissions is an urgent objective to limit the damage caused by ongoing climate change. In transportation, particularly local public transportation fleets operating their vehicles currently contribute 16% of CO_2 emissions and other pollutants. Promoting the transition of public transportation fleets to electric vehicles is therefore critical. Today's available charging technologies make it feasible to adopt battery-powered electric vehicles with lengths up to 24 meters to meet all urban public transportation needs, including rapid mass transit, with significant cost advantages in terms of total cost of ownership (TCO) compared to other electric traction solutions (e.g., trolleybuses). Optimizing the TCO involves adopting various charging strategies and technologies for different transportation needs within the same urban network. Hitachi Energy developed the Grid-eMotion technological platform to optimize solutions for the unique transportation needs of different cities, which include:

(1) Overnight slow depot charging (Grid-eMotion Fleet)

(2) Fast charging at terminals (Grid-eMotion Fleet)

(3) Flash charging at terminals and some intermediate stops (Grid-eMotion Flash)

The Grid-eMotion solution will play an incredible role in powering a sustainable energy future for all.

(Hitachi Energy Ltd.)

［13］ Electric buses charging devices implemented at the Vasteras depot in Sweden

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