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CIGRE UK Technical Seminar

The UK Grid of the Future – to meet the net zero challenges

14th November 2023

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How did we get here?

CIGRE UK AGM
November 2023
John Finn

Introduction

The theme of this afternoon’s discussion is “**The UK Grid of the Future: Meeting the Net Zero Challenges**”

However before we start to look at the grid of the future I have been asked by Ray Zhang the CIGRE UK Technical Committee Chair to give a brief explanation of the UK grid system development over the past 100 years.

I have called this talk “How did we get here” and this short presentation intends to explain the major developments that have changed the structure and functionality of the grid system since it initial conception to the present time.

Original Grid System Concept

- Initially each major town or city would have its own generation with basically no interconnection between these individual companies.
- This meant that each organisation needed to have a spare generator large enough to cover the maintenance or loss due to a fault of the largest machine.
- A grid system was established such that spare generating capacity could be shared and provided the basis for a coordinated approach to electricity supply.
- As the generation was still located close to the loads the grid system did not need to have high capacity circuits as the flows would be relatively low.
- This grid system was established around 1926 with the creation of the Central Electricity Board and the grid operated at 132kV.

Grid for Optimal Location of Generating Plant

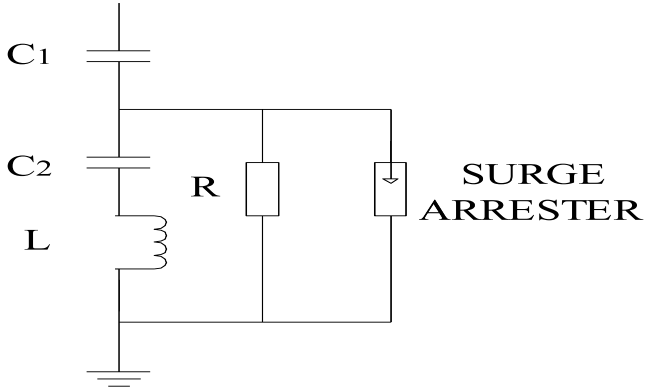
- After the second world war it was decided to locate the Generating Stations where there was a plentiful supply of fuel (basically coal) and also water.
- The generation was no longer located close to the load centres and the power transmitted from where it was generated to the load centres, creating a Generation, Transmission Distribution system
- The current flows on the circuits would be much higher
- A higher voltage was required initially 275kV, however it was soon realised that a higher voltage was required and so the voltage was increased to 400kV.

Need for control of Voltage profile

- The voltage cannot be 400kV at every point on the grid. There is therefore a voltage profile across the grid.
- The voltage is highest at the generating stations and falls away towards the load points.
- At heavy load conditions the points far from generation can fall to a very low voltage.
- To support the voltage it is necessary to inject some reactive power (VArs).
- For steady state control of the voltage then mechanically switched capacitors are used rated at 225 MVARs on the 400kV system.
- Conversely, at light load the voltage at remote points rises and so it is necessary to absorb some reactive power to bring the voltage down. This is done by installing shunt reactors rated at 200MVArs on the 400kV system.

Mechanically Switched Capacitors with Damping Network

- The mechanically switched capacitors used are basically a “C” filter.
- They include a damping network that is there to prevent magnification of the pre-existing harmonics on the network



- C1 provides the required capacitance for VAR support
- The other components provide the damping network for minimising magnification of harmonics

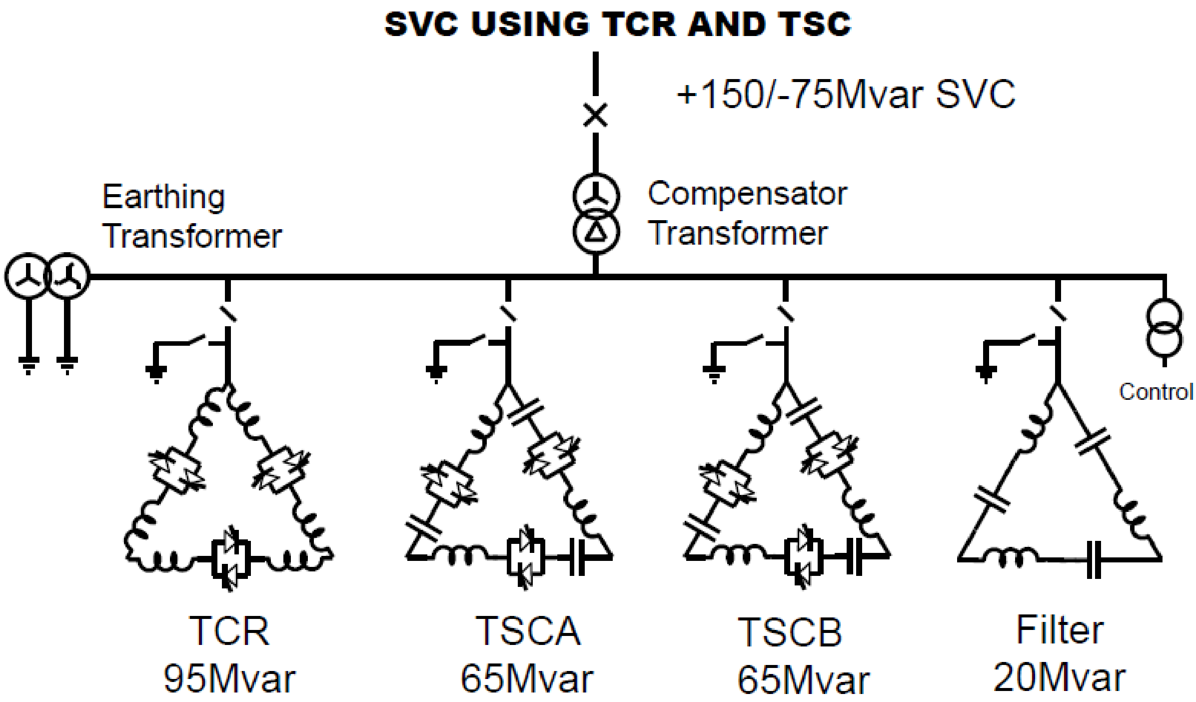
Shunt Reactors

- The shunt reactors used for steady state voltage control are oil immersed with a rating of 200 MVArs.

- In order to get the required inductance they are usually equipped with a gapped core so that each of the limbs have several air gaps which are supported by porcelain spacers as can be seen on the photograph.

Static Var Compensators (SVC)

- When a rapid response to sudden changes in load or generation or outages is required then a Static Var Compensator (SVC) is used.
- This typically uses a thyristor controlled reactor in conjunction with one or more thyristor switched capacitors. The single line and layout of a typical SVC are shown below.



Flow of real power on the Network

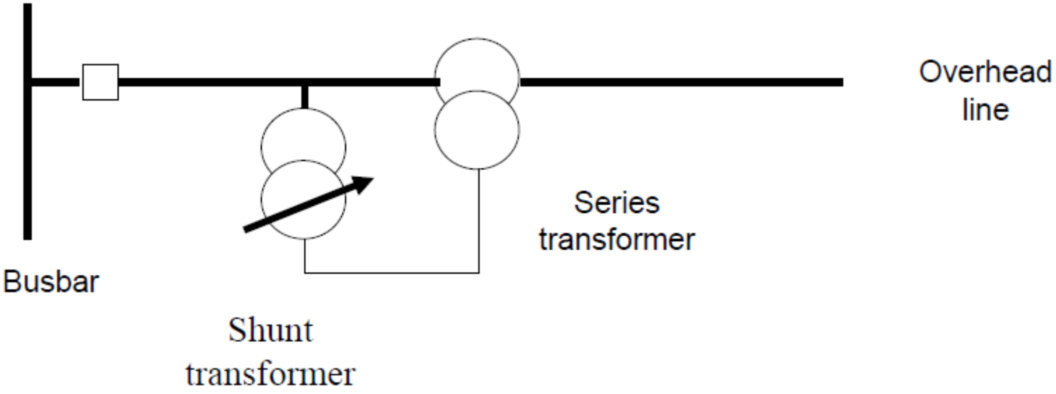
- The flow of real power (MW) on the network is dependent upon the voltage angular difference across the circuit δ (or more precisely sin δ) and the reactance of the circuit X.

$$P = \frac{V_1 V_2}{X} Sin\delta$$

- With a number of parallel circuits connected between the generation and the load some circuits can become overloaded before others are near their limit.
- In order to balance out these circuit loadings then a phase shifter can be used to alter the effective voltage angle at one end of a circuit,
- If the angle across the circuit is increased then more power will flow and if it is decreased then less power will flow.
- In the UK the type of phase shifter which is used is a quadrature booster.

Quadrature Booster

- Basically a quadrature voltage is derived from the other two phases.
- A controlled amount of this quadrature voltage is injected via the shunt and series transformers by adjusting the tapchanger.
- The voltage can be injected to increase or decrease the angle. A picture of a quadrature booster under construction is shown to the right

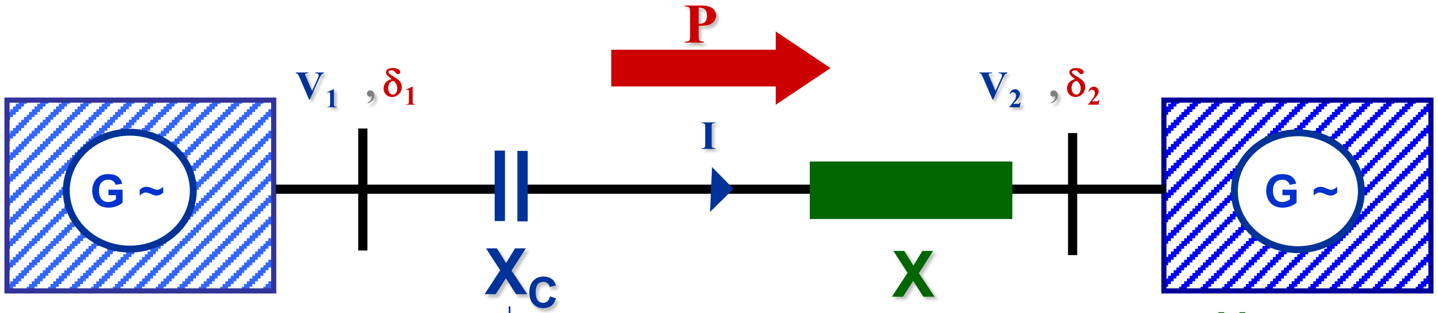


Series Capacitors

- More recently series capacitors have been installed on the UK grid system in the interconnections between Scotland and England which for many years had been constrained by voltage instability problems.

- Series capacitors have been installed to allow the interconnection to reach its thermal limit by effectively reducing the reactance and hence the angle shift across the circuit avoiding voltage instability.

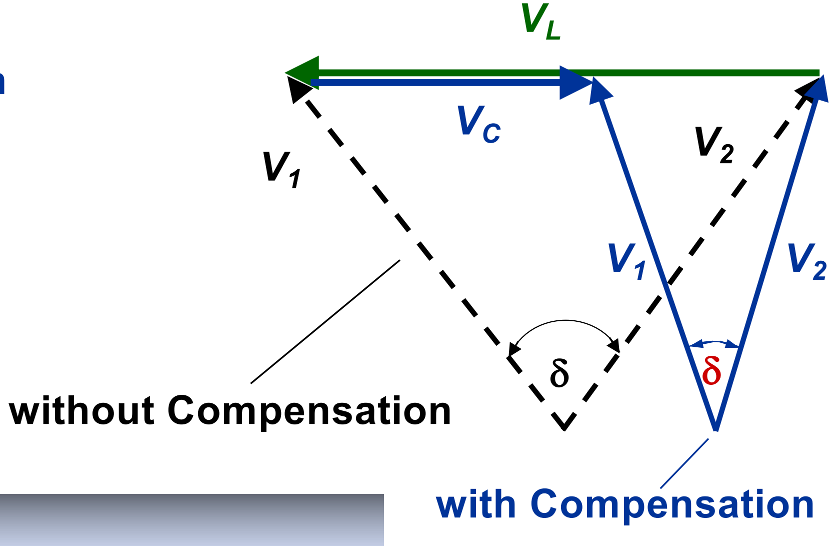
1st Step: Influence of Series Compensation



Series Compensation

$$P = \frac{V^2}{X - X_C} \sin \delta$$

where $V_1 = V_2$, $\delta = \delta_1 - \delta_2$



Benefits

- Reduction in Transmission Angle
- Increase in Transmission Capacity

Auto-close and Operational Intertripping

- Some circuits may be kept on hot standby.
- Under certain outage conditions these circuits can be automatically closed. The conditions required to trigger the auto-close may be local or over a much wider area.
- Where generation is connected to the network via a relatively weak link, if certain outages occur there is a risk of cascade tripping. Under these conditions an intertripping signal is sent to the generating station to trip one of the generators.
- More recently a similar scheme has been introduced to de-load the HVDC link with France for certain operating conditions along the south coast of England This scheme operates on two time scales fast for stability concerns and slow for thermal.

Introduction of HVDC

- In the 1960s power electronic components advanced sufficiently to enable the installation of a high voltage and high power HVDC link between Kingsnorth and Beddington/Willesden. This HVDC link was put into service in 1974.

- Following on from this when a cross channel link between France and England was proposed a HVDC link was chosen because

- it enables control of the magnitude and direction of the power flow

- it provides frequency independence for the systems at either end of the link

- it provides fault level independence for the systems at either end of the link.

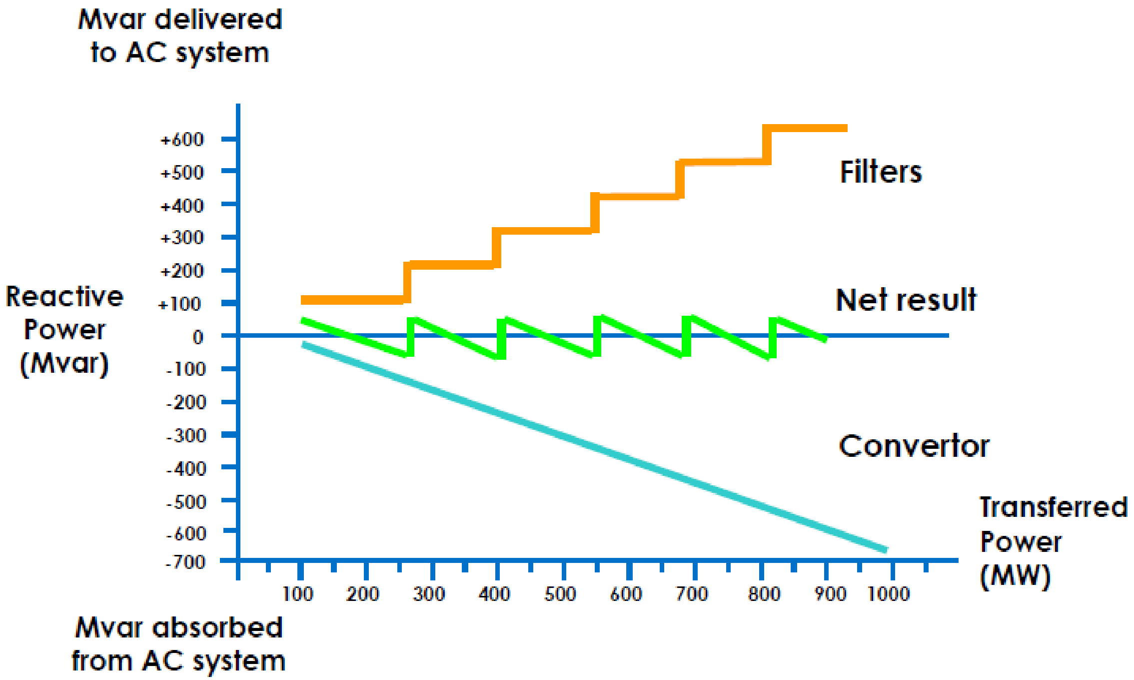
- The 2000MW cross channel link was put into service in 1986. Since then other HVDC links have been built including Britned, North Sea Link with Norway, Western HVDC link and another cross channel link through the tunnel to name but a few.

Line Commutated HVDC

With line commutated HVDC we do not get away from the need for compensation at the AC terminals.

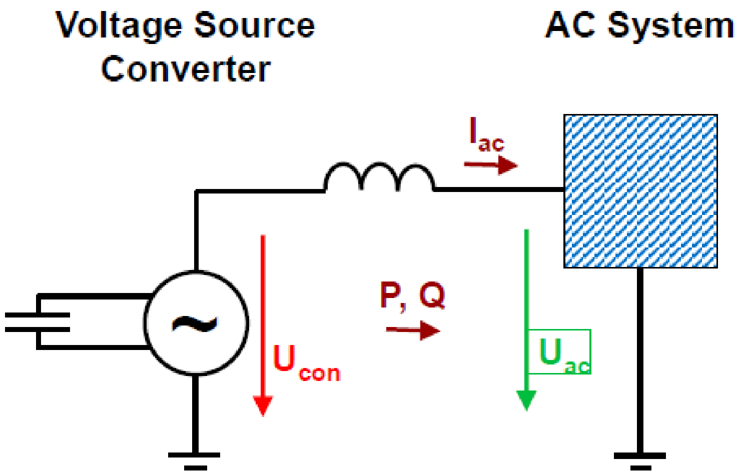
A LCC convertor absorbs reactive power (MVArs) and its demand is approximately 55 to 65% of the real power transmitted at full load

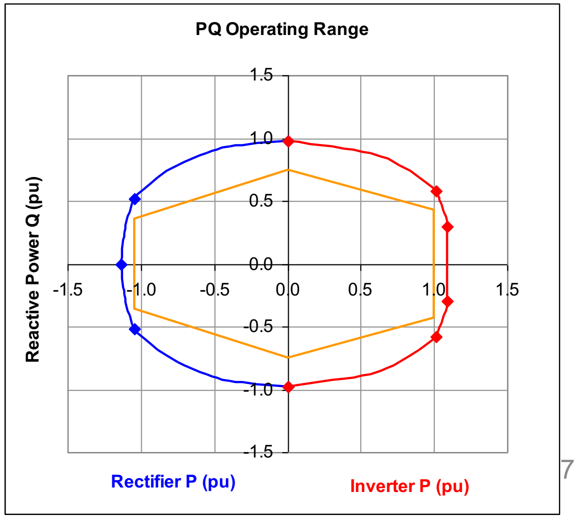
The lagging power can be offset by switched filters as shown.



VSC HVDC

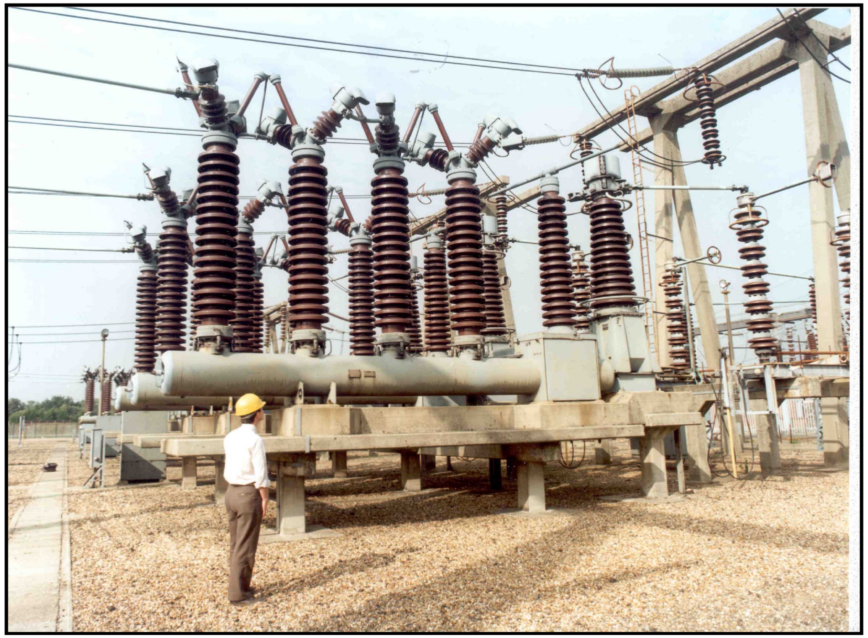
- Generates an ac waveform from a dc voltage source – in this case a capacitor
- Provides independent real and reactive power control
- AC System can have a low short-circuit power or even no existing generation
  - 4 Quadrant Operation for U_N = const.
  - Continuous Power Range:
    0 to +/- Pmax and
    0 to +/- Qmax
  - All by control of phase angle and magnitude of convertor generated ac voltage with respect to the ac system voltage





Introduction of SF_6 Switchgear

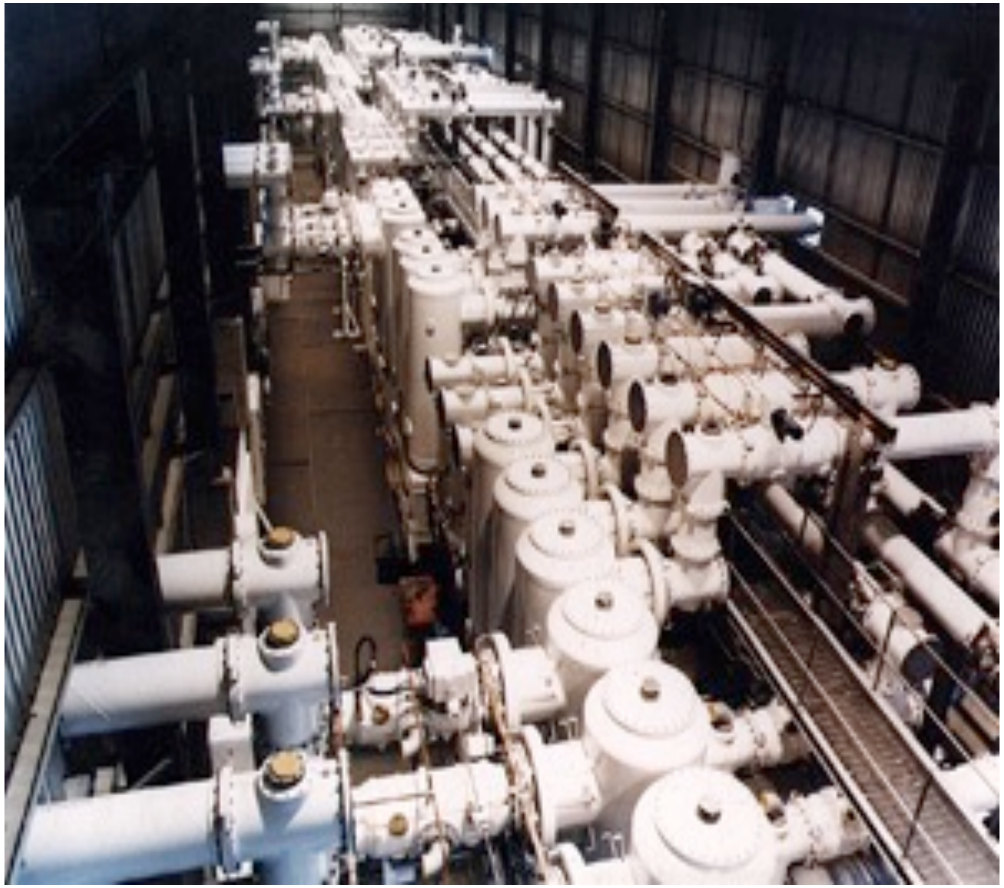
- When the 400kV supergrid was first installed virtually all of the switchgear was air blast similar to the picture below left.
- During the 1970s the advantages of SF_6 with its excellent insulation and arc quenching properties became apparent and so virtually all of the switchgear in the last thirty years has been SF_6 similar to the circuit breaker shown below right.



Gas Insulated Switchgear Substations

- In certain circumstances there is a need for very compact substations such as in city centres where the land costs are so high. In these cases the use of a gas insulated switchgear substation can be used.

- Another consideration is pollution either salt pollution in coastal areas or industrial pollution in heavily industrialised areas. In these polluted areas the use of GIS substations can be very useful.



Privatisation

- In 1990 the UK power supply industry was privatised.
- Before privatisation the industry was run by engineers whose sole objective was to ensure the technical performance of the system.
- After privatisation the industry is run by Accountants whose main objective is to ensure a good return on investment to the share holders.
- Whereas the amount of, and location of new generation was planned to meet the system needs and to ensure a satisfactory spare capacity it is now done by entrepreneurs who believe that they can make a profit from the generation.
- Whereas in the past generation was connected to the network in merit order (most efficient plant connected first) now it is done by a bidding process.
- This makes the system planning and operation much more difficult requiring extensive use of probabilistic techniques to look at the various operating scenarios which can arise.

The Kyoto Protocol

- The Kyoto protocol was first introduced in 1997 and eventually ratified in 2005. It has had several modifications since then to try to give it more teeth but fundamentally its original objective of trying to reduce the generation of green house gases and in particular the reduction of CO_2 emissions still remains valid.
- The greenhouse gas most extensively used in the power supply industry is sulphur hexafluoride SF_6. Originally it was hoped that careful control and monitoring of the use of the gas to minimise the amount of gas released into the atmosphere would suffice.
- It is now becoming apparent that a controlled removal of SF_6 from the system will be required and extensive work has already been done in seeking suitable gases to replace it.
- With regard to the reduction of carbon emissions this has affected the industry by requiring the removal of fossil fired power stations and also the move towards electric vehicles requiring a significant increase in load in the lower voltage networks to provide the charging facilities.

Removal of Fossil fired generating stations

- The UK system had a high dependence upon fossil fired generation. It was required to replace this by renewable generation.

- Possible sources of renewable generation are tidal, wave power, solar and wind power. Although the first two have been around for a very long time there has not been significant commercial exploitation of them.

- Both solar and wind power utilise electronic components and there is virtually no inertia in either form of generation. This leaves the system at risk of instability following rapid changes in load or generation.

- The other problem with these forms of renewable generation is that they are not always available and so other sources of generation need to be available to cover any short fall.

Solar Generation

Solar generation has been used both as specific generation sources and also directly at consumer level.

Wind Generation

- Wind power has been used both onshore where it is connected at lower voltages and also larger concentrations offshore.
- As the offshore wind farms get larger and further offshore the use of HVDC connections has become more prevalent
- The onshore substation for an AC connected wind farm has extensive compensation plant.

Where we are now

- The system is no longer generation, transmission and distribution
- We now have a fully integrated system where loads and generation can be connected at any voltage level and flows are bi directional.
- A controlled systematic replacement of SF_6 needs to be undertaken.
- Extensive probabilistic studies need to be undertaken to cover all of the uncertainties in system planning and operation
- Methods to stabilise the network against changes in load and generation are required with the drastic reduction in inertia.

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End of Presentation

Cairns Symposium 2023
Senior Industry Leaders Forum
Key Issues Raised

Key Issues Raised (1)

1. **Reliability**
   - The market and regulatory structure will be a major influence on long term and short-term reliability – changes are needed
   - The timely installation of infrastructure will be required if reliability is to be maintained. Regulatory and societal processes are slow – high risk of 'too little too late'
   - We need to focus on ways to speed up the transition while maintaining reliability
2. **Standardisation**
   - Standardisation is critical if we are to accelerate the energy transition
   - Early identification of plant and equipment needs is essential
   - Setting priorities will be important to ensure effort is aligned with the most critical work.

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Key Issues Raised (2)

1. **Markets and regulation**
   - Redundancy in both networks and generation should be flexible to ensure optimum use of scarce capital.
   - Market modifications are required to reflect changing nature of power systems and associated services.
2. **Stakeholder engagement**
   - Stakeholder engagement is critical to ensure support for the required rapid changes.
   - A focus on the transition and the use of new technologies is very important.
   - Essential for stakeholders to have access to accurate information.
3. **Resources**
   - Need to urgently ramp up the supply of skilled resources and highlight the energy transition as a major issue for humanity.
   - Targeted investment of scarce capital is required.
   - Need to optimise use of mineral resources and equipment.
4. **Evolving Technologies**
   - Need to understand the alternative technologies that are available now or will be available in the near term.

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What can CIGRE do to help with the transition?

CIGRE:

1. Is a provider of unbiassed advice. We need to find ways to demonstrate this.
2. Is not a lobbyist – it can provide factual information for others to use.
3. Requires collaboration across Study Committees more than ever – driven by evolving issues from the energy transition, particularly in non-traditional areas.
4. Can solve complex problems through global industry collaboration and promote the priority of the greatest impact projects.
5. Can promote itself to ensure key decision makers are aware of its potential as a resource.
6. Can help explain the transition challenges to government and other key stakeholders.
7. Can help attract skilled resources to the transition.
8. Can review its own operating model to deliver outputs far more quickly and flexibly to match the pace of the changing external environment.

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