enertechnos

Capacitive Transfer System:

Powering decarbonisation delivery

Contents

Glossary of terms

Capacitive Transfer System	CTS
Electric Vehicle	EV
Alternating Current	AC
Direct Current	DC
High Voltage Direct Current	HVDC
Fixed Electrical Ground Power	FEGP
Auxillary Power Unit	APU
Power from Shore	PfS
Carbon Capture and Storage	CCS
Distribution Network Operator	DNO
Wireless Power Transfer	WPT

Summary

Enertechnos has developed a disruptive power delivery technology: the first fundamental change to power cable design and fabrication in decades. 'Capacitive Transfer System' (CTS), brings a solution to reduce losses in electrical power delivery between renewable generation and consumers.

CTS-enabled systems drive opportunities for decarbonisation of industries and the transportation sector by providing more effective charging of Electric Vehicles (EVs) and powering airport infrastructure in the drive towards a net zero world.

By tackling voltage drop between sending and receiving ends, an identically sized CTS cable can deliver more power, further, while reducing capital expenditure and operational costs. CTS solutions can be applied for systems from 400V up to 150kV and up to 500MVA.

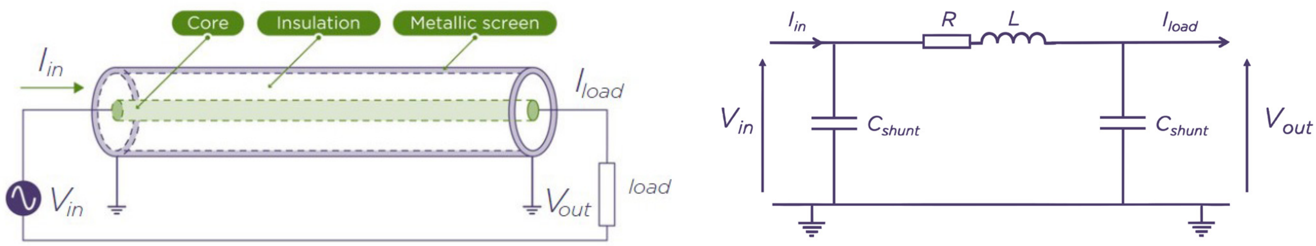
Enertechnos has worked with key players in the energy industry to adopt CTS solutions in a way that doesn't demand extensive re-training for their staff or upgrade of cable manufacturing infrastructure.

In five different case studies that include Power Network applications, Renewables integration, Remote Grids, Wireless Charging and Airport Electrification, we've analysed how CTS technology can demonstrate its unique ability to provide better and more cost-effective solutions for net zero challenges.

Technology

Operating principles of traditional cables

Traditional underground cable connections have been used for over 150 years with minimal changes to their core design. A power cable can be represented by a key elements model.



Physical representation and key elements model of traditional cables

R	is the equivalent AC conductor resistance, responsible for active power losses in the cable.
L	is the inductance of the line, affecting the generation of reactive power in the cable.
Z=R+jX	is the cable impedance that defines the current delivering capability of the cable.

C_{shunt}	is the equivalent shunt capacitance between the core and the cable sheath, responsible for current leakage to earth.
V_{in}	is the voltage at the sending end.
V_{out}	is the voltage at the receiving end.

Key power cable transmission challenges

Voltage drop

Cables under heavy loads exhibit significant voltage drop with V_{out} falling significantly below V_{in}, resulting in sub-optimal performance in electrical equipment. As cable length increases, this effect is further exaggerated. Currently it is tackled with the following methods:

Increasing the transmission voltage, decreasing the required load current.

This requires larger and more expensive equipment.

Reducing transmission line impedance.

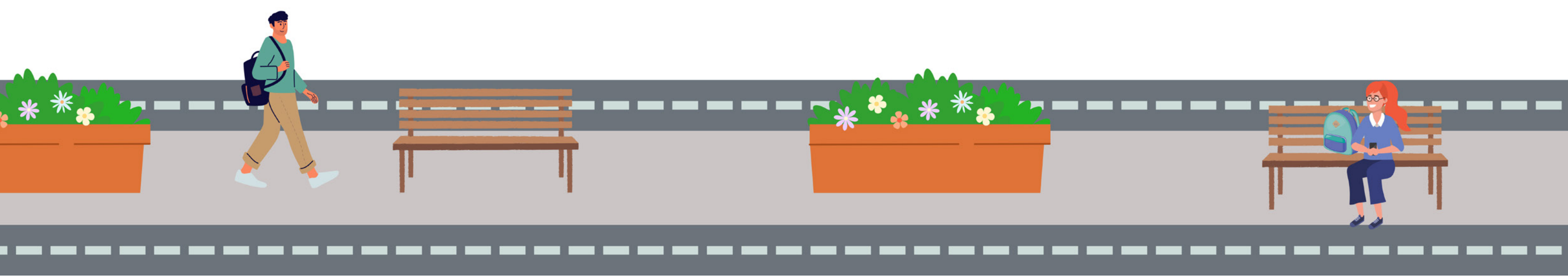
This requires running an additional cable in parallel or increasing the cross section of the conducting core.

Employing high voltage direct current (HVDC) technology.

This requires large and costly power converter infrastructure with potential operational challenges.

Applying reactive power compensation to boost the voltage level (Flexible AC Transmission Systems).

This requires additional equipment and leads to high grid operating costs.



Technology
Key power cable transmission challenges

Current carrying capacity
Without addressing voltage drop, additional current is required to deliver the same amount of active power. This additional current increases power losses (I^2R), and dissipating this through the heating of the cable core further increases the AC resistance, increasing the voltage drop. The generated heat limits current carrying capacity as cable materials have defined operational temperature limits.

Voltage rise and currrent leakage
Cables under light loads, owing to current leakage through shunt capacitance, experience a rise in voltage at the receiving end (so-called Ferranti effect) restricting their power transfer capabilities. This effect becomes more severe at both higher voltages and larger conductor cross sections.

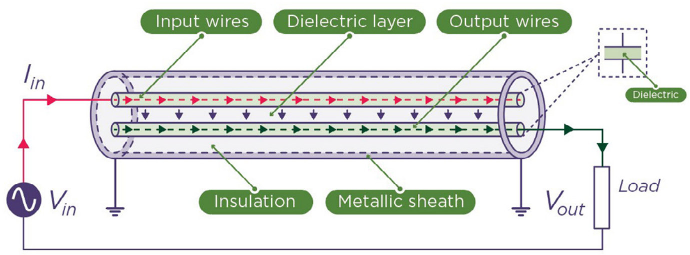
AC resistance – skin and proximity effects
Resistance to the alternating flow of current through a conductor increases with frequency due to so-called skin effect, and the additional effect of eddy currents induced by the changing magnetic field.

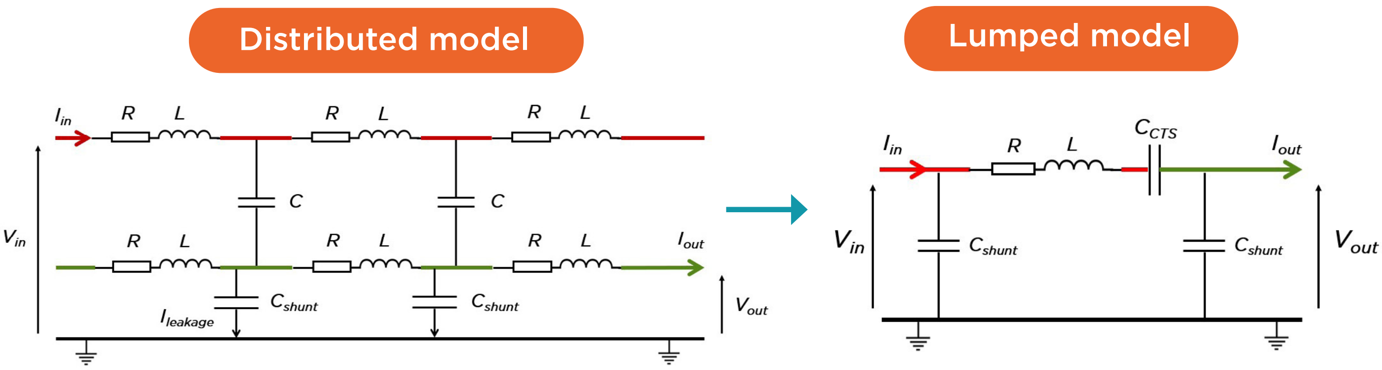
As the AC frequency increases, skin effect increases, reducing skin depth, and even less of the cable area becomes usable, increasing resistance and losses.

How CTS works

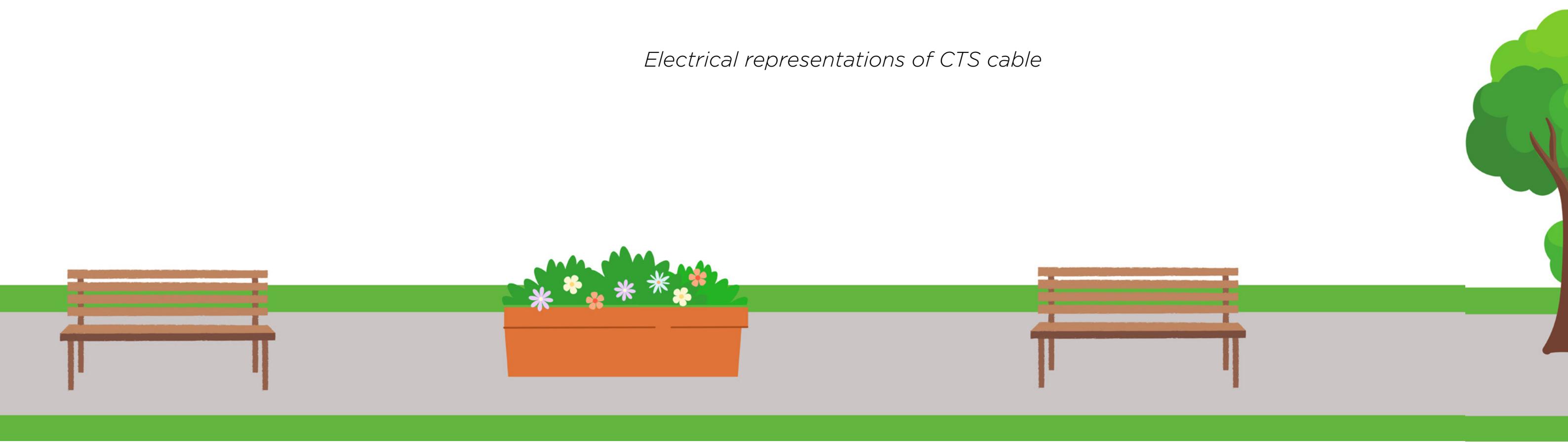
To overcome the challenges of traditional power cables, Enertechnos invented an innovative cable concept – Capacitive Transfer System (CTS)

CTS cable comprises a conductor split into two parallel terminals separated by a dielectric material. The red terminal forms the sending end of the cable, and the green terminal the receiving end, with a distributed capacitance between them across the cable length. This provides a series capacitive effect and can be added as ‘C_{CTS}’ to the lumped element PI model of a CTS transmission line.





Electrical representations of CTS cable



$$Z = R_{AC} + jX = R_{AC} + j\left(\omega L - \frac{\mathbf{1}}{\boldsymbol{\omega C_{CTS}}}\right)$$

$$where\ \ \omega = 2\pi f$$

$$Z_{CTS} \rightarrow R_{AC}$$

$$V_{drop} = I_{load} Z$$

$V_{drop} =$ *voltage drop* $[V]$,
$I_{load} =$ *load current* $[A]$,
$Z =$ *impedance* $[\Omega]$,
$R_{AC} =$ *AC resistance* $[\Omega]$,
$X =$ *reactance* $[\Omega]$,
$L =$ *inductance* $[H]$,
$f =$ *frequency* $[Hz]$,
$C_{CTS} =$ *series capacitance* $[F]$

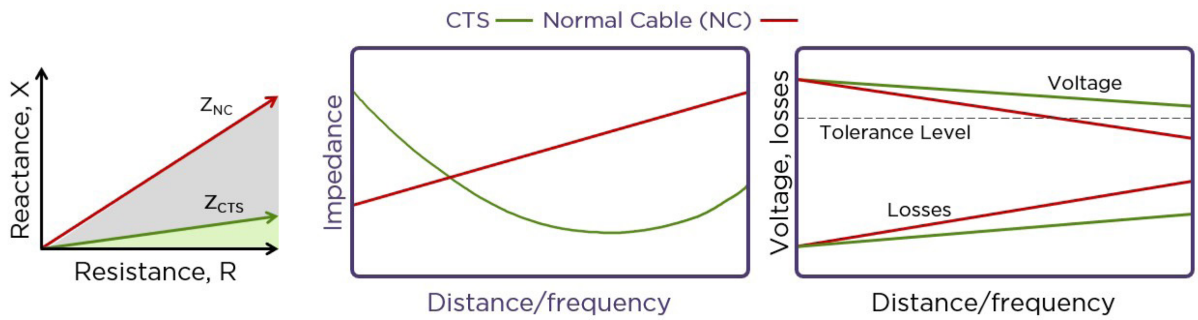
The built-in series capacitance C_{CTS} of the cable balances the reactive power produced by the cable's inductance, resulting in a reduced cable impedance, lower voltage drop and consequently greater delivery of active power through the cable.

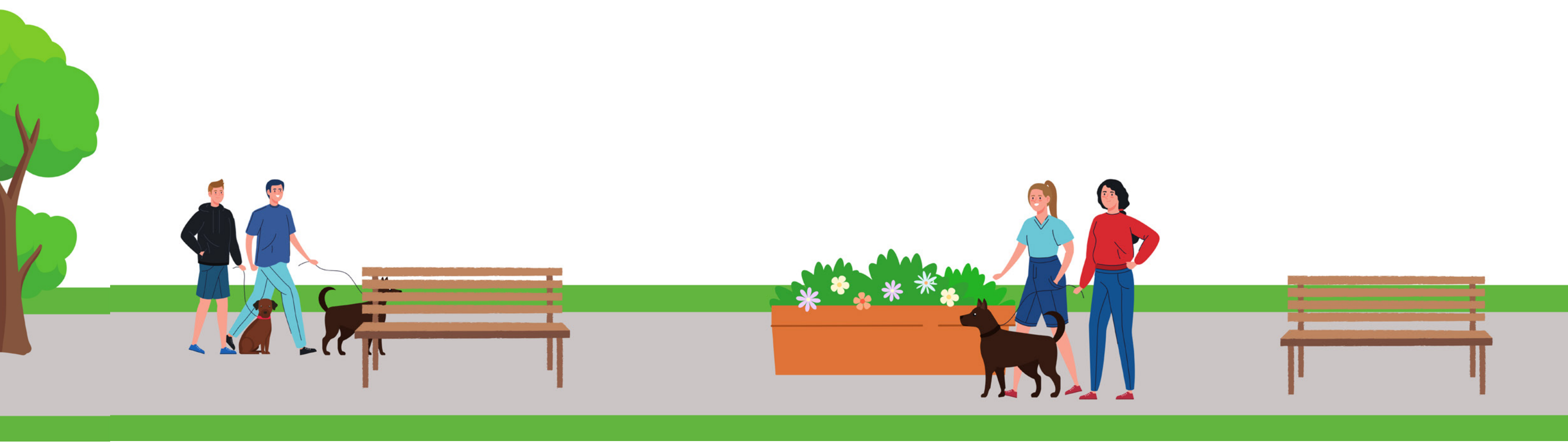
As the length or frequency increases in a normal cable, inductance increases accordingly, leading to a reduction in the receiving end voltage and increased losses.

In a CTS cable, however, its capacitance counterbalances the inductance. At Enertechnos, we design cables with the right properties to capitalise upon this benefit for every application.

The construction of the CTS cable core results in a lower AC resistance than that of a conventional cable, as the eddy currents that cause skin effect are restricted by the conductor layout, evening out the current density.

The CTS system has two operational modes termed CTS mode and uncompensated mode. In uncompensated mode, the cable performs like a normal cable with reduced skin and proximity effect, while switching to CTS mode offers further performance enhancements and benefits through self-compensation.





Overall benefits of CTS

Choosing CTS over conventional cables opens opportunities to:

1 Supply more power

The system allows greater current flow (I_{load}) for the same voltage drop as in a conventional cable of identical cross-section.

2 Send power further

The voltage drop reduction allows a longer length of cable to be installed before the receiving end voltage drop reaches its established regulatory limit.

3 Lower AC losses

Skin and proximity effects are significantly reduced, increasing the current carrying capability of the cable and reducing power losses.

4 Improve voltage regulation

Voltage drop deviations are reduced, keeping the connected network within established grid code tolerances. This allows the same power delivery with lower current, thus reducing losses proportional to the square of the current.

5 Lower transmission voltages

Large current-induced voltage drop with a conventional cable system requires upgrades to higher voltage. CTS can achieve the required power at lower voltage with the existing current, reducing the cost and size of the equipment. $P=I\uparrow V\downarrow$

6 Reduce Ferranti effect

During low load, due to reduced cable reactance, the voltage at the receiving end will not exceed the sending end voltage, expanding the operational range of the power line even further.

CTS applications

Upgrading networks and maximising the capacity factor of renewables - 50-60Hz

See p. 14-16

- CTS, in comparison with normal cables, reduces voltage drop allowing greater active power transfer over long distances or with smaller cable diameter
- Reduces the need to upgrade system equipment for higher transmission voltage levels and power factor correction, allowing reduced-cost brownfield modifications in future projects
- Reduces voltage rise during low current periods (Ferranti effect), avoids curtailment of power extraction from solar farms during periods of low insolation or in wind farms facing low wind speeds, increasing the capacity factor of renewable sources

Remote grids: e.g. offshore Oil and Gas decarbonisation - 50-60Hz

See p. 17-18

- Subsea versions of CTS used for delivering power to offshore Oil and Gas platforms from sustainable sources can significantly reduce carbon footprint
- Similar to its benefits in networks, CTS's ability to deliver power with lower voltage drop can simplify installations of cables for long lengths, allowing more efficient use of expensive offshore operations vessels and limited space on the platforms
- The use of a smaller cable cross section reduces size and weight of cable, the use of materials, the shunt capacitance and leakage current

Wireless EV charging - 85kHz

See p. 19-21

- CTS enables better power transfer over distance at higher frequencies (e.g. 85kHz) with lower voltage drop than existing cables
- Owing to high reactance, conventional cables are ineffective in transferring high frequency power from converters to EV charging pads from as little as 6 metres, leading to the need for frequency converters at every parking spot
- CTS cables overcome this problem with built-in reactive compensation and enable the use of longer cables to connect several pads around a centralised converter, achieving better economies of scale and reducing capital expenditure per groundpad

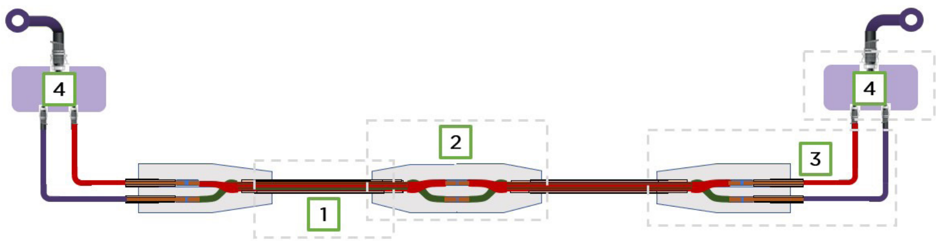
Decarbonising airport operations - 400Hz

See p. 22-23

- CTS enables better power transfer over long distance at higher frequencies (e.g. 400Hz) with lower voltage drop than existing cables
- CTS cables with built-in reactive compensation enable the connection of multiple aircraft across airfields to centralised converters in terminal buildings, rather than installing converters at every aircraft stand. This significantly reduces installation costs and maintenance requirements
- Thermal recovery from centralised power units enable combined heat and power solutions for terminal buildings
- Delivers infrastructure for further aviation electrification

CTS system design and components

A key goal for the Enertechnos team is to ensure that all CTS systems uphold existing operational practices for their installation environments. As a result, the system can be directly installed from end-to-end using existing cable installation methods.



1 - cable
2 - joint
3 - termination
4 - control system

CTS system components

1. Cable

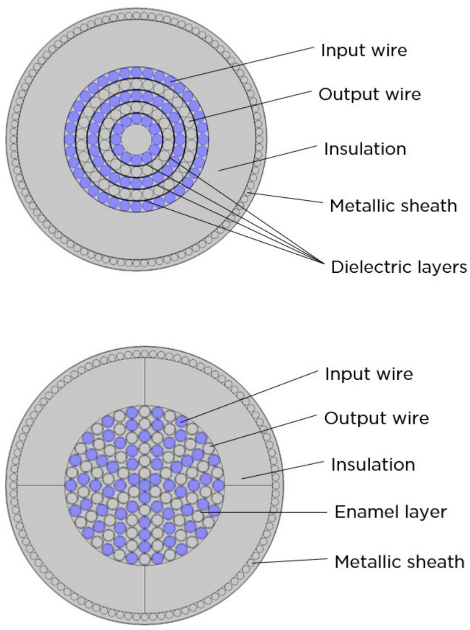
Aside from the cable core, the manufacturing of CTS cable is identical to that of existing power cables. For underground or offshore applications, conventional insulation and jacketing modifications are applied to the cable to suit the environment.

Core design

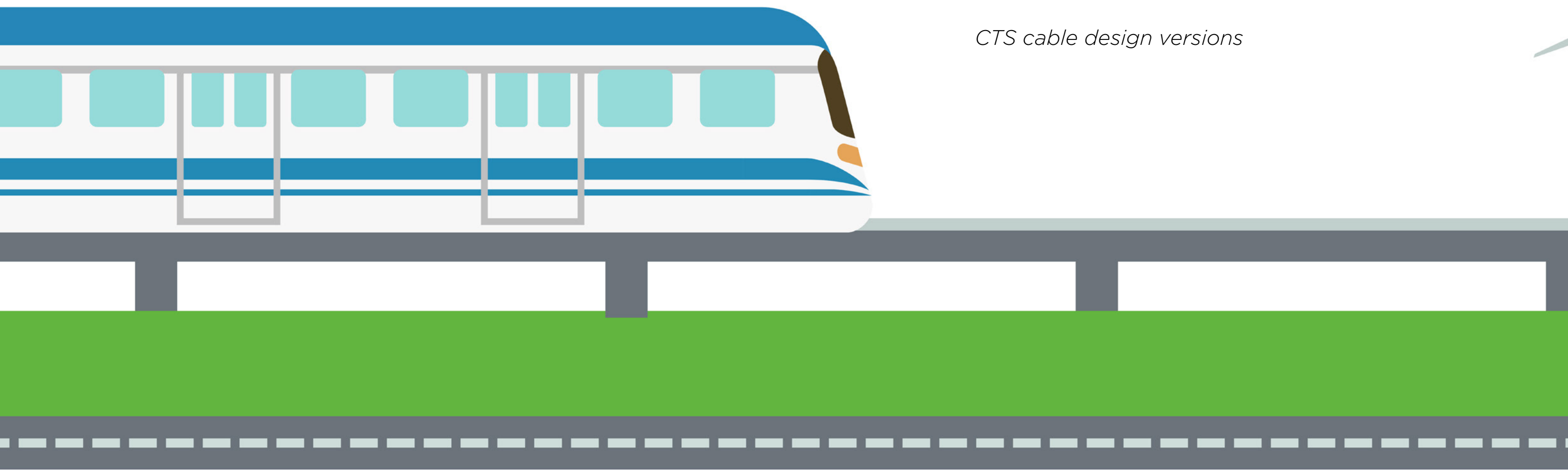
Dielectric capacitance between the cable terminals is engineered by increasing or decreasing the dielectric layer thickness and the surface area between red and green internal layers, while the choice of conductor cross sectional area is determined by the power delivery requirements of the system. Proposed designs are validated through multiphysics and industrial grid modelling software and backed up by real-world testing using respective standards to provide systems that best suit any of our applications. Nominal, cyclic and emergency current ratings are determined in the design phase in accordance with industry recognised standards, e.g. IEC 60287 and IEC 60853.

To suit the end user application, the key modifications are made in the following areas:

- Conductor cross section
- Number of layers
- Dielectric material and thickness
- Dielectric placement between strands or layers, resulting in Layered or Enamelled design versions



CTS cable design versions



Manufacturing

- The cable has been successfully produced by several manufacturers, on existing production lines with minimal changes and 'off the shelf' materials.
- Both versions can be made by most cable manufacturers, thanks to its standard concentric construction interspersed with layers of dielectric material that can be wrapped or extruded over each layer of conductors.
- Both copper and aluminium can be used, with other materials selected and dimensioned in line with industry standards.
- High voltage routine testing and quality control can be performed on a cable sample or complete cable system.
- Additional CTS dielectric testing can be carried out by using familiar handheld multimeter equipment.

2. Joints

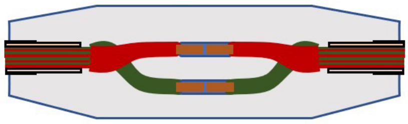
Enertechnos has worked with industry partners to develop joints for CTS cable and to ensure conventional jointing techniques can be used without excessive training.

CTS terminals can be visually identified and separated thanks to the individually coloured or coated strands and routed to the appropriate connections in joints.

Cable ends can also be separated in a factory, ready for the connection on site as "plug-and-play."

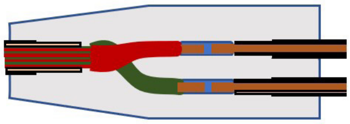
In-line joint

A conventional joint to keep the entire length of a section of cable as one long continuous capacitor. During jointing the CTS terminals are separated and both re-connected to the corresponding terminal on a new length of cable.



Termination joint

A joint used to separate terminals prior to cable terminations. During installation the CTS terminals are separated and each connected to a short section of a conventional cable.



Branch joint

A joint used to make a connection from a load or generator to one of the terminals. During installation, the CTS terminals are separated and the branch-off terminal is connected to a conventional cable. Both terminals are then re-joined inside the in-line joint.

3. Terminations

The cable is terminated at either end using a termination joint where it is connected to the CTS control system. In CTS mode, power is sent and drawn from opposing terminals. The cable termination, or cable sealing end connected to the busbar or overhead line, is identical to a conventional cable.

4. CTS control system

CTS control system protects the dielectric materials from over-voltage and allows the switch between primary capacitive (CTS) mode and non-capacitive ('uncompensated') mode, where the cable will operate as a conventional cable with enhanced current carrying performance.

The control system continuously monitors the voltage between the cable terminals and manages the transitions between cable modes due to internal failure or external fault.

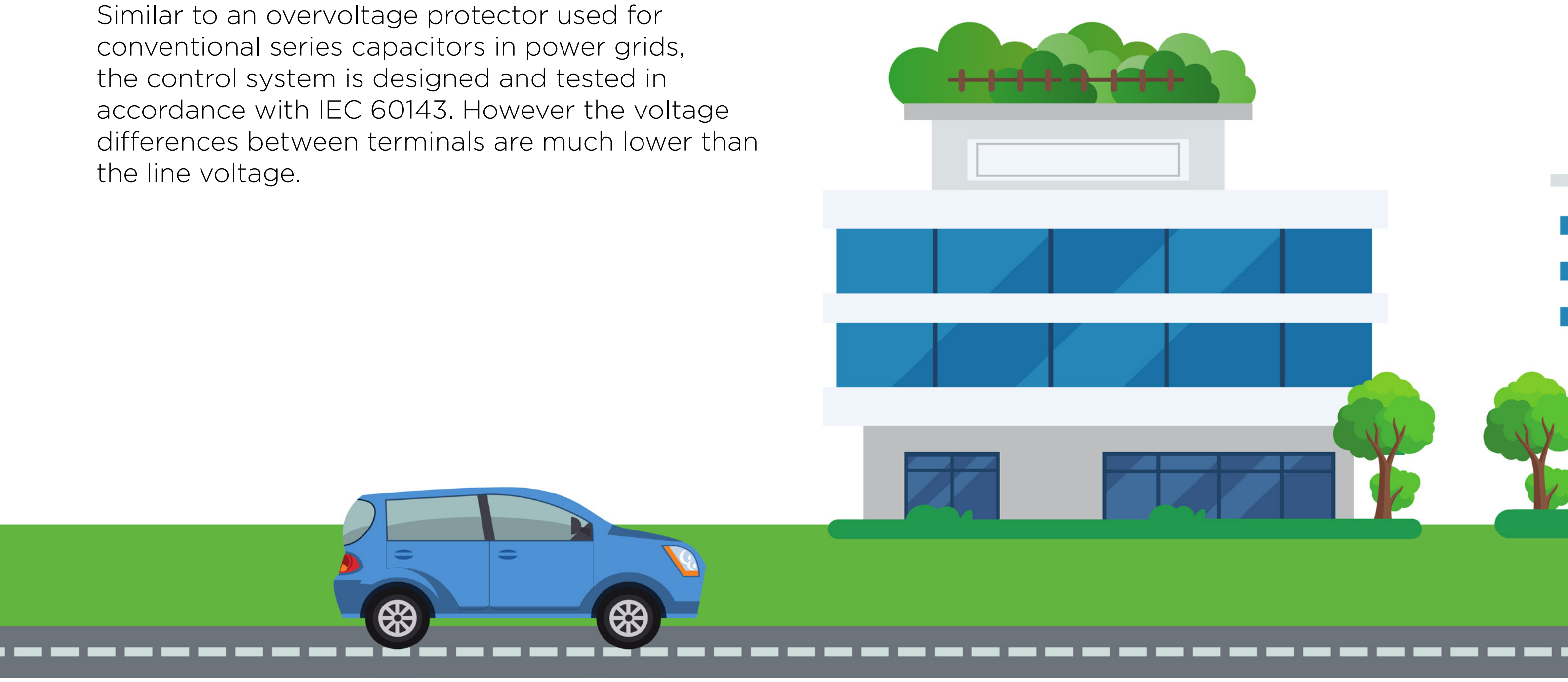
Similar to an overvoltage protector used for conventional series capacitors in power grids, the control system is designed and tested in accordance with IEC 60143. However the voltage differences between terminals are much lower than the line voltage.

Control system operation

- Detection of the voltage deviation between terminals happens within milliseconds. Time domain reflectometry (TDR) based methods are applicable and used to classify and find faults
- The system operates by safely connecting the capacitor terminals together
- Specifications are defined for each application and are primarily dependent on the controllability requirements and voltage rating

The system operates in certain scenarios:

1. Increased voltage differential between terminals caused by:
    i. System disturbance events
    ii. Line/Cable energisation
    iii. Lightning strikes
2. Safely discharging the cable for maintenance
3. Intentional switching between CTS and uncompensated mode, such as during energisation



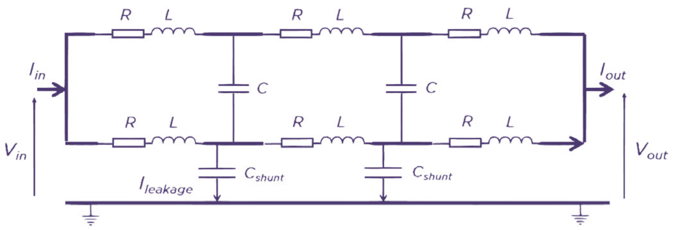
System operation

Energisation

To avoid surge currents and overvoltage, the cable is energised in what is termed ‘uncompensated’ mode, where the red and green terminals are shorted together at both ends of the cable, prior to being switched to CTS mode by the control system.

Uncompensated mode

While not benefiting from full self-compensating features, the separation of the conductor core into parallel conductors prevents the circulation of eddy currents, subsequent skin effect and uneven current distribution. This maintains an effective electric transfer area and still reduces resistive losses in the cable caused by skin and proximity effects.



Electrical representation of uncompensated mode

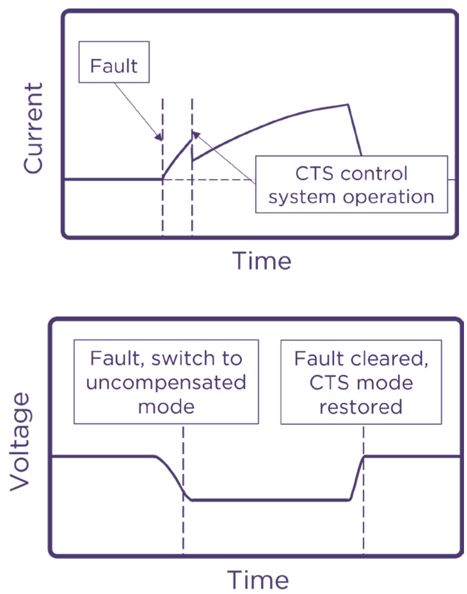
Steady state

During steady state operation, the system runs in self-compensating CTS mode, passively balancing cable impedance.

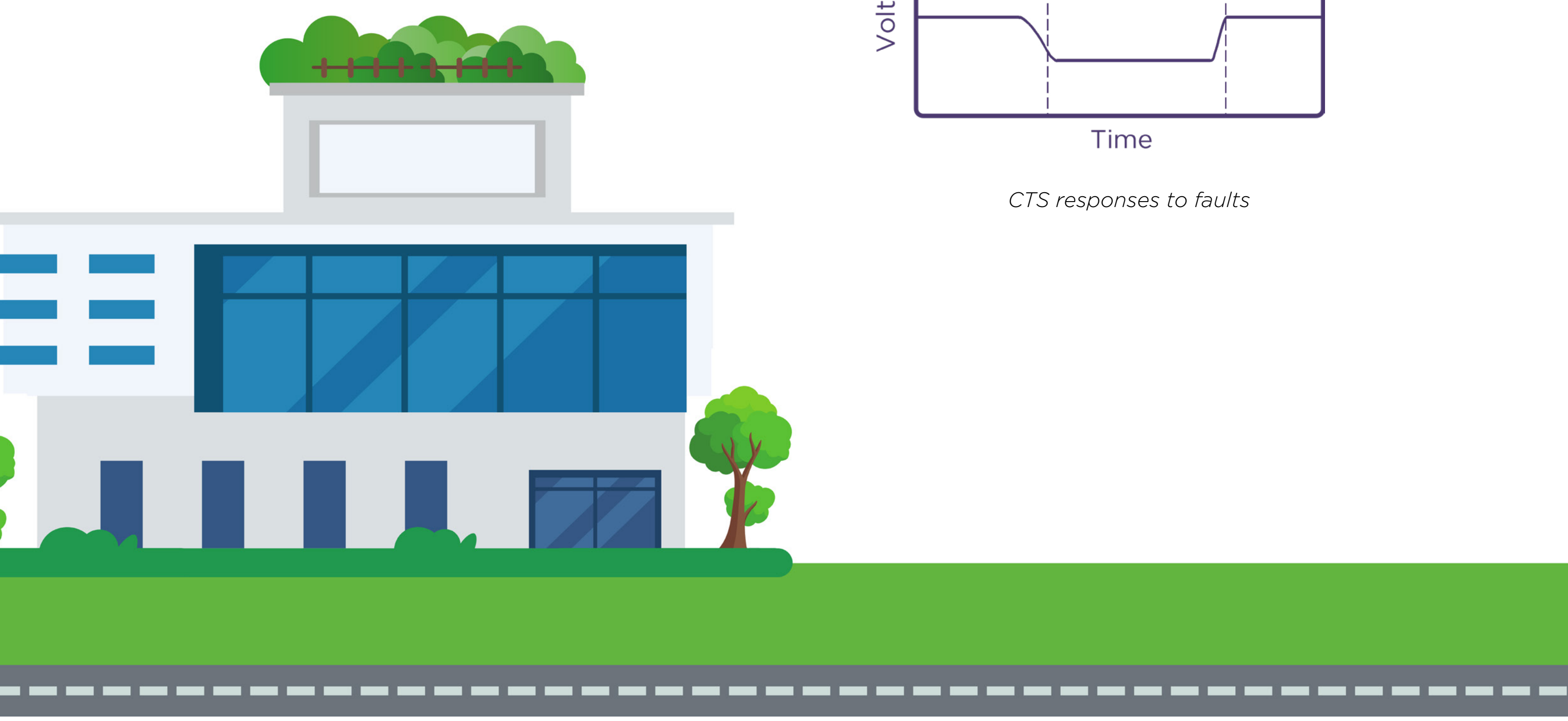
Short circuit fault

CTS has been extensively evaluated under different fault scenarios without the aid of the control and protection system. The CTS control system limits the fault current by switching the cable to uncompensated mode.

The control system does not replace any conventional circuit protection, but rather is integral to CTS, acting as a first stage response to a fault to protect the dielectric inside the cable. After the fault is cleared by the circuit protection system, CTS control system switches the cable back into CTS mode returning to steady state operation.



CTS responses to faults



System operation

Capacitive layer faults

In the unlikely event of a breakdown of the dielectric material between the red and green terminals, the cable is switched to uncompensated mode, allowing the cable to maintain function until the fault is physically removed by the repair team.

A failure of the dielectric material would be detected by an observed voltage drop across the cable, triggering the operation of the control system. The location of the failure will be automatically detected and reported to the repair team.

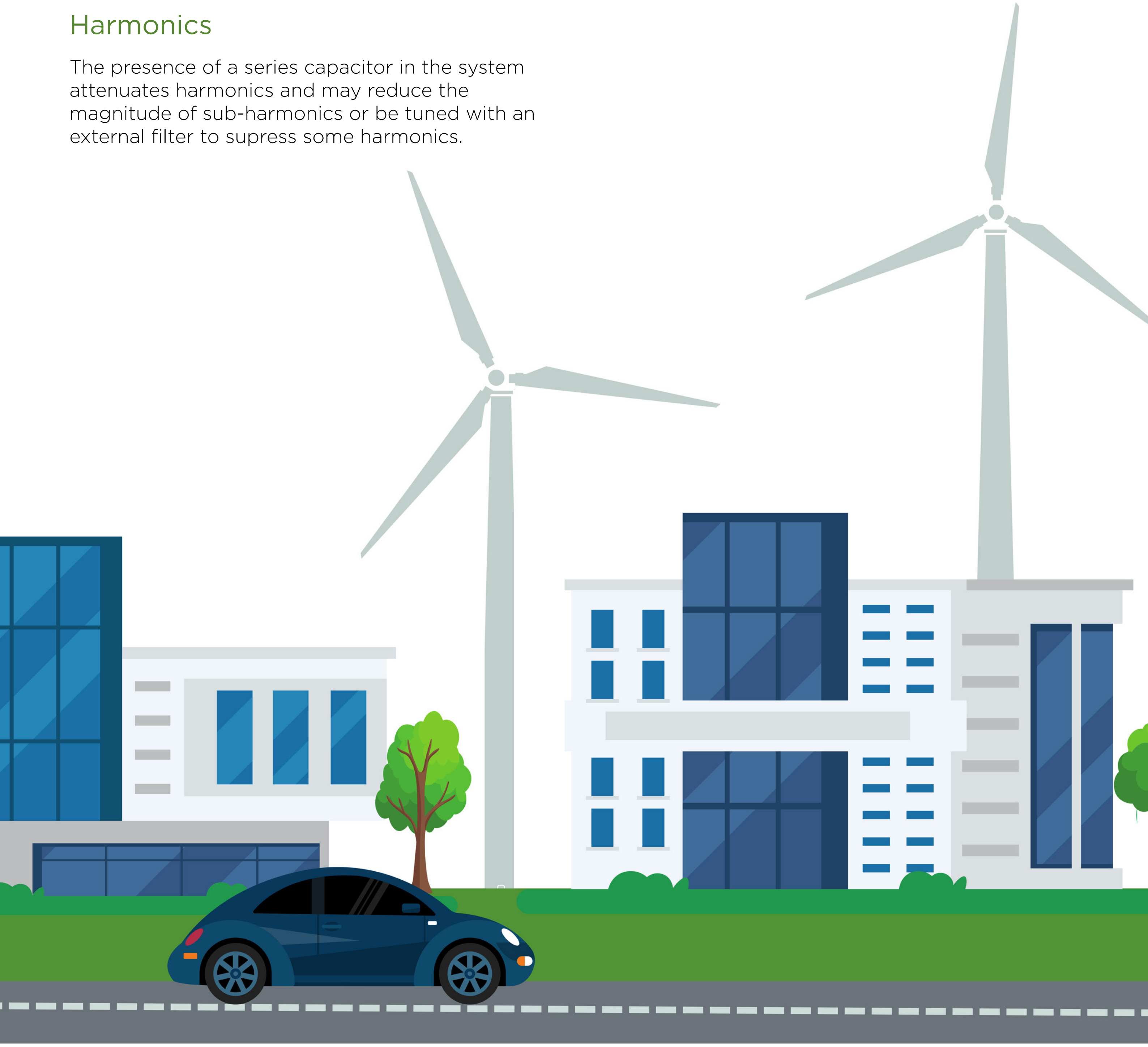
Harmonics

The presence of a series capacitor in the system attenuates harmonics and may reduce the magnitude of sub-harmonics or be tuned with an external filter to supress some harmonics.

Resonance

Impedance frequency characteristics of CTS's installation network are considered in the design of every system. Modelling suggests the addition of CTS into a network will have no significant effect on resonance at high frequencies.

The series capacitance is chosen for the cable, such that the transmission line remains slightly inductive, maintaining sufficient reactive power in the system.



Testing and quality assurance

The dielectric material is what makes CTS different from normal cables. Its integrity is fundamental for the full operation of a cable and the research and development team at Enertechnos carry out rigorous testing of these materials to withstand the high voltages that a cable may experience over its lifetime. Resistance, inductance and capacitance (RLC) testing between terminals is key in the determination of the cable's inductance and capacitance to ensure the cable is suitable for its application in the field.

As for any innovative technology there are not yet dedicated standards written for a Capacitive Transfer System. However its similarities with conventional power cables allow the use of existing standards for high voltage testing, e.g. IEC 60502. The series capacitance effect of CTS is similar to series compensation capacitors used in the power industry, who advised us to adopt for our dielectric testing methodology in accordance with their respective standards, IEC 60143 - Series capacitors for power systems. High Voltage Direct Current (HVDC) and Very Low Frequency (VLF) tests from IEEE 400.1 and IEEE 400.2 are frequently carried out on cable designs. We carry out additional tests to determine the characteristics of the cable insulation and loss characteristics to assess its performance as part of the CTS system.

Factory Acceptance Tests (FATs)

CTS FATs follow the IEEE 400-2012 standard alongside specific additional tests required to assure the correct operation of the inherent series capacitor provided by CTS.

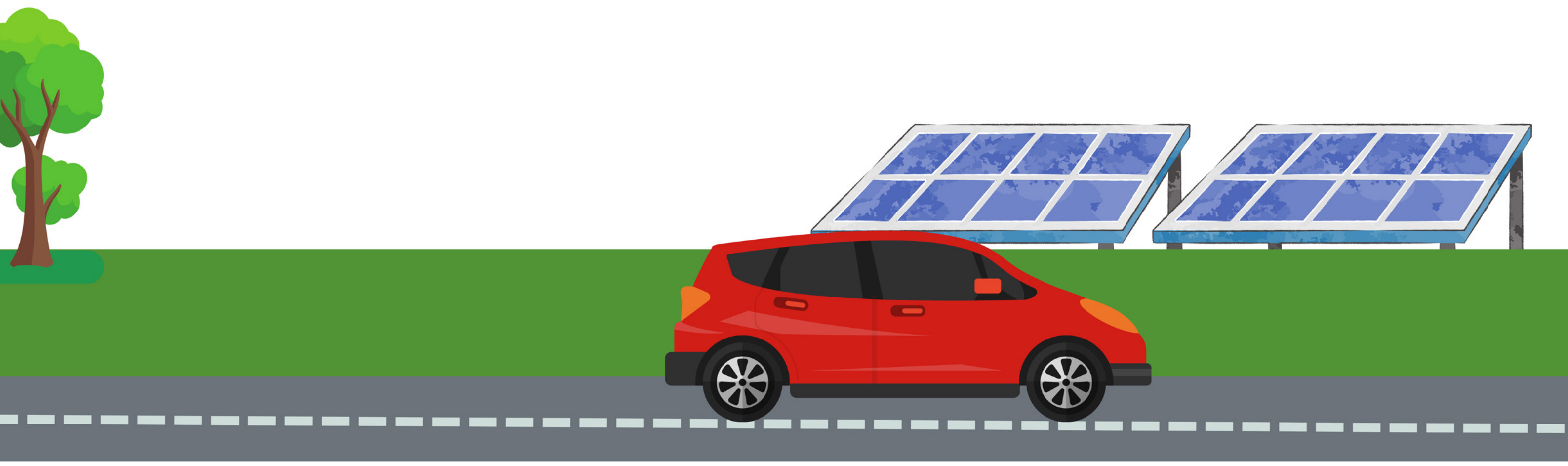
Conformance/Type Tests

Where applicable, CTS Type tests follow those of conventional power cables. Previously manufactured 33kV CTS cables have been tested in accordance with IEC 60502-2 or BS 7870-4.

Enertechnos has worked with joint manufacturers who have themselves carried out their standard tests on CTS accessories (joints and termination) according to IEC 61238-1.

Materials used in CTS are compliant with standards such as IEC 60317, familiar to the power industry and readily available to cable manufacturers.

Enertechnos works with manufacturers who follow the standards expected in industry, such as the ISO 9001 quality assurance, ISO 14001 environmental management and ISO 14064 carbon footprint standards.



Case studies

How can CTS be used? In the following five different studies we analysed how CTS technology can demonstrate its unique ability to provide better and more cost- effective solutions for net zero challenges.

Power networks

Improving efficiency of cable connections

The situation

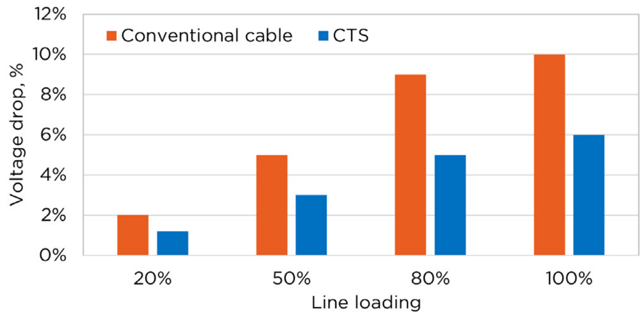
Owing to a growing number of renewable generation connections, a Distribution Network Operator (DNO) is looking to increase power transfer capacity between two 33kV substations located approximately 30km apart. The forecasted capacity requirement is 33MVA with peak current of 600A.

System modelling

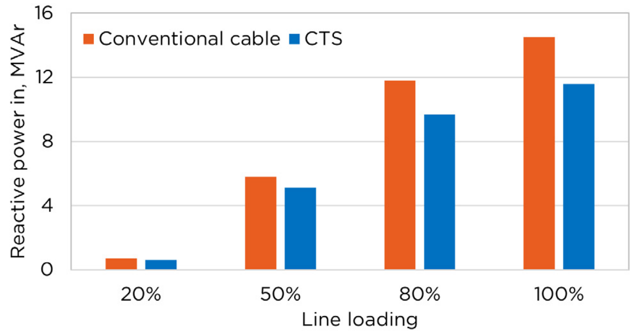
Cable circuit design methodology suggests selection of a 300mm^2 copper core cable with current rating of required 600A. Power system modelling of the connection comparing conventional and CTS cables demonstrates that the voltage drop of a 300mm^2 conventional cable at peak load is outside of the 6% limit mandated by the grid code while CTS complies with the requirement. In addition, CTS cable reduces requirements for reactive power delivery while improving power factor and reducing power losses across the line.

Cost-benefit analysis

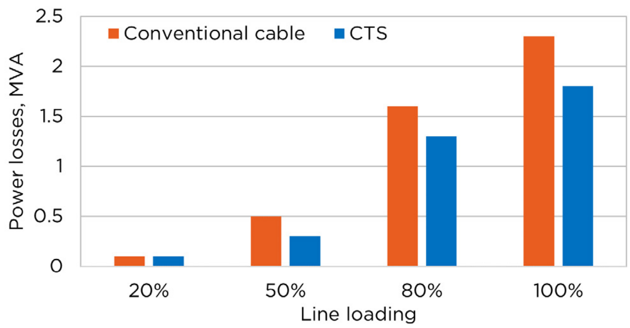
To comply with the voltage-drop requirement, the network would need to either double the cable cross section to 630mm^2 or install two parallel cables of a smaller cross section, leading to increases in connection costs, leakage current, operation complexity, carbon footprint and use of raw materials. Cost benefit analysis for the studied case, when comparing conventional and CTS cable, demonstrates that CTS cable has up to 40% lower lifetime costs. The relative lifetime cost of a project using CTS remains less than normal cable even with higher initial capital expenditure on novel CTS equipment.



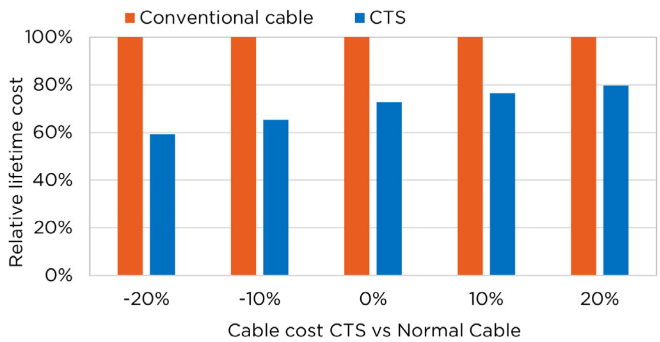
Percentage voltage drop for varying line loads



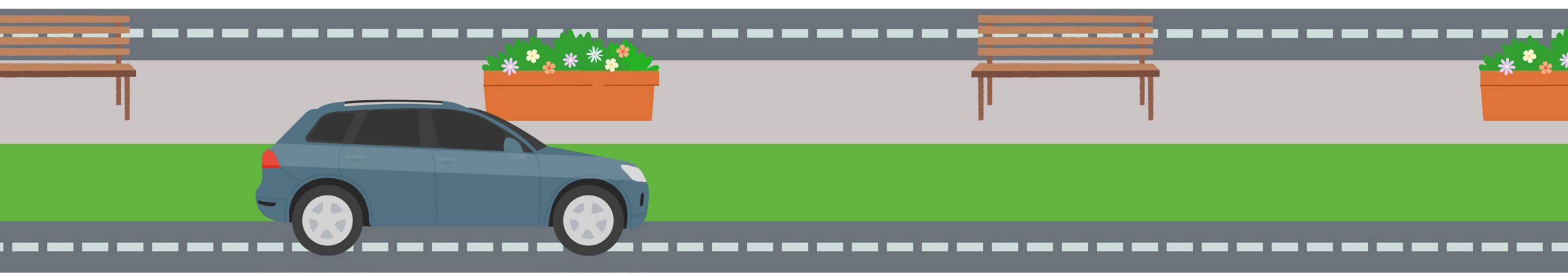
Reactive power generation for varying line loads



Power losses for varying line loads



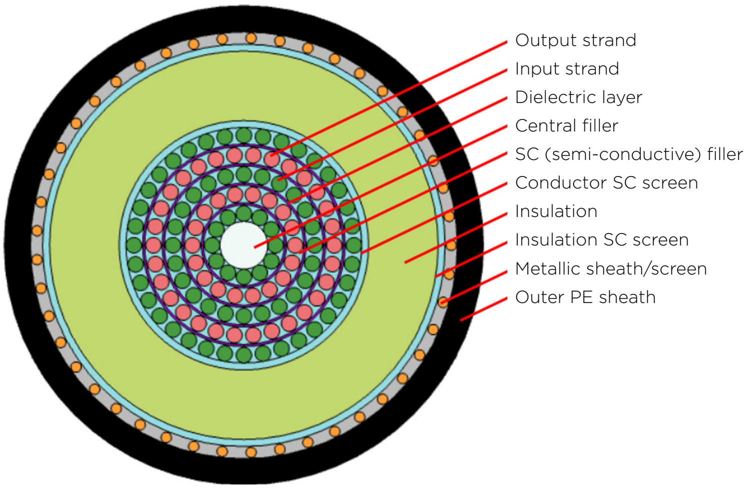
Relative lifetime cost with varying initial cable expenditure



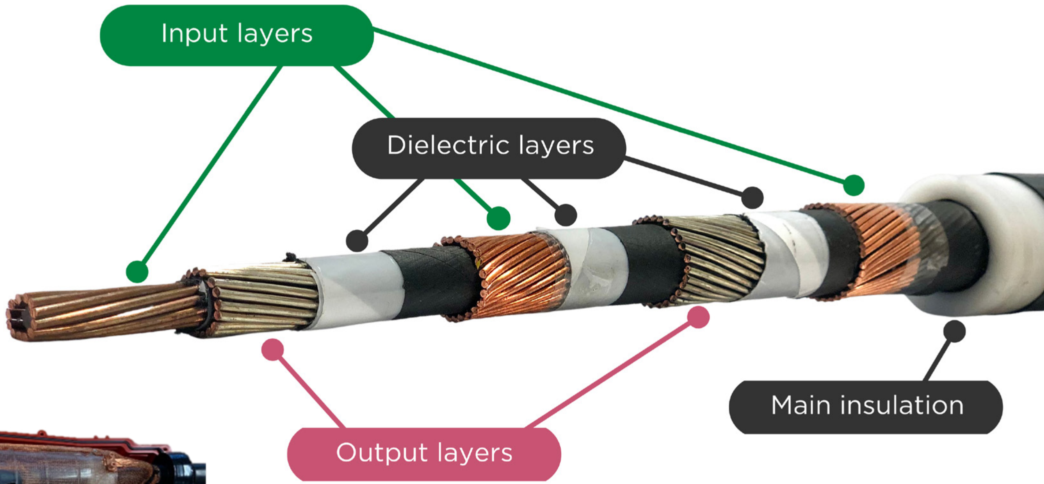
CTS cable design

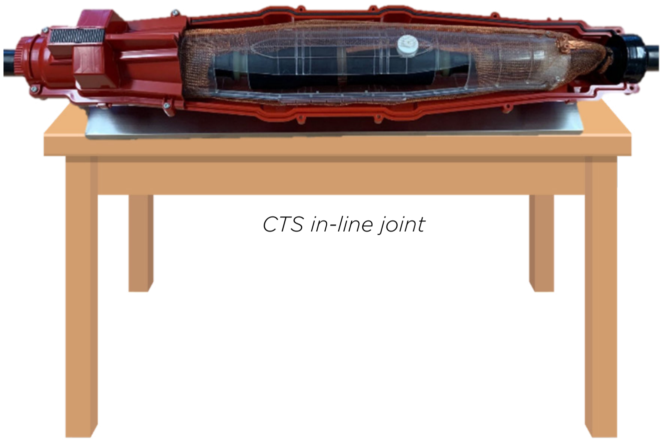
Enertechnos designed a 300mm² CTS cable prototype that complies with all system requirements and that can be produced with minimal changes to existing manufacturing processes. The cable has a layered design where red and green layers are separated by dielectric layers creating a series capacitive effect. The proposed design also allows for more efficient current distribution across the core, lowering skin effect, losses and improving temperature distribution.

Working closely with cable manufacturers, we designed the cable with 'off the shelf' materials that are widely used in MV/HV electrical applications, thus minimising cable production costs and complexity, and increasing confidence in the lifetime performance of the system.



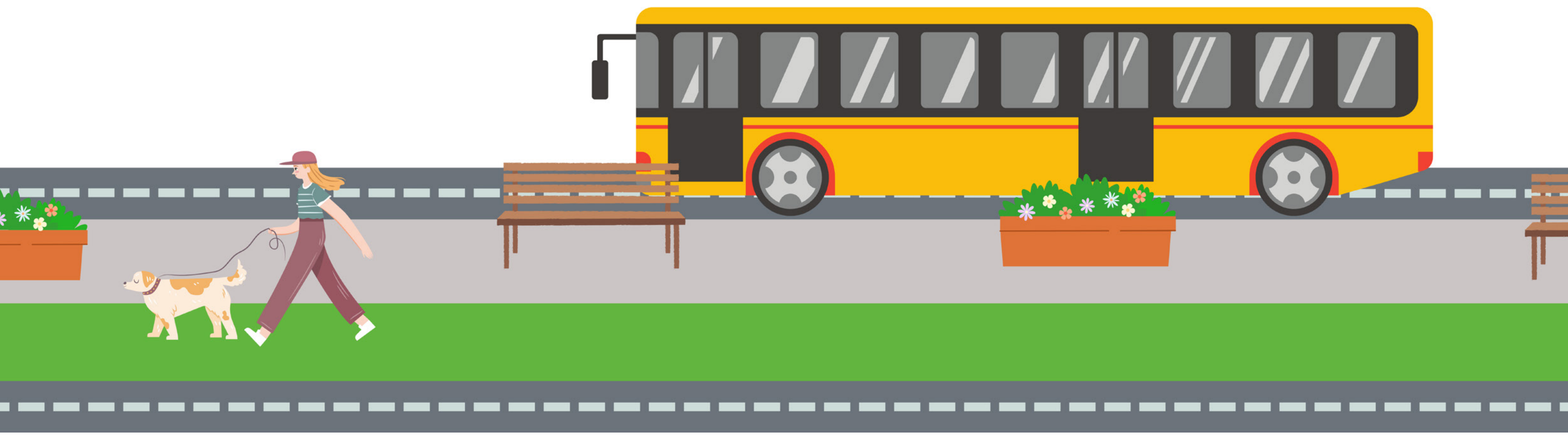
CTS cross section





CTS in-line joint

In cooperation with a cable joint manufacturer, we developed in-line and termination joints which were tested to comply with a standard for MV cables and accessories (IEC60502). The developed CTS control system was tested to detect any internal or external faults and safely operate the cable system over its lifetime.



Renewables

Reducing the cost of renewables integration

The situation

Development of renewable generation is driving the demand for more cable connections on land and in the sea. Existing cable solutions often reach limits owing to restrictions for length or size/weight. This is especially relevant in offshore applications.

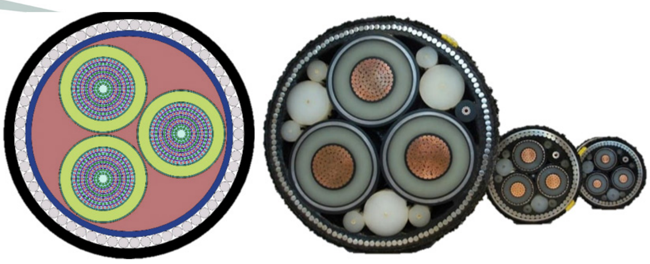
System modelling

We have determined that CTS cable solutions can bring significant benefits to renewable generation developers. Modelling of various wind and solar farms' connections at different voltages demonstrates that CTS cable can deliver the same power as conventional cables with larger cross sections. In addition, CTS brings the benefits of reduced voltage drop and reactive power compensation requirements. Higher current rating and lower power losses allow the use of smaller and lighter cables that are especially beneficial in an offshore environment. In addition to costs, reducing copper content also improves the project's carbon footprint by reducing mining and materials processing which are carbon and energy intense.

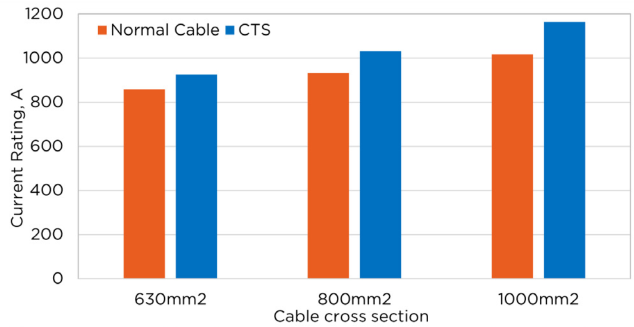
When compared on lifetime costs the CTS cable can be up to 30% more cost effective than conventional cables used today. This allows a reduction in Levelised Cost of Energy (LCOE) making renewables more competitive against fossil fuel powered energy and improves return on investment for developers.

CTS cable design

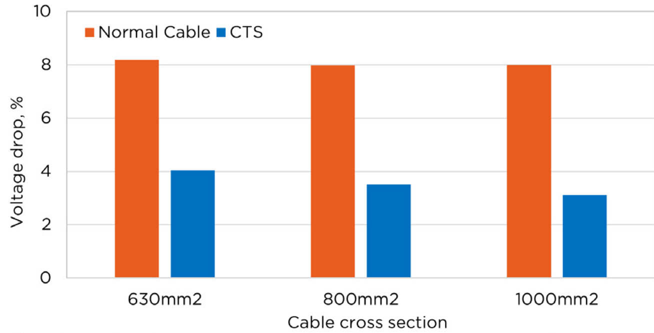
Enertechnos has designed a variety of designs that can be used in onshore and offshore applications. For a three-core cable, traditional methods can be used to assemble the cores in a cable that can be manufactured on existing equipment and installed by conventional methods.



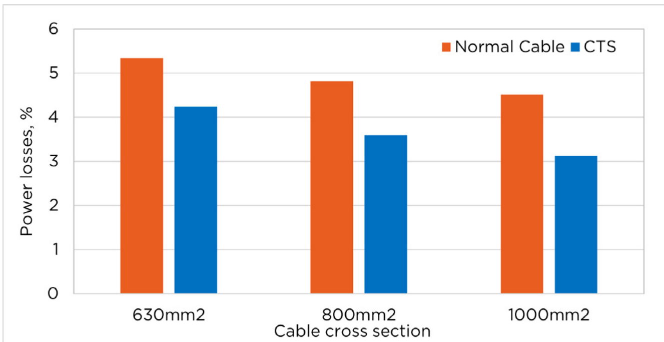
CTS and conventional multicore cables



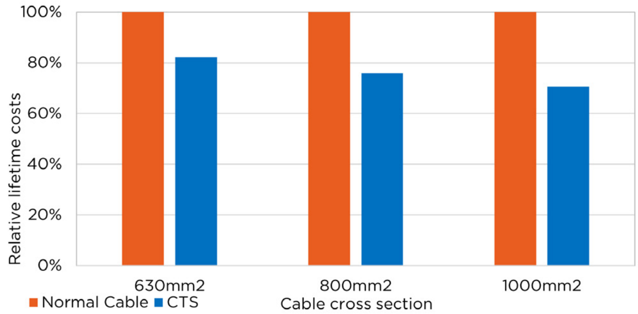
Cable current rating for cable cross sections



Percentage voltage drops for cable cross sections



Percentage power losses for cable cross sections

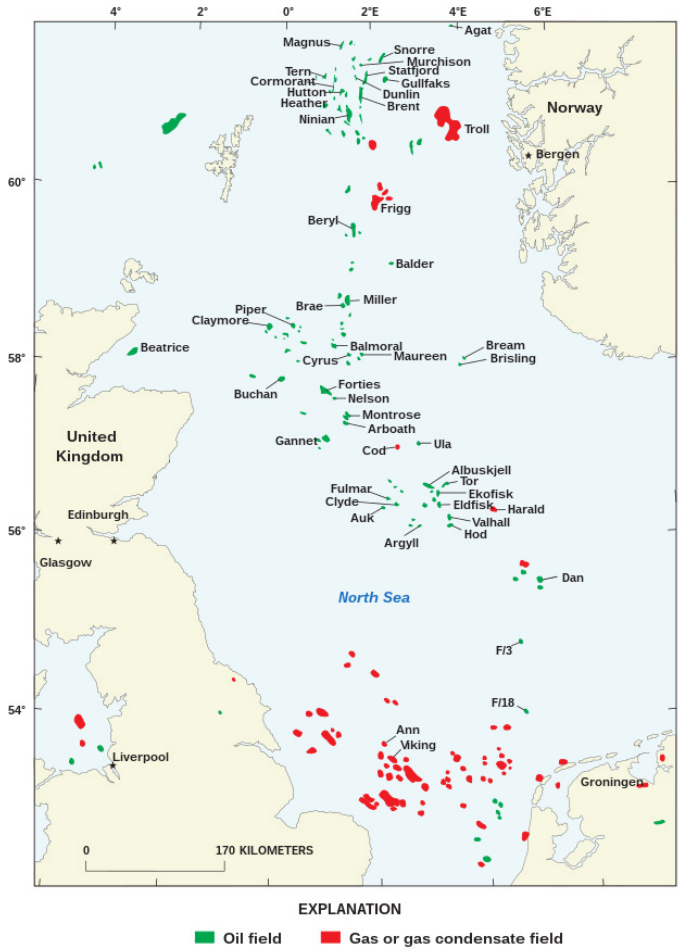


Lifetime costs for cable cross sections

Remote Grids

Decarbonising Oil and Gas by powering operation with sustainable energy

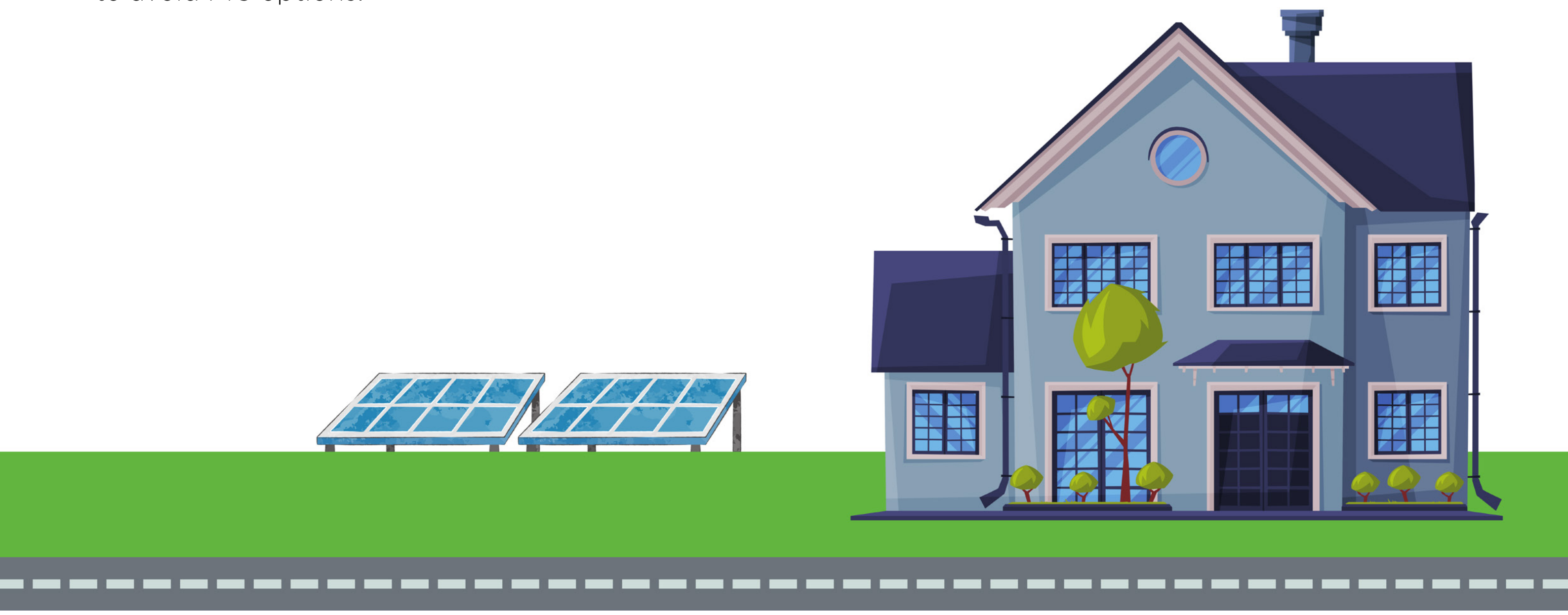
CTS enables the development and operation of self-sustaining power grids where these are remotely located and difficult to connect to existing power networks. There are multiple situations where these networks can leverage local sustainable resources to decarbonise operation and accelerate transition to net zero. For example, offshore wind resources to power Oil and Gas extraction, green hydrogen generation, carbon capture and storage (CCS) or solar energy powering mining or processing operations and many more. Enertechnos is working with partners to develop optimised solutions for multiple remote grid applications.



The situation

The Oil and Gas industry is under growing pressure to reduce the operation's carbon footprint. One of the key sources of emissions coming from extraction and processing is the powering of the equipment on the platform, as it is entirely sourced from burning gas in an open cycle gas turbine (OCGT). Powering all these operations using renewable generation would significantly reduce emissions and open up opportunities to power future CCS applications and green hydrogen production.

Electrification of offshore Oil and Gas is not easy – it is neither trivial nor cheap to replace the power from onboard generators – but the imperative to do so is plain. In addition, the platforms are located across a vast area, making the use of cost effective AC systems for power from shore (PfS) connections technically challenging, when compared to excessively expensive HVDC PfS solutions. Thus, platform operators across the North Sea are searching for economical and sustainable solutions to avoid PfS options.



The solution

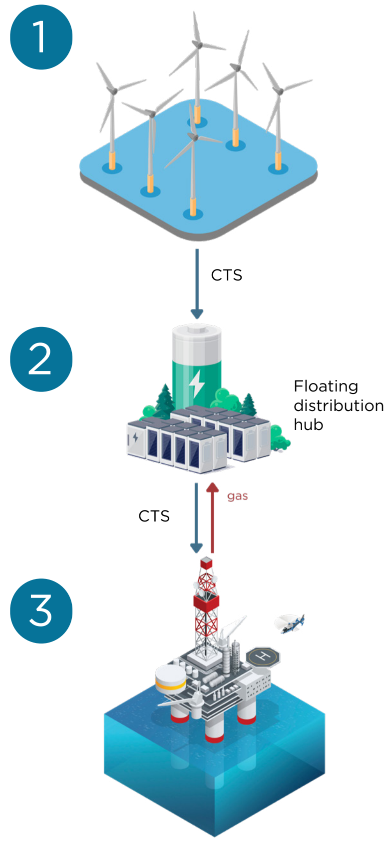
Working with partners from the Oil and Gas sector we have proposed a design for a viable, reliable, off-grid option for powering platforms across the North Sea.

The Microgrid concept has three components:

1. A floating wind farm distributed around the platforms powering the majority of the demand with sustainable electricity.

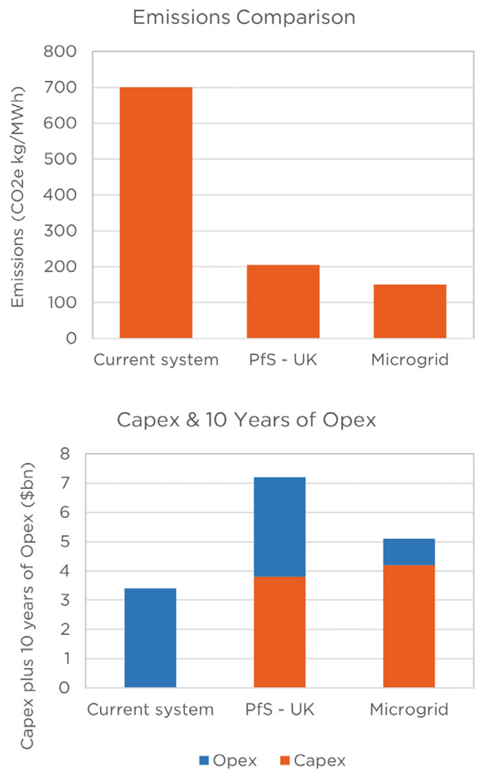
2. A floating distribution hub, which will collect power from the wind turbines, that, in combination with energy-efficient, gas fired reciprocating engines will deliver all the necessary power during the time when wind power is not sufficient. There will also be modest battery capacity for frequency control and to minimise the spinning reserve requirement.

3. A network of CTS cables to deliver power from wind turbines and distribute it across the platforms. The interconnection of platforms for a studied case requires multiple submarine cables at voltages from 33 to 132kV at distances from 20 to 200 km.

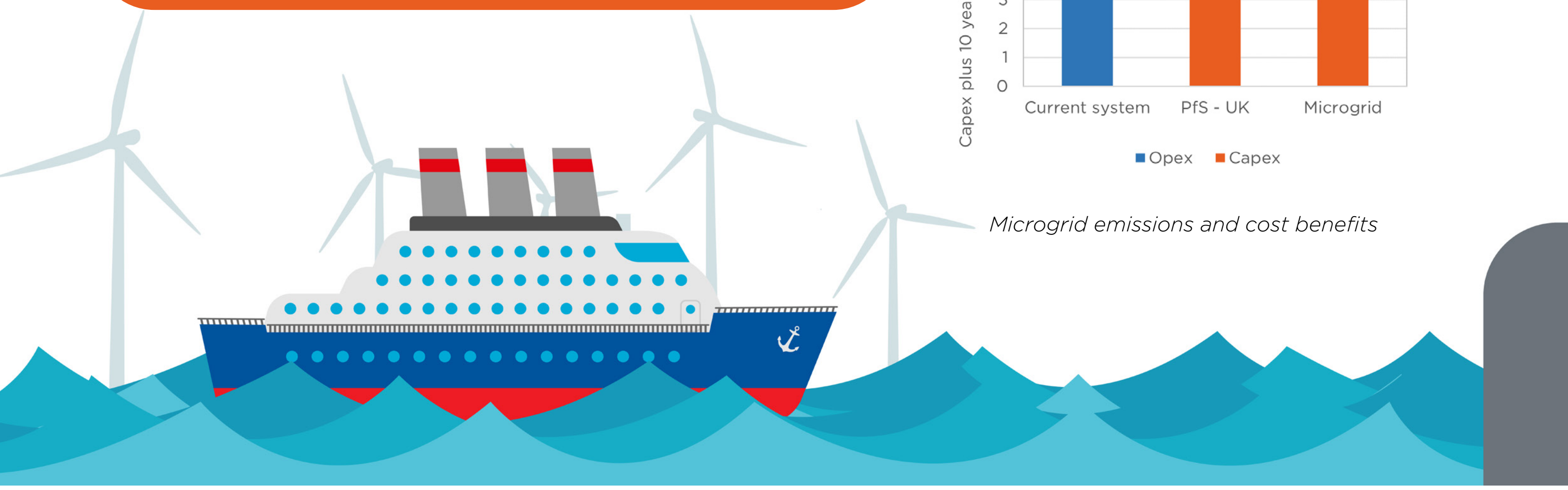


The proposed design is more effective and costs substantially less than PfS. It will deliver an earlier and deeper cut to emissions, and by reducing future costs it can enable mature fields to keep producing longer. After the oil or gas well is exhausted, the platform can become an offshore wind collection hub, carbon storage or green hydrogen production facility.

Where CTS and conventional cable options were considered, CTS cable was the cheapest configuration owing to the lower impedance of CTS cables reducing the voltage drop and resistive losses, allowing smaller cable sizes to be used relative to conventional cable for specific links. In some cases CTS allows the reduction of the number of parallel circuits, which significantly reduces connection costs.



Microgrid emissions and cost benefits



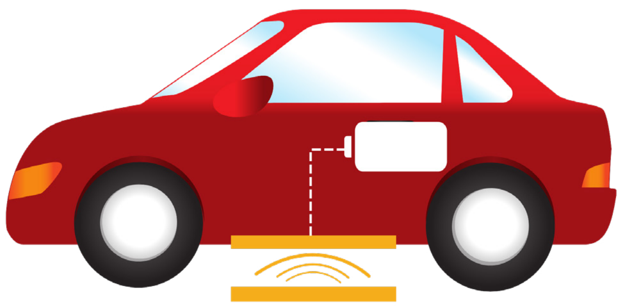
Wireless electric vehicle charging

Enabling cost–effective and effortless charging infrastructure

The rollout of EVs penetrates all areas of existing road vehicle use. While the majority of EVs will be driven by the public, organisations which operate fleets of vehicles will be significant. With an increasing total number of EVs, plug-in charging stations will become cumbersome features of carparks and depots, with charging cables presenting a multitude of hazards. Wireless EV charging technology is a simpler and more convenient way to charge an EV, without a cable in sight.

Wireless charging technology

Instead of transferring power to the vehicle battery via a cable, wireless systems achieve the same thing but with greater convenience for the EV user. Charging is enabled through a high frequency inductive coupling established between coils inside a groundpad and on-vehicle pads, then connected to the EV battery.



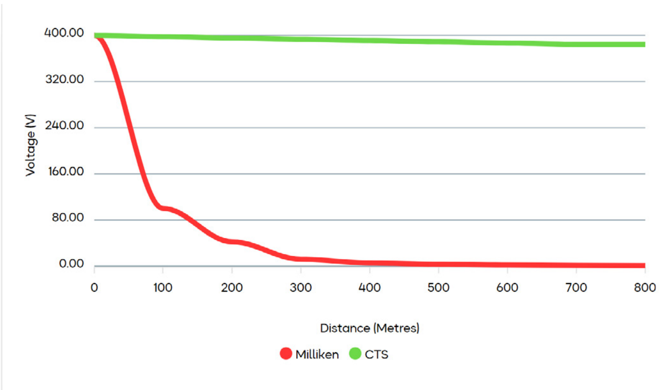
The situation

Wireless charging takes place at a frequency of 85kHz, 1700 times higher than the grid. It's very difficult to send this high frequency electricity over long distances without significant voltage drop.

As a result, with conventional cable, the converters required to produce the 85kHz signal are restricted to only serving one or two parking spaces at a time, resulting in a high capital and operational expenditure when dealing with multi-chargepoint requirements (e.g. fleet charging). For this reason, many companies struggle to deliver a scalable, cost-effective version of wireless charging infrastructure.

The solution

The Electric Green solution utilises benefits of CTS technology to make installation far more efficient. When comparing a 100 metre sample of CTS and conventional cable using a stable 50A current and 400V, the conventional cable causes the voltage to drop by 65% at 85kHz whereas CTS only has a 5% voltage drop. Therefore the converter doesn't need to be located near to every groundpad, so no street furniture is required near the parking lot.



Output voltage of CTS in comparison with Milliken cables

The Electric Green solution delivers many benefits including:

- Significant economies of scale ideal for fleets, depots, taxi ranks etc
- No street furniture at point of charge
- Increased system availability through multiple redundant power supplies
- Heat recovery from a centralised converter
- Modular growth – easy to expand

The solution

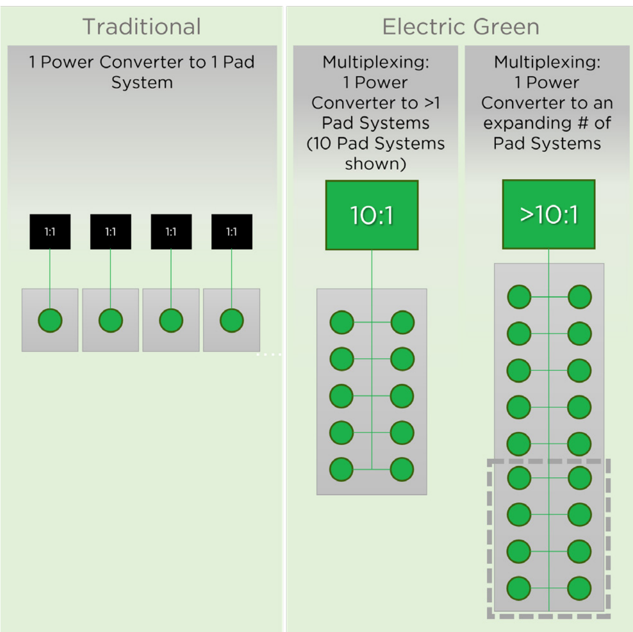
While private vehicle owners find the wireless charging process more convenient and easier than plug-in. For instance, taxi drivers and ambulances do not want the charging process to impact their service availability and revenues. Wireless charging 'opportunistically' enables them to top up their batteries while they go about their everyday jobs. Fleet operators also want the reliability and reduced running costs offered by wireless infrastructure.

All charging pads across the parking area can be supplied from a central power supply point. This reduces the number of expensive power electronics components and makes maintenance and heat recycling much easier. Parking areas can be described by their groundpad to converter ratio, which is where Electric Green has its impact.

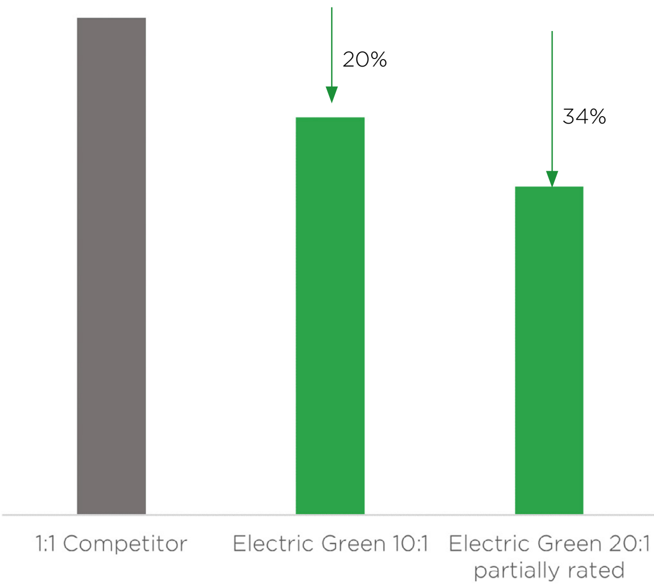
The Electric Green solution enables economies of scale, yielding a 20% reduction in the end-to-end cost of purchasing and installing the technology for a wireless charging parking space in a centralised system. A 34% reduction can be made for a space in a car park where 50% of the spaces are charging vehicles at one time, reflecting that the car park may not be at capacity, or vehicles parked there do not require instantaneous charging. In addition, the grid connection requirement is reduced. We refer to this as power multiplexing with prioritisation and load assessment.

This evaluation does not consider operational costs, expected to be significantly lower for Electric Green due to the ease of maintenance and physical separation of the centralised power supply.

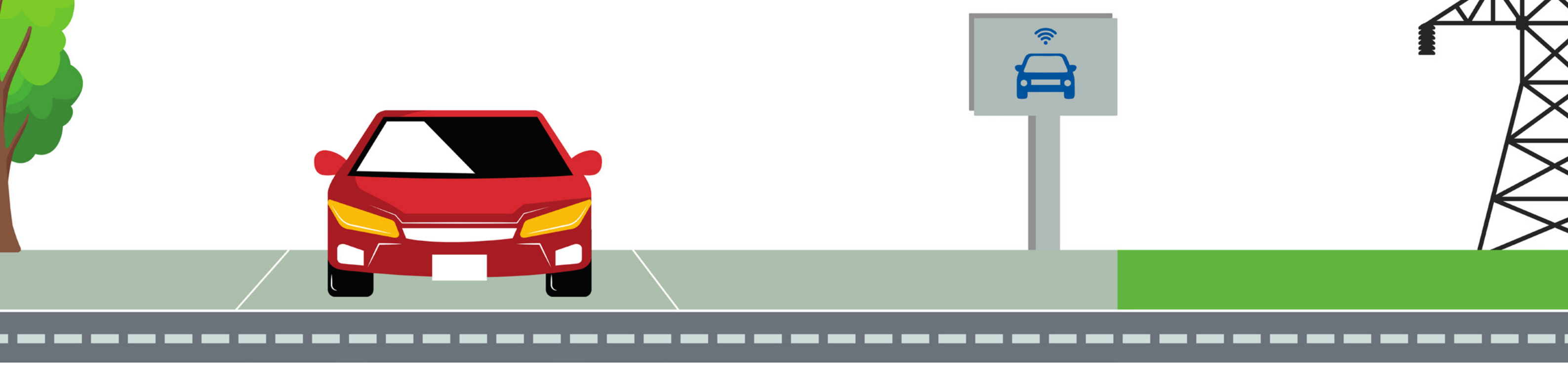
ELECTRIC GREEN POWER DISTRIBUTION ROADMAP



Economies of scale reductions on a per-space basis

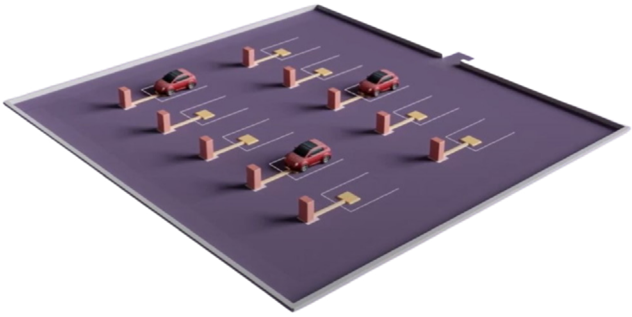


On the left, the standard 1 converter: 1 pad architecture is shown – on the right, this systems' multiplexing capability of having a singular converter (CA) connected to many ground pads (GAs) thus servicing many EVs (VAs) is shown

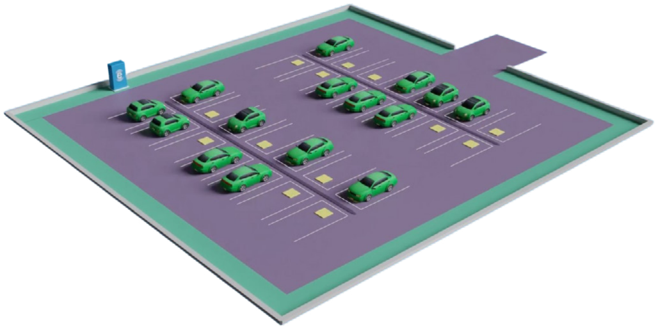


Wireless electric vehicle charging

Technical system overview - an overview of the Electric Green system



Traditional wireless



Electric Green

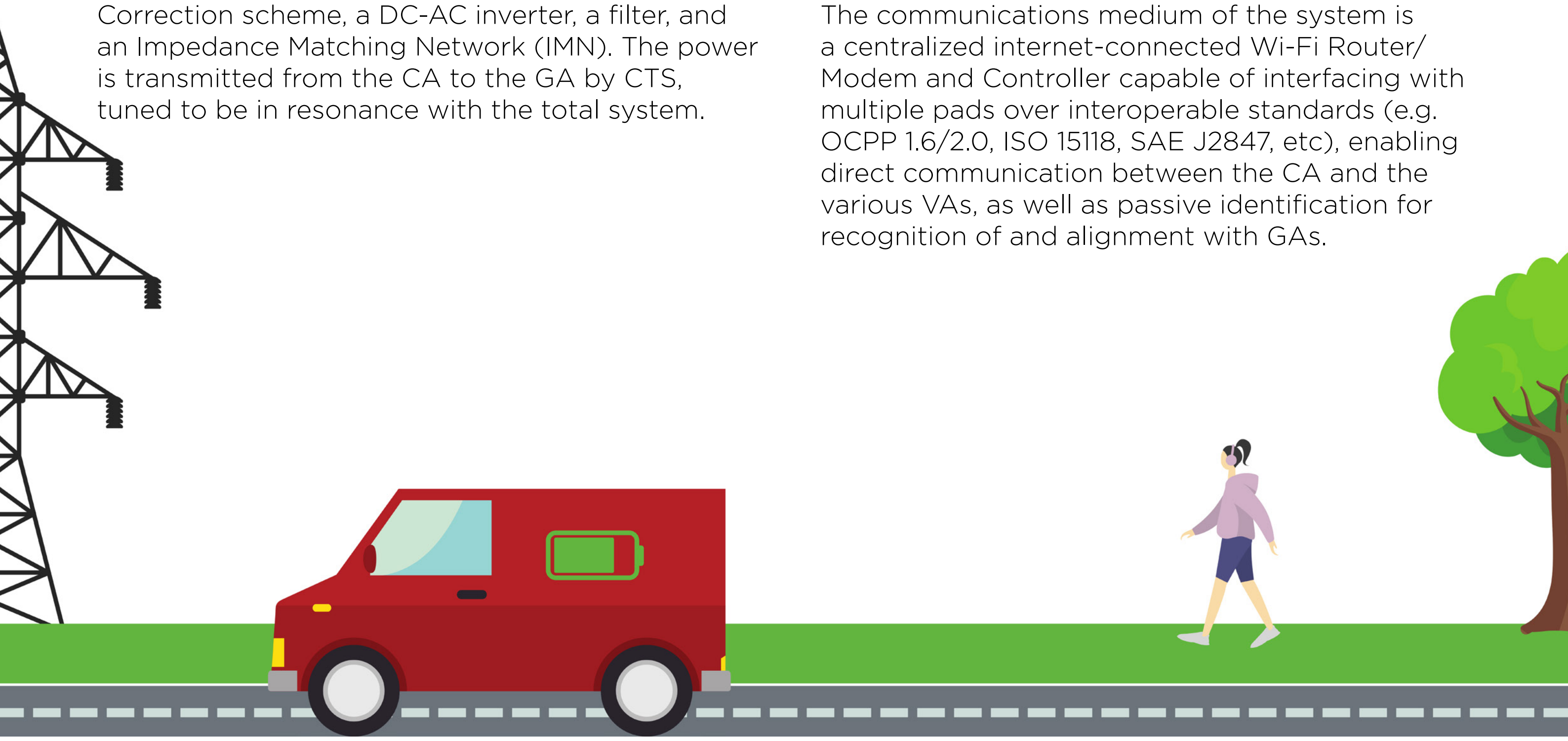
The Electric Green solution is a Magnetic Frequency Wireless Power Transfer (MF-WPT) system as classified by the key standards for wireless EV charging (SAE J2954 and IEC 61980-1). This MF-WPT system consists of two ground mounted components: the central assembly (CA) and the ground assembly (GA), and one on-board vehicle assembly (VA). Unlike a standard WPT charging system, which is constrained to a 1 power converter to 1 pad system relationship, the Electric Green system uses a common backbone enabled by CTS cable to service multiple pad systems from one central power converter allowing the so called “multiplexing” schema.

The CA has a bidirectional power flow capability connected to the local power grid. It consists of a power frequency converter, a Power Factor Correction scheme, a DC-AC inverter, a filter, and an Impedance Matching Network (IMN). The power is transmitted from the CA to the GA by CTS, tuned to be in resonance with the total system.

The GA consists of a coil generating an electromagnetic field at 85kHz, creating an inductive coupling to the VA coil to transfer magnetic energy over the air gap between these two coils. The power flow can go in both directions allowing charging of the vehicle battery or discharging to provide local power supply, a concept termed vehicle to grid (V2G).

The VA consists of a coil inductively coupled with the GA for power transfer, an IMN, a filter, and a power converter interface with the EV battery. The controller is capable of communicating with the CA as well as with the EV’s on-board charger for power flow control. The controller then interfaces with any existing User Interfaces (Safety Systems & Alignment) for charge initiation.

The communications medium of the system is a centralized internet-connected Wi-Fi Router/ Modem and Controller capable of interfacing with multiple pads over interoperable standards (e.g. OCPP 1.6/2.0, ISO 15118, SAE J2847, etc), enabling direct communication between the CA and the various VAs, as well as passive identification for recognition of and alignment with GAs.



Airports electrification

Accelerating aviation decarbonisation

The situation

Aviation is one of the most challenging sectors for decarbonisation and everything that can be done to improve efficiency helps on the road to net zero.

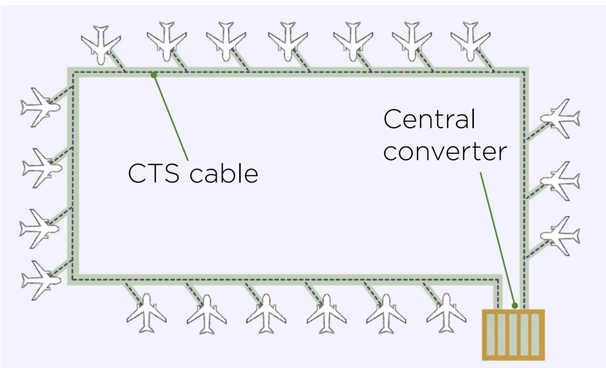
400Hz Fixed Electrical Ground Power

As airports work to decarbonise and improve local air quality, one of the key targets is to end the use of diesel engines and auxiliary power units (APUs) to provide aircraft with electrical power on the ground. To make this feasible it is necessary to have Fixed Electrical Ground Power (FEGP) at all stands and to ensure that each supply point is reliable.

The present approach to ground power is to have a single FEGP unit at each gate and typically use a mobile diesel unit for remote stands.

The primary reason for having an individual unit at each stand is that at 400Hz, the distance the power can reliably be sent to the aircraft is about 50m. Beyond that length, problems with voltage drop become excessive and falls outside the acceptable voltage tolerance for the aircraft.

Many airports are already encouraging their suppliers and contractors to adopt EVs on the airside. Some standard vehicles, such as cars, vans and trucks can be replaced with standard EVs. And custom pieces of Ground Service Equipment (GSE) such as stairs, elevators, scissor lifts and baggage tugs may require bespoke design. In both cases installing plug-in infrastructure across the airport could increase safety risks and operation complexity.



The solution for powering aircrafts

CTS technology enables the construction of a 400Hz distribution network where all aircraft stands are supplied by a centralised frequency converter system. Reducing the number of 400Hz converters leverages on economies of scale, increases reliability and provides operational benefits as listed:

1. Even providing an extra unit for redundancy, the capital expenditure on centralised converters could be as little as half compared to a legacy system
2. Determining the peak and average loads of all the stands combined, it is possible to use fewer converter units at a centralised location
3. With multiple converters deployed as a shared resource between multiple aircraft, the loss of a single power unit no longer takes a stand offline
4. Thermal energy can be recovered from the centralised converters and used to heat water for use inside the terminal, improving the energy efficiency
5. Owing to the re-location of the converters within the terminal building where they are landside accessible, maintenance access can be provided without the need for 'apron escorts'. 'Apron escorts' are personnel who have an airside security clearance. More often than not, the electrical engineers who would attend to a technical problem with a converter are not security cleared, and so must be escorted at all times when airside. Removing this requirement significantly reduces maintenance cost and Mean Time To Repair (MTTR)

The solution for powering on ground vehicles

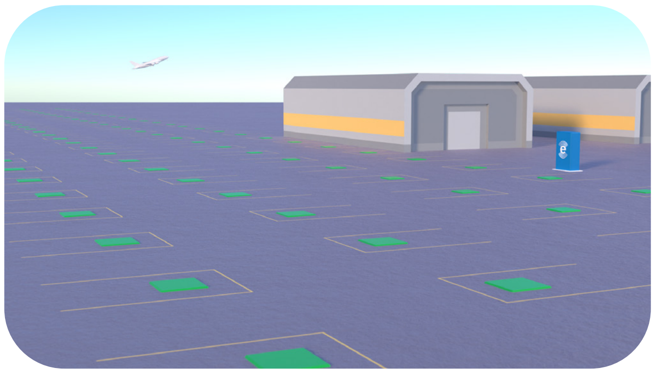
A CTS-enabled Electric Green wireless EV charging solution could be used airside in place of standard above-ground charging equipment and in locations where that cannot be installed. This allows vehicles to charge without plugging in which means no equipment to break or risk of forgetting to connect. When a vehicle is parked on a charging zone, the connection is made automatically and the battery charges while the vehicle is off-duty or being loaded.

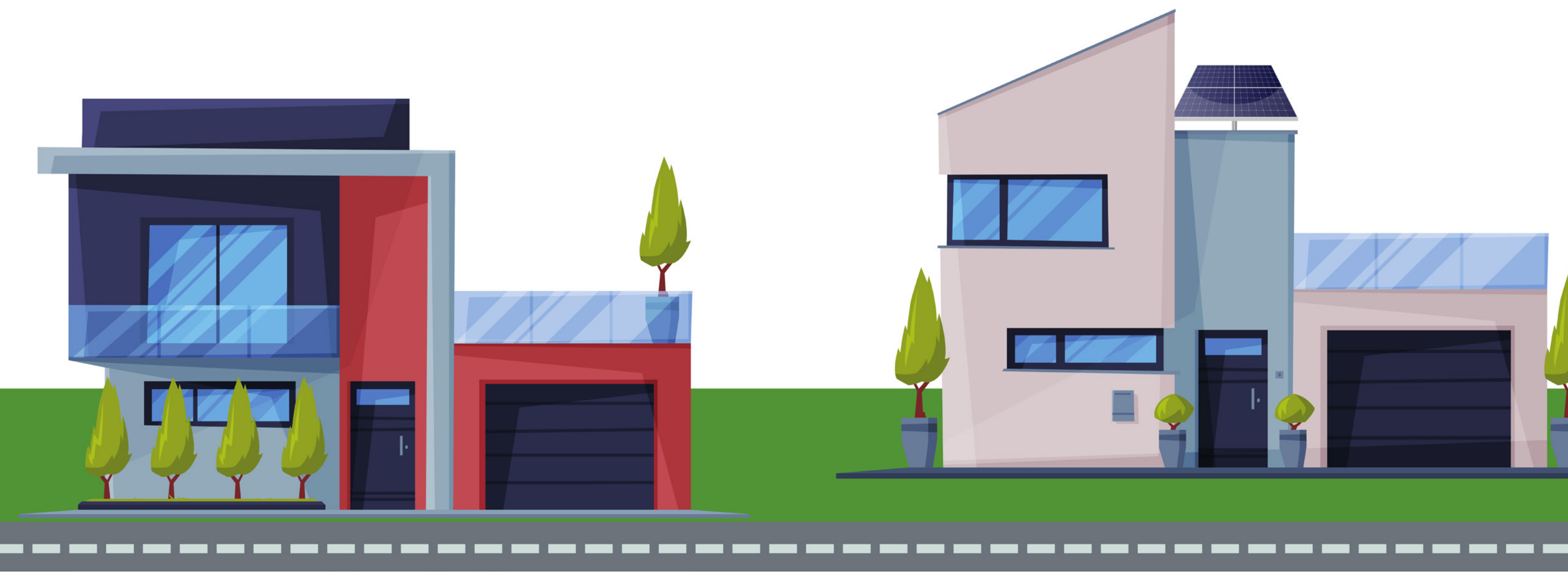
A summary of advantages include:

- No longer needing to drive all the way back to a maintenance hangar to charge
- Moving charging/parking areas closer to operation areas
- Ground vehicles for airports tend to have smaller batteries which are faster to charge, thus making a multiplexing CTS-common-backbone installation perfectly suited.

Traditional plug-in

Electric Green





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