MAXWELL

Electrotechnische Vereeniging

Issue 25.1 | February 2022

Time for Change

Switching on time
A themed exhibition at the Studie Verzameling

Powerelectronics: the future of our grid
The role of powerelectronics in state-of-the-art grids

The future of power system stability
The development of power system stability with the advent of renewable energy

From the Board

Commissioner of Career Affairs & Vice-President

By Maxim Mazurovs

Dear readers,

We are now nearing the end of the second quarter, but also the end of the first semester. During this time a lot has changed. The Board has found their way of functioning as a team, the darkest days are behind us, in the lockdown sense and weather sense, and the career prospect of the ETV is nearing its highlight with preparation of the biggest event of the year: the EEMCS Recruitment Days.

Earlier in the history of the ETV, the Commissioner of External Affairs was the only one to handle all the contact with companies and all career-oriented events in cooperation with the companies. However, as the number of Electrical Engineers grows, so does also our association and the interest of companies to contact the engineers. Everywhere we look, we see growth. This is also why we have named our Board: ‘The Magnifying Board’. Not only because the association has magnified in its numbers, but also in the number of Board members. Our predecessors have added an extra Board member which makes it 6 people who fulfill the daily tasks and take on the responsibilities of the Vereeniging. I have chosen to take on this role as the new commissioner and explore what this function has to offer and where it can help make the ETV a better place. I had named the extra role as the Commissioner of Career Affairs. A big reason for this was because Career is one of the 3 pillars the ETV stands on: Education, Career, and the Social Connection between students. As Commissioner of Career Affairs, I am the main organizer of the EEMCS Recruitment Days – the biggest career-oriented event meant for connecting EEMCS students with high-tech and rising companies with state-of-the-art technology and research. Next to this, I help my colleague Evelien with career-oriented affairs and are we planning on introducing new events that the ETV has not seen before. We believe it’s also time for change in the career aspect of our Vereeniging.

The motto of our Board of this year is “Omnia mutantur, nihil interit”. This stands for: “Everything changes, nothing perishes”. I believe this captures our year perfectly. Not only is it time for change within the ETV, but also in the world of engineering. After 4 months of talking with companies, you can see everywhere the beginnings of the worldwide energy transition. Everywhere you go, the world is preparing for a change within itself to counteract the change in climate and increasing economy. From updating the electricity grid to installing flexible solar panels on sea and from stepping out of the gasoline age and entering the hydrogen era. From power engineering to telecommunications, the change begins in every student of EEMCS.

With Magnifying regards,

Maxim Mazurovs
Commissioner of Career Affairs &
Vice President of the 150th Board of
the Electrotechnische Vereeniging

From left to right: *Evelien de Wolff, Maarten Groen, Mark Imhof, Maxim Mazurovs, Niels van Duivendijk, Jorrit van Drie*

Colophon

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Editorial

Dear readers,

Yet another year has passed as we have entered 2022. In spite of the rather unfortunate circumstances regarding Covid-19, and specifically Omicron, we hope that this quarter's edition finds you well.

In recent years there has been a large shift of attention towards pollution and other environmental problems. Several locations around the globe, such as New York and Glasgow, are now home to some rather remarkable timers that display the time that is expected to be left before we reach an environmental point of no return.

Electrical Engineering is, not so surprisingly, a field that is closely related to environmental problems, as its applications can offer valuable solutions. Mainstream media nowadays often tends to focus more on the qualitative implementation of renewable energy sources, but a major part of the energy transition that is often overlooked is the grid. In this edition, themed Time for Change, we have included a handful of articles that aim to cover some of the challenges in grid design and power system stability that come with the advent of renewable energy. Additionally, we have also included an article from our faculty's own "Studieverzameling" that dives into the history surrounding the mechanics of keeping track of time itself.

Special thanks to the board members of the ETV and all other contributors, without whom this edition would not have been possible. On behalf of the entire Maxwell committee, I wish you a pleasant reading experience.

Arman van Dijk

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Switching on time

A themed exhibition at the studieverzameling

Rob Timmermans

Clock expert and volunteer at the SV

For over a hundred years, there has been a need to execute and/or record actions at the right time. This could include an acoustic signal to indicate the start and the end of working hours in the factory, a signal at the start and the end of classes, and switching lighting on or off at a fixed time. But there is also 'switching on time' when using, for example, vault clocks, night watchman clocks, pigeon clocks, time clocks, and the like. A themed exhibition has been set up around this subject at the Faculty's Study Collection. Some hundred objects related to this theme are exhibited in the basements of the EEMCS low-rise building.

Figure 1. *An overview of the exhibition*

In this exhibition, special attention is paid to the principle of master and slave clocks (in Dutch, we refer to such clocks as to mother and daughter). When designing these timepieces - around the year 1900 - the idea was based on having an accurately running central clock (master clock) passing on the correct time to a large number of secondary timepieces (slave clocks). Passing the right time often went through electric pulses, but pneumatic systems were also used. The concept of this type of system is called a time distribution network.

To give you an example of such a time distribution network: some 125 years ago, the railways needed to display the same, correct time at all of their stations. After all, they were driving according to the timetable. Not every traveler had a pocket watch - the wristwatch didn't exist yet - and the tower clock didn't necessarily show the correct time. The idea then arose to distribute the right time; if a precision timepiece somewhere centrally ran precisely on time, the time of that master clock could be passed on to a large number of slave clocks, which would then by definition also display the correct time. That was the general idea.

At that time, the starting point for the design of a master clock was a clockwork with a pendulum, driven by a raised weight or a wound spring. A pendulum clock is a timepiece, the regular running of which is regulated by a reciprocating pendulum. When the time in which the pendulum swings back and forth is practically constant, the clock will run smoothly. This uniformity allows time to be measured reliably and accurately.

A pendulum clock requires a precise adjustment of the pendulum (length); otherwise, the clock will run too fast or too slow. By the way, the pendulum time is not determined by the material or weight of the pendulum (lens) but by the length of the pendulum stem.

The aim of the quest for improvement of the accuracy of pendulum clocks was to achieve the 'ideal' pendulum. After all, when the pendulum movement is even and thus the pendulum time constant, the timepiece's accuracy is optimal.

The pendulum period of a pendulum is shown in the next formula:
$T = 2\pi\sqrt{(l/g)}$, with l = the pendulum length in meters and g = the gravitational acceleration in meters per second squared.

In the pendulum time T, the pendulum swings once back and forth. The letter t represents half the pendulum period, either once forth or once back.

Because the above formula only applies to small pendulum angles, the deflection from its rest position (= pendulum amplitude) should not be too great. This formula also shows that a constant pendulum length is crucial for accurate time measurement.

A pendulum with a length of about 1 meter has a pendulum time T of 2 seconds and a t of 1 second. A seconds impulse could then be generated by a switching contact on the pendulum rod. Or a minute impulse using a counting wheel.

The distribution of those electrical pulses to slave clocks went through electrical wires. For the railways, use was made of the existing telegraph lines on poles along the railway embankment. When the distance to be bridged was too large, pulse amplifiers (line amplifiers, relays) had to be used in the wiring.

In the quest to improve the accuracy of pendulum clocks - de facto optimizing the accuracy of the pendulum movement - a number of changes were made to the respective master clocks over the past decades. For example, compensation for the change in the length of the pendulum stem due to temperature differences. After all, the pendulum length has a direct influence on the pendulum time. Several techniques the respective clock designers have used along the way in optimizing the accuracy of the pendulum movement are visible in the exhibited objects.

One of the many ways to blueprint the ideal pendulum was by eliminating as much as possible the adverse effects of the driving force of the clockwork (weight or spring tension) on the regular course of the pendulum. Achieving the ideal pendulum came one step closer by removing the drive weight or the winding spring. But also removing gears, pinions, and clock hands further improved the pendulum accuracy. Removal of the drive introduced a new problem; how should mechanical energy be supplied to the pendulum without disturbing the regular course of the pendulum motion? Various interesting solutions were devised for this; a number of these alternative pendulum drives can be admired at the master clocks present at the theme exhibition.

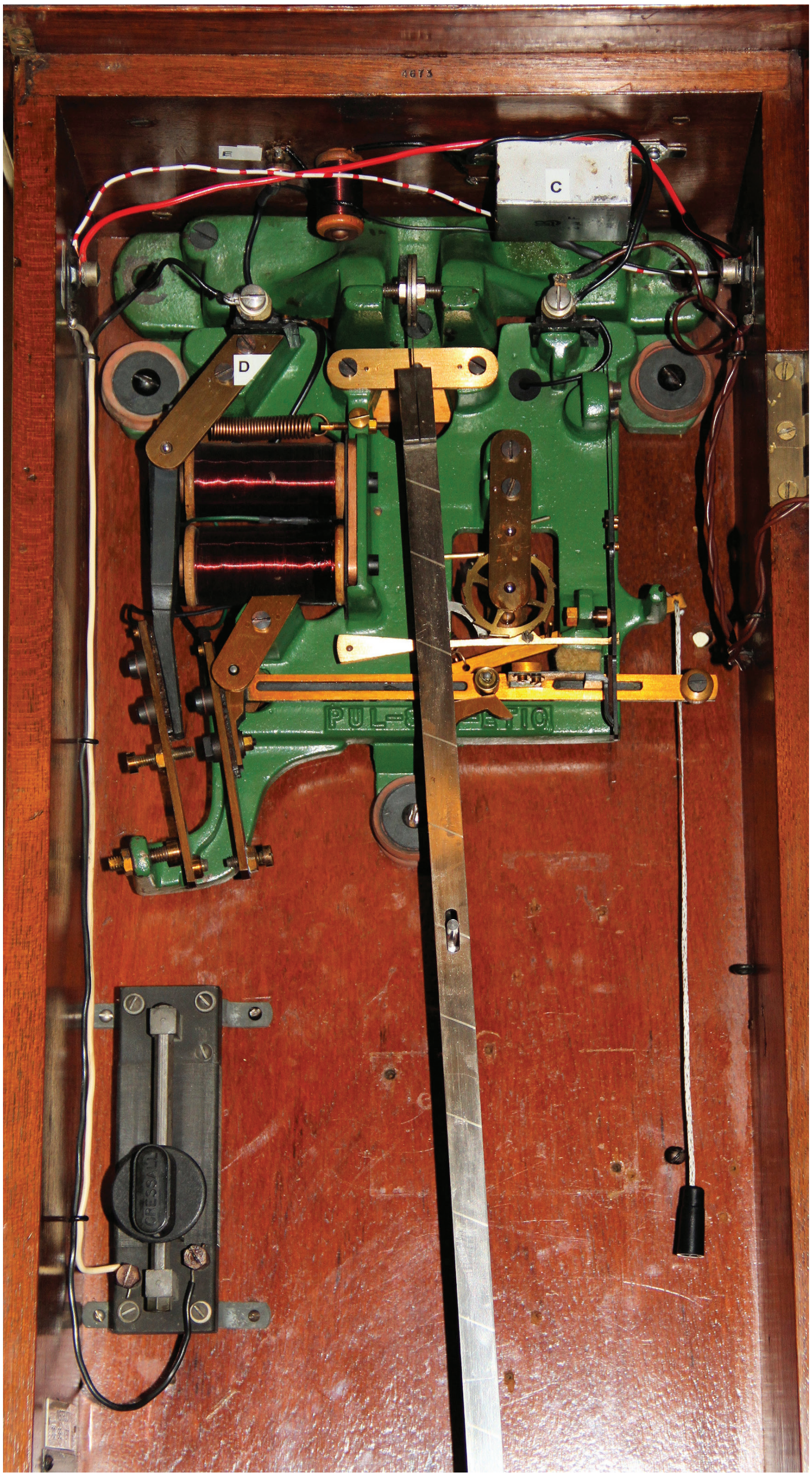

Figure 2. *A gravity arm driven pendulum of a PUL-SYN-ETIC master clock, built by GENT of LEICESTER (1938)*

General clock precision from 1650 to the present

The accuracy of a timepiece is usually indicated by its day-to-day running and deviations from the real time. This indicates the number of seconds (or fractions thereof) the clock is running ahead or lagging during a day. This gait also indicates the number of days or years the timepiece has needed to gain or lose 1 second.

Over the past few centuries, the accuracy of timepieces has increased enormously. The pendulum clocks from around 1660, designed by Christiaan Huygens, ran one second ahead or behind every 3 hours. A big step forward in terms of accuracy was taken when Marrison invented the quartz clock in 1928 with a deviation of maximum one second every three years. In other words, the quartz clock is about 10,000 times more accurate than Huygens' pendulum clock.

Over the past fifty years, the performance of clocks has improved even more rapidly; in particular (Cesium or Rubidium) atomic clocks have contributed to this development. An atomic clock uses the vibrations of atoms as the basis for measuring time. The frequency of these vibrations is so extremely constant and independent of the environment that the deviation of an atomic clock is almost negligible. The first atomic frequency generators around the year 1955 (atomic clocks) based on cesium-133 were only ahead or lagging by one second in 300 years, while later standards will only do so after 300,000 years. At the turn of the century, an accuracy of one second in 3 million years was achieved. In 2019 we noted an accuracy of one second every 5 billion years (i.e. inaccuracy is 6 x 10-18). Today there are ytterbium-based coupled atomic clocks with an accuracy of one second every 15 billion years.

Jump to the present

Today, the application of distributing time has become much more widespread. Just think of the many Radio Controlled clocks in use (based on the airwave signal DCF 77). But also the time displayed on our mobile phones, the time in satellite navigation systems such as GPS, time on the internet (Network Time Protocol NTP), the time on our digital radio receivers (DAB), smartwatches, etc.

In short: the need for 'always the right time in every place' has remained unabated throughout the years. However, the underlying techniques for the accurate determination and the dissemination of that time have changed greatly in recent decades; i.e. the

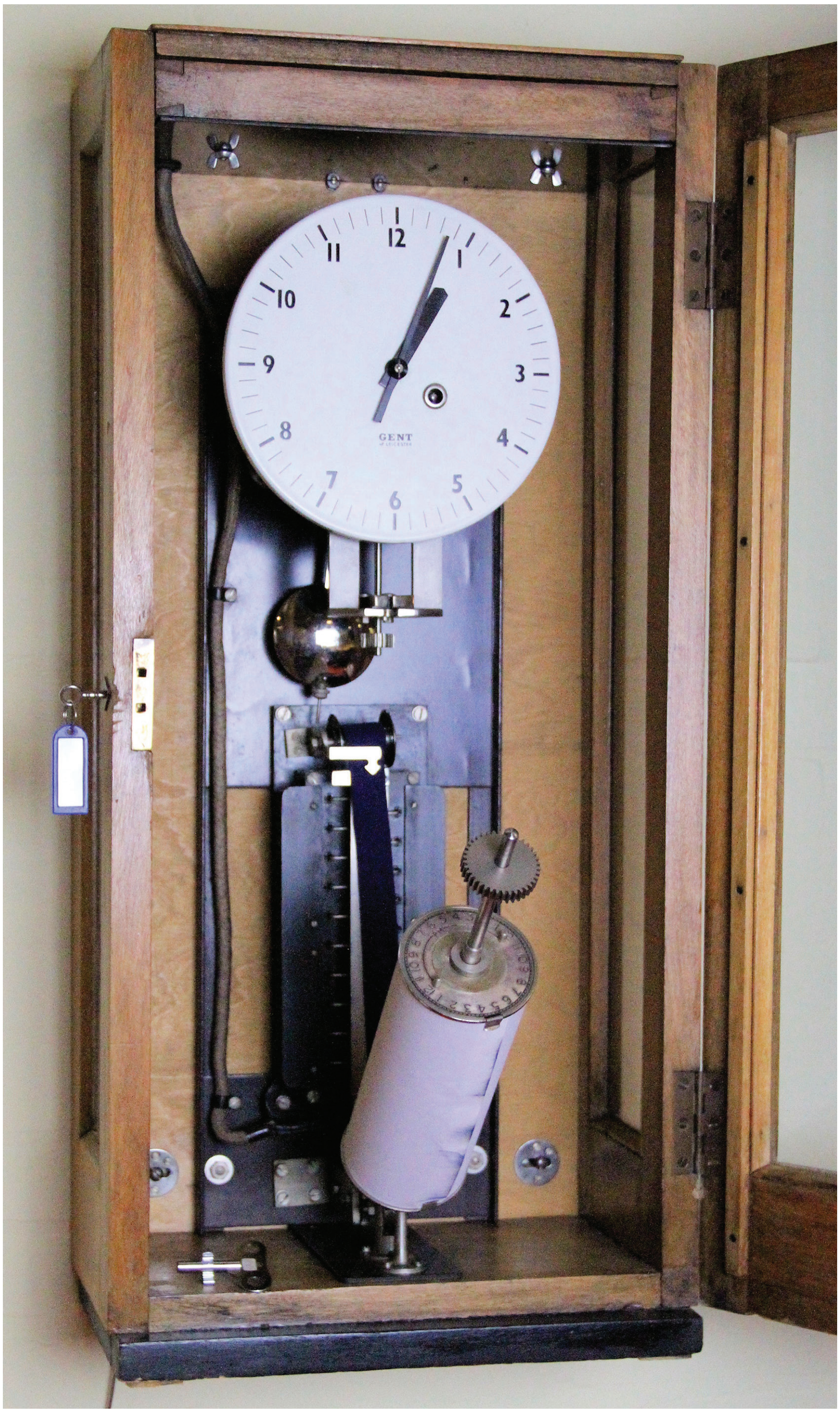

Figure 3. *Watchman's Tell Tale Clock by GENT of LEICESTER with registration cylinder (around 1950)*

• master clocks - originally pendulum clocks, later quartz clocks - have now become atomic clocks with unprecedented accuracy
• dissemination of time information is no longer wired but has become wireless, via both the ether (DCF 77) and satellite
• distribution networks have grown from local and national to continental (DCF 77 in Europe) and global (GPS, NTP)
• decentralized clocks (slave clocks) have become our mobile phones, GPS systems, Internet time, DAB radio receivers, smartwatches, etc.

In itself, this evolution is also an excellent example of ***switching on time***…

Power system stability

A rundown on its challenges and future prospects

Mart van der Meijden

The Maxwell committee asked whether I would be willing to write about the future of power system stability with the advent of renewable energy dominated power supply. System stability is challenging with a very high share of renewable energy. As a member of the Intelligent Electrical Power Grid (IEPG) Section, I am pleased to do so. It is not an easy topic, but for sure interesting. In fundamental terms, the electric power system consists of the electricity generators, the electrical distribution and transmission grids, and the electricity consumers (e.g. industry, households, prosumers). Due to the ambitious trajectory towards a climate neutral Europe in 2050, the electrical power system is facing, I would say, interesting and unprecedented challenges. The stability (i.e. the ability to survive to any type of disturbance) of the electrical power system is more and more at risk and understanding and safeguarding this stability is complex. What is the most important cause of this threat? With the ambition zero carbon electrical system, vast increasing amount of variable renewable energy sources, such as wind power and solar power, have to be integrated in the power system. With the growth of these renewable energy sources, less traditional synchronous generators, such as fossil fuel (coal, oil, gas) fired power plants are needed. However, these traditional generators have an inherent opposition against disturbances (e.g. present inertia and electromagnetic forces) and they also have a high degree of controllability needed to ensure continuous power balance and the fulfillment of technical limits (e.g. voltages and frequency within allowed operational limits).

What is inertia?

Inertia in electrical power systems refers to the energy stored in the rotating mass of large generators and some industrial motors. This stored energy slows down the rapid changes in rotational speed. When a large power plant fails, the stored energy in the remaining rotating masses of the power system can be particularly valuable, as it can reduce the degradation rate of the rotating speed, and with this the degradation of the frequency of the voltages and currents in the power system. This allows the mechanical systems, that control most power generation plants, to detect and to respond within few seconds time to the failure. Inertia contributes to the power system stability.

Figure 1. *2000 MW Voltage Source High Voltage Direct Current converter station connecting future large offshore wind power plants*

What is power system stability?

In this article the classification and definition of power system stability are based on the most recent publication of the IEEE/CIGRÉ Joint Task Force working on Stability Terms and Definitions in July 2021 [1].

Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact. Unstable situations in a power system can lead to loss of generation or loss of load to such an extent that in the worst case it results in a power system wide black-out. For a long time the Power System Stability classification could be based on synchronous generators and motors and could be described by: “Frequency Stability”, “Voltage Stability”, and “Rotor Angle Stability”.

Frequency Stability: Figure 2 depicts the three distinct periods during an event that causes decline in frequency in a system dominated by synchronous generators, and the related controls: (i) the initial inertial response of synchronous generators, with the Rate of Change of Frequency (ROCOF), (ii) the primary frequency response of generators and load damping, limiting the maximum frequency deviation (Nadir), and (iii) automatic generation controls (AGC) bringing the frequency back to its nominal value.

Voltage stability refers to the ability of a power system to maintain steady voltages close to nominal value at all buses in the system after being subjected to a disturbance [1]. It depends on the ability of the combined generation and transmission systems to provide the power requested by loads. This ability is constrained by the maximum power transfer to a specific set of buses and linked to the voltage drop that occurs when active and/or reactive power flows through inductive reactances of the transmission network. A possible outcome of voltage instability is loss of load in an area, or tripping of transmission lines and other network components, by their protective systems, leading to cascading outages.

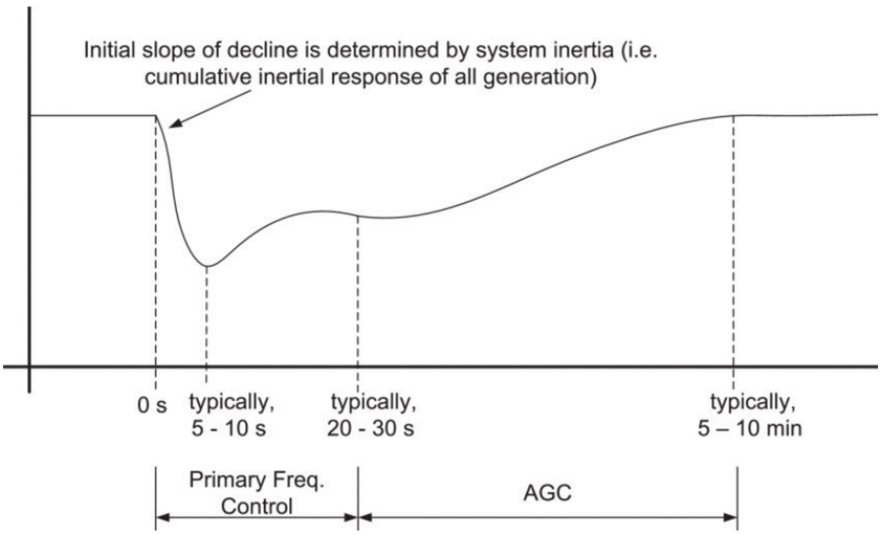

Figure 2. *An illustration of power system frequency response to a major loss of generation. (reproduced from [1] and [2])*

Rotor angle stability is concerned with the ability of the interconnected synchronous machines in a power system to remain in synchronism under normal operating conditions and to regain synchronism after being subjected to a small or large disturbance [1]. A machine keeps synchronism if the electromagnetic torque is equal and opposite to the mechanical torque delivered by the prime mover. Accordingly, this type of stability depends on the ability of the synchronous machines to maintain or restore the equilibrium between these two opposing torques.

What is the impact of renewable energy sources on system stability?

The variable renewable energy sources are coupled to the electrical grid with power electronic converters. This has led to unprecedented situations, first of its kind. For example. BorWin1 is the first grid connection with which TenneT has connected an offshore wind farm to the grid using direct current technology. Up to 400 Megawatts (MW) of clean electricity from the BARD Offshore 1 wind farm is transported via a high-voltage direct current transmission cable through the North Sea and overland to the landside grid connection point - the converter station in Diele, as shown in Fig. 3.

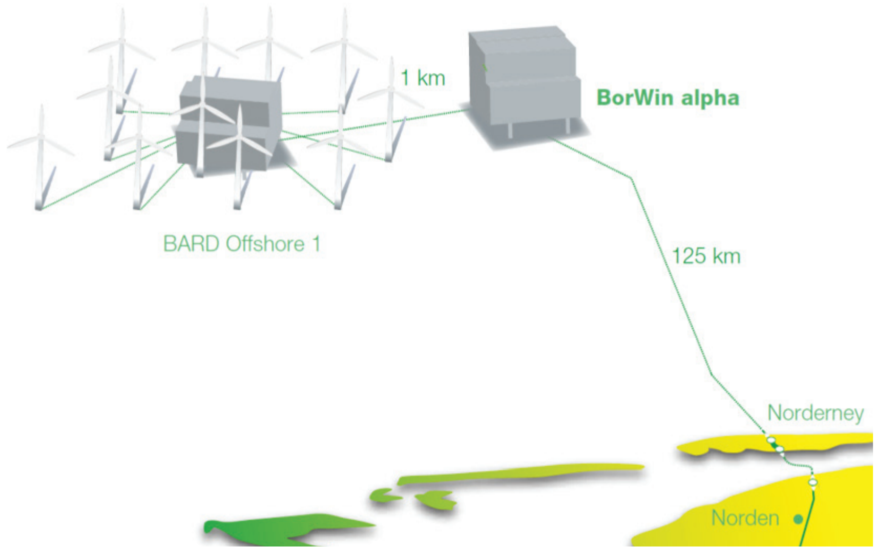

Figure 3. *BorWin Alpha converter platform configuration (courtesy of TenneT)*

Around 2012 unknown harmonic and stability issues between the converter platform and the offshore wind turbines were experienced resulting in unexpected switching-off the 400 MW BorWin Alpha converter station.

With the increased penetration of converter interfaced generation in modern power systems a growing number of challenging power system stability phenomena were experienced. This means that the effects of fast-response power electronic devices appeared, which do not fall among the above mentioned three classic definitions and classifications. Therefore two new stability classes had to be developed, namely “Resonance stability” and “Converter-driven stability”[1].

Resonance Stability: The resonance, in general, occurs when energy exchange takes place periodically in an oscillatory manner. These oscillations grow in case of insufficient dissipation of energy in the flow path and are manifested (in electrical power systems) in magnification of

voltage/current/torque magnitudes. When these magnitudes exceed specified thresholds, it is said that a resonance instability has occurred. The resonance stability encompasses sub-synchronous resonance, which means frequencies lower than the synchronous frequency (50 or 60 Hz).
For example a modern large wind turbine with variable speed doubly-fed induction generators (DFIG). This is an induction generator directly connected to the grid. In some situations of series compensation an electrical resonance between the generator and series compensation might be possible. When the series capacitor forms a resonant circuit, at sub-synchronous frequencies, with the effective inductance of the induction generator, and at these frequencies, the net apparent resistance of the circuit is negative and the sub-synchronous resonance occurs. If the total negative resistance exceeds the positive resistance of the circuit at or near the resonant frequencies, sub-synchronous resonance occurs. The resultant resonance primarily leads to large current and voltage oscillations that can damage the electrical equipment both, within the generators and on the transmission system.

Figure 4. *Real Time Digital Simulator in the TU Delft Electrical Sustainable Power lab.)*

Converter-driven Stability: In situations where Voltage Source Converter interface with the grid dominates, the dynamic behavior of Converter Interfaced Generation differs markedly from conventional synchronous generators. For example fast dynamic interactions appear between the control systems of power electronic-based systems, such as High Voltage Direct Current converter stations, converter interfaced generation and flexible AC transmission systems with fast-response components of the power system such as the transmission network, the stator dynamics of synchronous generators, or other power electronic-based devices. Unstable power system oscillations over a wide frequency range can be observed due to cross couplings between the "slower" electromechanical dynamics of machines and the "faster" electromagnetic transients of the network. Instabilities in power systems due to fast converter interactions may arise and may cause high frequency oscillations, typically in the range of hundreds of hertz to several kilohertz. Not only resonance but also multi-resonance issues are noticed, which makes the analyses more complex. Measures to prevent and/or mitigate this harmonic instability could be developed with active damping strategies.
Several inverters in close proximity to each other may also generate interactions leading to multi-resonance peaks.

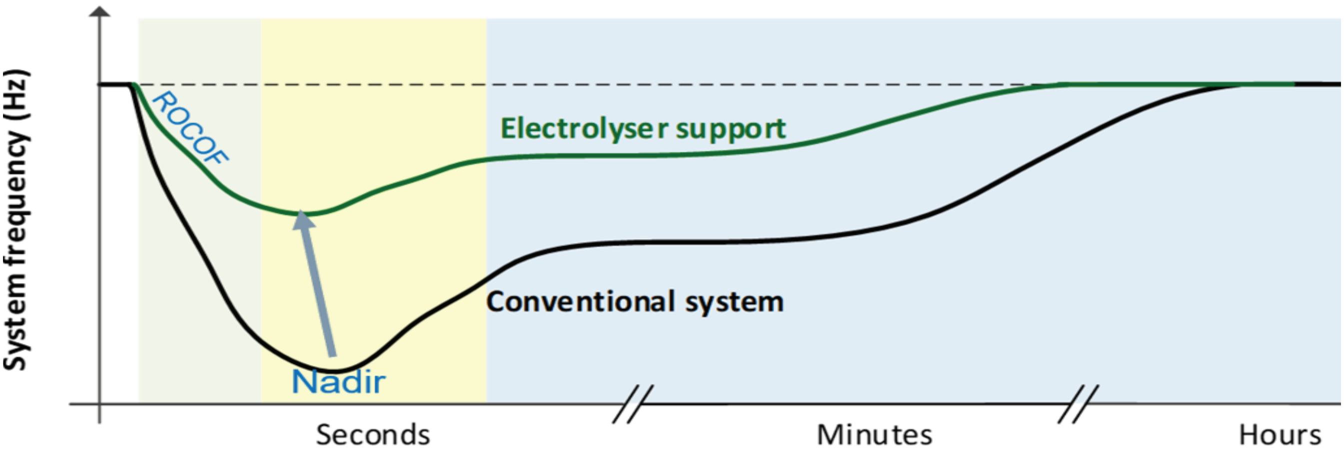

Figure 5. *Contribution of electrolyser to frequency stability: limiting the frequency deviatione Power lab.)*

Can power electronics installations also contribute to power system stability?
In the future sector coupling, such as Power-to-Gas, will become more important to meet the ambitious goals of zero carbon society. In the international research project TSO2020 [3] we investigated how electrolysers can contribute to power system stability by means of supporting the frequency stability. The studies were performed on the Real Time Digital Simulator (see fig.4.) with the electrolyser in a hardware-in-the-loop configuration.

After a fault in the power systems the frequency drops with a certain ROCOF to a certain low level, called Nadir. In Fig. 5, the lowest line shows the response of a conventional system. Because of the faster response time of the power electronics, an electrolyser will react faster, resulting in a lower ROCOF and a less deep Nadir. The frequency drop after a fault is less severe.

In the European research project MIGRATE [4], we investigated till what level of penetration of power electronic converters (with the conventional "grid following" control concept) the power system remains stable. The grid following control is dependent on an external reference signal, and the active power and reactive power output only can follow this external reference signal. For a futuristic situation of the UK (island) system, considering a synthetic model and projected demand and renewable generation profiles up to years 2030-2035 with grid following control, the maximum power electronics penetration is about 60%. It was concluded that a higher penetration of power electronic based equipment is possible if a certain part of the controllers are equipped with a newly developed "grid forming" control. This control forms an own voltage reference signal comparable with the voltage control principle of a conventional synchronous generator. If 30%-40% of the installed renewable power generation has grid forming control attached to the grid side converters, the power electronics penetration can go up to 90% . Further research with other situations and scenarios is necessary.

How is the situation in the Continental Europe interconnected system? At this moment the power system stability of the Continental Europe power system is not at risk, because of the widespread coupled AC system and moderate penetration of power electronics. However in case of system split after a major fault such as in 2016 resp. 2021 one of the remaining sub-systems (islands) can suddenly become critical for frequency instability. Up to now, the mitigation of undesirable frequency excursions, could be performed with traditional measures. Further research is needed, e.g. controlled islanding, optimal coordinated sharing of diverse types of distributed reserves.

Closing remarks

Future power networks with high penetration of power electronics will keep power system researchers and engineers busy the coming decade with challenging power system stability questions and above all surprises. The team of TU Delft Intelligent Electrical Power Grid (IEPG) Section of Electrical Sustainable Energy department with the new world class Electrical Sustainable Power laboratory is ready to bring not only students, engineers and researchers, but also power system operators in the control room to the next level of understanding power system stability.

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Figure 6. *TU Delft high voltage lab*

Power electronics : The future of our grid

An insight into the importance of power electronics for the integration of renewable energy into our grid

Thiago Batista Soeiro

Today the primary resource for electricity in the Netherlands is fossil fuels, while Renewable Energy Sources (RES) account for only approximately 12% of the total power. To reverse this grim statistic, recently the representatives of the Dutch government, energy sector and environmentalists have ratified on the “Energy Agreement for Sustainable Growth.”. This contains plans for investing in energy conservation and promotes widespread usage of Electric Vehicles (EVs). It also aims to improve industry competitiveness, increase exports and create new jobs.

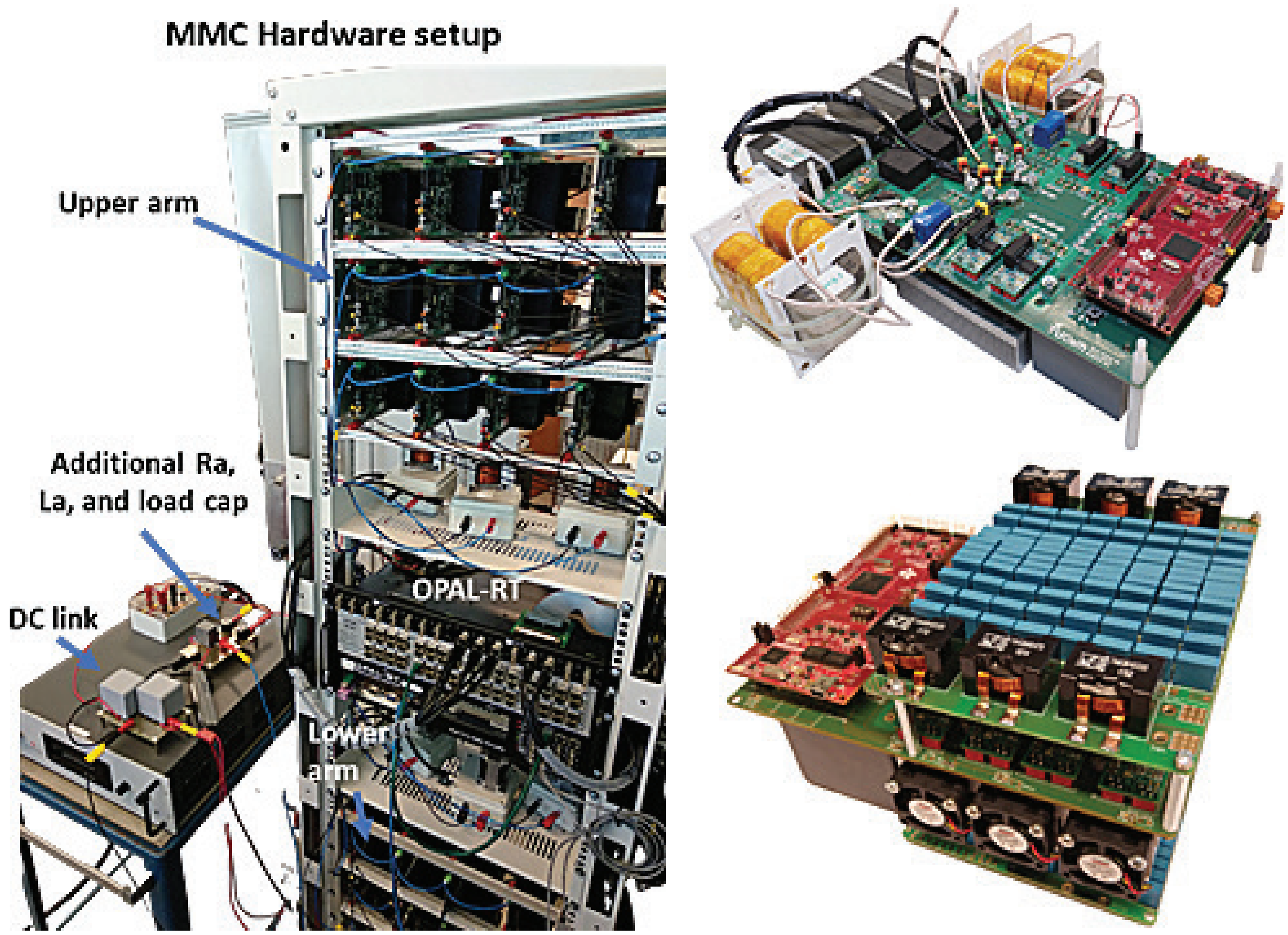
The new energy landscape for the Netherlands will see a rapid increase in Distributed Generation (DG), led by the usage of RESs like photovoltaic panels and wind turbines, and the proliferation of EVs and their chargers. Together with EV usage, the replacement of gas-heating systems to electric powered ones will create a rise on energy demand, calling for grid reinforcements. Retrofit and new power grid expansions will also pay more attention in the DC alternative with the concept of nano- and micro-grids employing DC networks. The business of these sectors, including the one of energy storage (battery systems and electrolysers) and heat pumps for homes and power grids, will also grow in the country. A great effort in standardization and certification of new grid assets will be required. The new technology usage and energy landscape will also have a profound impact in the society, thus business development and societal studies will be extremely important for enabling the future energy systems. Therefore, training of highly specialized engineers in the area of power electronics, power systems, computer science, business and administration will be necessary to feed the energy sector needs.

Power electronics provide means for the control and conversion of electric power. Without power electronics, electric energy cannot be harnessed and delivered efficiently and energy from stablished RESs cannot be fed into the grid. Example of power electronics converters developed at TU Delft are given in Figure 1.

The research of advanced power electronics systems in future power grids requires scientists with cross-functional multi-disciplinary knowledge who can meet the demands of complex integration challenges and customization. It is common practice to seek novel and high-end circuit components that bring a competitive advantage to the application. As a general observation, R&D in academia typically targets circuit designs and their control methods, which yield power efficiencies beyond 99% and ultra-high power densities. Industrial R&D strives for those metrics as well, but cost, reliability, scalability, and manufacturability are of utmost importance in any competitive market. Therefore, a bridge between the R&D targets from academia and industry can be made by a multi-objective design mind-set while considering the application needs - a “user-centric” design approach. R&D activities should lean on understanding the application needs/restrictions, and by all means to derive precise analytical models of the power electronic circuits and their components. This allows one to obtain an accurate analysis of the performance index which needs to be prioritized. Other relevant activities of a power electronic engineer are: the understanding of the state-of-art circuits and the proposal of new circuit improvements; the scout of new component technologies; to master control theory; and to propose new methods that can be applied to drive the circuits; the development of toolboxes which facilitate the “virtual design/prototyping”; the construction and test of the power circuits which verify the advantages of the designed system, among others.

It is noticeable that in the last twenty years, the increased usage of RESs to curb CO2 emissions and the development of rechargeable batteries resulted in the usage of grid-connected power electronics to grow rapidly in the high power (MW range) and MV energy business. The expected decentralization of generation by the usage of wind and solar generation as replacement of large synchronous generators create power quality issues, such as harmonic stability, and the reduction of available inertia. For the latter, frequency stability problems may be caused by a significant increment/reduction of power demand. This calls for provision of ancillary services to facilitate Fast Frequency Response (FFR).

The incorporation of energy storage devices and/or dedicate control



{Order: Clockwise} **Figure 1: (a)** *Downscaled modular multilevel converter for MV DC-distribution grids; EV battery chargers* **(b)** *11 kW DC-type EV charger based on a versatile phase-shift forward converter with voltage- or current-doubling functionality; and* **(c)** *7.7 kW wireless charging converter based on the LCC resonant converter (primary-side power electronics shown only).*

functionalities into power electronic systems can be devised to minimize the frequency deviation issue. The implementation of any of those solutions will affect the way the system should be designed. Therefore, power electronic research needs to narrow the gap with power systems research, and today many activities should go hand-to-hand.

The concept of nano-/micro-grids with DC-distribution has become a common research area for power electronics and power systems. The DC grid can reduce the requirement of power electronic converting stages, which has a positive impact on infrastructure cost and efficiency. Therefore, more often, the DC distribution grid is sought as a replacement for the typical AC distribution in high power data centres and IT systems, and in heavy transportation systems, like more electric ships, trains and aircrafts. Additionally, the reliability issues of the operation of DC grids due to faults is rapidly being mitigated, because the technology of solid-state circuit breakers is becoming mature and more efficient. However, power losses are still far from ideal, especially in high power and medium or high voltage grids where bipolar semiconductors are commonly used. The usage of more electric houses with roof-top solar generation and a plurality of DC loads, such as electric vehicles, can also take advantage of an inner DC distribution grid. In low capacity DC distribution grids, it becomes challenging to solve the stability issues created by the system integration of power electronics systems where each one has unknown control settings. The development of analytical and computational models for the grid small-signal modelling is a hot research topic today. Mitigation solutions for de-coupling of the interactions of the components such as the incorporation of short-capacity energy storage systems (as super-capacitors) are sometimes explored.

The concept of Solid-State Transformers (SST) is becoming an important topic in high power DC distribution grids. However, its applicability is still confined to MV operating levels because of the limitations in circuit technologies. In large solar farms, this can be used to considerably reduce the typical high cabling cost and losses in the local LV DC distribution grid by incorporating into the system a MV DC level collector grid. The main challenge for the SST technology is the design of the transformer-based on dry-type technology, which displays a robust breakdown voltage capability and thus can avoid the aging of its electrical insulation.

The operational integration of Battery Energy Storage (BES) and the necessary charger into the public grid or a local micro/nano-grid can mitigate several technology issues created by the usage of RES. The advantageous sizing and placement of stationary storage should take into account many factors, such as: the selection of ancillary service provision (ASP); the knowledge of the local energy infrastructure (local renewable energy sources, cost of energy from DSOs, etc); the selection of the BES technologies; the DSOs' and/or user/owners' specifications/requirements; the economics of the BES functionalities (remuneration for ASP, optimal (economical) power flows, life-time and Total Cost of Ownership (TCO)); among others. Moreover, aggregation techniques and control strategies need to be developed that will allow healthy system operation and encourage market participation, including considerations related to converter design and modularity. All in all, the development of BES should go along with the development of business and market tendencies for TCO evaluation, guiding regulatory policies and RES integration.

With regards to the usage of EVs, from the perspective of user convenience, the vehicle battery should be re-charged in the shortest time possible. This is particularly relevant while in long trips where the expected driving distance is not covered by the car energy storage. Therefore, high power chargers are necessary. Today's public available fast EV chargers are mainly designed for unidirectional power flow, i.e., Grid-to-Vehicle (G2V), and may process only limited reactive power for grid support. However, in future, due to the expected deployment close to cities, care must be taken toward the capacity of the available distribution grid. Additionally, EVs and charging infrastructures will have even greater power capabilities. Therefore, investment in new charging infrastructures must take into account future market demands. Direct MV AC grid connection will be sought, leading to the usage of MV power electronics using medium frequency SSTs.

The implementation of advanced Battery Management Systems (BMS) leading to the so called smart battery pack is of paramount importance for preventing the BES from operating outside its Safe Operating Area (SOA) and enabling greater charging speeds in EVs. Herein, the main challenge is to derive optimized cost-performance power electronic based BMS with innovative cooling methodologies and advanced control schemes. By monitoring vital system component stresses, such as voltage, current and temperatures, strategic power flows and operating profiles can be derived. Depending on the battery technology, its currently charging/discharging state, the distributed cell temperatures and voltage balancing, a maximum Charge Current Limit (CCL) and Discharge Current Limit (DCL) can be drafted which minimizes the Loss of Capacity (LOC) of the cells. These can be optimized to enhance the battery pack life-time (Optimal Reliability) and above all to reduce the TCO of the system. The development of accurate battery pack and power electronics charger analytical models (component losses, aging/lifetime, etc) and the data generated by the BES monitored electrical and thermal variables allows the construction of a digital or virtual representation of the BES components and/or the whole energy system. Therefore, the concept of Digital Twins (DT) can be used so that insights can be generated to the user of the BES about the system components' dynamics of operation and life cycles. This provides an unique opportunity for component lifecycle management creating knowledge for design, manufacturing, service provision and operations (real-time and future).

Power electronic serial and parallel circuit modularity is a crucial research field for grid-connected applications and highly relevant to overcome the lack of suitable high/medium voltage power components. The usage of modular multilevel converter topologies in energy transmission has become attractive for HVDC point-to-point transmission, particularly in off-shore wind farms. Key challenges to overcome are the system safety/protection during faults, system interconnection/meshing, structural/maintenance cost, and reliability. In electric transportation, the usage of multi-level converters brought the advantages of low voltage THD across the electric machine leading to loss reduction and improved common-mode-noise emission that enhances the machine lifetime. Because of the limits of the available semiconductors in high power, non-traditional modulation strategies, and sophisticated control routines using predictive methods to enhance dynamic behaviour of the system are researched. New high voltage (>10 kV) SiC-based semiconductors are coming to the market with the potential to simplify the operation of MV power converters. However, several challenges need to be addressed that can reduce the system's lifetime. For example, the typical extreme switching transitions, and hence the common-mode interference for the controls are difficult to be rejected, and degradation becomes a concern for the insulation of cables, inductors, machines, and transformers. Additionally, those new devices have limited short-circuit capability, demanding faults to be detected and cleared in a few 100 ns, which is difficult to achieve.

In all these contexts, it is essential to advance the research, education, and knowledge transfer in power electronic systems by applying current and future technologies and by proposing and testing innovative ideas for the individual challenges of each application. Above all, power electronics is at the heart of technology development and thus it is a science of paramount importance to the Dutch economy and society in general. It has the answers to accelerate the energy transition towards a more sustainable world, where everything starts by enabling and solving the technical issues associated to the widespread usage of RES.

A career in power electronics can be very exciting and rewarding, particularly due to the multi-disciplinary nature of the topics it involves. The power electronics community in the Netherlands covers a breadth of application areas and markets with prominent global players and innovative SMEs. Therefore, the job market is in high demand for competent power electronic engineers. At TU Delft several topics discussed in this article are currently been addressed by competent and motivated engineers. Take the opportunity to get to know the power electronics activities from the Electrical Sustainable Energy department, and the education and job opportunities it offers.

My time for change

Dr. Thiago Batista Soeiro shares his professional experience and journey in the field of power electronics

Thiago Batista Soeiro

I realized quite early on in my career in electrical engineering, and more specifically in power electronics, that working in research was my calling. I completed my bachelor and master studies in Electrical Engineering at the Federal University of Santa Catarina in my hometown of Florianopolis in Brazil. My MSc thesis work was a research collaboration with the Concordia University in Montreal, Canada, and the topic was related to ultra-efficient partial power processing line voltage conditioner to be used on medical power supplies. After completing my master, I worked for a short while for the main DSO in Santa Catarina, Brazil, that provides electrical distribution energy for the state. During this time, I missed being involved in the development of innovative solutions for power electronics problems and it was clear to me that I wanted to return to academia.

My ultimate goal was to become a professor, so I decided to head to ETH Zürich in Switzerland to complete my PhD studies. There, I worked with other researchers of many different nationalities and cultures. Not only did this experience expand my knowledge of power electronic systems, but it expanded my vision of what was possible for me in the future. I had the opportunity to collaborate with people in industry and academia, which helped me see the possible career paths open to me. My PhD research topic was sponsored by Alstom Sweden, so I had the opportunity to collaborate well with their Scientists and Engineers. My main research activity focused on the design of high-voltage, high-power supplies for electrostatic precipitators, and how to improve the grid power quality issues of the application. This technology is used as dust collector or air filter for the exhausting air created in coal-fired power plants, which is a relevant application to minimize the pollutants impacts to the environment. I had also the opportunity to work on Electric Vehicle (EV) chargers, based on the new circuit concept named SWISS RECTIFIER. This is an excellent candidate for deriving ultra-efficient (>99%) EV chargers.

I subsequently returned to Brazil for a year and a half to carry out a senior engineer position at the same university where I had previously studied. Being back where my career in electrical engineering started, made me feel there were still things missing for me to achieve my ultimate goal of becoming a professor. I felt that I needed some industrial experience, which led to my decision to return to Switzerland and work for the Corporate Research Center (CRC) of ABB. My time at ABB was an excellent time to develop professionally. I saw more clearly how research was carried out in industry and was able to manage several R&D projects. I believe this experience helped me very much during my time at TU Delft. After nearly 5 years at ABB, I began to feel like my learning curve was beginning to plateau and it was time to move onto the next step of my career. I was then lucky enough to be selected as an assistant professor at TU Delft. I am very grateful for the experience at ABB, particularly because I had the opportunity to work and interact with the company specialists of several relevant power electronics business, including electric vehicle battery chargers, traction auxiliary converters and motor drives, photovoltaic inverters, data centres, active power filters, solid-state-protection, and DC-distribution grids in general.

At TU Delft I have been able to fulfil my dream of being a professor and have met and worked with some inspiring and interesting people. I have been able to work on some cutting edge projects in E-Mobility, Battery Energy Storage Systems (BESS) and Medium Voltage (MV) power electronics, and collaborate with industry and other academic partners. I have found working at TU Delft very fulfilling. I have also had some great students to advise, which has made my job easier and daily work life fun. Hence, my work at TU Delft has helped me to further improve my technical abilities and also, through teaching duties, my ability to communicate effectively. The varied nature of the responsibilities in this role have helped me to better manage my time and multi-task. I have really enjoyed helping young engineers to develop their professional skills and I take pride of my work in forming the European next generation of power electronics engineering at the Master and PhD levels. I have also become more adept at attracting research funding and have expanded my network of contacts within the Netherlands and throughout Europe.

Being a professor was always my dream and it has been a tough decision to move on to another step in my career, but I also had another passion, I have always been fascinated by space. Since I was young I have always followed developments in space exploration on the news and watched countless documentaries about space, so when the possibility came up to work at the European Space Agency in Noordwijk and apply my power electronics knowledge to a different application, it was an opportunity I couldn't miss. I expect to use my experience on power electronic systems to help ESA and partners developing and testing cutting-edge technologies for the many different missions the company is involved.

My time at TU Delft has been one where that I will always look back at with fond memories and I hope to keep in touch with many people I have met here, but I am extremely excited about this next chapter.

Hydrogen

To a large majority of the population, the current energy transition might not seem like a very difficult problem; they might conclude that, in order to be able to comply with the climate agreement, there should simply be a focus on building more sources of renewable energy, such as photovoltaic arrays and wind turbines. While there is certainly a grain of truth to be found in the latter statement, it has become more and more clear in recent years that the grid itself—also including energy storage systems for that matter—is more of a bottleneck. Simply put: energy demand is usually higher at the times when (renewable) energy supply is lower, and vice versa.

The concept of using hydrogen as a replacement for fossil fuels in combustion engines has been around for quite a while. Just like electrical vehicles, it unfortunately still bears too much downsides when compared to standard fossil fuels to be able to claim a significant market share, without external intervention from governments in the form of subsidies for example. While these technologies keep improving, recently, in the context of energy storage systems, it has come up that hydrogen might prove to be a valuable addition to our grid. Even though there are significant energy losses in its conversion, it could be effectively used as a long-term energy storage.

We have asked two Dreamteams that are actively working on implementing hydrogen-based technologies about their projects and their vision on the future of hydrogen within the current landscape. If you are interested in reading more about these or other Dreamteams, you can do so by visiting ***https://www.tudelft.nl/ewi/studeren/dreamteams***.

Hydrogen is at the heart of the energy transition

But what is the role of hydrogen in the future of mobility?

Forze Hydrogen Racing Team

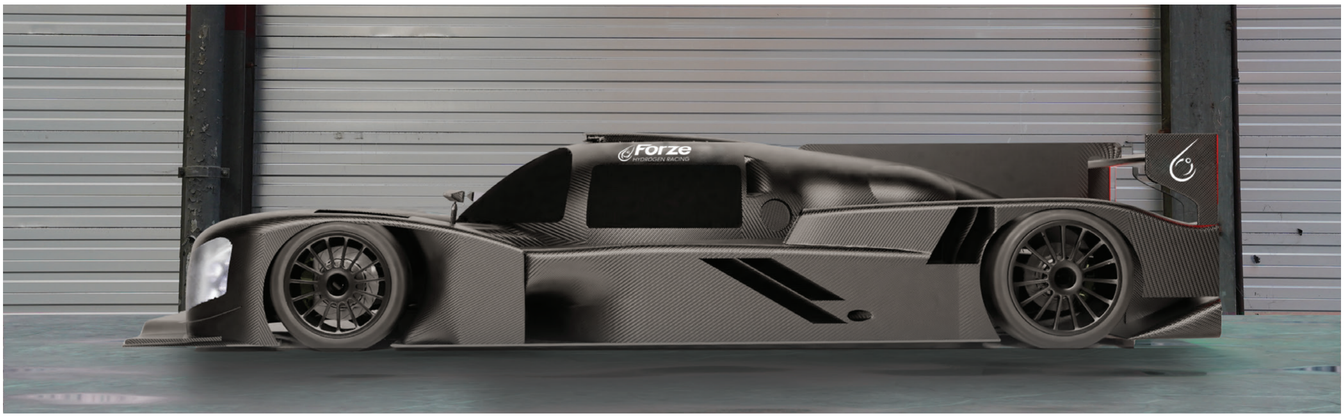


Figure 1. *Forze IX*

Energy is at the very core of our society. We have become increasingly better at harnessing its power and using it for applications that have long been beyond imagination. Mobility is one of the most fascinating examples of this, enabling us to move anything from perishable food products to complete excavators all around the world. Largely due to the new energy-intensive standard that has been set by this increased connectivity, the transportation sector accounts for around 24% of global carbon dioxide emissions [1]. Therefore, this industry has a pivotal role in the energy transition towards a sustainable future. Hydrogen systems are showing a promising potential, and at Forze we believe hydrogen will have a key role in the energy transition. However, what is the future of this technology and its role in the future of mobility? In this article we will dive into this, giving insights into the vision and mission of Forze on this topic. What can you do to propel sustainable technology?

What is Forze?

First of all, it is time to give a short introduction to the Forze team! We are Forze Hydrogen Racing, a team of over 60 students that designs, builds and races the world's fastest hydrogen racing cars. Our target is to show the potential of hydrogen technology by building a zero emission racing car that is capable of beating conventional petrol-powered cars on track. Our 15 years of existence started off by building a hydrogen powered go-kart, which was scaled up to a Formula Student-type of vehicle and eventually, the world's first full-size racing car to run on hydrogen was built. Forze has created the first hydrogen-powered car to ever participate in an official race against petrol cars. The most recent car, the Forze VIII, has even achieved a place on the second step of the podium at the Gamma Racing Days in 2019. In January of 2022, the team will reveal the Forze IX, which will participate in the Super GT class against the pinnacle of production cars from the likes of Lamborghini and Porsche boasting top speeds of around 300 km/h.

How does hydrogen work?

Now, let us get back to the matter at stake here. It is important to take note that there are a lot of factors involved in the transition process to a green future. There are numerous polluting exhaust gases besides carbon dioxide, such as methane and nitrous oxides. Environmental sustainability has a multiplicity of other definitions, such as the depletion of raw materials and circularity, not to speak of the social-economic situations and political stability. As one would expect in such a complex situation, the solution is not quite straightforward. Education is key in this, to make the technology comprehensible and increase trust. Therefore, to properly regard to the potential of hydrogen technology in the transportation sector, looking at the precise working mechanism is essential. Through the process of electrolysis, electrons are introduced to the single protons of the hydrogen and oxygen atoms in H_2O. This allows them to form H_2 and O_2 molecules. The heavier oxygen molecules are released in the atmosphere, while the lighter hydrogen ones are stored under 700 bars of pressure. Once fueled into the tanks of the car, the reverse electrolysis reaction is endorsed in the fuel cell. H_2O molecules are formed again, and the spare electrons produce electricity to power the car. In fact, the hydrogen car is just an electric car, but with hydrogen as an energy carrier instead of heavy batteries.

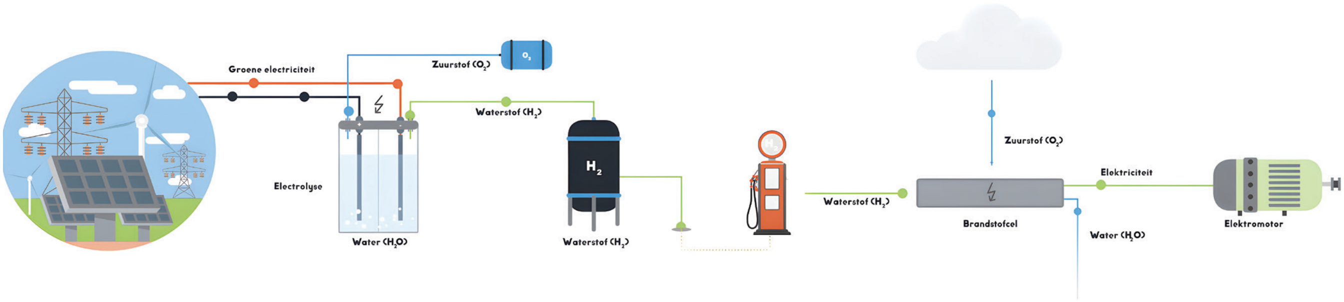


Figure 2. *Hydrogen Technology*

The future of hydrogen

Looking at hydrogen technology on a macro scale, it poses many advantages as a long-term energy storage. The current green electricity supplies are in principle not capable of producing a steady supply. Excess electricity could be used in large scale electrolysers to create and store pressurised hydrogen gas for later use. An important note here is that, in our opinion, there is no such thing as a competition between green electricity carriers such as hydrogen or batteries. Both have their own advantages and downsides and are necessary in the energy transition. Hydrogen systems can in fact be used in a number of particularly heavy applications where batteries are not efficient, or even an option. When implementing a battery system for trucks or airplanes, batteries simply have an insufficient energy density to fulfill this requirement. Besides, hydrogen functioning as an 'energy carrier' is being researched for a multiplicity of other non-electrifiable applications such as the heating of buildings -easily through the current gas infrastructure!- and long term energy storage. As a matter of fact, a large part of the industry has already incorporated hydrogen technology somewhere in their factories. Now it is time to take this technology into the future of mobility.

What is next?

As a team, we often face critics that overly stress the downsides of hydrogen technology. Yes, energy is lost during the production and usage of hydrogen, and batteries do a better job in this area. The point here is that it is already miles and miles better than conventional fossil fuels, and batteries are packed with scarce and/or politically destabilising raw materials such as Nickel or Cobalt. Nevertheless, both hydrogen and batteries are already much better than oil. Scepticism, to us, appears to be a direct consequence of exploring such a new area. However, we are convinced that we are onto something here. It is really energising to see the enthusiasm of all our partnering companies, racing fans and sustainability proponents. They make it possible for us to stay hungry and push the limits of the technology that is on our hands. A lot of the components that we develop are fully customised for our car, and we test prototype parts to the limit for partners. From an engineering perspective, a year at Forze is unique and challenging. But besides the technology, the message of inspiration that a sustainable future is within reach is, the team spirit that results from such hard work towards a common goal is one of the most motivating things that a lot of our team mem-

Figure 3. *Forze VIII*

bers take along in their lives. We now have our newest Forze IX car, which we aim to get on the racing track as soon as possible. From that point on, everyday is an opportunity to improve it and push it to be faster, safer and more efficient. Working on this is among the things you can do to accelerate sustainable technology in the transport sector. A lot is to be done here, but we are excited to push the limits. Are you joining?

Hydrogen's role in the energy transition

One answer to everything..

Eco-Runner Team

Eco-Runner Team Delft is a D:DREAM team (Delft: Dream Realisation of Extremely Advanced Machines) that fully dedicates itself to building the world's most efficient, hydrogen powered city car. We build an Urban Concept car, meaning that it is a prototype of what we see as the future of urban transport; a small, efficient car made for one person. On top of efficiency, we highly value the promotion of alternative (green) fuels that aren't widely known/used yet, such as hydrogen. Hydrogen is a very interesting option mainly for its high energy density. We want to promote the benefits of hydrogen and that is why we choose to use hydrogen to power our car.

At Eco-Runner Team Delft, we don't believe that there is one answer to everything. There won't be one alternative fuel to replace the fossil fuels. We need to find the right alternative for every separate application. Some alternatives are already in full swing, such as the use of batteries, and some have just recently started their development such as synthetic fuels or even the use of air pressure to push the pistons of an engine. One thing is for sure; we are not there yet. Not even close.

The previously mentioned batteries are a great first step towards clean transport, but it has its flaws. The batteries are very heavy. That means that the use of batteries doesn't make sense anymore if the transport gets bigger such as trucks, boats or planes. Batteries are toxic, especially if they break, and they can catch on fire relatively easy. On top of the dangers, they take a very long time to recharge and the action radius they provide to the vehicle is relatively low. Now we don't mean to discard the use of batteries; on the contrary. We support every alternative for fossil fuels. But we see the gaps that the use of batteries leaves behind. We believe that hydrogen can fill these gaps.

Hydrogen doesn't naturally occur on Earth; we must form it ourselves. We can do this in a grey or blue way, where carbon dioxide is still produced, but the future of hydrogen lies in green hydrogen; hydrogen gas produced with the process of Electrolysis. This method is only green of course if the electricity used to produce the hydrogen is also generated in a clean way (solar- or wind energy for example). Therein lies the current problem with hydrogen; the hydrogen produced today is mainly grey or blue. This is because there is not enough green electricity available to also produce green hydrogen. The electrical energy used in Electrolysis is stored in the hydrogen molecule. Therefore, hydrogen is the battery that stores the electrical energy. That is what we call an energy carrier. The green electricity that we have today is used in different ways, not to create other energy carriers. We hope that the green electricity market will keep growing exponentially until we can create enough green hydrogen to power our vehicles as well!

Hydrogen is the lightest element in the universe. Because it's so light, it has a very low energy capacity in terms of Joule/litre. But, due to the high amount of energy stored in each molecule, hydrogen is very energy dense in terms of Joule/kg. That is why a lot of focus in the innovation of hydrogen-use is on storing the hydrogen in tanks under extreme pressure; 350-700 bar, depending on the application. The higher the pressure, the smaller the area, the more energy you can carry. And this is just for gaseous hydrogen; liquid hydrogen is a whole other story where the hydrogen first must be cooled off to −252.87 °C. But let's stay in gaseous hydrogen for now.

These immense pressures are accompanied by some safety issues. The tanks must be extremely strong to hold the internal pressure and be able to withstand external forces. On top of that, the tanks must be completely sealed. Hydrogen combined with oxygen can quickly reach an explosive ratio. Vehicles that carry hydrogen tanks therefore have multiple sensors that can detect the presence of hydrogen in the air. Our own car, the EcoXII, has these sensors as well; if the sensors detect a ratio of 1/4th the explosive ratio, the entire system will shut down and the tank will be shut and sealed off to prevent accidents. Safety is still a big issue within the use of hydrogen. Not per se in your car, the tanks are more than safe enough, but mostly in transporting large amounts of hydrogen and creating hydrogen refuelling stations for example. To make this easier and safer we need more research and more funding into the hydrogen market. In other words, Eco-Runner believes that the hydrogen market needs to grow before we can safely and easily start using hydrogen on a larger scale. But it's worth it!

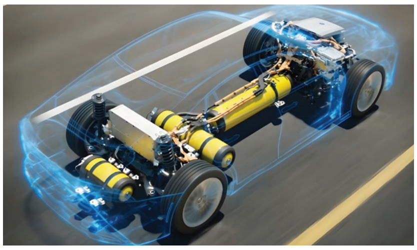


Figure 1. *Anatomy of Toyota Mirai*

Hydrogen cars are already in use. The Toyota Mirai and the Hyundai Nexo are production cars that are already on the road. An important distinction is that the Mirai, the Nexo and our EcoXII do not use a combustion engine. When burning hydrogen, you would still create greenhouse gasses other than CO2 and therefore would still fuel climate change. We do not burn the hydrogen, but we use a Fuel Cell to convert the chemical energy from the hydrogen molecules into electrical energy. This electrical energy is then transported to our electrical engine that will then ultimately create the motion of our car. This conversion in our fuel cell only has water as a by-product, meaning that this cycle is completely green, provided that our hydrogen is green as well.

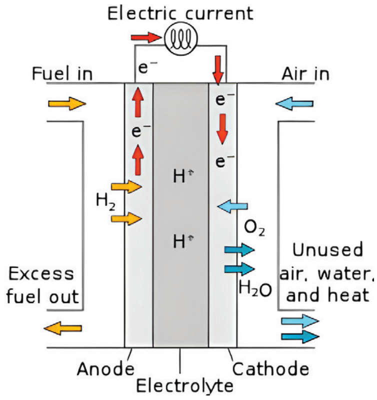


Figure 2. *Working of a fuel-cell*

There is one more problem with using hydrogen as a fuel. As explained, hydrogen can only be created by using electricity (electrolysis). In this conversion, some of the potential energy is lost. Then, after the hydrogen is put into the car, the hydrogen is converted back to electricity, losing a part of the energy again. The 2 conversions cause an energy loss that is still too big to justify using hydrogen rather than batteries, where you would skip these two conversions. The future does look promising; the innovations are in full swing to improve the efficiency of creating and using hydrogen, but it takes time, effort and money.

Hydrogen can play an essential role in the energy transition by filling up the gaps that other alternative fuels leave behind. It's the best option in a lot of sectors, especially the heavier transport that must travel far. But as of right now there are not enough investments in the safety, the efficiency, the refuelling stations, the hydrogen-fuel cell cars that are needed to bring the hydrogen market to the next level. Eco-Runner Team Delft aims to speed up this transition, simply by physically showing the world the benefits of using hydrogen. We do so by building the world's most efficient, hydrogen powered city car. Our car is extremely safe. We use green hydrogen and only produce water as a by-product. We created an extremely efficient energy conversion within our car, and we built a small, aerodynamic and lightweight car around it. This all leads to us being able to drive almost 3400 kilometres on just one kilogram of hydrogen gas. That is from Delft to Rome and back. One kg of hydrogen costs ten euros which you can already buy today at nine possible hydrogen pumps throughout the Netherlands.

Eco-Runner is working on creating a better future by combining a good message with the best engineers. Are you interested in joining our team next year? Don't hesitate to contact use! Recruitment for the new team is officially open!

Figure 3. *The EcoXI*

ASML - Challenge; When opportunity knocks

Advertorial

Arnela Masic

When opportunity knocks, dare to open the door

Experienced people know that careers are founded on as much luck as judgement and skill, as Arnela Masic discovered during her engineering studies in 2015. One lucky moment put her on a path to the career she enjoys today: she forgot her lunch. "A friend suggested I could get a free lunch at an ASML-hosted lunch meeting on campus that day. It was there I learned about the ASML scholarship. I applied and was eventually selected – it felt pretty special as only 25 scholarships are on offer in the Netherlands each year." Through the scholarship, ASML supported Arnela through a Masters in Systems and Control, which then led to her joining the company in 2017.

Nothing "grey-haired" about it

"Everybody at my university had heard of ASML – the logo is everywhere. But what they did there was more of a mystery. For me personally, 'lithography' did not sound as interesting as other technical industries like aerospace or automotive. I was picturing grey-haired guys doing boring experiments. It wasn't until I got to know them through the scholarship that I realized there's nothing 'grey-haired' about it. There are so many different careers here, with such diverse, super-smart people. It was nothing like I expected."

Engineering and so much more

"I was looking for more than just a 'technical' job. After learning about the many different careers on offer, the role of Customer Support Applications Engineer really appealed to me. I get to travel to customer sites around the world – the US, Korea, Japan, China and Taiwan - and work on projects to improve the performance of our lithography systems. I get to use my engineering knowledge – not in terms of always knowing the answers, but in terms of applying logic, troubleshooting, analysis and identifying which experts can help – and I combine it with communications, project management and implementation. There's great team spirit; I'm supported by a wide network of experienced colleagues who all help each other."

An idea worth millions

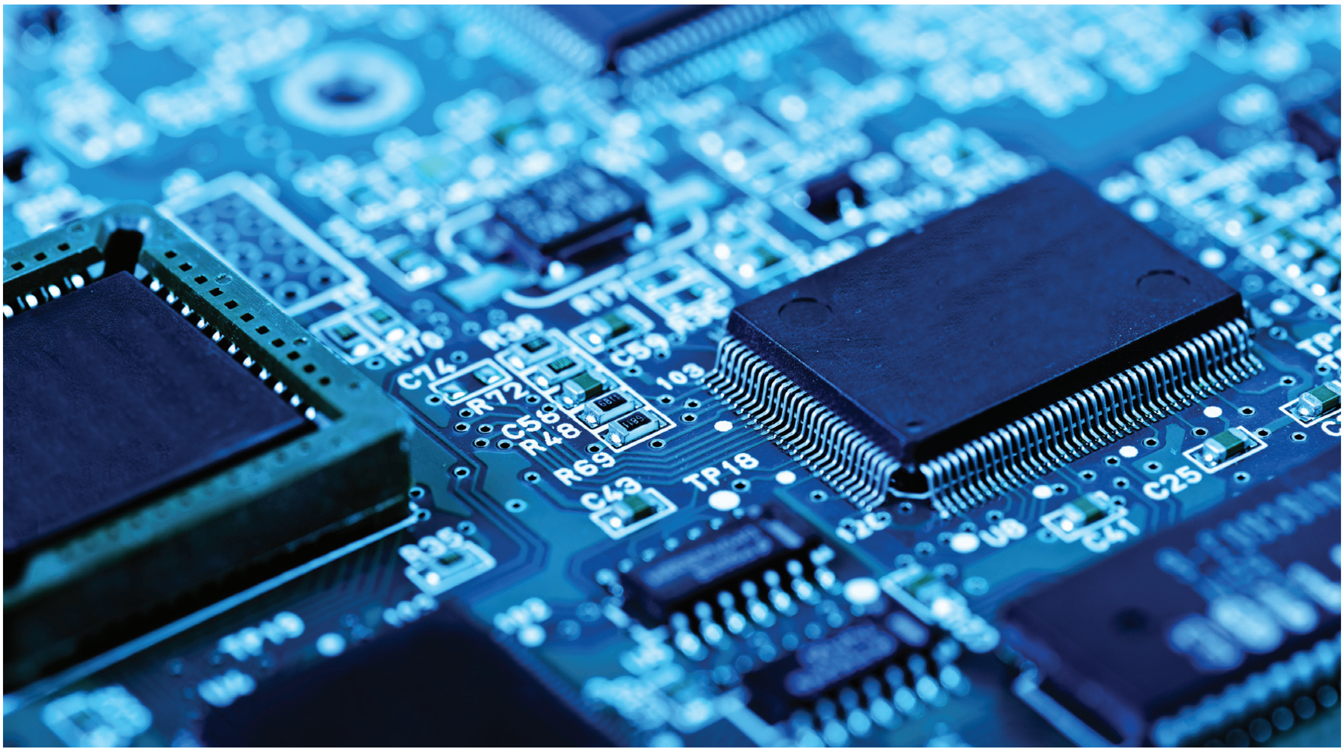
"And I receive lots of training, both technical and non-technical –

soft skills like customer focus and influencing without power." Arnela quickly found out how useful her newly acquired skills are. "There was project at a customer where it was important to prove a certain output of a machine in order to make the sale. However, at that moment, there was an issue with one of the machine parts that would not have helped my demo test. My training helped me convince people to make this issue a priority over their own projects, resulting not only in a permanent solution, but also in the sale of the system worth millions!"

Arnela's advice – 'go for it'

"My advice is if something about a job sounds interesting then don't overthink it, just try it, because you never know exactly what you will be doing on a day to day basis. That's ok, nobody does when they start. But at companies like ASML, you will have excellent training, support and inspiring colleagues, so there's no need to be afraid to go for it. When opportunity knocks, dare to open the door. For me, there's has literally been a whole world to discover, and I'm really enjoying the journey – it was worth stepping into the unknown to start it."

*Are you interested to learn more about ASML? Visit **www.asml.com/students** for more information about our events, internships and scholarship program.*



About ASML

ASML is a high-tech company, headquartered in the Netherlands. We manufacture the complex lithography machines that chipmakers use to produce integrated circuits, or computer chips. Over 30 years, we have grown from a small startup into a multinational company with over 60 locations in 16 countries and annual net sales of €14.0 billion in 2020.

Behind ASML's innovations are engineers who think ahead. The people who work at our company include some of the most creative minds in physics, electrical engineering, mathematics, chemistry, mechatronics, optics, mechanical engineering, computer science and software engineering.

Because ASML spends more than €2 billion per year on R&D, our teams have the freedom, support and resources to experiment, test and push the boundaries of technology. They work in close-knit, multidisciplinary teams, listening to and learning from each other. If you are passionate about technology and want to be a part of progress, visit **www.asml.com/careers**.

Upcoming activities

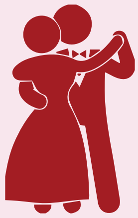
For members of the Electrotechnische Vereeniging

Maxim Mazurovs

MotiBo

In order to recover from a heavy exam week and gain some new motivation for the next quarter, the ETV organises the MotiBo: Motivational Borrel (social drink)! Get in touch again with your friends from your year but also other years, play some fun games and drink as much as you want since the first 3 kegs are free!

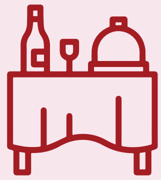
When: February 8th
Where: /Pub
Price: Free



Lustrum Gala

Thursday the 5th of May the Lustrum Gala will take place, which is the most exciting activity of the past 5 years! The Gala will this time take place in Kasteel Maurick. With live music, open bar, the option for dinner and the real enthousiasts can stay the night in a nearby hotel.

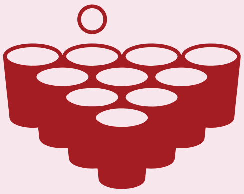
When: May 5
Where: Kasteel Maurick
Price: €110,- (duo ticket)



Females Diner

As the world of technology grows, we also see a rising number of women in this fields. Still, it can be hard to face all the challenges along the way, so the ETV organizes a diner for all the ETV females together with a few female representatives from high-tech companies to chat about how they made it to the position they're now in, and to give them some perspective on what they can achieve as an Electrical Engineer.

When: February 17
Where: Eetcafé & Restuarant De Waag
Price: TBA



IFBT

The Inter-Faculty Beerpong Tournament will be an evening with lots of fun and challenges. You'll have the chance to prove yourself as the beerpong masters against the members of the study associations Froude, LIFE, Hooke and Variscopic. Stay tuned for more information such as the location, the programme and the subscriptions on the ETV website or Whatsapp announcements!

When: March 21
Where: TBA
Price: TBA

Recruitment Days

During the recruitment days, master students get the chance to have a one-on-one conversation with a lot of companies. These conversations can lead to an internship, thesis project or even a first job. At the end of each day, there are drinks where students get the chance to have a casual conversation with some of the recruiters.

When: March 14 till March 18
Where: EEMCS Building 28
Price: Free

ETVerjaardag Cake

On the 26th of March, our association will be yet another year older and that is cause for a celebration. Everybody from the EEMCS is welcome to have a piece of our enormous Dies Cake for the 116th birthday of the ETV on Monday the 28th. A whole week filled with activities to further celebrate the ETV's birthday will take place in the fourth quarter.

When: March 28
Location: EEMCS Central Hall
Price: Free