Long-Term Trends and Disruption in Medium Voltage Power Electronics

Identifying Future Power Electronics Technologies of High Impact

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***Abstract*— Medium voltage converters are a key component of renewable energy systems like photovoltaic and wind, of large-scale energy storage systems like batteries or hydrogen, and of applications like electric vehicle charging, datacenters, large medium voltage drives, hydrogen production and "green steel". All these high-power applications went into exponential growth in the last decade and will keep growing during the next decades driven by the so-called "electrification", the trend to replace fossil fuels by electricity based on renewable energy. The drivers of these trends and the role of power electronics are discussed, especially also the Solid-State Transformer (SST).**

Keywords—energy transistion; technology disruption; electric vehicle; fossil fuel; oil production; renewable energy; SST

I. INTRODUCTION

After the year 1800, fossil fuels were employed in increasingly vast amounts to build and run our advanced global civilization based on industrial processes which can provide food for about 10 times more people than before and allows us to use technologies in our daily life which were assumed "magic" not so long ago. However, fossil fuels are limited, and if we run out of them before having them replaced by renewables, civilization could quickly decline, probably with disastrous consequences for most people.

In this paper we discuss what kind of fossil fuels are used for which applications, and which usages can be replaced by renewables like photovoltaic (PV) and wind energy with minimum effort. Cost is critical because if a technology is too expensive for general use, it cannot be considered as a viable solution.

Based on published data we will show that oil as employed for mobility can be replaced relatively easily (in comparison with most other usages) by renewables, and since mobility is also the largest fossil fuel usage in our categorization, the impact of introducing E-mobility is significant.

We discuss the key technologies for the transition from oil-based mobility to E-mobility, which are (1) electric vehicles (EV) and chargers, (2) low-cost renewables in form of PV (and wind), and (3) dedicated medium-voltage power converters to prevent that copper shortages might significantly slow down or even prevent the Clean Energy Transition. We will put the focus of this paper on the adaption of these technologies which follow disruptive patterns, which have been described generally in the literature and make it possible to estimate future developments.

II. FOSSIL FUEL USAGE IN 2023

A. Electrification Drives Medium-Voltage Power Electronics

The world is currently running on fossil fuels, and most of today´s systems running on electricity are connected to the low-voltage (LV) grid requiring LV power electronics for the power supply. If the world replaces fossil fuels by renewable electricity, a process usually called "Electrification", then there will be many new consumers of power in the tens- or hundreds of Megawatt (MW) range, that currently use fossil fuels, and that need to be connected to the medium-voltage (MV) grid with MV power electronics. Some examples of such systems of several MW in the MV grid, which all went into exponential growth in terms of installed power in the last couple years, are

- PV and wind generation, grid scale batteries storages
- Electrolysis for hydrogen-production
- Steel produced in arc furnaces
- Datacenters
- Fast chargers for EVs, trucks, and ships.

A strong long-term trend that will drive electrification is the limitation of fossil fuels, which need replacement. Another driver is, in many countries, the tax on CO2 emissions.

B. Usage of Fossil Fuels: Type and Sectors

If we want to efficiently replace fossil fuels with renewables, we need to first explore how fossil fuels are used today. In the following, we discuss the five sectors that are distinguished by the question if Carnot-efficiency process is involved and if so (in case of thermal usage) high or low temperatures are required. The five sectors and the type of fossil fuel used are shown in Fig.1 for the year 2023.

- Residential heating: We use the thermal energy directly in small-scale processes (heating, cooking); low temperatures are required.

- Industrial heating: Thermal energy is directly used in large-scale processes (steel, cement, oil production, metal production, chemical industry, etc.); high temperatures required.
- Chemical industry: Usage as chemical feedstock - fossil fuels are converted into plastics, food (fertilizer, pesticides), pharmaceuticals, etc.
- Electricity generation: Due to the Carnot-efficiency of thermal power plants the electrical energy output is just about one third of the thermal energy (without consideration of combined cycle operation).
- Transportation: Due to the Carnot-efficiency the energy output in the form of a moving vehicle is just 20 – 30% of the thermal energy. Energy usage is roughly 1/3 by trucks and 2/3 by cars.

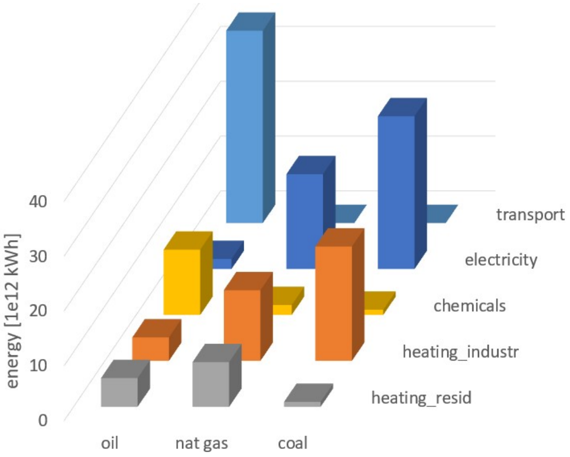

Fig. 1. Global fossil fuel consumption in 2023 by type (oil, natural gas, coal) and usage (residential heating, heating in industrial processes, production of chemicals like plastic, electricity, and mobility). The consumption is given by the thermal energy content of fossil fuel and usage.

The data used in Fig.1 is also shown in Table I. For comparison, the electricity production from renewables and nuclear power plants is shown in Table II. Note that throughout the paper we convert all energy into kWh.

Fossil fuel consumption in residential heating can be reduced by building insulation (but this requires chemical feedstock), heat pumps and reduced room temperatures.

In industrial heating it is significantly more difficult to replace fossil fuels, especially because thermal energy is directly used and one cannot gain an advantage by eliminating Carnot efficiency. Furthermore, the required temperatures are typically much higher.

In chemicals, e.g. hydrogen can be produced by hydrolysis, but the cost is much higher as compared to synthesis from natural gas. Many chemical feedstocks are very difficult to produce without fossil fuels as input material [7].

Electricity production from PV and wind can indeed replace fossil fuels, especially because the Carnot-efficiency is eliminated, but there is an unsolved problem with low-cost large-scale energy storage. In case of fossil fuel usage, the storage happens simply by, e.g., storing a pile of coal, which is nearly for free.

In transportation it would already be helpful to burn the oil not directly in the car (efficiency typically 20-30%) but in a centralized power plant (efficiency 35-40%, without considering combined cycle operation), and employ electric vehicles. If the energy would be produced by PV and wind, the required energy amount would go down by a factor three because the Carnot-efficiency is eliminated. Furthermore, since the EVs contain large batteries, a part of the required storage is already available for free and could be used for optimizing the charging in terms of times and availability of chargers. Since the fossil fuel usage in mobility is by far the largest bar in Fig.1, and technology solutions are available, this would naturally be the target of further optimization.

TABLE I.
GLOBAL FOSSIL FUEL CONSUMPTION IN 2023

	Electricity production	Industrial heating	Residential heating	Chemical feedstock	Mobility, transport
Oil*	1.82 [1]	4.27 [8]	5.23 [5]	11.89 [3], [6],[7]	35.06 [6]
Gas*	17.29 [1]	12.88 [8]	8.14 [5]	1.80 [2], [7]	0**
Coal*	27.85 [1]	20.84 [8]	0.90 [4]	0.94 [7]	0**

* The consumption is given by the thermal energy content of fossil fuel in [1e12 kWh_therm]

** The amount is negligible in the context of this paper.

TABLE II.
RENEWABLE AND NUCLEAR ENERGY PRODUCTION IN 2023

	Electricity output
Nuclear*	2.68 [1]
Hydro*	4.33 [1]
Renewables* (PV plus wind)	4.20 [1]

* The consumption is given by the electrical energy output of the plant in [1e12 kWh_el]

C. Natural Boundaries – How much Fossil Fuel is Left?

Based on discoveries in the past, estimates have been made and published on how much fossil fuel might be available in the future. The predictions are based on past discoveries whereas our planet has been explored in a way that the likelihood of big new discoveries is small. However, the predictions are strongly dependent on the likelihood that a past discovery can be exploited due to technology and economic limitations, and on the definition, e.g., if an oil field is likely to be exploited in the future (decades) or not.

The numbers in Table III show that there is 55 and 59 years for oil and gas at the current consumption rate and 212 years for coal. If all oil and gas is used up, there will be a switch to coal, which will see an accordingly increased consumption rate. Therefore, coal will finally last about 107 years.

It is interesting to note that uranium would provide just another 8 years if the world would hypothetically switch to 100% uranium, because the typically employed nuclear power plants are so-called “Generation-1” types use U235 [50].

TABLE III.
HOW MUCH ENERGY IS LEFT (ESTIMATED 2020, 2022)

Fuel	Energy [1e15 kWh$_{therm}$]	Time remaining(*)
Uranium	Identified recoverable resources : 1.3 [51], [50]	186 years [1], (**)
Oil	Most likely estimate for existing fields, discoveries and yet undiscovered fields: 2.9 [52], [53]	55 years [54]
Natural gas	Proved reserves [57]: 2.3 [55], [56]	59 years [58]
Coal	Proved recoverable reserves [61]: 9.5 [59]	212 years [60]

[*] Time remaining at the year-2022 energy production rate of the specific fuel, whereas global primary energy consumption in 2022 is 165e12 kWh per year [49]

[**] Switching the whole primary energy system of the world to uranium, it would last just 8 years

Fig.2 and Fig.3 show the past discoveries of giant gas and giant oil fields. This is usually "conventional" oil and gas which is easy to exploit, resulting in low-cost fuel with high Energy Return on Energy Invested (EROI) rate. EROI indicates the energy required to exploit an energy source, e.g. the amount of energy to get a barrel oil out of the ground. It can be clearly seen that all big discoveries have been made well before 1970, although the effort of exploration has been increased significantly driven by ever rising energy prices with increasingly sophisticated search and exploration technology.

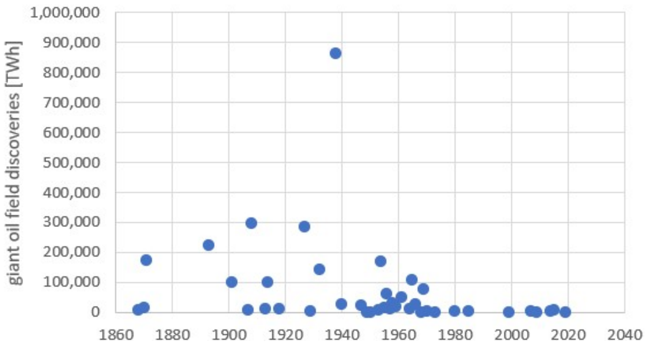

Fig. 2. Discoveries of giant gas fields [19] (fields with more than 500 million barrels-oil-equivalent (850 TWh)). Each dot represents the sum of all new discoveries in the specific year.

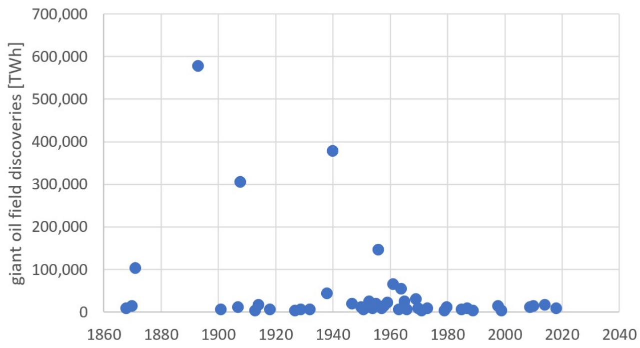

Fig. 3. Discoveries of giant oil fields [19], (fields with more than 500 million barrels (850 TWh)). Each dot represents the sum of all new discoveries in the specific year. Production of many of these fields was started often decades after discovery.

The accumulated discoveries of the giant oil fields are shown in Fig.4 as blue line. After 1960 it becomes flat because (nearly) all giant fields have been found. The accumulated global oil consumption shown in orange crosses around 2010 indicating the end of high-EROI oil. This also triggered low-EROI oil, as shown in Fig.5.

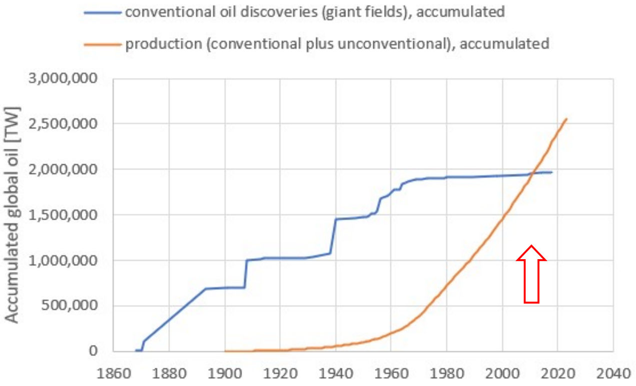

Fig. 4. Accumulated global oil discoveries (blue line) from giant fields [19] vs. total global oil production [21] (orange line). Giant fields are often easy to exploit resulting in oil with very high EROI. The total global production (orange line) is composed of conventional oil (giant fields plus small fields which make about 12.5% of the ultimately recoverable oil [22]) plus unconventional oil (deep sea, shale oil, tar sands). The cross-over marks the peak of conventional oil and, therefore, the end of high-EROI oil.

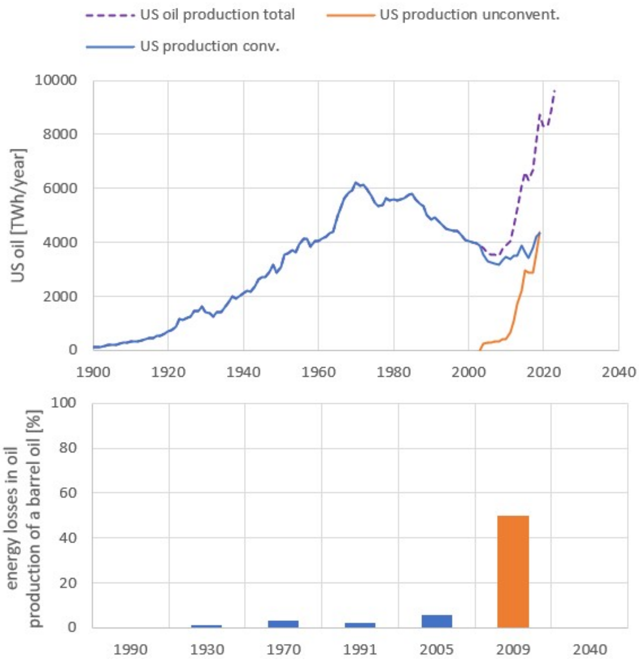

Fig. 5. (a) Yearly US oil production [21] (before 2000: blue line, after 2000: dotted line) with conentional oil (solid blue line) peaking in 1970. The cross-over in Fig.4 triggers the production of expensive unconventional oil (orange line) [20] with very low Energy Return on Energy Invested (EROI). (b) Producing conventional oil (blue bars) in form of crude oil required energy input of about 1% – 3% throughout the 20th century. The required energy input raised into the range of 5% - 10% after the year 2000. Unconventional oil (orange bar) has been in the range 30% - 50% with rising tendency ([23], [24], [25]). The energy to produce the oil (orange bar) comes often from natural gas and does not show up in the oil statistics, therefore.

D. Political Boundaries – The CO2-Tax

In the European Union (EU), the CO2-tax on processes that emit CO2 started to rise very fast around 2018 and is politically designed to keep rising in order to force European industry to step out of fossil fuels in the early future. In order to prevent deindustrialization, the EU plans an import tariff on steel, aluminum, fertilizers, cement and electricity which is called CBAM [11] and is supposed to start in 2026. The CO2-tax would make fossil fuels in Europe increasingly uncompetitive against electricity which comes from CO2-free sources like PV or wind.

As a result, at least in Europe, very large currently fossil fuel-driven consumers will be forced to turn into electricity consumers like steel production based on arc furnaces ("green steel"). They all need to be connected to the MV grid via high-power MV power electronics.

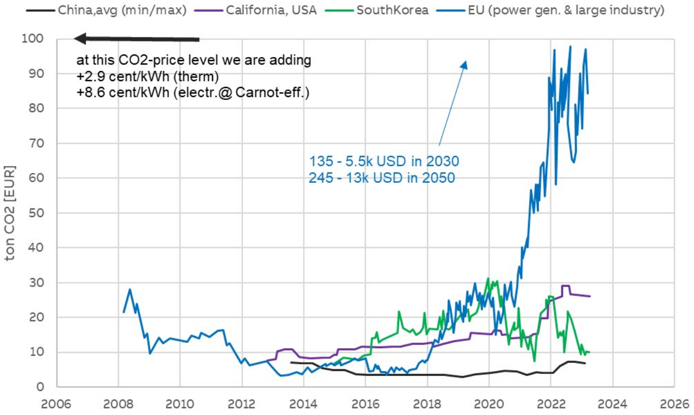

Fig. 6. Cost of CO2-tax [9], [10], as added onto energy-intensive processes emitting CO2.

With 1 kg bituminous coal giving about 2.4 kg CO2 [12], [13] and 29 MJ thermal energy [14] (8 $\text{kWh}_{\text{therm}}$), we can calculate the CO2-tax cost per energy. The price of 1 kg Newcastle coal [15], which is a major energy carrier in Pacific Asia, but also in Germany, was around 13 USD-cent during 2024, and has been fluctuating between 6 and 12 USD-cent in the decade before 2021.

Thermal energy from coal produced in the Asia-Pacific region is, therefore, about 1.5 EUR-cent per kWh [16] in 2024. A price of 100 EUR per ton CO2 would add about 2.9 EUR-cent onto each thermal kWh.

In case of electricity production from fossil fuels, the cost has been in 2023 typically 6 USD-cent/kWh_{el} for large coal-fired plants. Due to the process-inherent Carnot-efficiency [18], about 2.5 – 3 times as much coal is needed and 2.5 – 3 times as much CO2 is produced. Without carbon-capture in the plant, a CO2-tax of 100 EUR/tonCO2 would add approximately another 8 – 9 USD-cent, resulting in a wholesale price of 15 USD-cent/kWh_{el} (compare this to the long-term whole sale prices of electricity in Europe in the last two decades which was typically between 2 and 6 EUR-cent/kWh_{el} [17]).

III. TECHNOLOGY DISRUPTIONS MOVING THE ENERGY TRANSISTION STEP-WISE FORWARD

A. General Pattern of a Technology Disruption

Technology disruption is a sudden replacement of an existing state-of-art technology with a new technology. Although many people assume that disruptions are not predictable and happen in a random way, there is a well-researched pattern that can be found whenever technology disruptions happen [26]. With knowledge of this pattern one can get insights in the potential of a technology and possible timelines when and how a disruption might happen. Furthermore, the knowledge of the pattern helps to navigate industry and research through disruptions. The general pattern of a technology disruption shows the following characteristics [26]:

- A new technology enters the market.
  - It is potentially superior but still has many disadvantages as compared to the mainstream product.
  - Despite several disadvantages, it might be expensive.
  - Some features allow success in a niche market, where it can make some money. The niche is too small to be interesting for the mainstream competitors.
- The new technology falls in cost and improves in performance, but remains in a niche market. The profits are used to improve the new technology.
- Entering the price band of the mean stream mass market suddenly triggers huge sales. The state-of-art technology quickly loses market share.
- The established state-of-the-art technology is disrupted.
  - Established companies can usually master disruptive technologies in their research centers, but they often fail to make a successful product out of it
  - Established companies try to fight disruptive technologies because they cannibalize their best-selling state-of-the-art product.
  - Sales networks of established companies are usually not flexible enough for technology disruption because existing sales networks are optimized around the state-of-the-art product. This is identified as a key problem for established companies [26].

In the following we look into technologies associated with the Energy Transition and discuss their disruptive potential. From this, we can identify mid- and long-term research strategies for power electronics with high impact.

B. Grid-Scale PV and Wind as Disruptive Technology

The Levelized Cost of Electricity (LCOE) gives the production cost of electricity (e.g., in cent/kWh) for a specific energy source. Comparing the LCOE of coal, traditionally one of the cheapest ways to produce grid-scale electricity with PV and wind (both grid-scale), we see in Fig.7 that before the year 2000 wind energy could not compete with coal-based electricity, and before 2010 PV could not compete. But with income from niche market applications (like “green” government funding, satellites, etc.) the LCOE of PV and wind kept falling exponentially, and based on the data, one could anticipate a disruption around 2010. The crossing of the lines in Fig.7 triggered exponential growth in PV and wind installations, which triggered huge demand in PV installations including inverters, DC/DC converters and transformers.

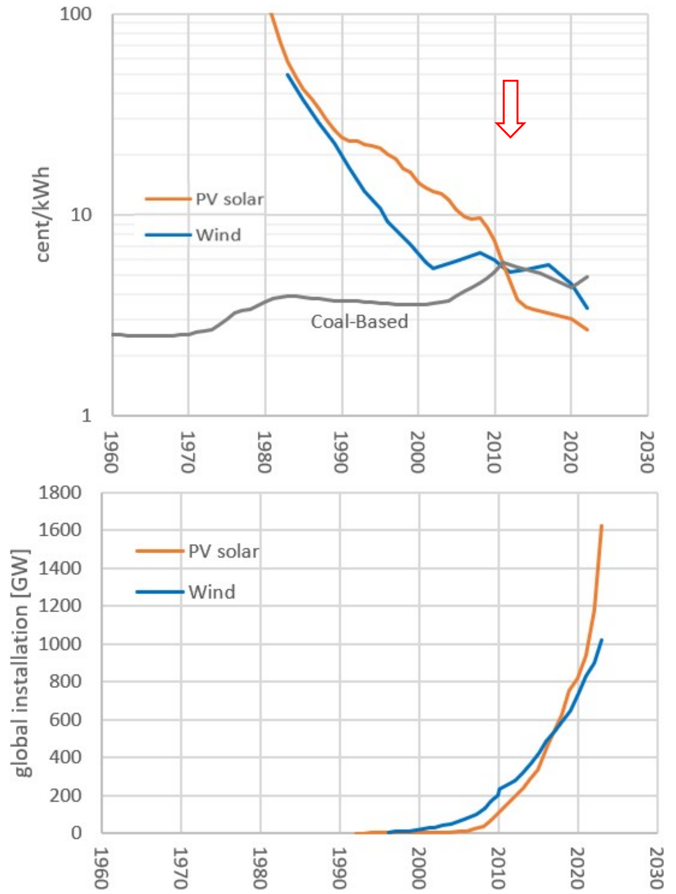

Fig. 7. (a) Levelized Cost of Electricity (LCOE) of different grid-scale generation technologies [35], [37], [38], [39]; here comparing grid-scale PV solar in USA [29], [30], wind-onshore [31], and coal-fired power plants [32], [33], [34]. The arrow marks how PV (location USA) and/or wind power disrupts coal plants. (b) The disruption triggers exponential growth in installed power [40], [41].

However, there was no coal disruption (yet) because PV and wind require energy storage due to weather changes and day-night cycles, and storage would approximately double their LCOE (see PV in Table 1.2 in [39] with cost data from 2024). Today, PV and wind require other energy producers to match the electricity production with the demand, and those are based on fossil fuels (coal, gas) or nuclear. With storage cost coming down, we will see a “real” disruption of fossil fuel-based generation, resulting in even steeper growth of renewables.

C. Electric Vehicles as a Disruptive Technology

Electric Vehicles (EV) in combination with renewables like PV and wind, will allow to reduce the oil consumption in transportation significantly, theoretically entirely, and will allow long-term alternative usages of oil like e.g. chemical feedstock which is hard to do without oil and which is essential for our civilization (plastics, fertilizer, etc.). Another important point is that in order to exploit low-EROI oil, huge amounts of energy are needed (see Fig.5), usually natural gas which is part of the very-difficult-to-reduce “industrial heating” bar in Fig.1.

As surveys of people who have actually bought an EV have shown, the main reasons are typically the expected cost savings ([72], [73]). Therefore, we can expect a wide-spread adaption of EVs only if there are significant cost advantages for the individual. This is, of course, a well-known part of the pattern of disruption as discussed at the begin of this section.

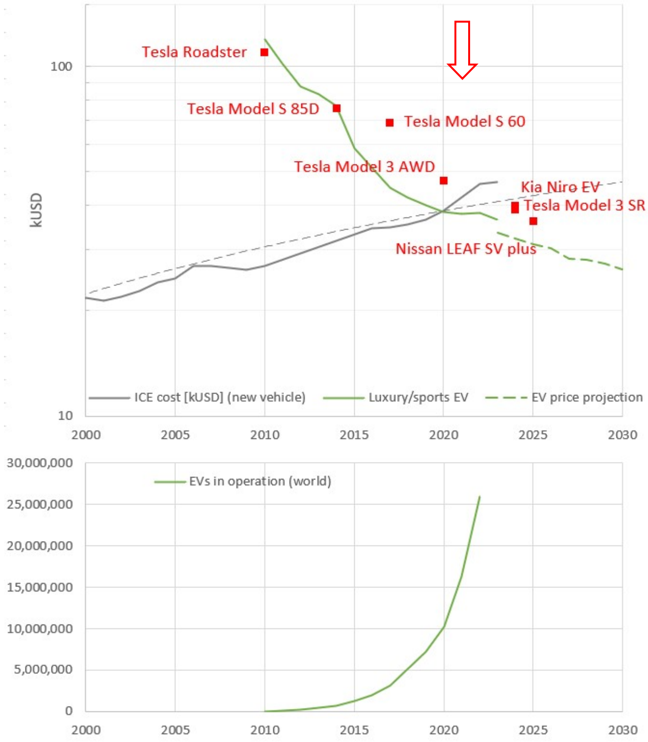

Fig. 8. (a) Purchse price of selected new EVs [42] vs. price of new gasoline cars [47], [48] (gray line: average budget for car purchase in USA) over time. EVs with batteries allowing a minimum of 200 miles (320 km) ranges are considered. The dotted green line shows a projection based on future battery prices [43], [44]. The arrow marks the disruption. (b) Absolute number of EVs world-wide in operation [44] grows exponentially after the disruption but is still below 3% of all cars (worldwide) in 2024.

We employ the general idea of the EV price trend vs. the price of a car with internal combustion engine (ICE) to identify a disruption as described and shown in [28] and [75], but we update and define our EV price model as follows:

We take the EV battery prices since 2010 as given in [43], [44], and employ a 60 kWh battery which is usually said to allow 200 mile (320 km) ranges. Battery prices dropped exponentially between 2010 and 2020, and became more flat afterwards as the minimum price is defined by the battery materials. From EV cost breakdowns [45], [46], we assume a cost of 15 kUSD for all EV components without the battery, and assume this to be constant over time in a first approximation. We add the time-dependent battery cost (for a 60 kWh EV-battery) to the constant cost of all other components, and multiply this bill of material (BOM) with a factor 1.5 to take manufacturing into account, and another factor 1.1 to consider profits. Both factors are extracted from the referenced cost breakdown reports, but will vary between various types of EV.

As shown in Fig.8, our EV price model curve crossed the price of ICE cars around 2020, but EVs that really entered the market (red rectangles, see [42]), seem to be a little delayed, so the real disruption happens right now. The number of EVs sold starts rising exponentially, which is typical for a technology disruption, but note that in 2024 that number means that less than 3% of all cars on the streets are electric [44].

D. *Solid-State Transformers as a Disruptive Technology*

A very general cost trend comparison of the Solid State Transformer (SST) vs. the line-frequency transformer (LFT) has been shown and discussed in [75] and [76]. In this section we employ updated and more detailed cost trend models with cost data from the literature.

The converter cost models (nominal USD) in this section are based on (1) the cost changes of metals which define distribution transformer price trends, (2) the cost of LV inverters in the lower MW range, and (3) an assumption of a factor between the cost of a typical SST cell and the cost of the equivalent power electronics of a state-of-art AC/DC converter.

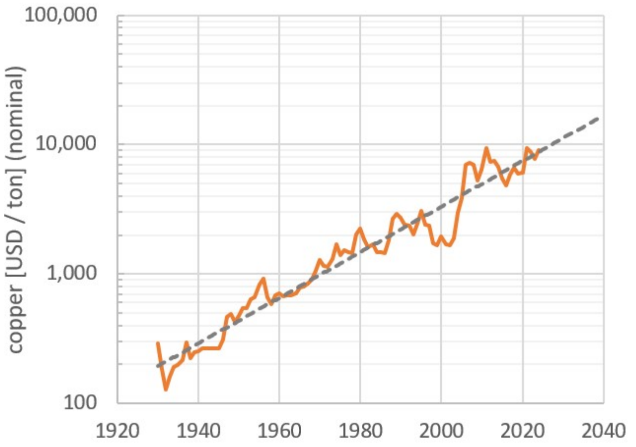

Fig. 9. Copper price development over the last decades.

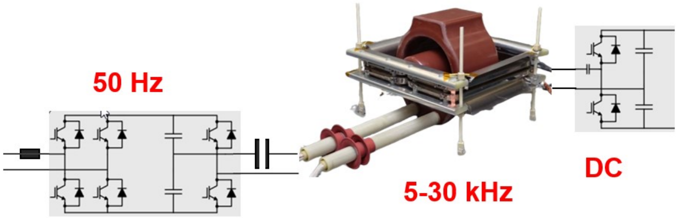

Fig. 10. Typical SST cell composed of an input-sinde AC/DC converter and an isolated DC/DC converter employing a medium-frequency transformer (MFT) [63], and generating a LV-side DC output.

The cost of metals (copper, steel, aluminum) in nominal USD keeps rising more or less continuously since 1920 by approximately 3.5% per year ([64], [65], [66], [67], see Fig.9). With the assumption that a typical 1 MW distribution transformer might contain 550 kg copper windings and 600 kg silicon steel core, that silicon steel is about four times more expensive than hot-rolled-steel (based on a data comparison of [67] and [68]), and that there is a factor 1.7 on the bill of material (BOM) of windings and core giving the transformer price, we can build a simple price model of a distribution transformer. Since the simplified price model is fully material-based, it shows a continuous price rise of 3.5% per year and we employ a reference data point in 2018 with 10 USD/kW.

The price of a state-of-the-art LV inverter in the MW-range is given in [35], [36], [37], [38] and [39] for grid-scale PV installations between 2010 and 2024. According to this data, between 2010 and 2024 the inverter price continuously dropped by about 11% per year. Therefore, in our simplified model, we assume a yearly price drop of 11% and a reference data point in 2020 with 63 USD/kW.

To estimate the SST price, we in a first approximation assume that the power electronics of an SST cell is roughly 1.5 times more expensive than an equivalent state-of-the-art 2-level inverter, because it employs a higher number power semiconductors and gate drivers (see Fig.10). The MFT price is estimated based on an MFT which has been on the market [69], [74], and which we estimate (based on the BOM and a scaling factor) to be at 15 USD/kW and approximately constant (because it is comparably small and does not contain a larger amount of metals).

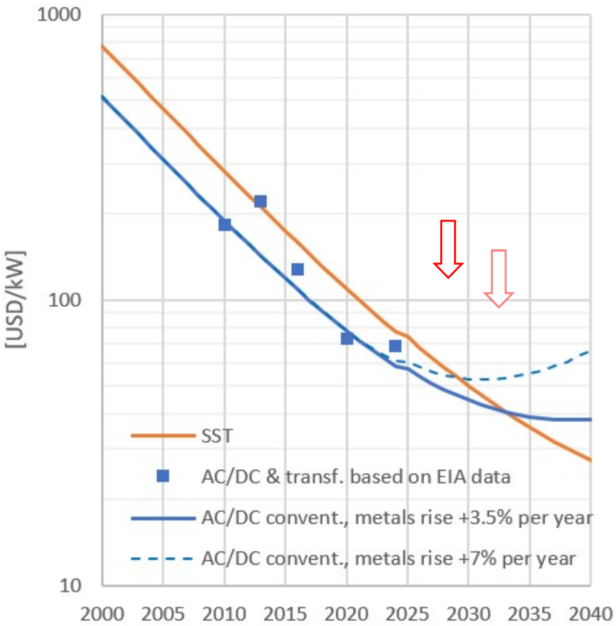

Fig. 11. Price trend comparison (nominal USD per kW) of state-of-art AC/DC converter vs. SST, with both converters operating in the MW-range connected to the MV grid. Assumption of a rise of metal prices after 2020 of +3.5% p.a. vs. +7% p.a. (on average) results in a shift of the disruption by a couple of years as indicated by the two red arrows. The blue dots represent real inverter cost data from [35], [36], [37], [38], [39] plus the cost of a 50 Hz distribution transformer (as modeled based on the material price trend, see also Fig.9).

Based on the simple price models described above and with its key parameters (underlined), we can calculate and plot the price trend of a state-of-art AC/DC converter vs. an SST, with both converters operating in the Megawatt-range and being connected to the MV grid. The resulting curves are shown in Fig.11, and a cross-over indicates disruption, marked by a red arrow.

This model is very simple and makes some parameter assumptions that might need adaptions in the future (when more data is available). There are uncertainties like material price developments, e.g., as shown in Fig.11, with two different assumptions of metal price increases after the year 2020 (+3.5% p.a. vs. +7% p.a.), resulting in a shift of the disruption from 2032 to 2028.

Although the price trend comparison shown in Fig.11 is quite parameter sensitive, it shows that a disruption will happen around the end of this decade (plus/minus a few years). The SST has features like:

- no requirement for fast DC-side breakers because simply putting all switches into off-state within well below one microsecond will prevent a further increase of a short-circuit current;
- relatively low weight and reduced size, modularity;
- no handling of distribution transformers of several tons;
- significantly reduced amount of copper.

which might help to find a niche market. Various niche markets have been discussed and tested during the last two decades but with no convincing application found yet.

Recently the IEA started to discuss the scarcity of metals in the near future [70], especially copper, when many countries start their Energy Transitions more or less at the same time. Besides the increased demand for renewables, the currently operating copper mines will soon need replacement, which can take nearly up to two decades.

In addition to the huge amount of new additional energy infrastructure to be installed, renewables require many times more copper than fossil fuel-based energy generation of the same power [71]. This is because wind, but especially PV, are typically distributed over very large areas with very long LV cabling as compared to highly compact fossil fuel-based plants. Here an SST might be very helpful to significantly bring down the amount of copper required in a grid-scale PV plant, due to the elimination of the large 50 Hz distribution transformers, and probably also due to its modularity which allows more, but smaller converter units distributed over the PV plant´s area. The possibility of an accelerated rise in copper price due to scarcity is modeled in Fig.11 with the dashed curve indicating an increased copper price rise of 7% p.a. after the year 2020.

IV. SUMMARY AND OUTLOOK

Natural limits in the supply of fossil fuels plus CO2-taxes start to force big energy consumers (industrial processes in metal production, cement, chemicals, food production) to switch from fossil fuels to electricity which requires them to connect to the MV grid with converters in the Megawatt-range. The same happens with energy production, where a technology disruption of renewables (PV, wind) around 2010 facilitated the begin of the transition significantly.

The largest consumer of fossil fuels, which is oil-based mobility, is at the brink of disruption by EVs which will require a huge amount of additional electricity production, probably provided by renewables. In addition to MV grid-connected AC/DC converters (especially for fast-chargers for EVs and grid-scale PV plants), a huge number of LV power electronics systems will be required for EV drive trains and at-home charging.

From the power electronics point of view, one promising topology is the SST which will disrupt the state-of-art AC/DC converter (50 Hz distribution transformer plus LV converter) around the end of this decade. A major force of this disruption will be rising metal prices, especially copper, where the SST provides significant cost advantages. The rise of metal prices will be driven by the Energy Transition because of the large number of additional renewable energy systems to be installed and because renewables like PV and wind require multiple times the amount of copper as compared to conventional fossil power plants of the same installed power.

The Energy Transition from fossil fuels to electricity will require Megawatt-converters connected to the MV grid, whereas up to now, the dominant power electronics global market has been Kilowatt-converters connected to the LV grid, and, of course, power supplies with very low power for consumer electronics. There will be long-term exponential growth for MV power electronics, which already started from a very low level about a decade ago. Power electronics research strategies in this field might prove highly important.

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