Efficiency in alternative power systems

What efficiency really means and why "good" isn't good enough

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In October 1983, a record-breaking wind generator was taken into operation and the world's largest wind energy converter called Growian (artificial German abbreviation meaning large scale wind power plant) went live. The 3MW machine can be considered an example how the world has changed since this happened.

Though it was an ingenious design by the time, the power harvested by an asynchronous generator was transferred to the grid by means of several gearboxes and conversion from variable frequency to fixed frequency involved a mechanical converter utilizing rotating machines. Stacking five mechanical systems resulted in a conversion efficiency of less than 80% and more than 600kW of losses were generated. Today, harvesting, transferring, storing and using electric energy is one of the major challenges industrialized nations face. Though the scale changes from Watt to MW, the task itself remains the same

An issue in watts

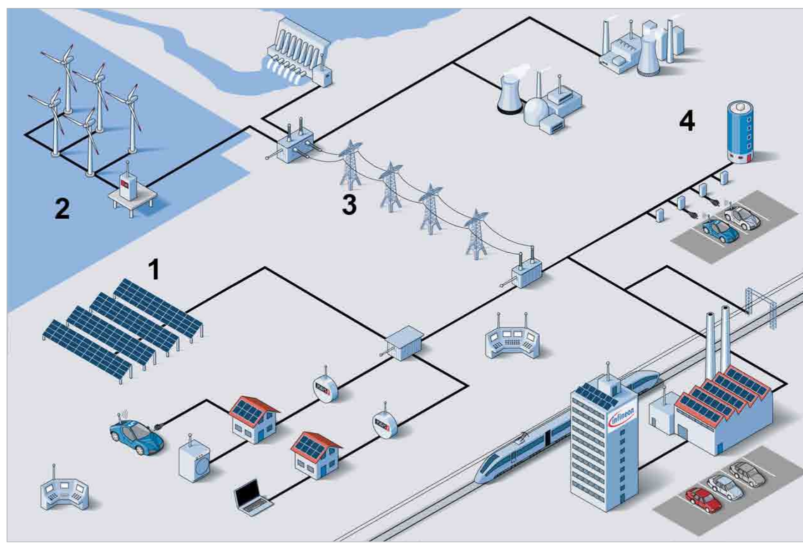

Figure 1: Sketch of a supply grid integrating renewable power generation and battery based energy storage.

Saving energy in a scale of 1W seems to be peanuts but the number of devices within this range is enormous. A mobile phone is one of these applications. Using an USB-port, a cell phone charges at 5V consuming 2.5W. Prior to the era of high-voltage MOSFETs, the task would have been fulfilled using a transformer, a rectifier and a linear regulator, leading to a system efficiency of about 50%.

Today, compact switch-mode power supplies can do the same task achieving 85% conversion efficiency. With about 100 million mobile phones in Germany alone, charging one hour every day, the improvement due to semiconductors sums up to 146,000MWh per year.

A task in under one kilowatt

Personal computers have made their way into almost every house in Europe, starting with the Commodore C64 in 1982. It took until 2004 to start the 80Plus initiative to foster power supplies that feature at least 80% efficiency. While most of these computers operate at a 100W-level, high-power graphic cards and further accessories can

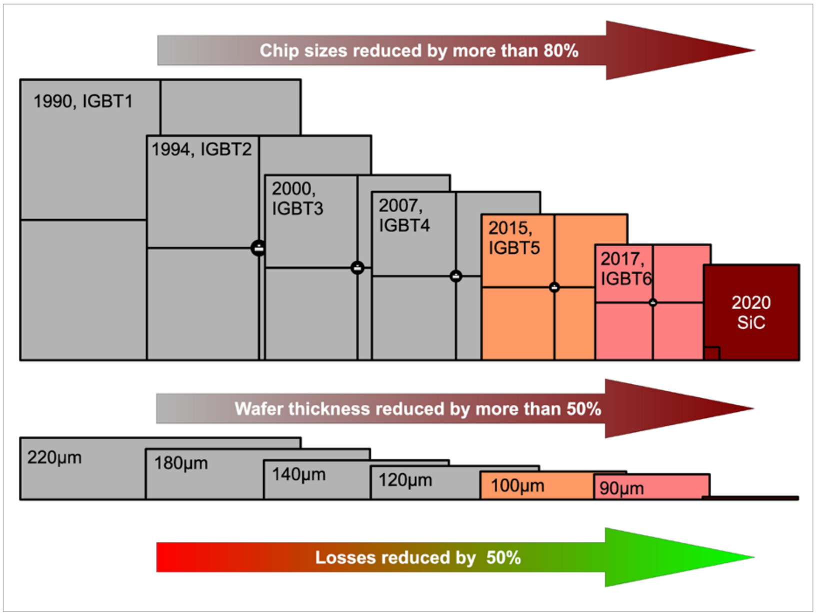

Figure 2: Three decades of power semiconductor development

boost the power consumption up to 1000W.

Compared to the C64's power supply based on transformer and linear regulators, modern switch mode power supplies feature a more complex structure but also higher efficiency, lower weight and volume and thus fewer resources per Watt of output power. With 66 million privately owned computers, power semiconductors contribute to saving 10,000,000MWh per year in Germany alone. This quote would double if the average efficiency changed from 80% to 90%

A challenge in handling megawatts

The German "Energiewende" is a project to eliminate the need of nuclear power by 2020, substituting the centralized power plants using renewable energies. As any renewable power source is of fluctuating nature, energy storage will be needed. Balancing between times of production and times of consumption will become a key element to achieve stable supplies with the availability desired. The challenge for power semiconductors now becomes obvious, taking a look to the flow of energy as depicted in the scheme in **Figure 1**:

Energy, harvested from solar arrays or wind energy converters is processed by power electronics to be grid compliant. Comparing today's wind converters to the 1983 Growian, efficiency grew by roughly 20%. An average modern 2MW wind power plant, operated 1000 full power hours per year, has an additional energy harvest in a regime of 400,000kWh due to efficiency improvement, replacing the mechanical converter by power electronics. Germany's renewable power generation in 2013 was about 135 billion kWh. Without power electronics, 27 billion kWh would have been lost.

Long-distance energy transmission is most efficient using High-Voltage DC lines (HVDC) making AC/DC and DC/AC conversion part of the transfer. Storing energy in batteries (4) again demands AC/DC conversion while recovering energy is a DC/AC path. Even before the energy reaches the end customer it passed power electronics five times at least and was converted seven times if chemical conversion in the batteries is taken into account. Considering 95% conversion efficiency for each state, 30% of the initial energy would be lost. Enhancing the situation in regards of the power electronic conversion systems can be done on different but interacting levels.

Technical improvements

To a certain extent, adapting processes or introducing slight changes to materials can enhance existing technologies. Power semiconductor switches, IGBTs, benefit from thinner wafer technology as this reduces the switching losses. Changing the cell design but remaining with the same raw materials allows optimization regarding forward voltage. Increasing the junction temperature without sacrificing

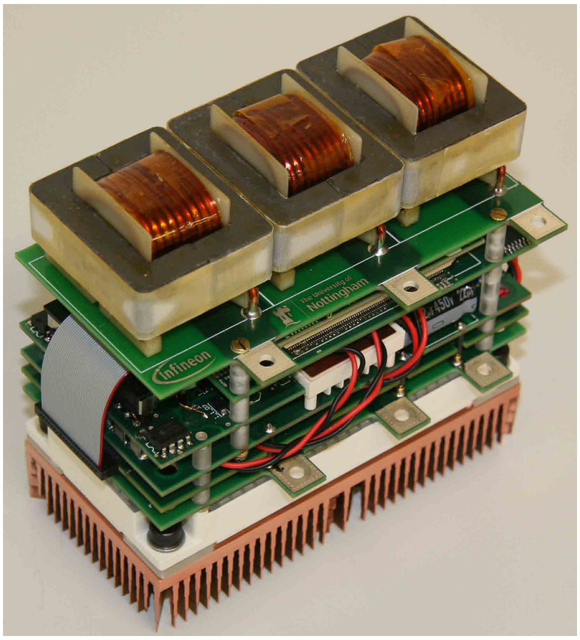

Figure 3: Built in efficiency, 20kVA converter with SiC-JFETs measuring 12.2cm x 6.2cm x 11.7cm and weighing 1.7kg

lifetime leads to higher power densities along with less material used per kW installed. The diagram in **Figure 2** summarizes recent and ongoing developments in power semiconductor technologies.

Technological change

Figure 2 also hints to the fact, that from a certain point on, a technological change is needed to overcome the drawbacks of an existing technology. In case of power semiconductors, wide band gap materials like Silicon Carbide (SiC) or Gallium Nitride (GaN) are promising candidates to further improve efficiency. Two options arise from using these new materials.

First, a change from IGBTs being bipolar transistors towards field effect based devices overcomes the PN-junction dilemma. Paralleling IGBTs still leads to a forward voltage across a PN-junction and thus limits the benefit in regards of efficiency. Field effect based devices however feature a channel resistance and paralleling n devices results in an improvement of the overall resistance by a factor n-1. Efficiency becomes a question of how many devices are integrated, immediately correlating it to money spent.

A second approach leads to hybrid devices, combining silicon IGBTs with SiC Schottky barrier diodes as depicted in Figure 3. SiC diodes allow higher turn-on speed for the IGBT, reducing the turn-on losses; the absence of a recovery charge eliminates the diode's recovery losses.

System development

Today, the most widely used topology in power electronics includes a three-phase inverter based on a 2-level half-bridge as a basic building block. Depending on the application, a change in topology may lead to benefits regarding efficiency. Recently, solar inverters have seen a transition from two-level to three-level designs. The change was driven by the efficiency gain that results from using 650V semiconductors instead of 1200V components. Among others, the inherently lower switching losses contribute to the gain in efficiency.

In an approach to minimize material content while maximizing efficiency, Infineon has successfully cooperated with the University of Nottingham to combine new technologies in a different topology. The outcome was a matrix converter that was built using silicon carbide JFETs. This 4-quadrant converter achieved 97% efficiency at full load and even higher values at partial load (see **Figure 3**).

Good enough?

Efficiency in modern energy conversion has massively grown throughout the last decades. Nevertheless, growing energy demand along with harvesting and storing renewable energies makes further improvements in this field a necessity. More and more, electricity has to pass semiconductors on its way from generation to consumption, making highly efficient semiconductors a true gateway to saving energy. Engineers will have to strive to achieve even higher efficiencies in future with a clear target ahead. Less than "1" is never good enough.

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