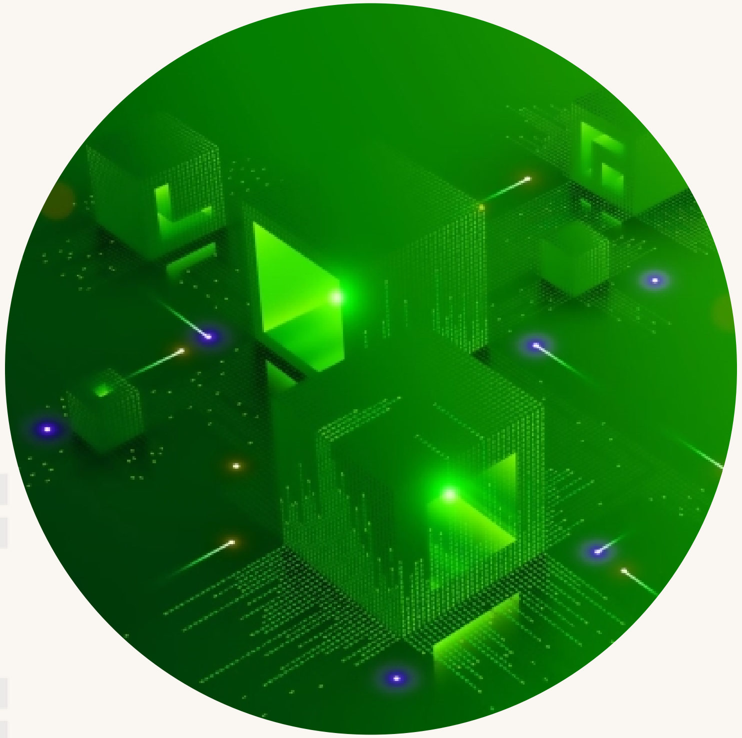
Synergistic Evolution: The Convergence of Signal Processing, Communication Technologies and Computational Intelligence for Smart Energy Systems



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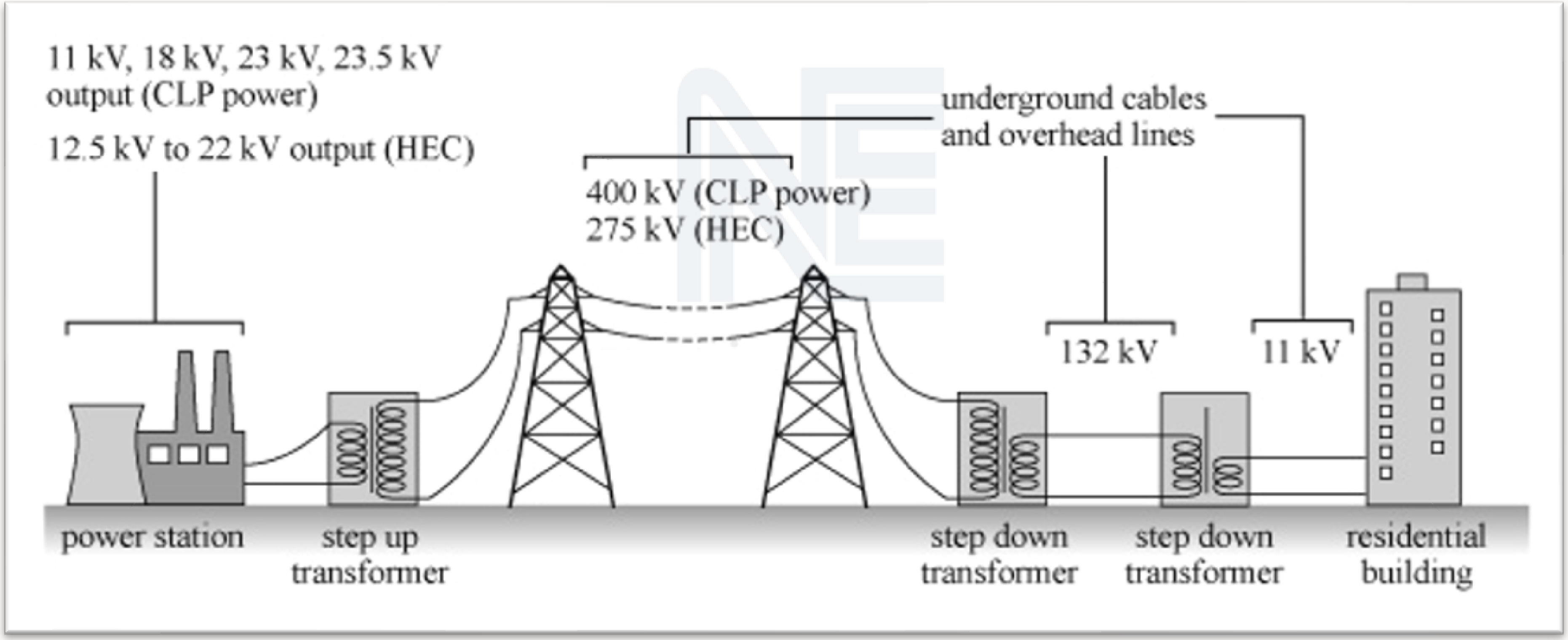
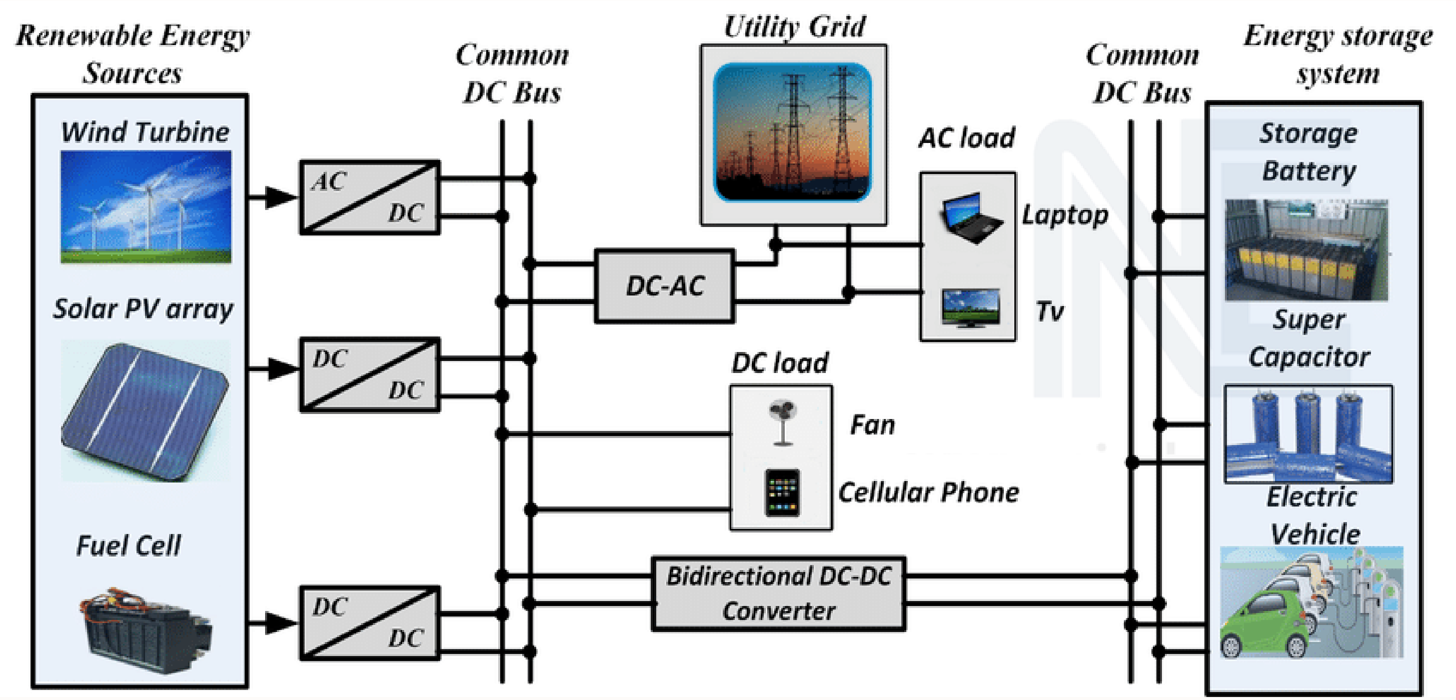
Hong Kong

Paradigm shift of power industry



Source: http://www.hk-phy.org/energy/power/print/elect_is_print_e.html

Power electronics in smart grids

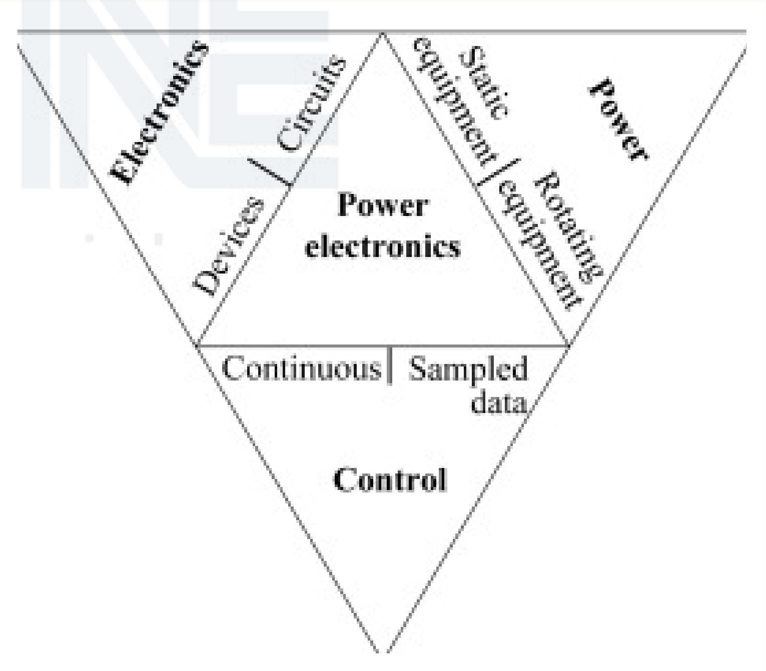


Source: S. Alatai, et al, A Review on State-of-the-Art Power Converters: Bidirectional, Resonant, Multilevel Converters and Their Derivatives, *Applied Science*, 2021

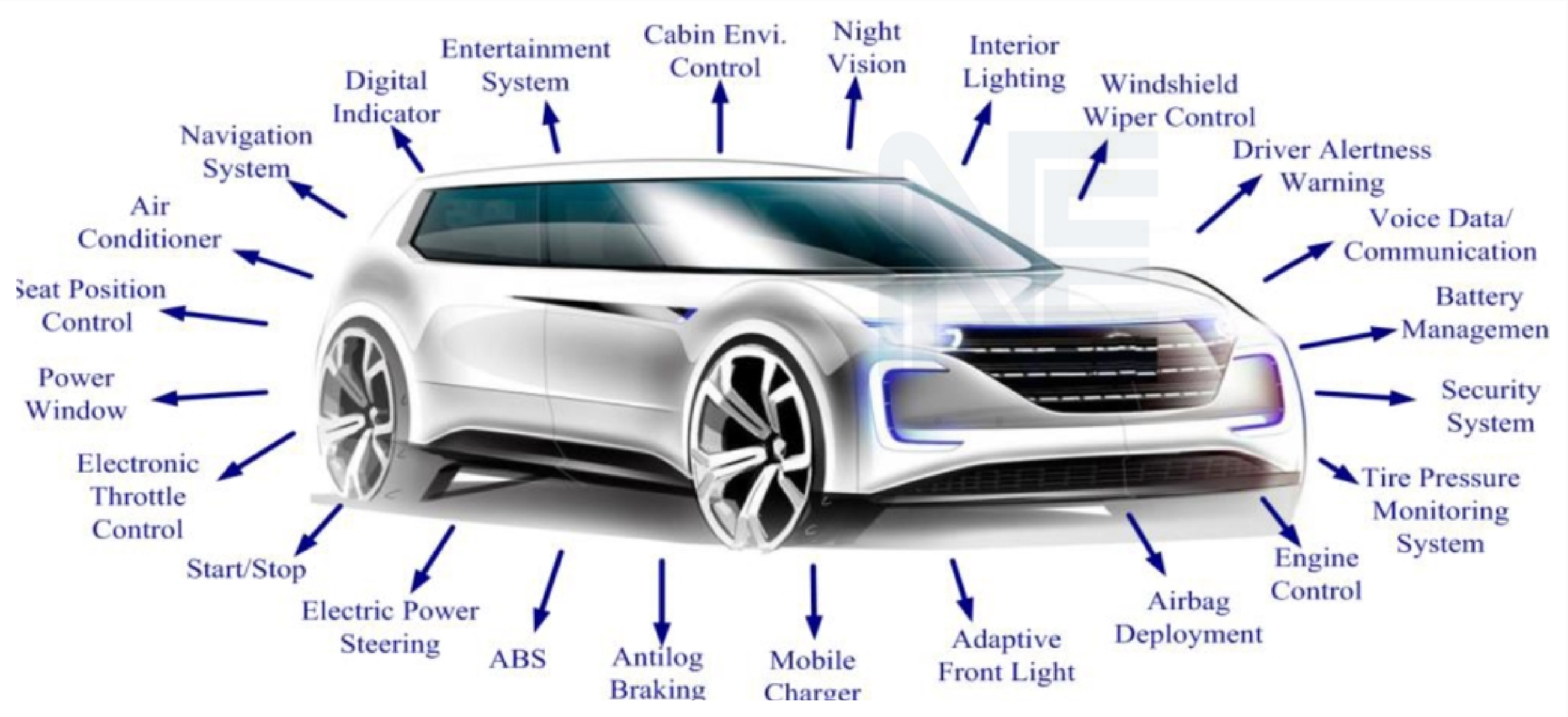
Smart grid consists of three main components, including local energy generation, storage, and utilization. Each component requires various types of power electronic converters to meet input and output requirements.

What is power electronics?

In June 1973, **Dr. William E. Newell** introduced the concept of power electronics as a technology at the interface of three core disciplines: electrical engineering, electronics, and power and control. He illustrated this concept using a triangle diagram.



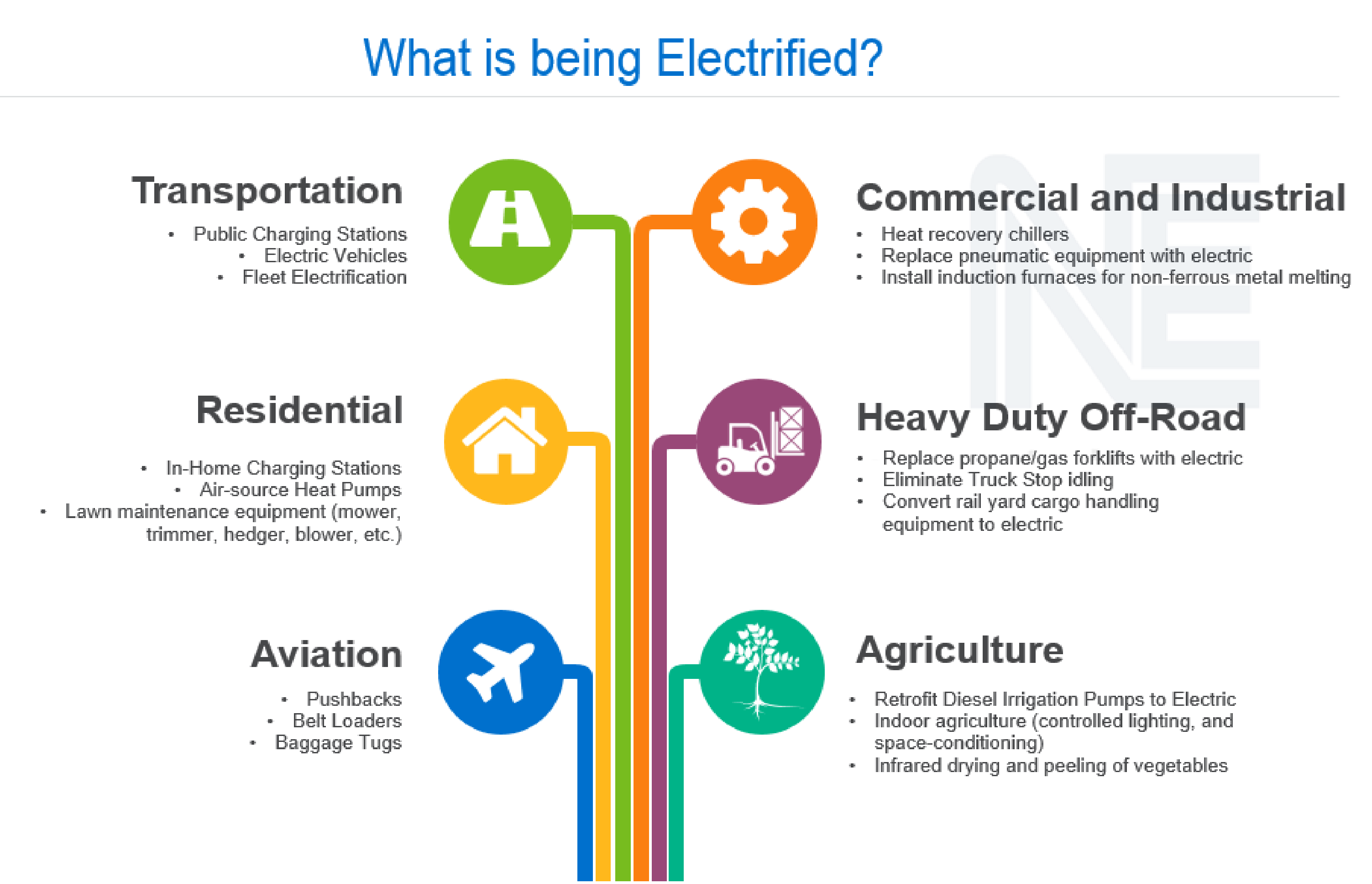
Not just AC or DC power conversion!



Different power electronic systems for different applications

Source: P. Maroti, et al, The state-of-the-art of power electronics converters configurations in electric vehicle technologies, *Power Electronic Devices and Components*, 2021.

Future perspective - **Electrification**

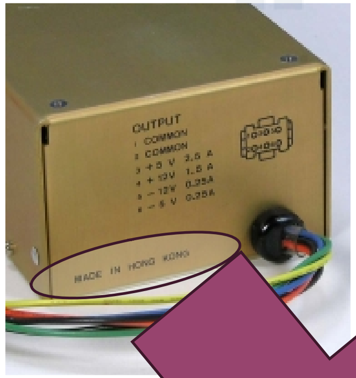


Source: https://www.wtsenergy.com/glossary/electrification/

It is anticipated that by the **Year 2030**, approximately **80%** of all electric power will likely incorporate power electronic systems at some point among generation, storage and consumption.

Key Drive (Smaller size, High Power Density, High Efficiency)

Apple II computer



AC Adapter (2024)
Max. Power: 60W
Dimensions: 5.5cm x 6.6cm x 2.2cm

Apple IIe computer supply (1983)
Max. Power: less than 60W
Dimensions: 11 in x 4 in x 2 in

Reasons: [Power Stage + Controller]

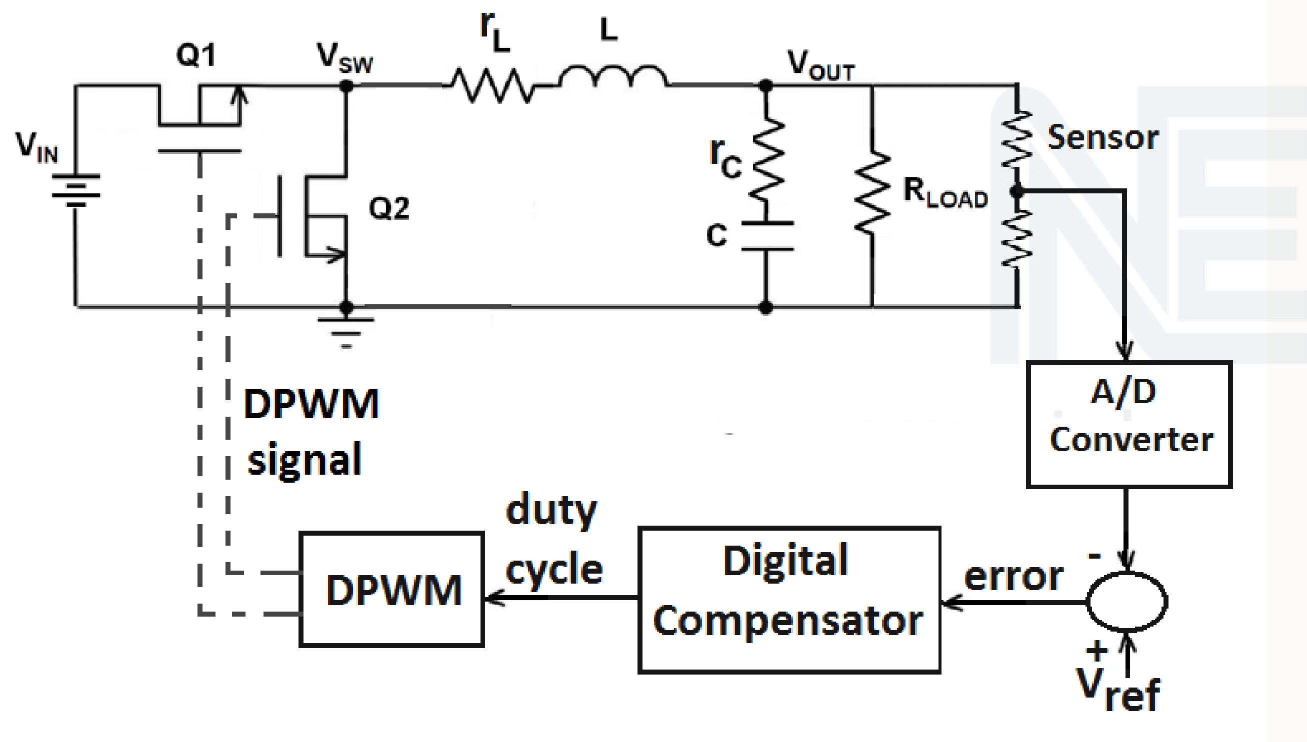
Power Stage

- ***Efficiency Improvements:*** Enhanced semiconductor materials and designs lead to more efficient power conversion, reducing the amount of heat generated and allowing for smaller heat sinks and components.
- ***Higher Switching Frequencies:*** Operating at higher frequencies allows for the use of smaller passive components like inductors and capacitors, contributing to a more compact design.
- ***Advanced Semiconductor Technologies:*** The development of advanced semiconductor technologies such as SiC (Silicon Carbide) and GaN (Gallium Nitride) enables higher power density and efficiency in smaller packages.
- ***Enhanced Thermal Management:*** Better thermal management solutions help dissipate heat effectively, allowing for the miniaturization of switching converters while maintaining reliability and performance.

Controller

- ***Improved Control Algorithms:*** Sophisticated control algorithms and digital signal processing techniques optimize power conversion, enabling the use of smaller components without compromising performance.

Typical power electronic system



Power stage

- Circuit topology
- Active components
- Passive components

Controller

- Sampling frequency & resolution
- Control algorithm
- Sample-to-update propagation
- Modulation technique

Example: A synchronous buck converters with closed-loop digital controller

Source: Solomon Banteywalu, et al, A Novel Modular Radiation Hardening Approach Applied to a Synchronous Buck Converter, Electronics, 2019.

What are our opportunities?

上善若水。水善利万物而不争，处众人之所恶，故几于道。

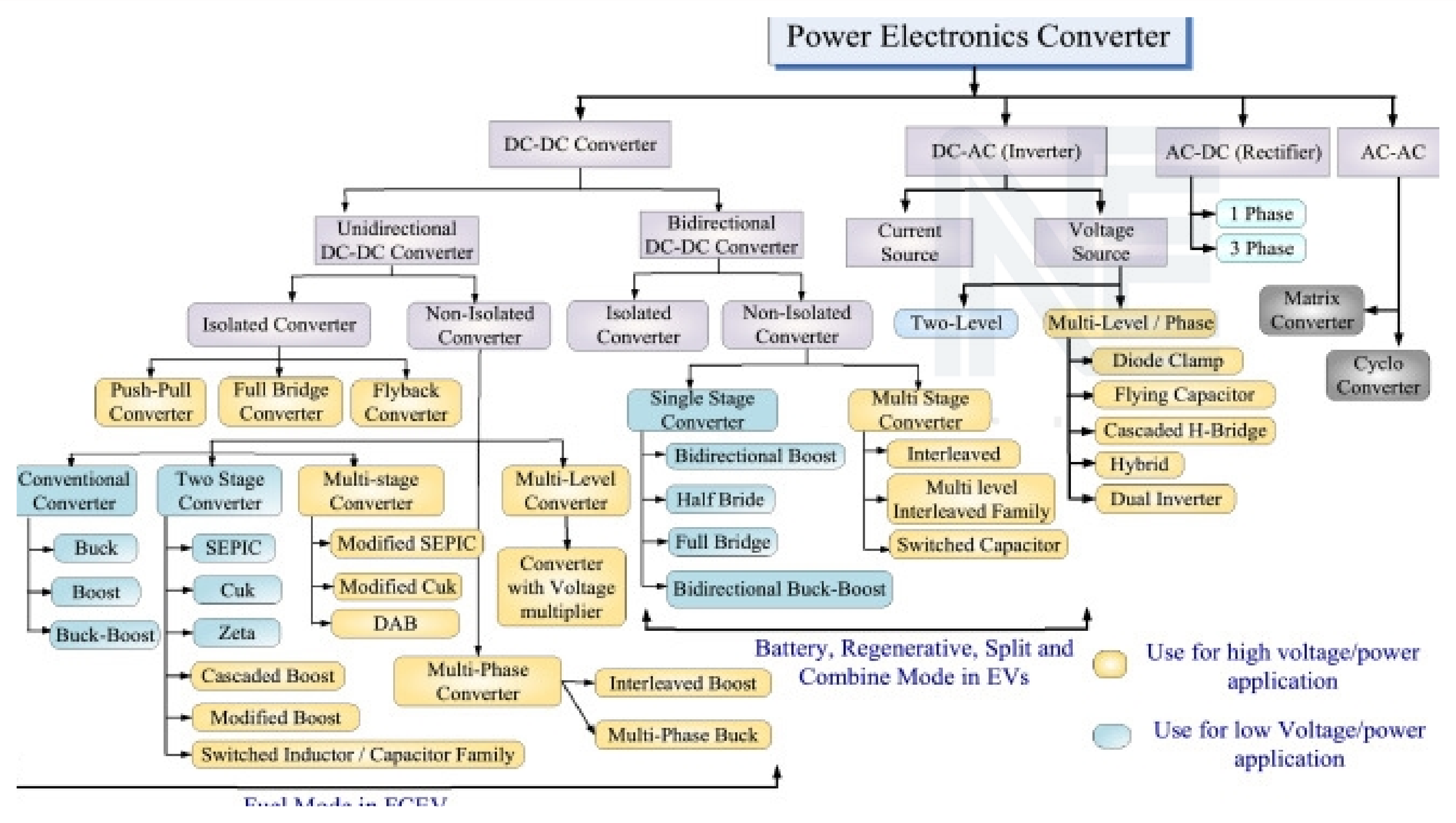
The highest goodness is like water. Water benefits all things and does not compete. It stays in the lowly places which others despise. Thus, it is near The Eternal.

上善若**电**。**电**善利万物而不争，处众人之所恶，故几于道。

The highest goodness is like **electricity**. **Electricity** benefits all things and does not compete. It stays in the lowly places which others despise. Thus, it is near The Eternal.

Depending on how we cook, we have different soups, desserts, …
Depending on how we process electricity, we have different converters, applications, …

Power Stage - Topology

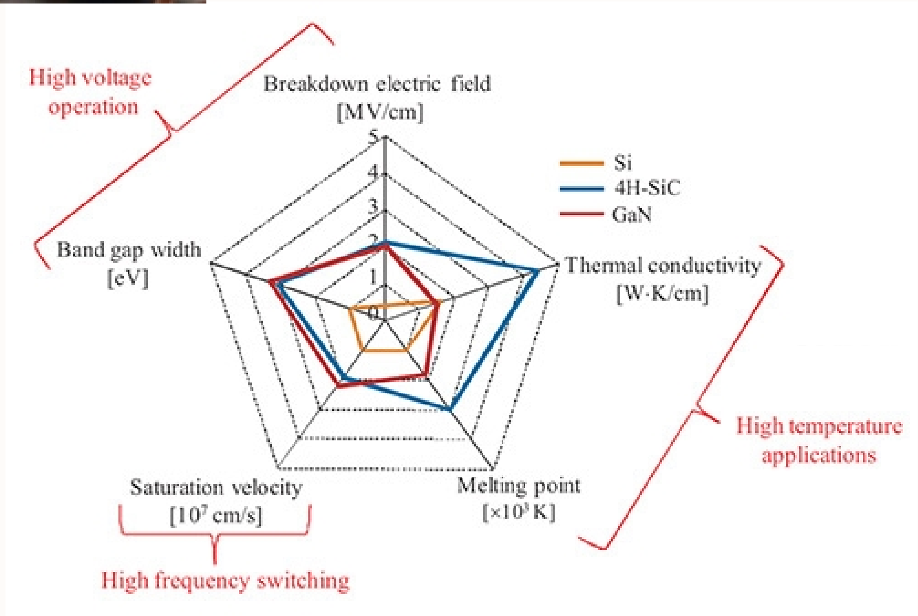


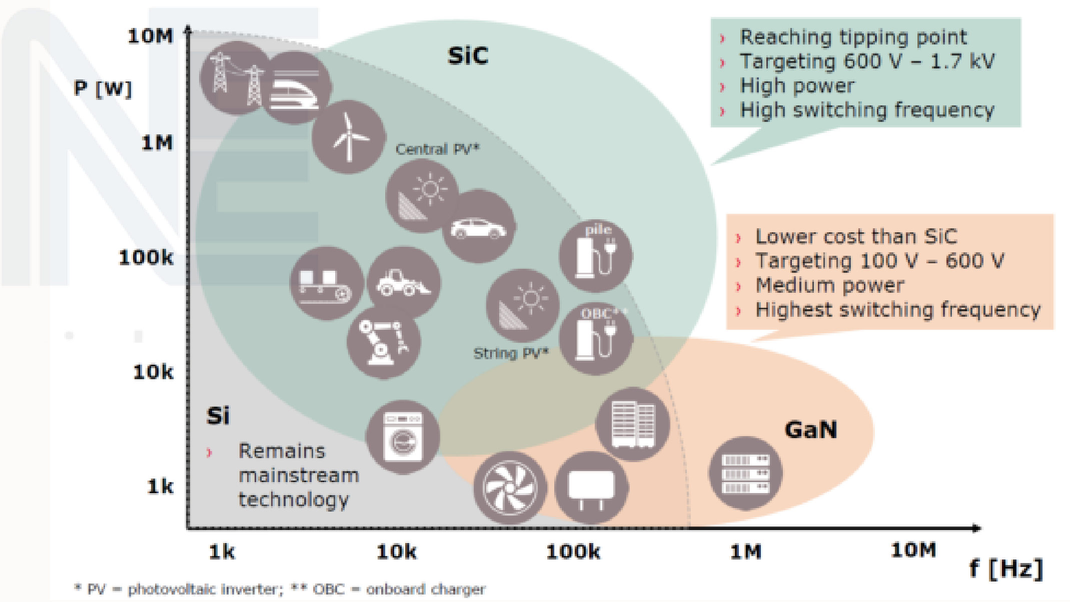
Considerations:

- Power requirement
- Voltage and current ratings
- Switching frequency
- Efficiency
- Control strategy
- Size and weight constraints
- Cost
- Input-output isolation

Active elements – New materials

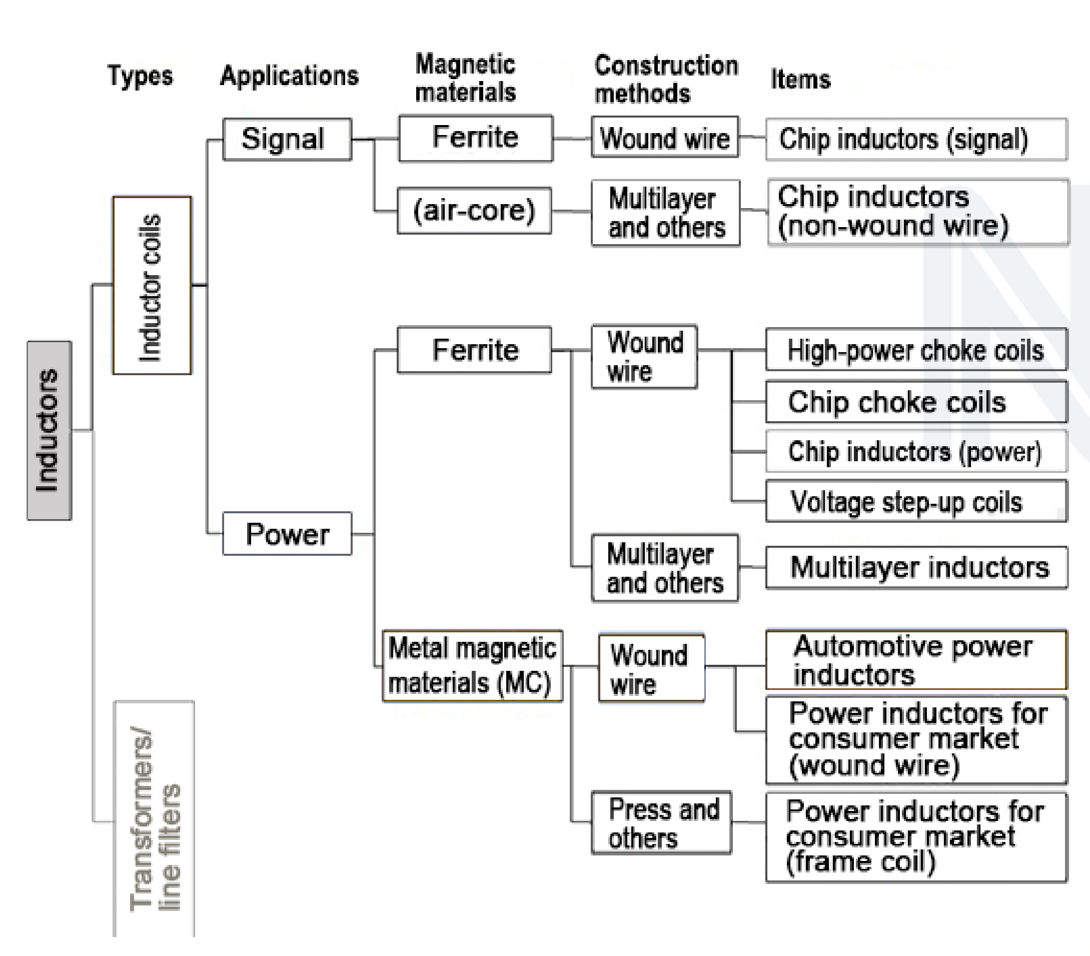
In 2014, Obama said the wideband gap semiconductors will revolutionize energy conservation.





High voltage, high frequency switching, high temperature, low switching and conduction losses, high power density

Passive elements - Inductors

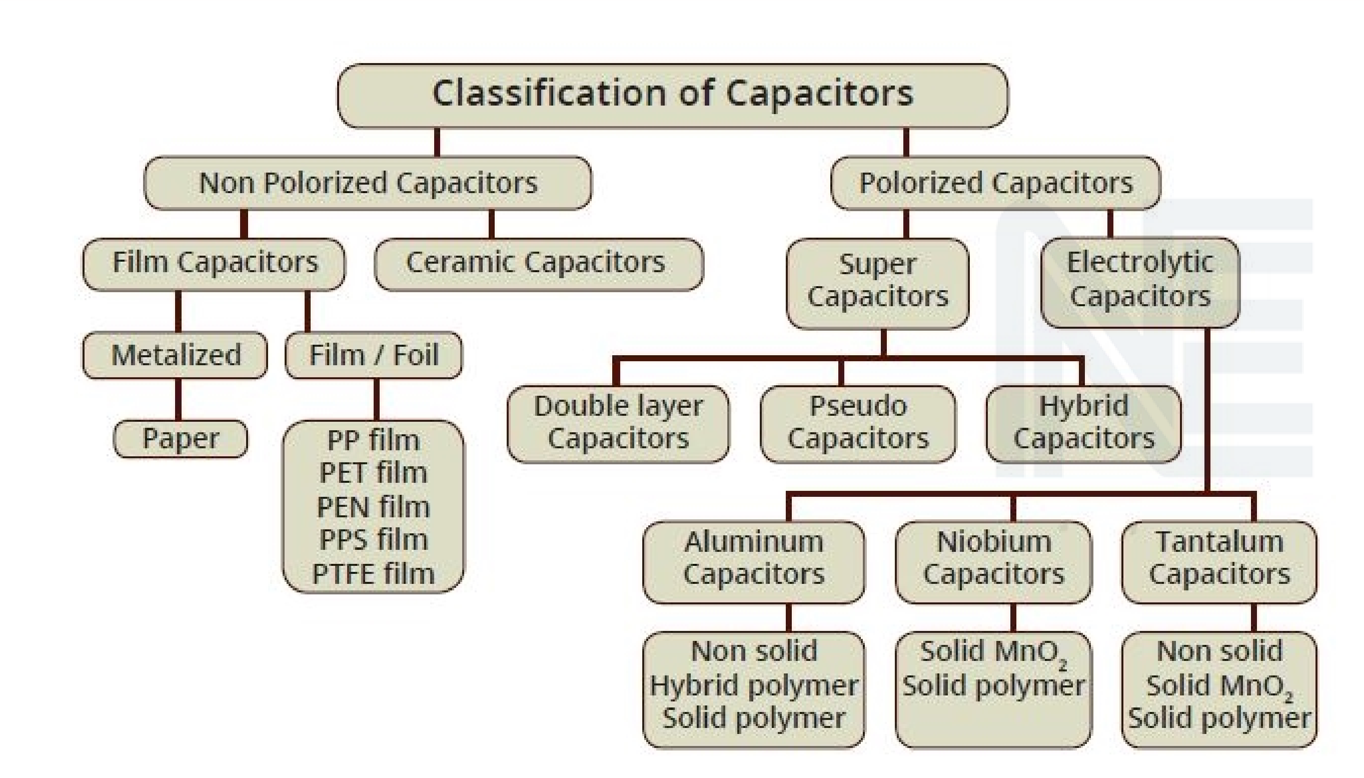


Source: Panasonic

Considerations:

- Inductance characteristics
- Current rating
- Saturation current
- DC resistance
- Temperature rating
- Size and form factor
- Operating frequency
- Core material

Passive elements - Capacitors



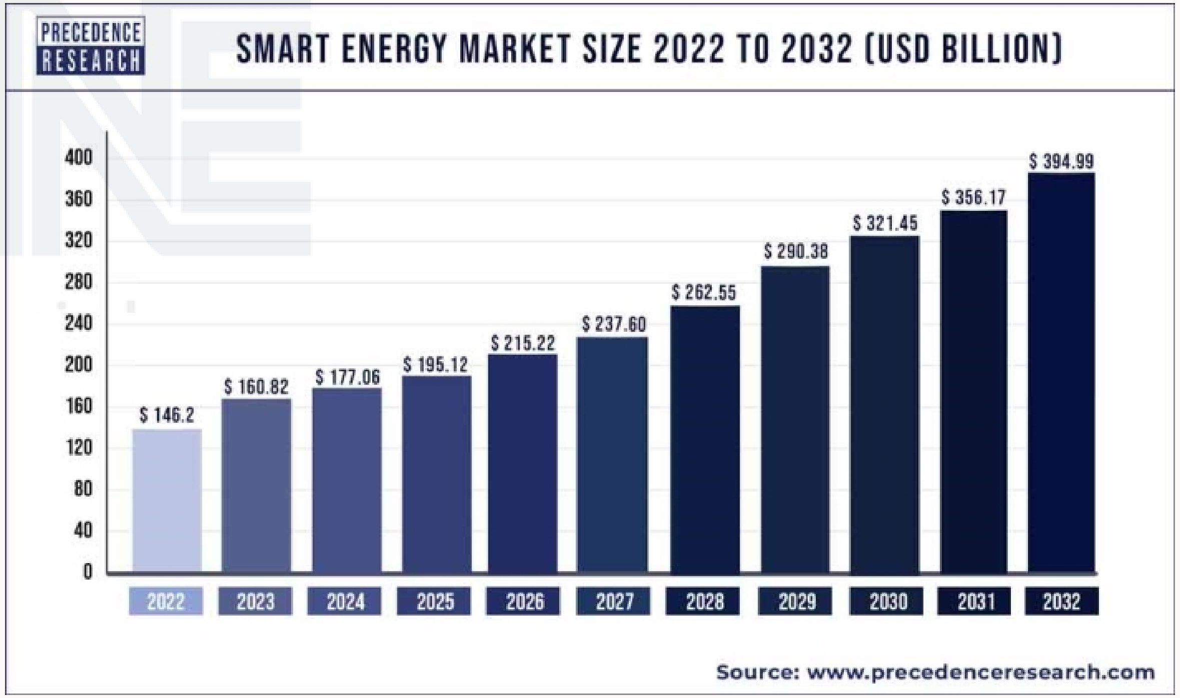
Considerations:

- Capacitance characteristics
- Current rating
- Equivalent series resistance
- Temperature rating
- Ripple current rating
- Lifetime Expectancy
- Size and form factor
- Dielectric material
- Operating frequency
- Self-healing capability
- Cost

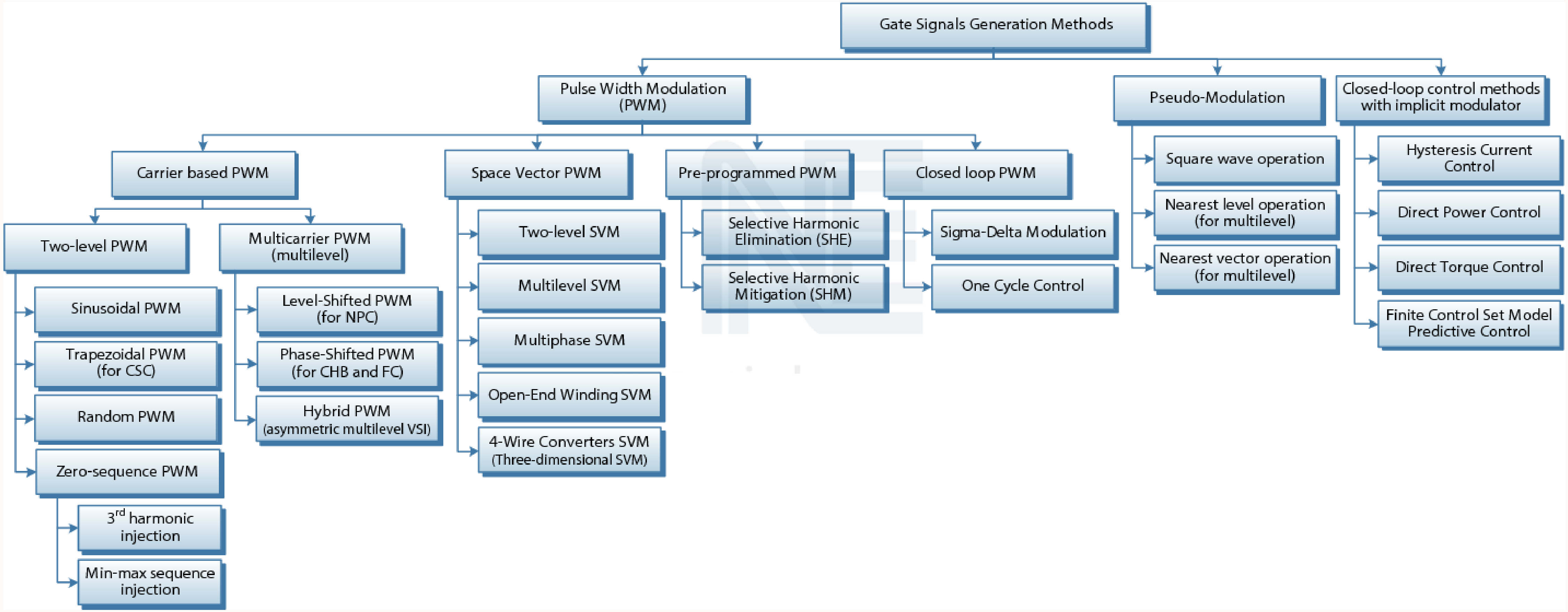
Smart Power Electronics

Smart Power electronics is the application of computational intelligence and solid-state electronics and to the control and conversion of electric power.

Motivations
- Growth of digital power
- Penetration of 3rd generation devices, Information Communication Technology, control algorithm, IoT, Cloud services, …



Modulation techniques



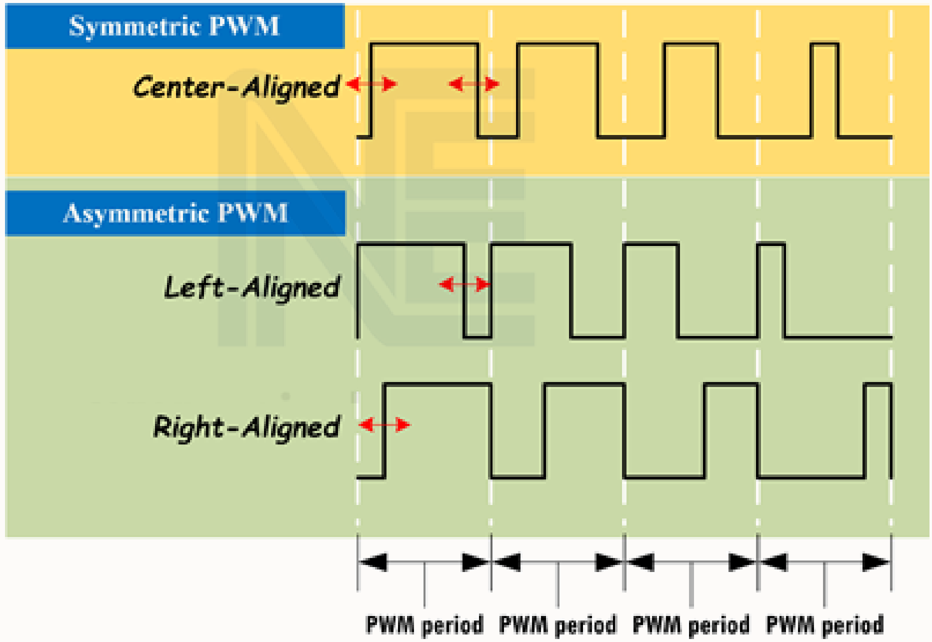
Source: J. I. Leon, et al, "The Essential Role and the Continuous Evolution of Modulation Techniques for Voltage-Source Inverters in the Past, Present, and Future Power Electronics," in IEEE Transactions on Industrial Electronics, vol. 63, no. 5, pp. 2688-2701, May 2016

Pulsewidth modulation (PWM)

Considerations:

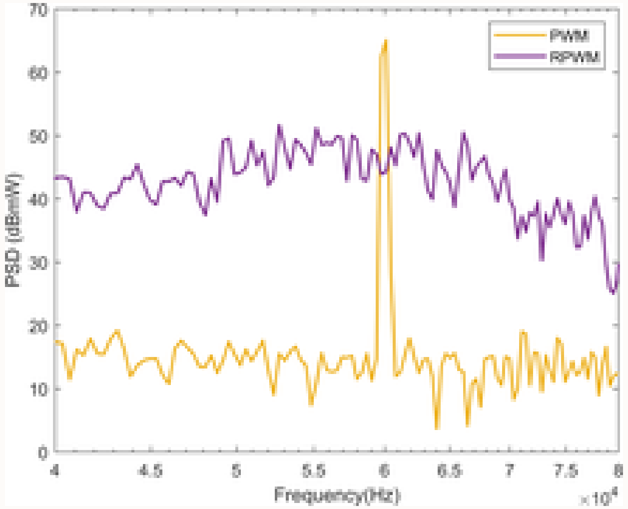
- Switching Frequency
- Efficiency
- Harmonic Distortion
- Control Complexity
- EMI Considerations
- Dynamic Response
- Sensitivity to Parameter Variations
- Compatibility with Control Strategy
- Power Rating
- Cost

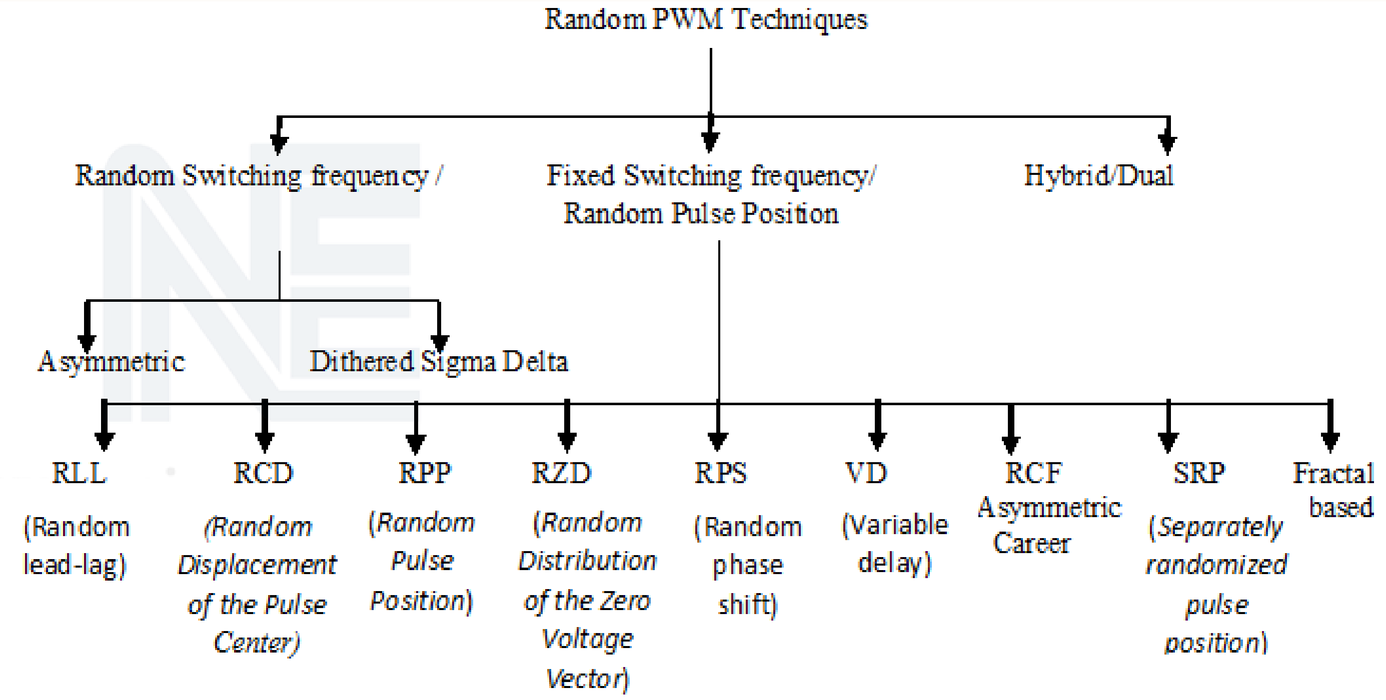
Example: Center-, left-, and right aligned PWM



All have the same average (DC) value but have different frequency spectra.

Randomization of PWM



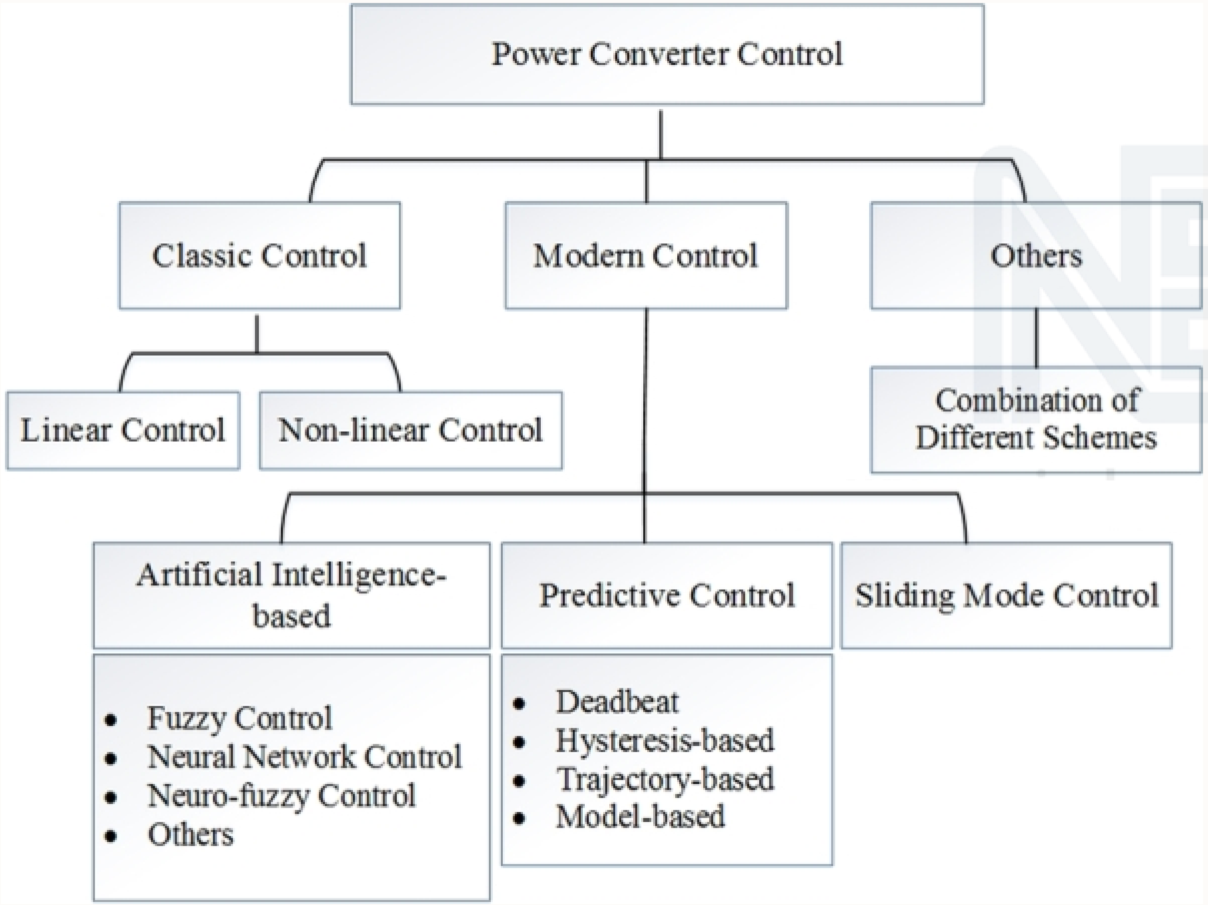


Typical effects

- Change discrete spectrum into continuous spectrum
- Introduce ultra low frequency component
- Frequency spreading for lowering electromagnetic interference

Advanced signal processing techniques are required.

Control algorithms



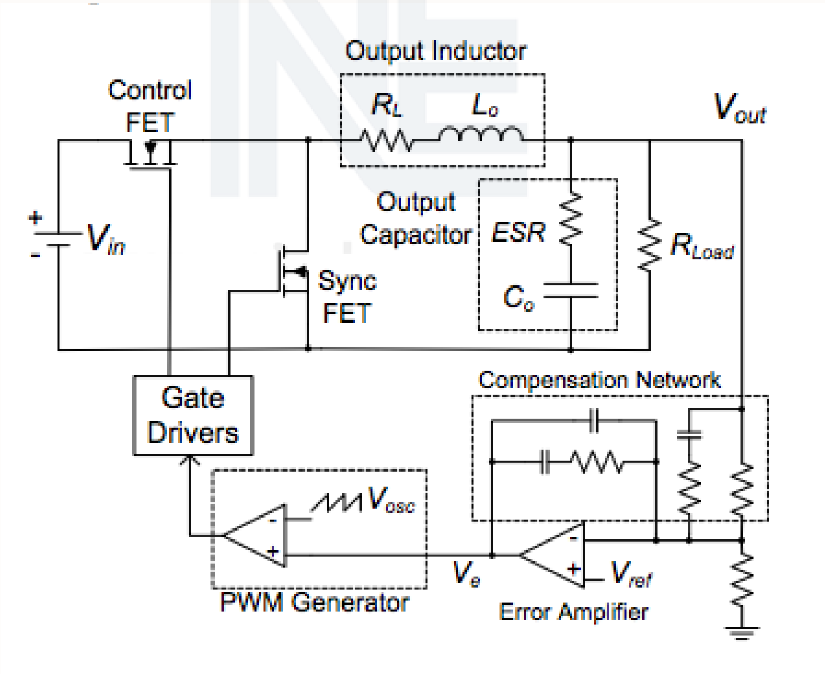
Considerations:

- System requirements
- Control objectives
- System dynamics
- Feedback sensors
- Control complexity
- Control strategy
- Response time
- Stability
- Robustness
- Compatibility with modulation technique
- Cost

Why machine learning?

Present scenario

There are significant advances in the hardware architecture for digital power, but the controllers are still designed in traditional approach – use of a digital controller to implement classical analog control laws or variants.



Source: http://s.eeweb.com/articles/2014/07/11/Compensator-Design-for-Buck-Converter-with-Voltage-Mode-Error-Amplifier-1405055837.png

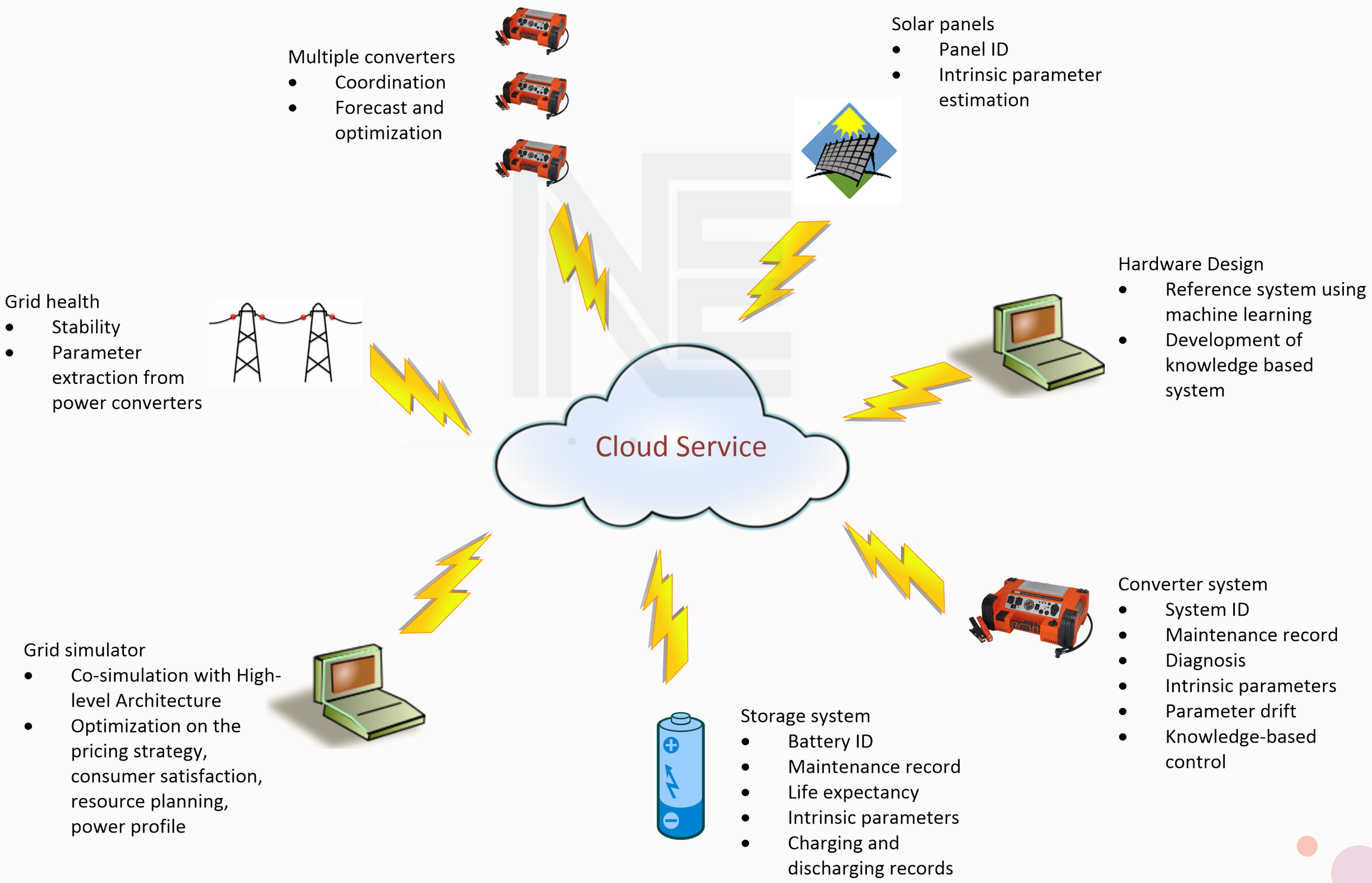
New-generation Smart Energy Systems

Future scenario – *Exploring the potential of digital controllers*

Apart from performing power flow control, the new-generation smart energy systems would have the abilities of

- extracting real-time intrinsic information about the connected entities
- determining and optimizing the operating points of the connected entities and operations of the power electronic systems
- tracking and forecasting static and dynamic operations of the power electronic systems
- forecasting the life expectancy of the power electronic systems and the connected entities
- alerting possible system failure
- centralizing and sharing resources of the intrinsic information about the connected entities through IoT and Cloud

Advancement with Cloud



Apart from traditional power conversion, Smart Energy Systems integrates machine intelligence to extract the status of the devices connected to them. Then, the operation of the entire system can be optimized.

With the growth of computational power of signal processors, learning algorithms that could not be implemented in the past can be realized in the future.

With the connection to the Cloud service, there is room for future expansion of information exchange and resource sharing extracted by the power electronic systems.

Conclusions

Numerous opportunities await our exploration!