Power Electronics
Principles, Evolution and Trends

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Part – I

Principles
What is Power Electronics?

Efficient Conversion, Conditioning & Control of Electrical Power
Using Power Semiconductor Devices
Why Power Conversion?

Incompatible Source and Sink

Source: www.pixabay.com
Conversion Functions

\[ AC \leftrightarrow DC \leftrightarrow AC \]

\[ \omega_i, v_i \leftrightarrow V_o \]

\[ V_i \leftrightarrow \omega_o, v_o \]
The Switch Matrix
Restrictions

KVL

\[ V_1 = V_2 = V_3 \]

KCL

\[ I_1 + I_2 = I_3 + I_4 + I_5 \]

Source: Wikimedia Commons
Switch Can’t be Closed!
Switch Can’t be Opened!
Source Must Be Dual To Sink

Voltage Source

Power Converter (Buck)

Current Sink (inductive)
Source Must Be Dual To Sink

Current Source

Power Converter (Boost)

Voltage Sink (Capacitive)
Passive Elements

L: Current-Stiff Element
Can interface two voltage sources

Source: Wikimedia Commons
Passive Elements

C: Voltage-Stiff Element
Can interface two current sources
Power Switching Devices

MOSFETs
IGBTs
SCRs
GTOs
IGCTs....
Part – II
The Evolution
History

1902-1920

Mercury Arc Rectifiers
Thermionic Vacuum Tubes

Triodes/Diodes as variable resistors (gate control)/current Control
History

1925-28:
The First “Inverter” using triodes as switches
(D. C. Prince, GE)

Source: Wikimedia Commons
Semiconductor Devices

- **BJT**: 1970s
- **Thyristor**: 1956
- **IGBT**: 1983

Source: Wikimedia Commons
Modern Power Devices

Ruggedness
Controllability
Modern Power Devices

Switching Time Losses
Modern IGBTs

60% Reduction in $V_{CE}$

Trench FieldStop

Infineon Module
Source: Wikimedia Commons
MOSFETs

Planar MOSFETs
(Conventional)

Source: www.eenewspower.com
Modern MOSFETs

SuperJunction MOSFETs

Source: www.eenewspower.com
Modern MOSFETs

Up to 50% Reduction in $R_{DS(ON)}$

Source: www.eenewspower.com

Gate Cap, Output Charge, Die Size
Challenges

• Packaging
  - Wafer Handling
  - Low $R_{th}$
  - Low $L_s$
## Wide Bandgap Devices

<table>
<thead>
<tr>
<th>Property</th>
<th>Si</th>
<th>SiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band gap energy (eV)</td>
<td>1.12</td>
<td>3.26</td>
</tr>
<tr>
<td>Breakdown electric field (V/cm)</td>
<td>(2 \times 10^5)</td>
<td>(2.2 \times 10^6)</td>
</tr>
<tr>
<td>Thermal conductivity (W/cmK)</td>
<td>1.5</td>
<td>4.56</td>
</tr>
<tr>
<td>Maximum junction temperature (°C)</td>
<td>200</td>
<td>600</td>
</tr>
</tbody>
</table>

SiC FETs

Source: micro.rohm.com
What Yole Development showed in 2011 as future view

A SiC supplier’s view of future

A Super Junction supplier’s view of future

Now that 600V GaN-on-Si is qualified, a GaN solution supplier’s view for future

Source: www.pntpower.com
The Old Question

MOSFETs Or IGBT?

Voltage Rating  
>1700V, <400V

Switching Frequency  
kHz, MHz?
The New Question

SiC Or GaN?

MOSFETs or IGBTs?
Control/Modulation

Mature

- PWM
- Predictive

Some Future Directions

- Heuristics based
- Model Based Control
What remains the same?

Topologies

Source: Wikimedia Commons
Major Topologies

- Bridge (2-Level, 3-Level)
- Interleaved Topologies
- Soft-switching (ZVT - LLC)
- Isolated Low Power Topologies
- Dual-Active Bridge (DAB)
- Current-Fed Dual Topologies

Architectures!
Bridge

\[ V_{DC} \]

\[ S_u \quad S_v \quad S_w \]

\[ d_{1u} \quad v_u(t) \quad d_{1v} \]
\[ d_{2u} \quad v_v(t) \quad d_{2v} \]
\[ d_{1w} \quad v_w(t) \]
Interleaved Boost
LLC Converters

Switching Network

Resonant tank

Rectifier

\( V_{in} \)

\( S_1 \)

\( S_2 \)

\( C_r \), \( L_r \), \( T_1 \)

\( n:1:1 \)

\( + \), \( V_o \), \( - \)

\( D_1 \), \( D_2 \)

\( R_L \), \( C_o \)
Isolated Low Power Converters
Integrated Low-Power DC-DC Converters

Source: Murata Power Solutions

Source: Linear Technology (Now Analog Corp)
Isolated High Power Converters

Dual Active Bridge

Source: researchgate.net
What remains the same?

Magnetics
Materials
Limitations

Source: Wikimedia Commons
Some Modern Trends

Geometry: Planar, PCB

Source: Wikimedia Commons
Application Areas
“Technology Space” in PE

New Areas

- Smart Grid: Evolution of Power Grid
- Distributed Power Systems
- Transportation: EVs, HEVs, More Electric Aircrafts, Ships.
Electric Vehicles

- Regenerative braking (AC/DC)
- On-board charger (AC/DC)
- Dual-battery system (DC/DC)
- Battery management for Lithium-Ion (Li-Ion) batteries
- 48V-12V bi-directional power supply
- 400V Battery Systems
- Bi-directional 400V-12V power supply (DC/DC)
- Traction motor (DC/AC)
New Targets

New Targets

Source: www.infineon.com/power
New Targets

- Power Density
- Efficiency
- Costs
New Paradigms

- Power Conversion -> Energy Management
- Converters -> “Systems”
- Life Cycle Costs

Source: mathisfun.com
Summary

• Trends in a mature field influenced by external factors

• More emphasis on system level design and optimization
References


2. KAWANO Masashi, HIROSE Jun And AIHARA Takashi, “Power Electronics Technology: Current Status and Future Outlook,” Fuji Electric


References

7. www.eenewspower.com

8. Industry Sources: Web sites of Infineon, Onsemi, Rhom, Mitusbishi Electric, IRF, Toshiba, etc.
Thank You