Switching Power Supplies
with
Soft Commutations

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OBJECTIVE

Demystifying power electronics

and

SMPS technology

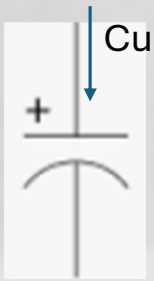
Switching Power Supplies

- Convert an electrical energy source from one form to another
- Power electronics is defined as the management of energy exchange between reactive components
  - Reactive components (capacitors and inductors) store and release energy
  - Power transistors and diodes manage energy exchanges to achieve the desired results.
- Examples:
  - Optimization of energy provided by solar panels (MPPT)
  - Energy transfer between batteries and the electrical grid in a UPS system

Reactive components / Energy bank

- The level of the bucket of water cannot change instantaneously; we need a water flow for a while
- The Voltage across the capacitor cannot change instantaneously; we need a Current flow for a while
- The Current in the inductance cannot change instantaneously; we need a Voltage across it for a while



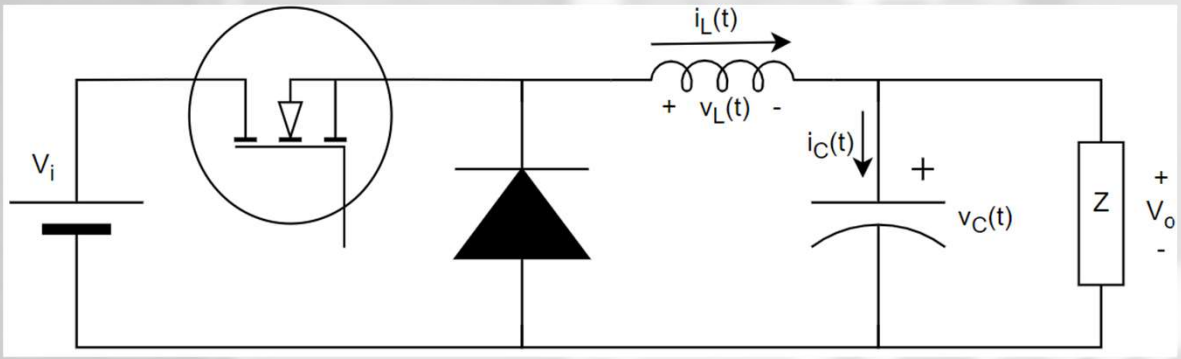




Switching Power Supplies Example

- BUCK basic topology
- The inductance (L) and the capacitor (C) are the energy banks interfacing the source (V_i) and the load (V_o)
- The voltage is applied to the load when the MOSFET is "ON" and no voltage is applied when it's " off "



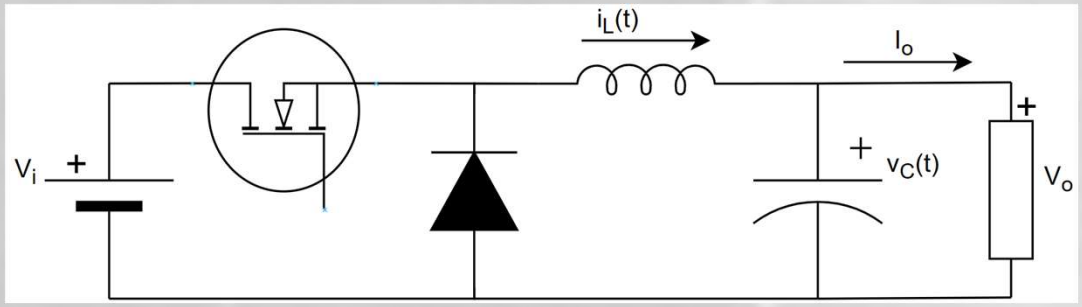


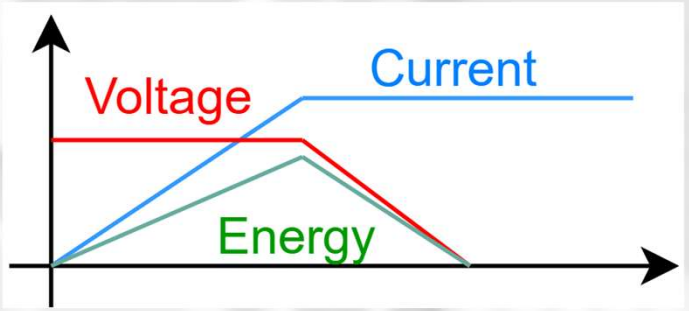
Problems to be mitigated

- Weight & Volume
- Operating Canadian standard voltage of 600Vac with standard semiconductors developed for American standard 480Vac
- Faster dynamic control to filter the 50th harmonic (Hydro-Québec's C.25-01 requirement)
- Reduce excessive EMI conducted and radiated with new SiC semiconductors
- Better Failure Rate
- Cost Reduction

Hard Switching Losses ON

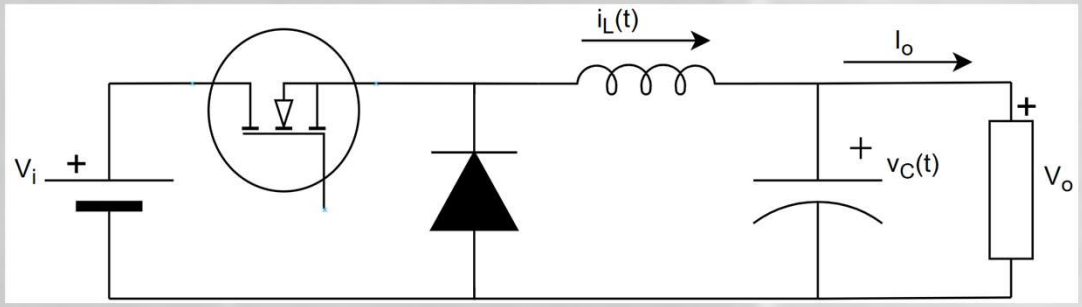
- The Current in the MOSFET (in **BLUE**) increase from zero to i_L when the gate voltage is applied and the maximum voltage V_i is applied across the MOSFET (in **RED**) during that time. The diode then becomes reverse-biased and its voltage starts building voltage from zero to V_i. The voltage across the MOSFET decreases as the voltage across the diode increases.
- Both V_i across the MOSFET and i_L in the MOSFET are simultaneously present and create a huge peak power in the transistor (for example, at 500V et 25A, the peak power is 12 500 Watts). The energy dissipated in the MOSFET is shown in **GREEN** that is the power dissipated with time.
- Switching frequency should obviously be reduced to keep the switching losses at a reasonable level

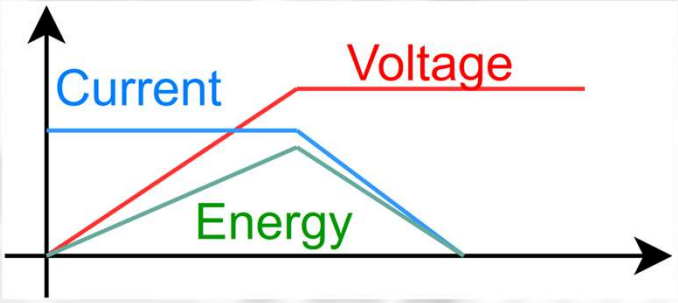




Hard Switching Losses OFF

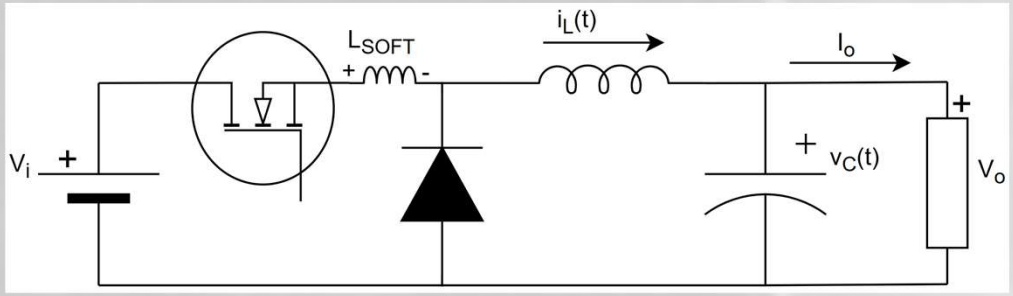
- The voltage across the MOSFET (in **RED**) increases from zero to V_i when the gate voltage is removed and the maximum current $i_L(t)$ circulates in the MOSFET (in **BLUE**) during that time. The diode then becomes positively polarized and starts conducting the current from zero to i_L. The current in the MOSFET decreases as the current increases in the diode.
- Both V_i across the MOSFET and i_L in the MOSFET are simultaneously present and create a huge peak power in the transistor (for example, at 500V et 25A, the peak power is 12 500 Watts). The energy dissipated in the MOSFET is shown in **GREEN** that is the power dissipated with time.
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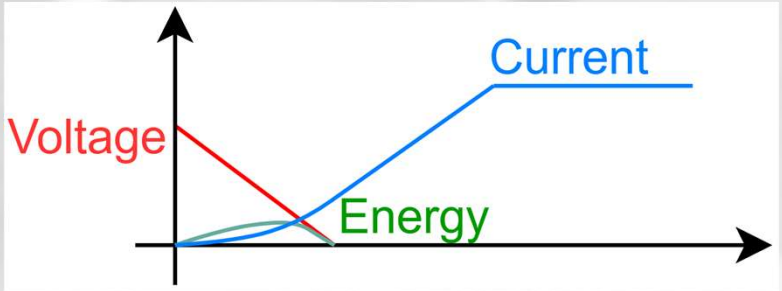




Soft Switching Losses ON

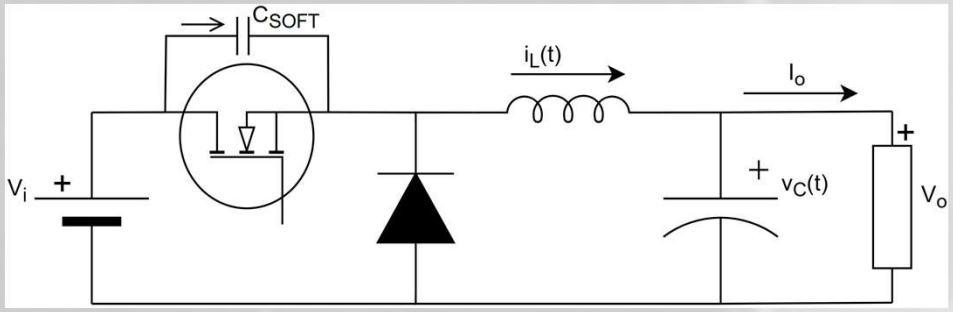
- The concept of the Soft turn-ON is to insert an inductance (L_{SOFT}) in series with the MOSFET
- The inductance slows down the current rise in the MOSFET which allows the voltage across the MOSFET to decrease as soon as the gate is up to "1"
- The minimum voltage and minimum current simultaneously generate very low losses

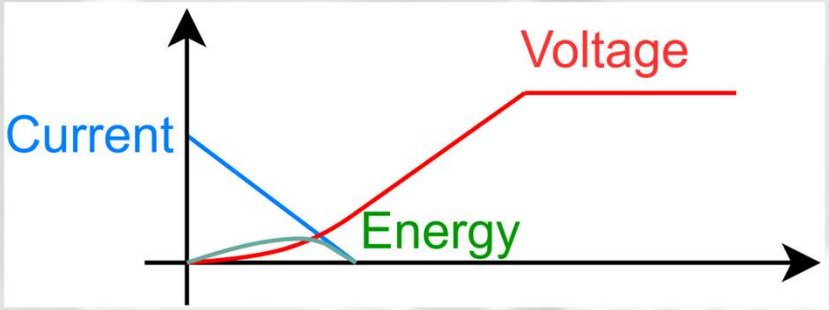




Soft Switching Losses OFF

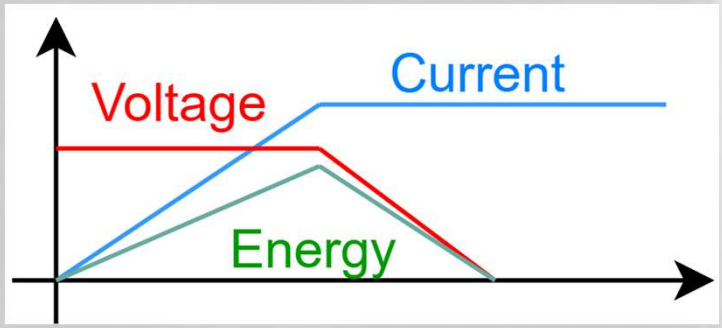
- The concept of the Soft turn-OFF is to place a capacitor (C_{SOFT}) parallel to the MOSFET
- The capacitor slows down the voltage rise across the MOSFET which allows the current of the MOSFET to decrease as soon as the gate is down to "0 "
- The minimum voltage and current simultaneously in the MOSFET generate very low losses



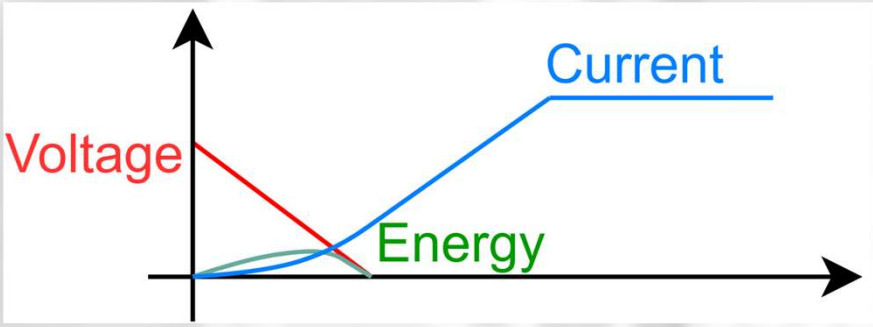


Soft and Hard Switching Losses Comparison

- The power dissipated in the MOSFET, in GREEN, is the result of the product of the voltage (in RED) and current (in BLUE) of the MOSFET
- The energy loss is the surface under the green curve, including the duration of the commutation
- Considering the amplitude (power dissipated) and duration of the commutation, SOFT switching losses are 20 times lower than HARD switching losses
- The same for the turn ON and turn OFF



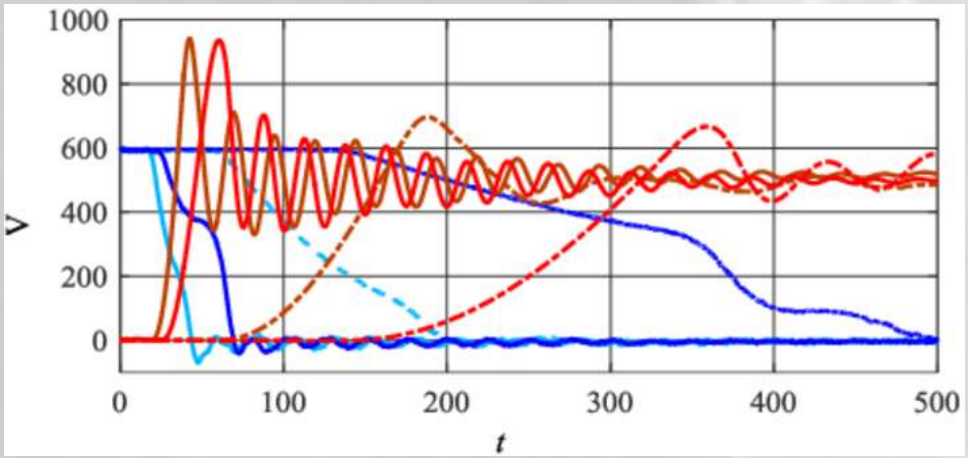
Turn-ON Hard Switching



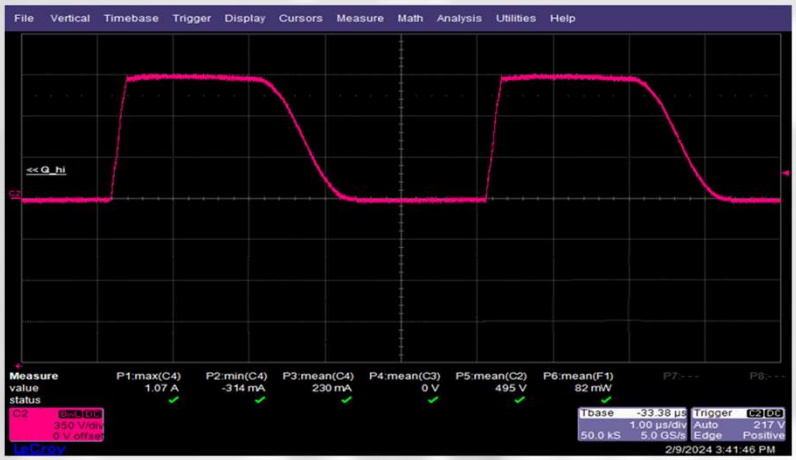
Turn-ON Soft Switching

Efficiency vs Overvoltage and Noise

- Power losses are reduced with faster switching but causes overvoltage and noise
- It is possible to slow down the dV/dt and dI/dt with Soft Switching
- SiC MOSFETs are very efficient but cause very high overvoltage



Overvoltage caused by high dV/dt in Hard Switching



Overvoltage with Soft Switching Technology

Higher operating voltage

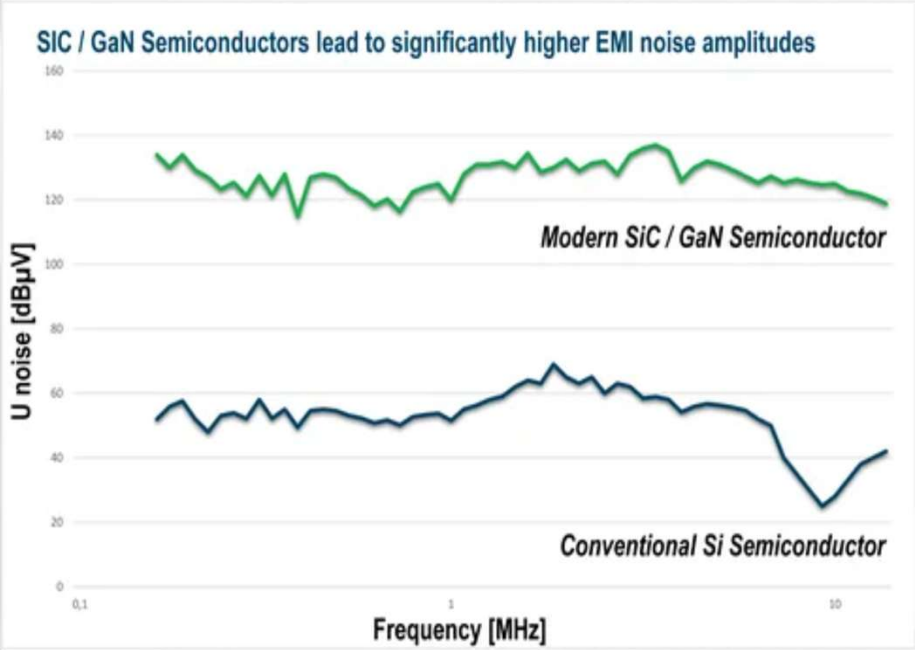
- The cost and performance of the MOSFETs deteriorate with higher voltage rating
  - The stress on a MOSFET caused by switching depends on the DC Input Voltage and the Output Current
  - The same MOSFET can operate at a higher DC voltage and then provide a higher AC voltage at the output
  - The same MOSFET rating can deliver higher output power with Soft Switching Technology
- The most optimized MOSFET in the industry is rated at 1200V to accomodate the 480Vac standard in the US
  - It is the most popular and cheapest
  - The 1200V rating MOSFETs adresses the American 480Vac applications
  - The Input Voltage may be increased to1000Vdc with the same 1200V rated MOSFET to accomodate the standard 600Vac in Canada

Higher Dynamic Response

- As per Hydro-Québec Standard C.25-01,
  - Odd harmonics of orders 3 through 50 must be attenuated
  - The bandwidth of power supplies connected to the Hydro-Québec grid must exceed 3 kHz. Soft switchiung means:
    1. Higher frequency
    2. Lower Output Filter
    3. Faster Dynamic

Excessive electromagnetic interferences (EMI)

- Advantage of SiC semiconductors:
  - Lower losses
  - Higher switching frequency
  - Lower Volume
- To benefit these advantages
  - Faster dV/dt and dI/dt induce higher EMI Emission
  - Faster dV/dt and dI/dt generate Higher Ringing Voltage

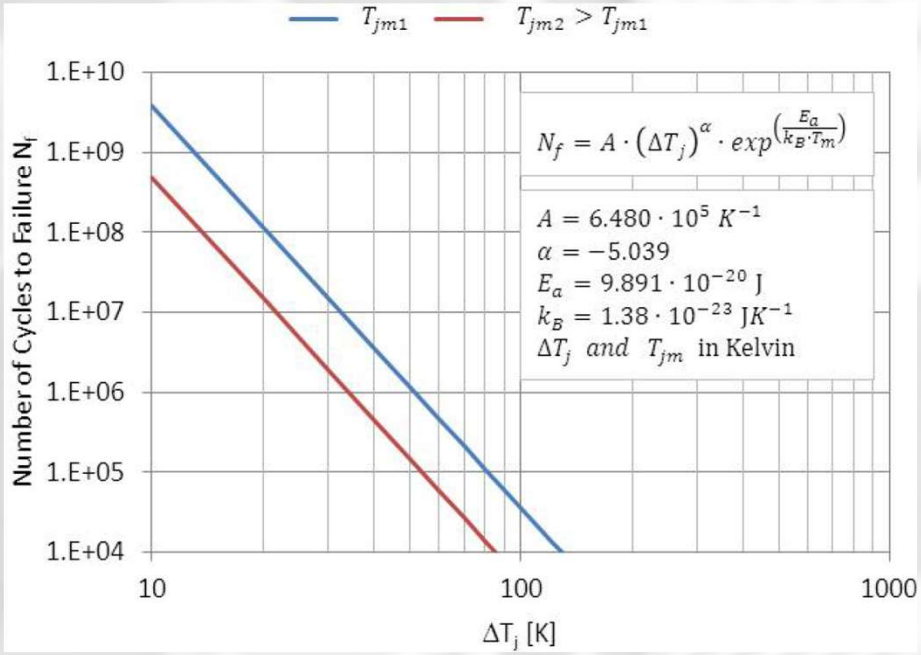


Reduced weight and size

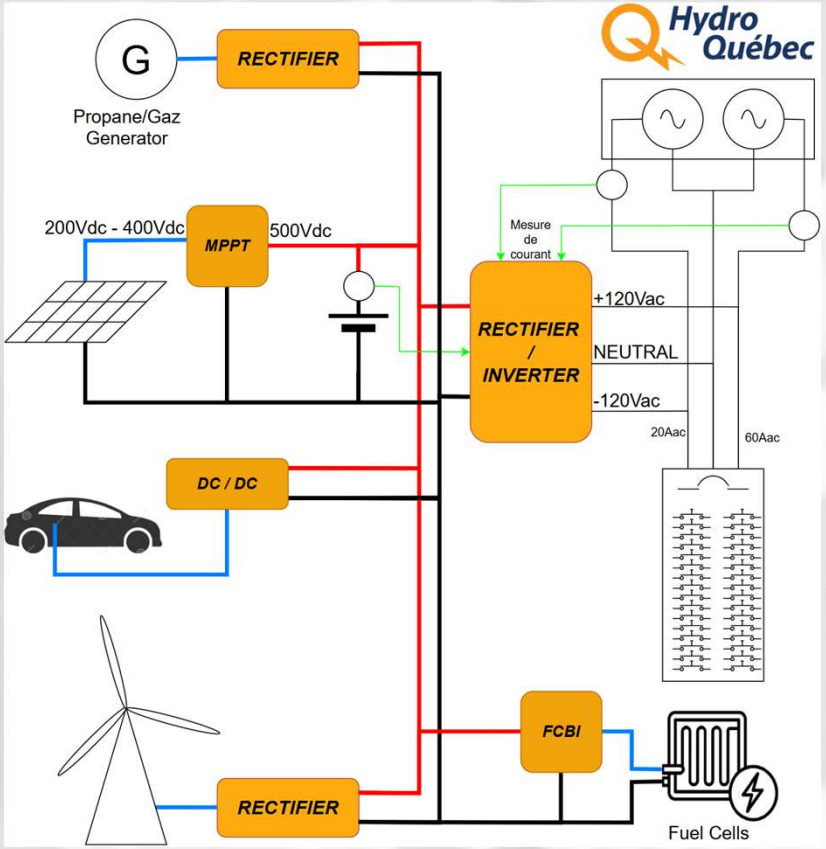
- Smaller reactive components due to the higher operating frequency
- Smaller Heatsink due to lower switching losses
- Almost no EMI Filter

Failure rate of semiconductors

- The primary failure mechanism in semiconductor devices is substrate delamination
  - Thermal Cycles are generated by the Peak Energy dissipated in the MOSFET
  - The second factor of Failure Rate is the operating temperature
  - Soft Switching Technology adresses these two main limitations



Soft Switching Technology Applications



CONCLUSION

Soft Switching Technology

- Reduces switching losses
- Improves efficiency
- Allows higher operating frequency
- Reduces weight and volume
- Provides an output voltage of 600Vac 3ϕ / 60Hz with 1200V rated MOSFET
- 50^{th} harmonics attenuated from the 60Hz grid voltage (3000Hz)
- Eliminates the EMI issue with fast SiC MOSFETs technology
- Improves failure rate caused by hard switching
- Lowers the overall COST

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QUESTIONS