Multiphase Permanent Magnet Motor and Interleaved Converter

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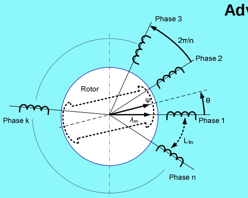
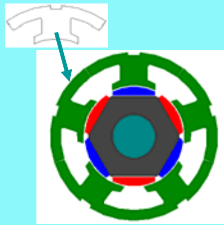
Multiphase Machines



Advantages

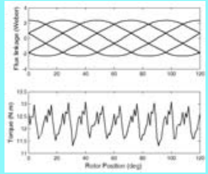
- Higher power density
- Increased reliability
- Torque pulsation frequency is increased but the amplitude is reduced
- Reduced stator phase currents
- Improvement of noise characteristics
- Reduced stator copper losses

Multiphase Modular Machines



- The stator phases are realized by modules.
- Stator coils are concentrated type.
- Integrated Power Electronic Modules (IEPM) are mounted on each stator modules
- Reduced cost
- Increased reliability

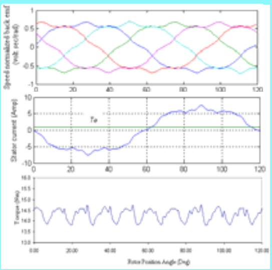
Optimum Control of Multiphase Machines



Torque Pulsation 14.4%

- concentrated windings and modularity cause large output torque pulsation.
- Torque pulsation can be reduced by: *i) Proper machine design: skewing, pole shaping, etc.* *ii) Current profiling : Modifying the stator excitation currents.*
- Current profiling technique reduces design complexity and manufacturing cost significantly.

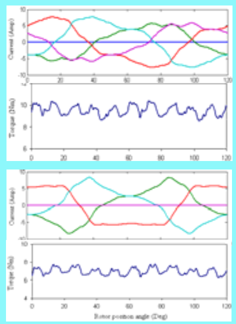
Optimum Control of Multiphase Machines



$$i^* = T^*.k/(k^T.k)$$

- Current profiling: excitation currents are modified to match the back emf in the stator windings.
- Optimum control can be achieved by minimizing the stator ohmic loss and constraining the output torque ripple to zero.
- Optimum current profiles can be calculated from the prior back-emf information of the machine.

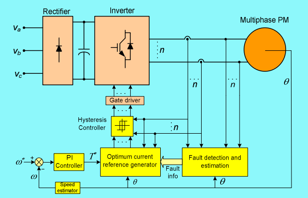
Optimum Fault Tolerant Control of Multiphase PM Machines



- Under fault condition, current in the healthy phases are controlled to compensate the faults.
- The machine is controlled to produce minimum copper loss and minimum output torque ripple. Furthermore, neutral current is constrained to zero.
- Control technique is developed for general n-phase machines and for any number of phase faults.

$$i^* = \frac{n_H T^T QK + T^T F^T QKQF}{n_H K^T QK - F^T QK\bar{F}QF}$$

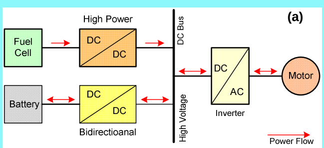
Fault Tolerant Control of PM Multiphase Machines



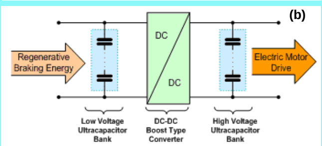
Block diagram of the proposed optimal fault-tolerant control scheme for an n-phase PM drive.

- Current profiles are calculated and stored in look-up tables.
- Rotor position, stator voltages and currents are sensed for fault detection and motor control.
- Based upon the fault condition, appropriate look-up table is used to generate the current references for the healthy stator phases.
- A hysteresis current controller generates gate drive signals for the voltage source inverter.

High Voltage Step-up High Power Converter

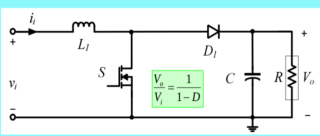


(a)Fuel cell based hybrid electric vehicle



(b) Ultracapacitor based regenerative braking energy storage system in hybrid electric vehicle

- Electrical Vehicles (EV) and Hybrid Electric Vehicles (HEV) have distributed energy sources: battery, fuel cell etc.
- Standard voltage level of these distributed energy sources are low (e.g. 42 V).
- Electrical motor is driven from high voltage DC bus (e. g. 300 V).
- High voltage step-up DC-DC converter interface is needed.

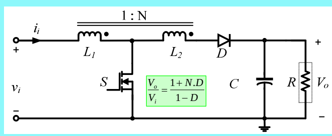


Conventional boost converter.

- Conventional boost converter is inefficient and not suitable for such high step-up applications. Due to:

- Extreme large duty ratio operation .
- Boost switch is subjected to high output voltage stress. MOSFET R_{ds_on} increases with a square law with its blocking voltage.
- Parasitic ringing increases loss & switch voltage rating further.
- For high power, high ripple current flows through the output capacitor and the diode. This causes significant losses and increases the size of the components.

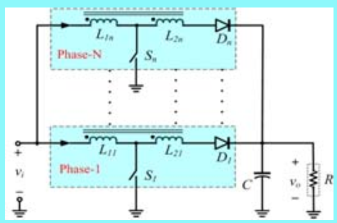
Efficient High Step-up Interleaved Coupled-inductor Boost Converter



Coupled-inductor boost converter

- Coupled-inductor boost converter can address the problems of conventional boost converter to achieve high efficiency.

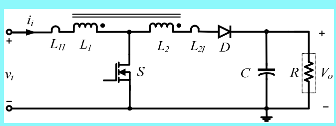
- Converter is operated at low duty cycle.
- Boost switch is subjected to a fraction of the high output voltage. Hence, high performance devices can be used.
- Diode and output capacitor are subjected to low-current ripple.



Proposed interleaved coupled-inductor boost converter.

- Interleaved coupled-inductor boost converter is proposed for high power application.

- Increased reliability.
- Reduced filter size.
- Better thermal management.
- Individual units can be operated at their best efficiency or can be kept standby to operate the interleaved converter with high efficiency over a wide range of load.

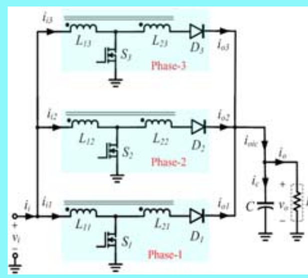


Practical coupled-inductor boost converter.

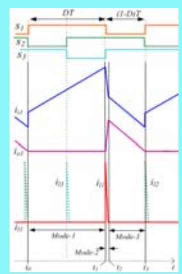
- Practical converter have leakage inductance

- Large voltage spikes across boost switch. - Leakage loss.

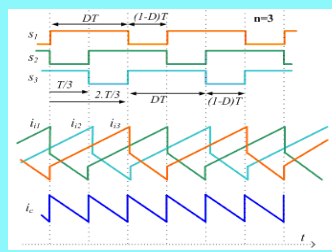
Boost Converter Clamp for Interleaved Coupled-inductor Boost Converter



Coupled-inductor boost converter with the proposed boost converter clamp



Operation modes of the converter



Output capacitor charging current of the interleaved converter.

- A boost converter clamp circuit is proposed.

- Clamps the all the boost switches to a lower voltage. Controlled reversely: input voltage is regulated.
- Processes only leakage energy.
- Recycles the leakage energy to output capacitor.
- Uses single clamp capacitor.
- Common active clamp circuit.
- Duty cycle of boost converter clamp is not is not extreme. Can be operated efficiently.
- Can be used for output ripple cancellation.
- Interleaved units and clamp circuit can be modular.

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