Electrical and Computer Engineering

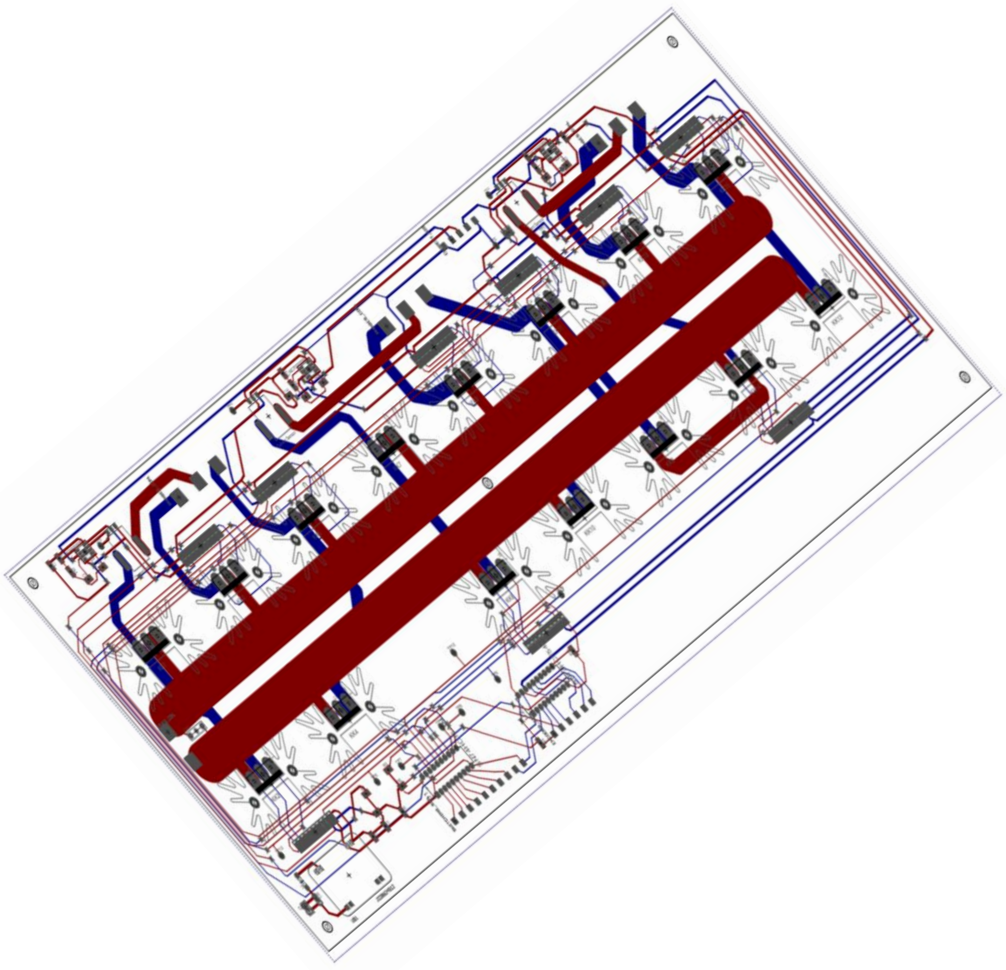
Switched Reluctance Machine Controller Design

Quantum Motors Corporation has this completed and ready for production. Step One is Cooling Towers (5HP Level) a 4 Billion Industry. May 10, 2022

Introduction

This first report of switched reluctance machine controller design project presents;

- The Machine Model
    - Geometrical model and Finite element analysis (FEA)
    - Obtain characteristic of the machine
- Converter Topology
    - Literature review
    - Tests and comparison

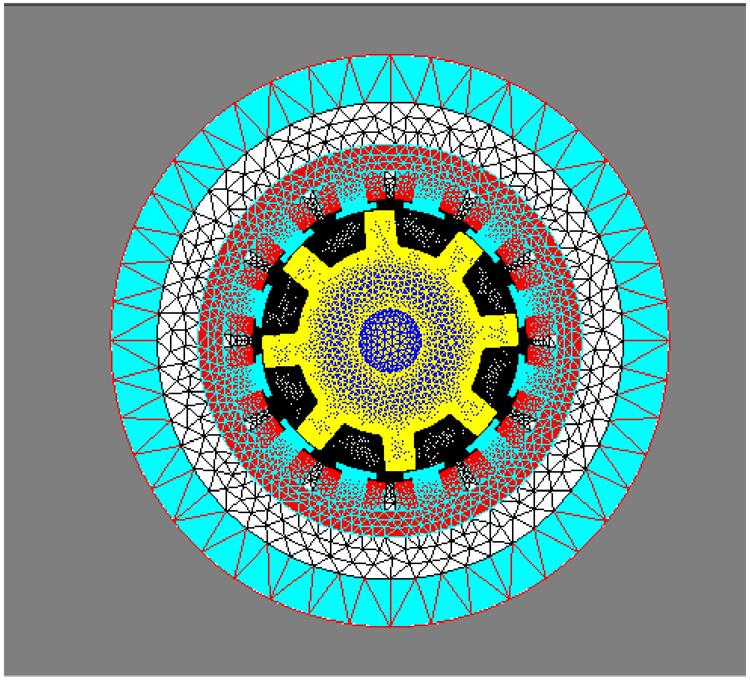


The Machine Model

Finite Element Analysis

1.5kW 3 phase 12/8 SRMs are modeled geometrically. The detailed model obtained from geometrical specifications which include airgap, rotor and stator dimensions, overlapping, taping and operation conditions of the machine.

Steady state and dynamic behaviors of the machine have been obtained via finite element analysis (FEA). The method analyzes magnetic distribution and magnetic performance of the machine.



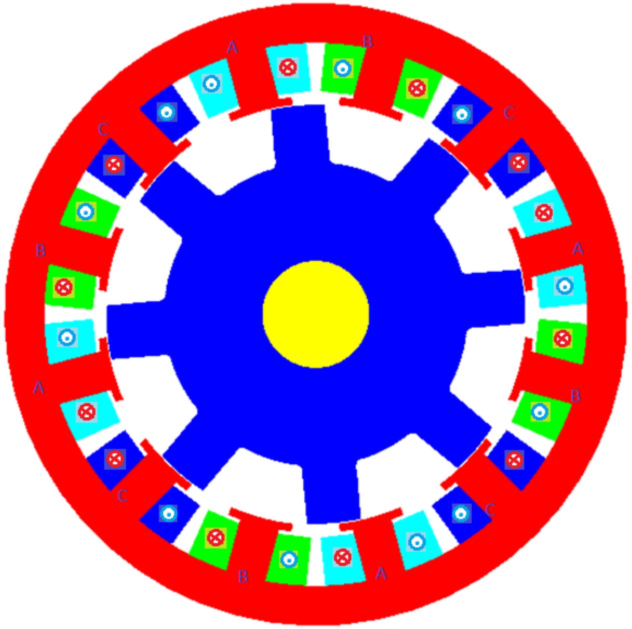
1.5kW 12/8 3 phase Switched Reluctance Machine

The Machine Model

Finite Element Analysis

The windings are presented on the coil of the geometrical machine model. They are connected as series configuration with opposite polarities between the following phase pole. In this configuration, stator phase coils are sharing the current.

Each pole has 8 number of turns.



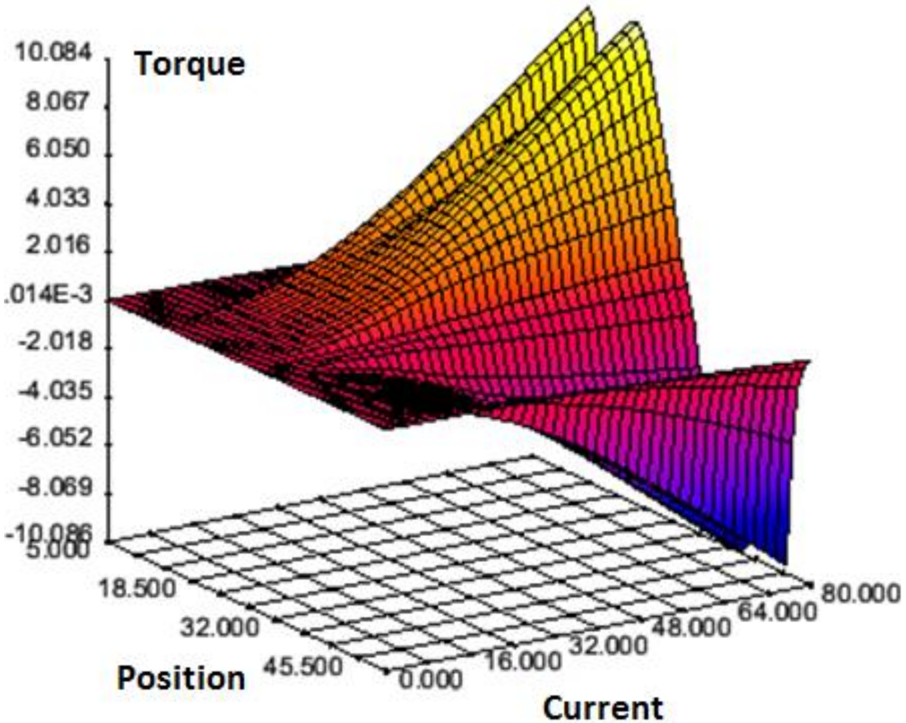
Winding Configuration of the machine

Characteristic of The Machine

Torque and Flux Characteristic

To obtain torque and flux characteristic of the machine, phase A energized one electrical cycle by constant current which slipped 0 to 100A with 2A step.

Other phases characteristics are only phase shifted from the phase A.

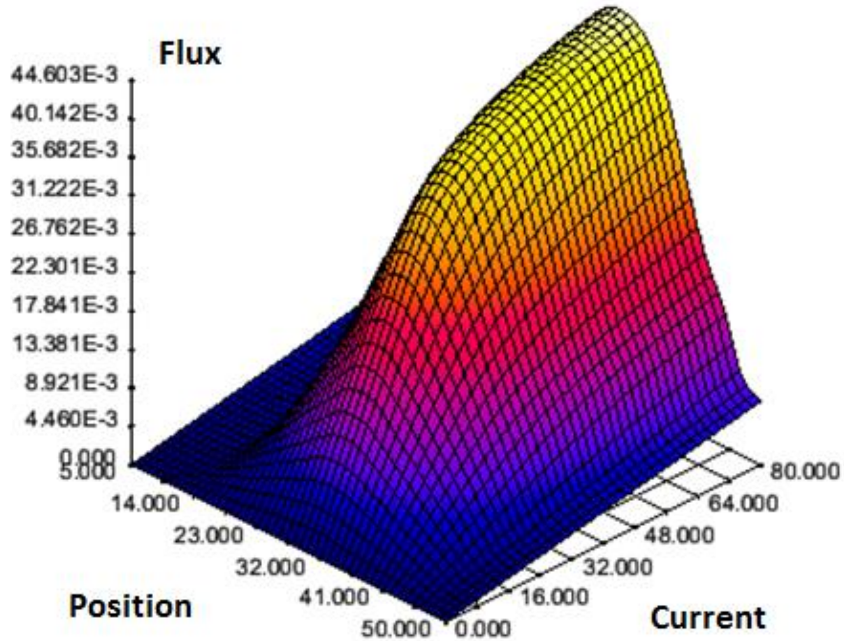


Characteristic of The Machine

Torque and Flux Characteristic

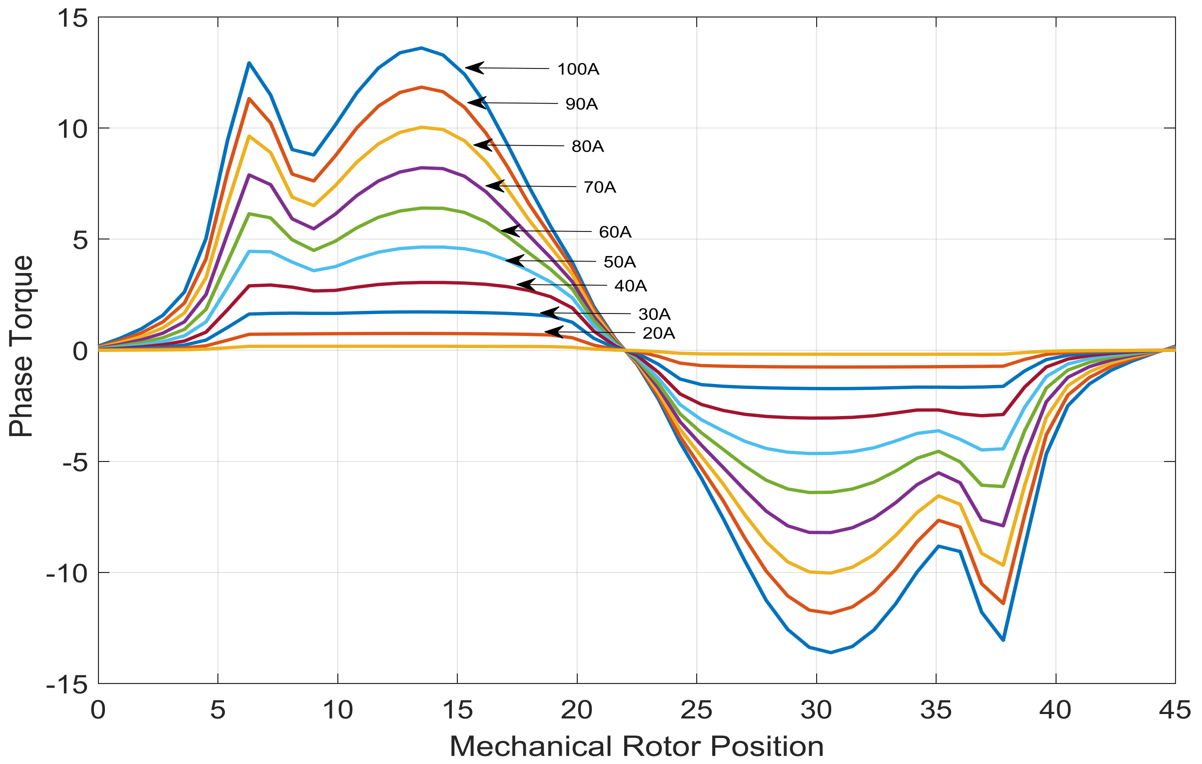
Torque-current-position $(T - i - \theta)$ and flux-current-position $(\lambda - i - \theta)$ characteristics are obtained from geometrical model of the machine.

Integration of the phase voltage gives flux and given position and current values point the flux value.



Characteristic of The Machine

The machine phase torque characteristic with respect to rotor position at different current levels from 10 to 100A shown. Torque ripple increases when the higher current needs. Total output torque of the machine can improve with optimum converter and control method.



Characteristic of The Machine

Current Density

The current density criteria was considered by limiting the RMS
current for each phase, according to totally enclosed non-ventilated (TENV) cooling maximum current which tolerate from machine ;

$$J = \frac{I_{rms} N}{2 K_s A}$$

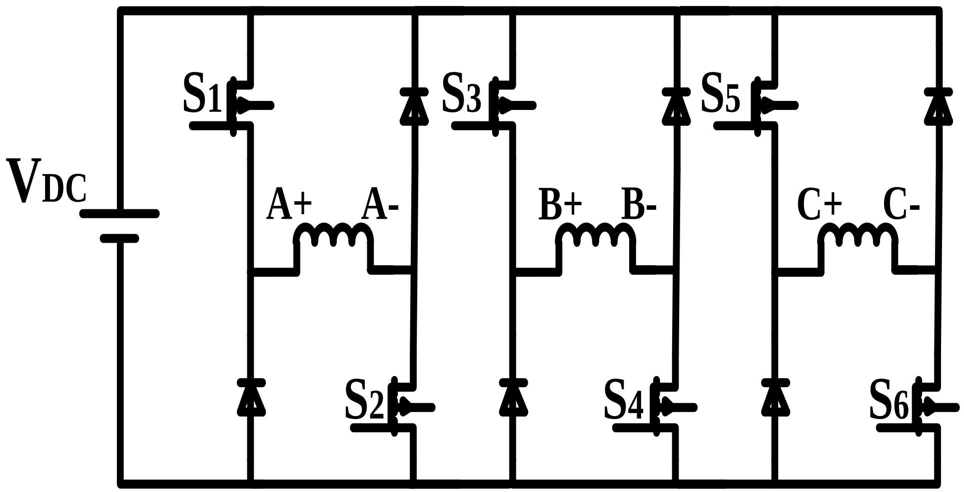
J is the current density A/mm2 which chosen as 5A/mm2. N is number of turns (8), Ks is the slot-fill factor 0.45 (guess), A is the slot area 313.07 mm2.

$$I_{rms}=176A$$

Converter Topologies

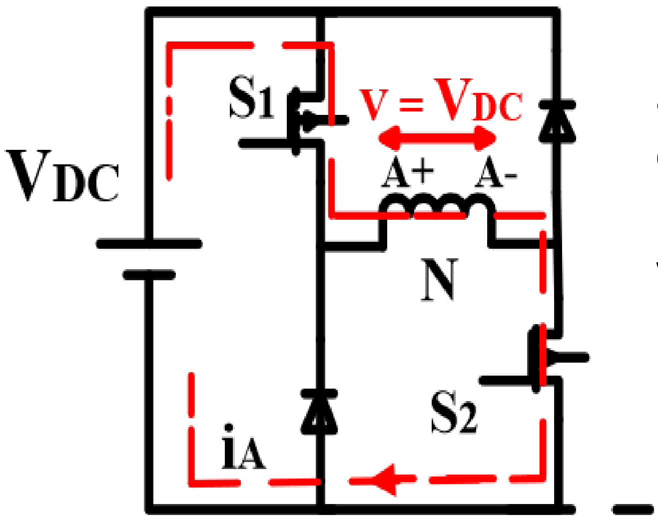
For switched reluctance machine drive, unipolar current and, electrically isolated stator poles allow several power converter topologies. In this report only h-bridge (asymmetric), c-dump and proposed converter topologies are modelled and tested with the machine model.

Asymmetric/novel converter is the most common power converter which has two switches and two diodes for each phase.



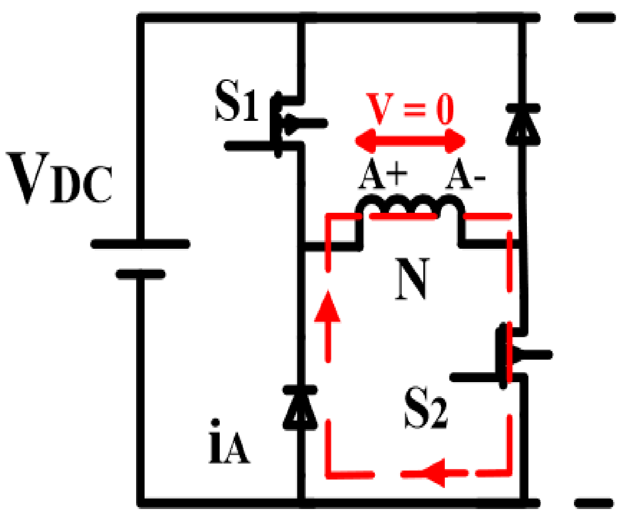
Asymmetric/H-Bridge converter

Asymmetric Converter

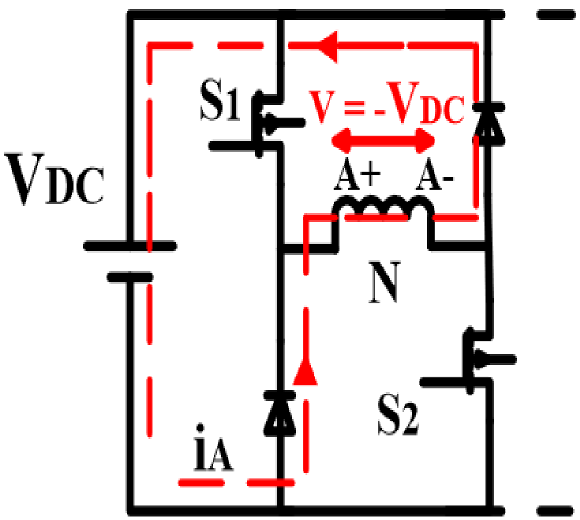


DC bus voltage is applied across the phase windings, allowing the phase current to freely build up within a certain limit defined by the controller.
For the magnetization mode, the two switches are ON while the two diodes are reversed biased

In which zero voltage is applied across the phase windings, to allow the current to discharge slowly in order to follow the desired reference current defined by the controller.
For the freewheeling mode, one of the switches and its associate diode are ON



Asymmetric Converter

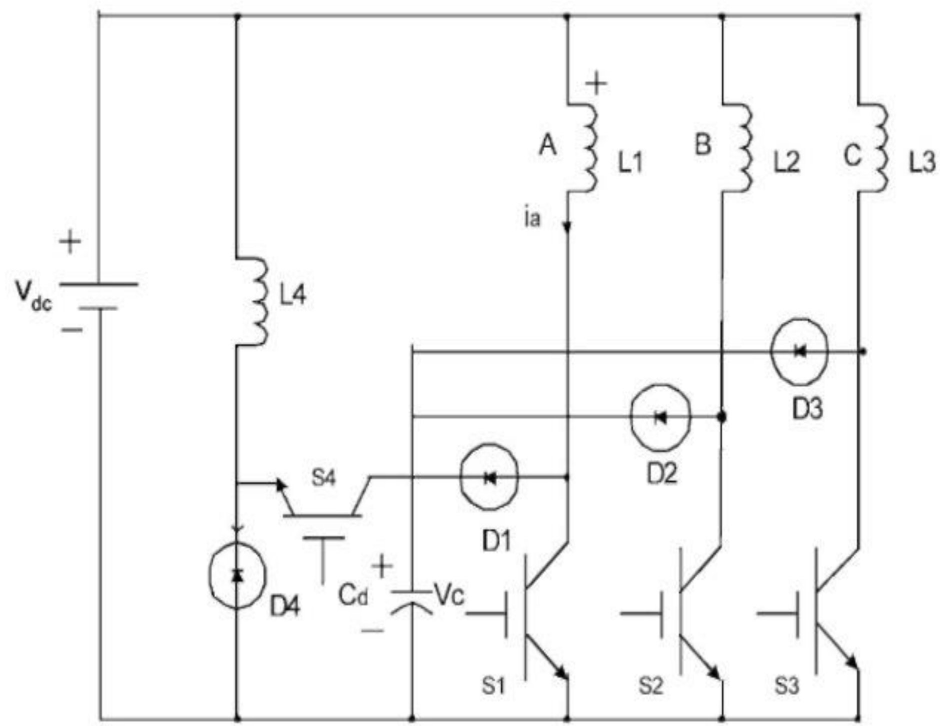


The demagnetization starts when the controller turns the two switches OFF, and the phase windings will be connected to the DC bus with a reversed configuration, hence a negative DC bus voltage will be applied across the phase winding through the two diodes.

C-dump Converter

The C-dump converter has lower number of elements per phase which decrease cost and switching losses.

C-dump converter is capable of giving a good performance, the size of the dump capacitor, the voltage rating of the capacitor and the switching devices, the control requirements and the energy dump inductor makes the converter expensive and complicated.



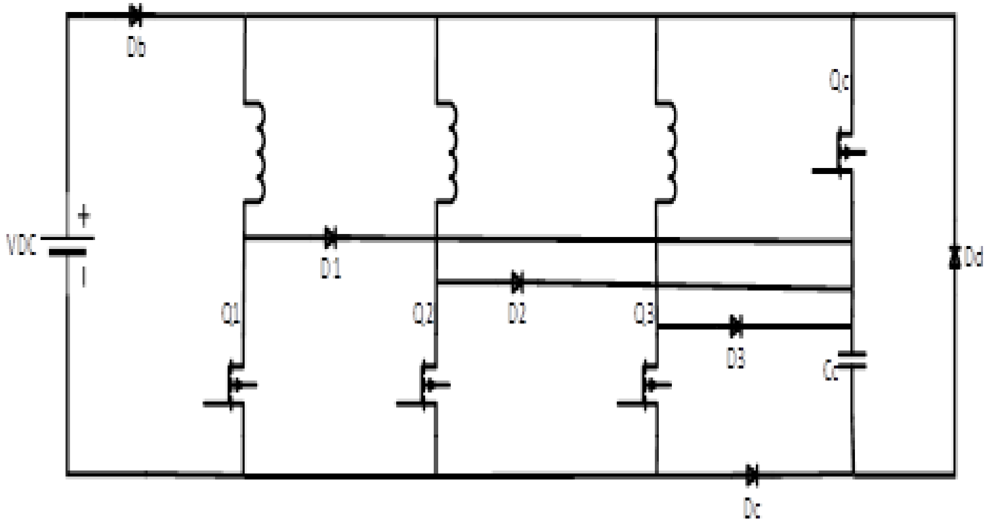
C-dump converter

Energy efficient C-Dump Converter

The dc voltage source is not in the path of demagnetization.

The voltage of the capacitor is maintained at Vdc, which applies -Vdc across the off going phase during demagnetization.

The reduced level of capacitor voltage in this converter cuts the size of the capacitor energy storage to one-fourth of that in the conventional C-dump converter.



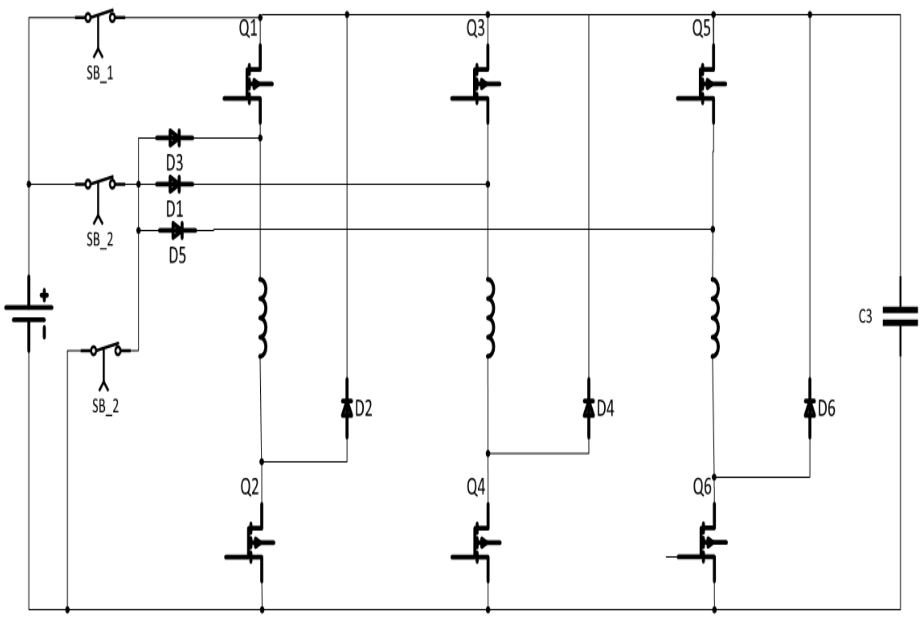
Energy Efficient C-Dump Converter

Proposed Converter

The proposed converter topology have been developed to use as conventional asymmetric and new type converter via positioning to relays.

Dump capacitor stores at least two times as bus voltage to implement a negative voltage on the phase during the demagnetization.

The upper side switches regulate to dump voltage on the capacitor. Each one uses during its phase exciting



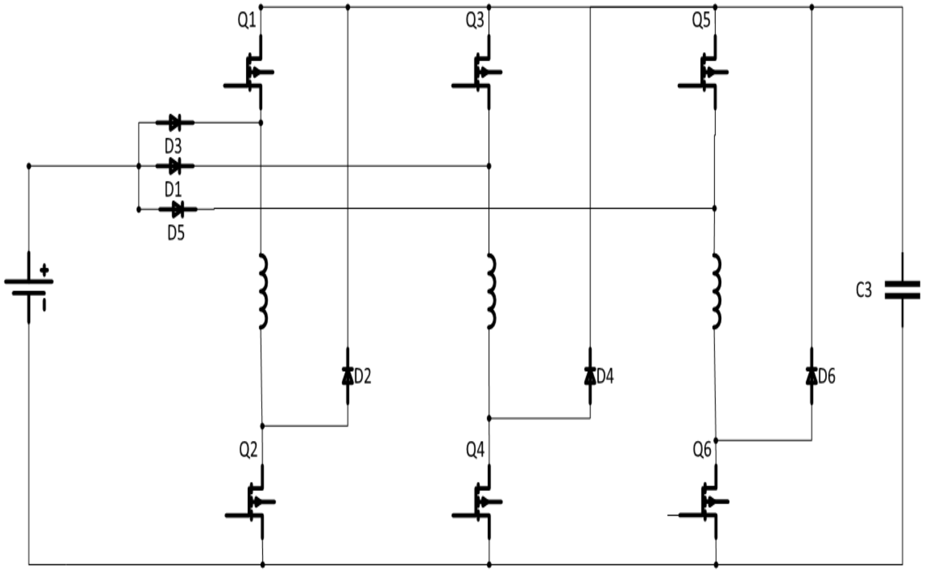
The proposed converter

Proposed Converter

The advantages of the new converter topology are;

- Both conventional asymmetric and new topology can use
- Magnetization is improved with 2Vdc dump voltage
- Lack of inductance
- Dumping switch frequency is reduced,
- Dumping voltage regulate via three switched, more robust.

The main disadvantage of the converter is voltage drop into diode which is on magnetization and demagnetization path.

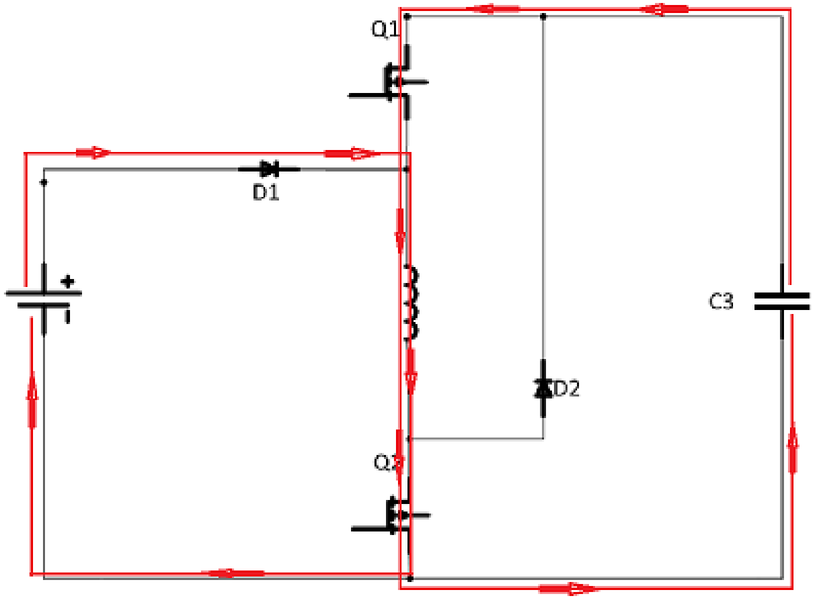


The proposed converter

Proposed Converter

The lower switch is used to regulate phase current and the upper switch responsible to keep dump capacitor voltage at desired value. If the upper switch is on capacitor voltage regulated by DC bus voltage.

When both switch is on, dump capacitor voltage 2Vdc is applied to phase, that allows us to push more current on the phase.

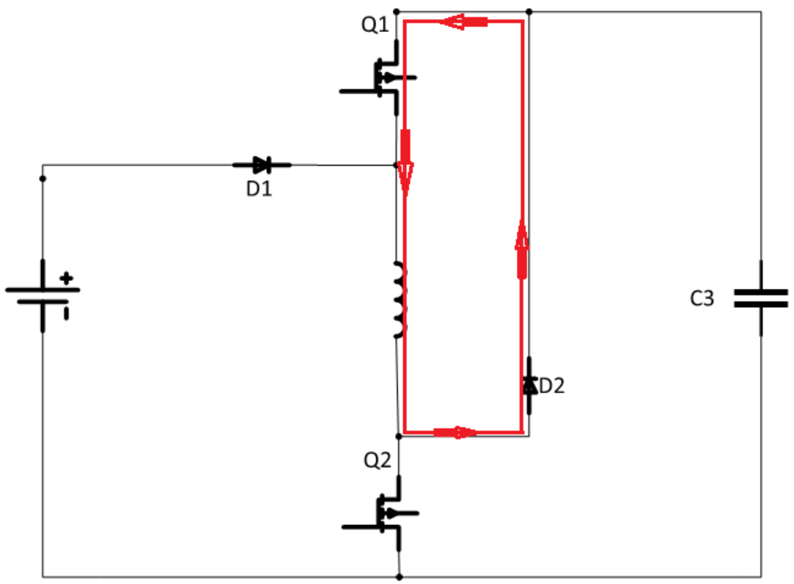


Magnetization Period

Proposed Converter

The converter allow us use freewheeling mode to apply zero voltage on the phase. When the upper switch is on, the lower one can regulate the phase current with soft chopping.

The main advantage of the soft chopping is reducing switching frequency and that reduces the switch losses.

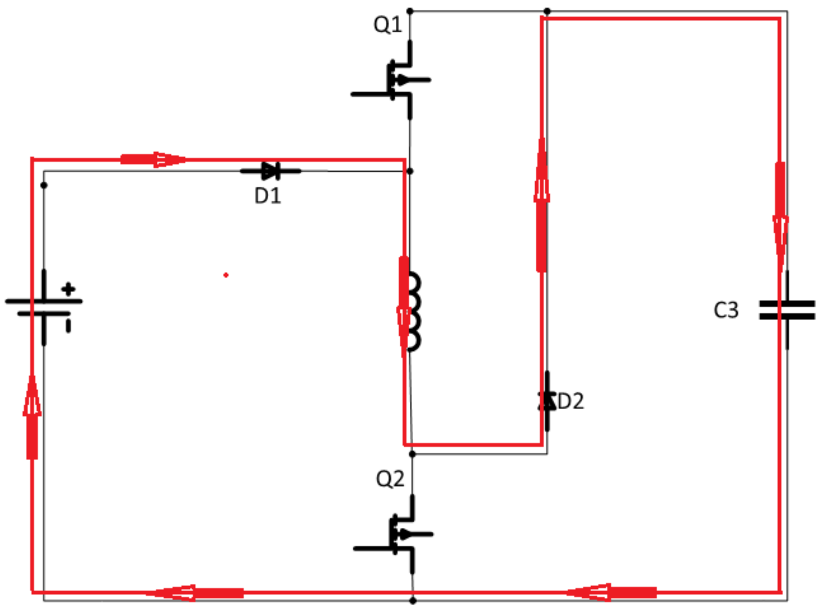


Freewheeling Period

Proposed Converter

Phase demagnetization path goes on the two diodes around phase winding and energy recovered to DC source as shown.

To apply –Vdc on the phase winding, dump capacitor stored at least 2Vdc voltage.



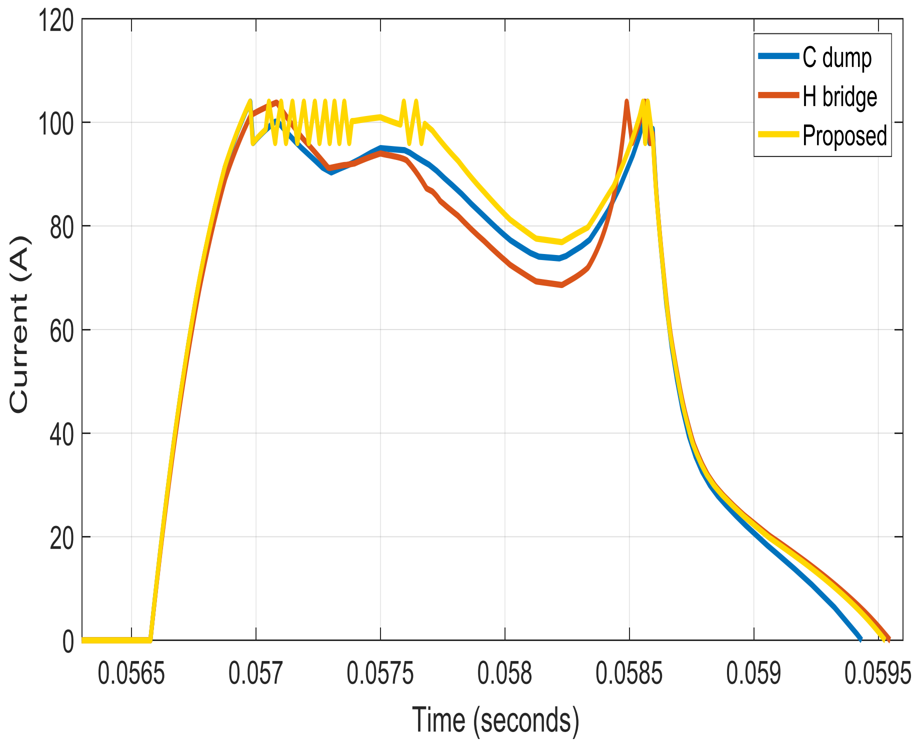
Demagnetization Period

Comparison of The Converters

Phase current with 100A reference at 1600 rpm shown in the figure, on c-dump, h-bridge and proposed converter. Higher magnetization voltage (2Vdc for new topology) improves current profile.

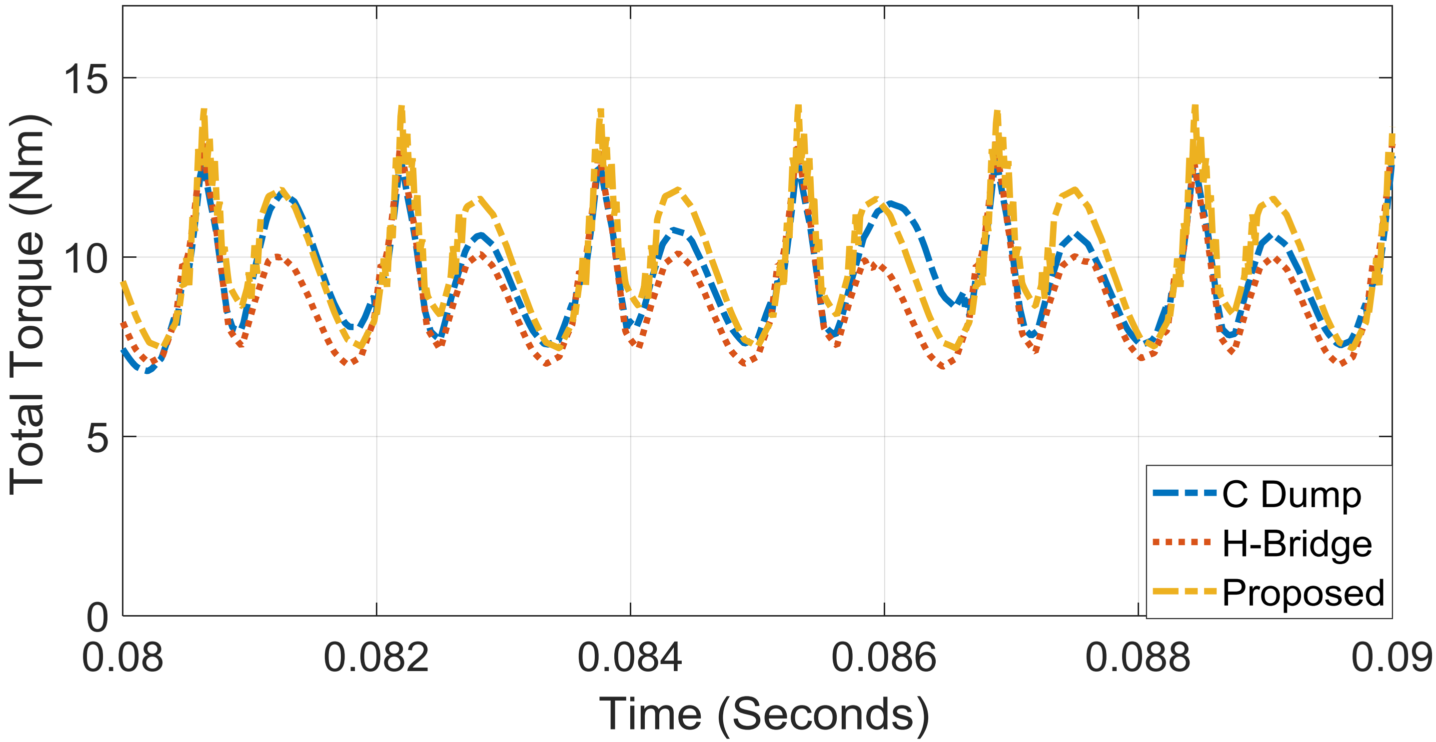
As a result improving current profile, the torque profile is improved with reducing torque ripple for the same reference current and bus voltage.

Power-speed and torque-speed characteristic shows the improvement of the converter.

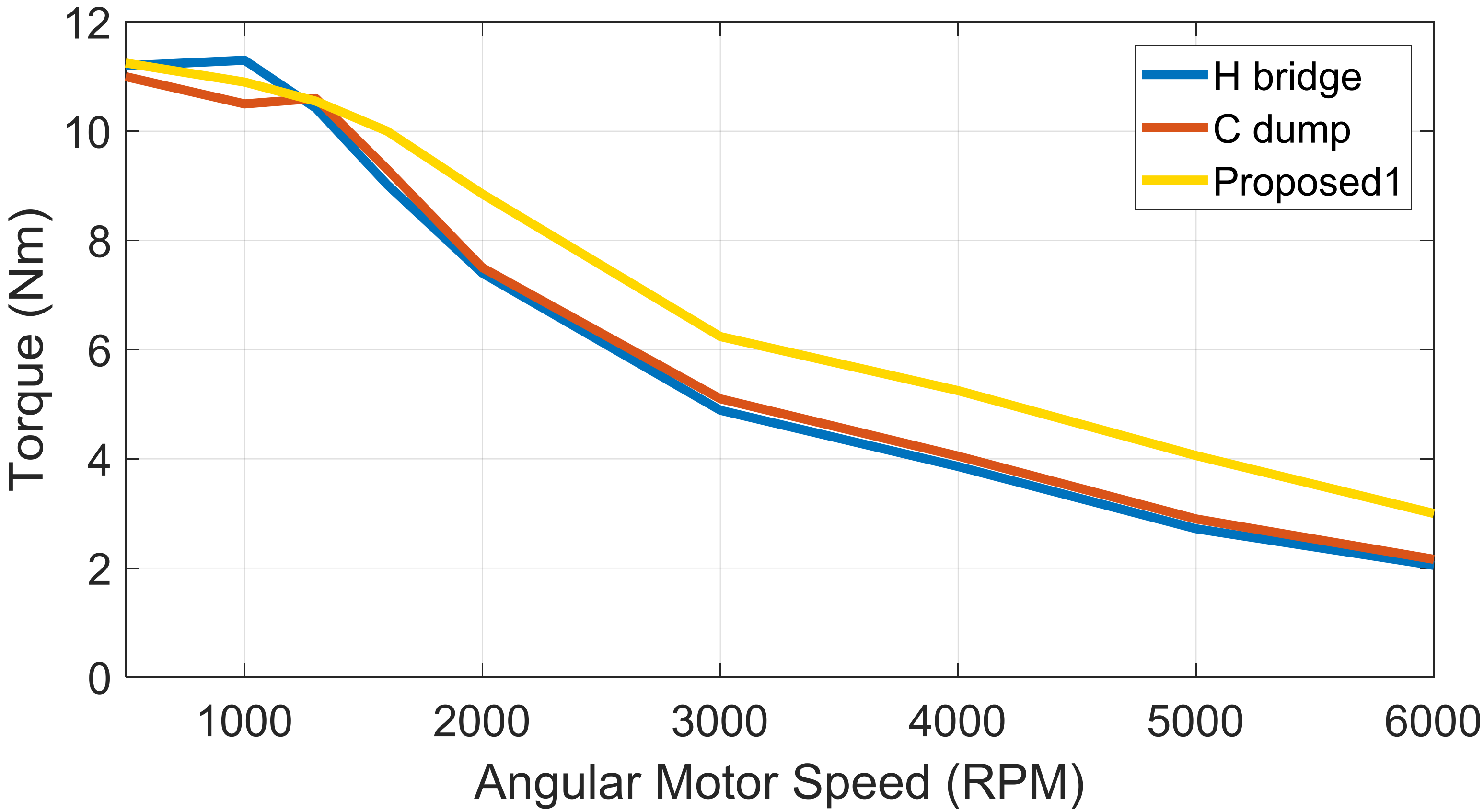


Phase Current Profiles

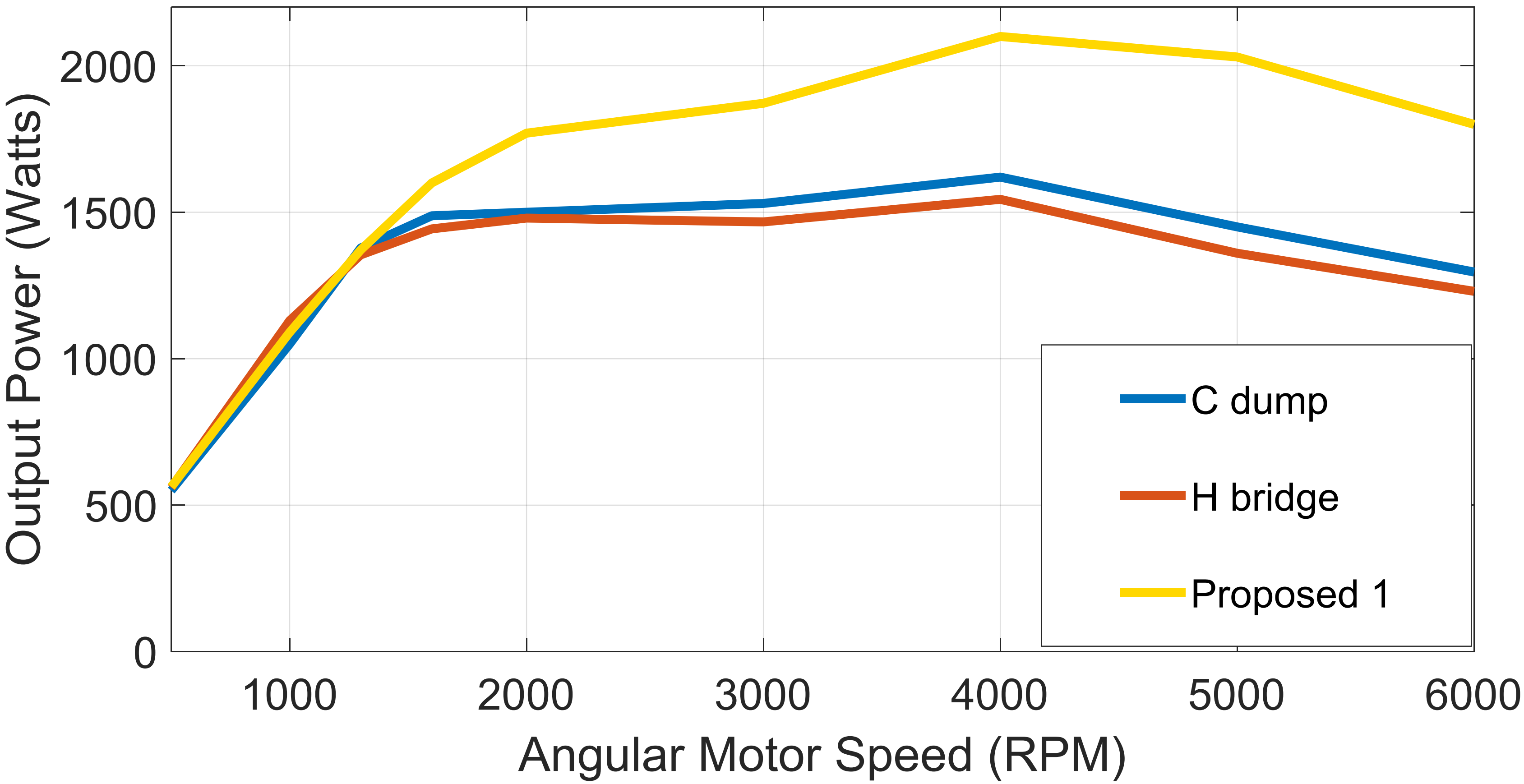
Comparison of The Converters



Comparison of The Converters



Comparison of The Converters



Selection of the Components

Inductance and capacitance values for converter topologies are investigated at given operational specification.

ΔV_{dc}=$\sqrt{V_{dc}^2 - I^2\, {}^{L}/_{C}}$ - V_{dc}

$L_d = ({}^{\Delta V}/_{\mathrm{Imax}})^2\ C_d$

$L_d = 0.2\ mH$

$C_d = 2000\mathrm{uF}$ for conventional c-dump and proposed converter

$C_d = 1000\mathrm{uF}$ for energy efficient c-dump and Asymmetric converter.

$V_{dc} = 42V$

I_{ph_ref}= 100A

I_{ph_rms}= 60A

Current Bandwidth=4A

ΔV_{dc}= 3V

Questions

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