Voltage Boost Type Drive Circuit without Additional Reactor for Switched Reluctance Motor

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Abstract :
When switched reluctance motor (SRM) is driven, higher input dc voltage of inverter, which is drive circuit of SRM, is preferred because SRM winding current can rise or fall faster in higher dc voltage. However, in EV application, it is difficult to use high-voltage battery. As a solution, voltage boost converter is inserted between the battery and the inverter. This solution requires additional reactor; thus, the circuit size becomes large. In this presentation, a novel SRM drive circuit with voltage boost function without additional reactor is presented.

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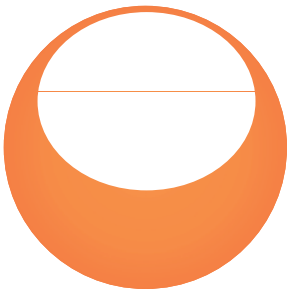
Outline of Today's Presentation

1. Research Background
2. Introduction of the project "Research and development of high-speed switched reluctance motor and 3D motor " sponsored by New Energy and Industrial Technology Development Organization (NEDO).
3. Introduction of Conventional Drive Circuits for Switched Reluctance Motor
4. Proposed drive circuit
5. Conclusion



Research Background

Prevalence of Low-emission Vehicles

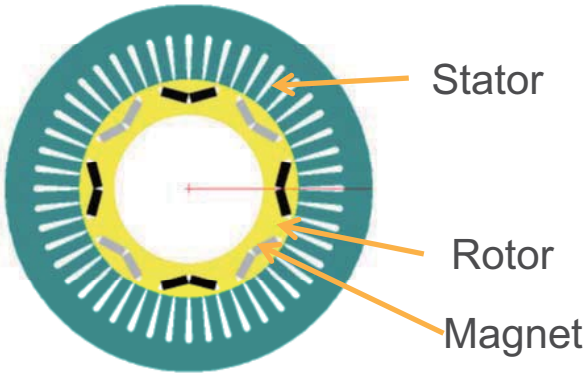
Low-emission vehicles are expected to expand and grow more prevalent in order to protect the global environment.

Example of vehicles driven by motors

- Hybrid electric vehicles such as Prius and Insight
- Electric vehicles such as iMiEV and LEAF
- Fuel-cell-powered vehicle such as FCX CLARITY

IPMSM（interior permanent magnet synchronous motor）is generally used as the traction motor.

Structure of PMSM and its driving method



- Rotating magnetic field is generated by applying three-phase AC voltage to the stator three-phase windings.
- Torque is generated by interaction between stator current and flux-linkage.

Permanent magnet synchronous motor and rare earth issue

Interior permanent magnet synchronous motor

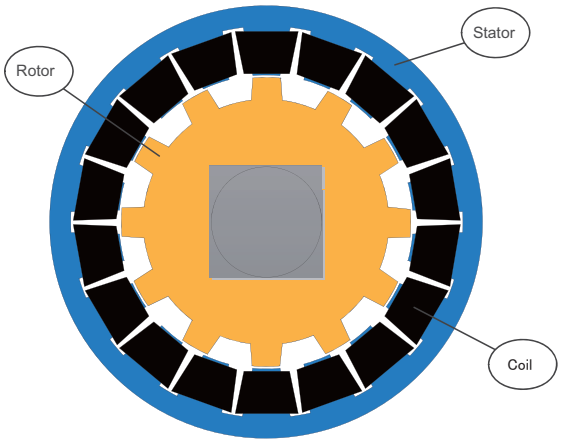
⇓

Rare earth is used for its permanent magnet

Maldistribution of resources exporting countries
⇒Price increase and strategic items
(resource diplomacy) issue

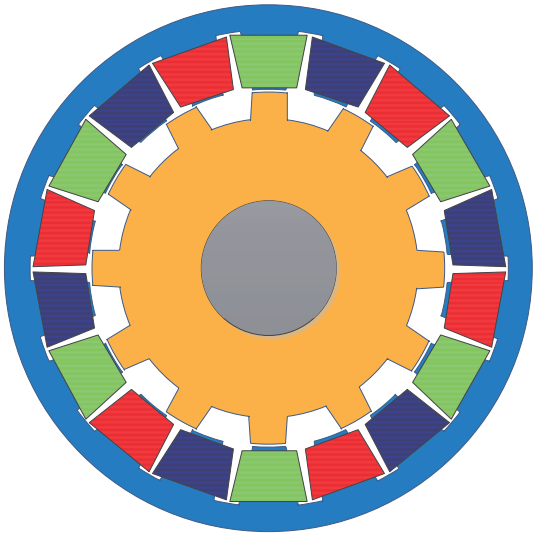
Solution: Development of motors that use little or zero rare earth
Research and development of Switched Reluctance Motors (SRM) supported by NEDO.

Structure and Feature of SRM

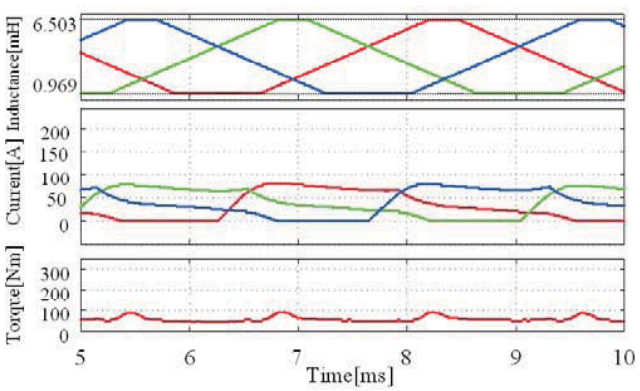


- Applying voltage to the stator coil generates a force (reluctance torque) that attracts convex poles.
- Rotor rotates by switching the coils in which current flows according to the rotor angle.
- No magnets are used.
  ⇒Robust
  ⇒Easy recycling
  ⇒No rare earths used

SRM Drive principle



1. Apply AC voltage to A-phase coil (red)
2. Apply AC voltage to B-phase coil (blue)
3. Apply AC voltage to C-phase coil (yellow-green)



A part of the Li-EAD project supported by New Energy and Industrial Technology Development Organization (NEDO) in Japan

Research and development of high-speed switched reluctance motors and 3D motors

Target of this research project

Research target:

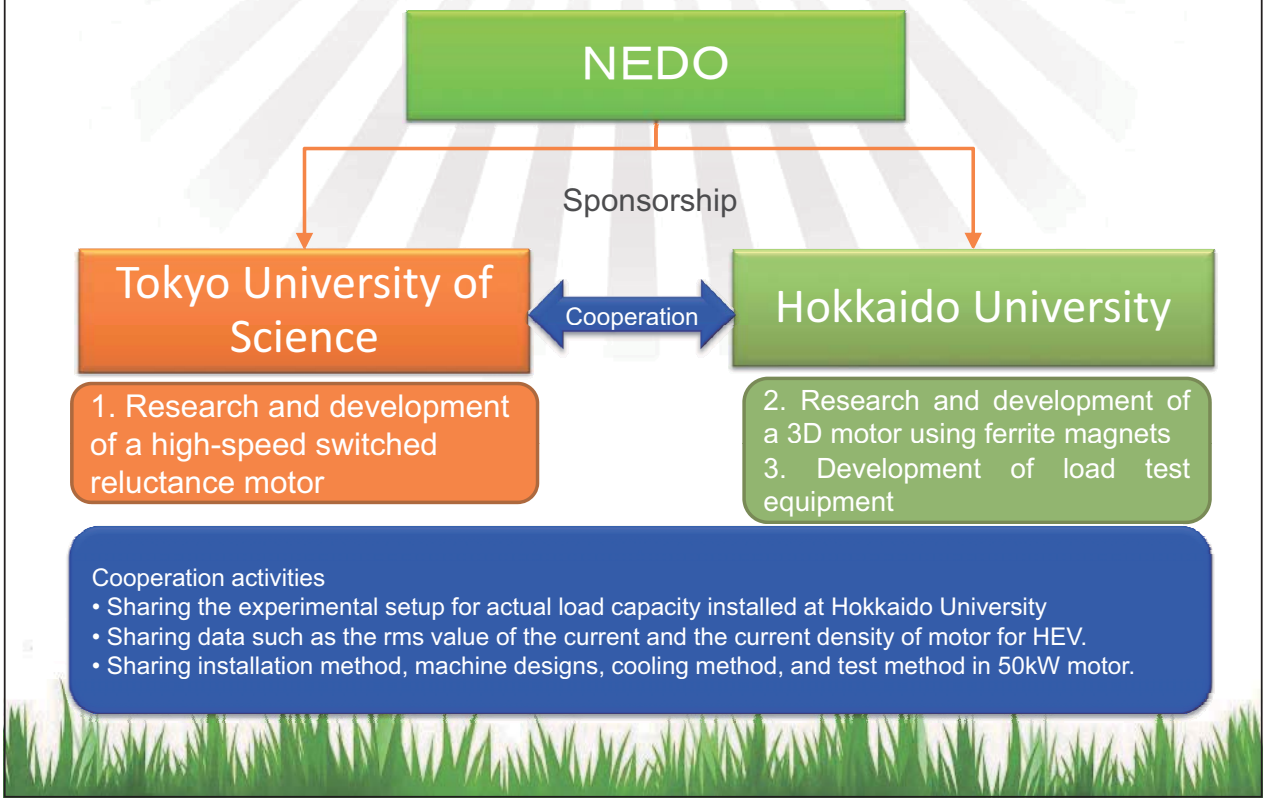
Developing a rare earth-free motor that does not use rare earths

Research goal :

Actualizing the size, output, and efficiency equivalent to the drive IPM motor that is mounted on the 2003 model of a Toyota Prius.

Actualizing 50 kW of shaft output with the size of diameter 269 mm and shaft length 156 mm (including the coil end), and with equivalent drive effects (85 to 95% by load point).

Organization of this research project



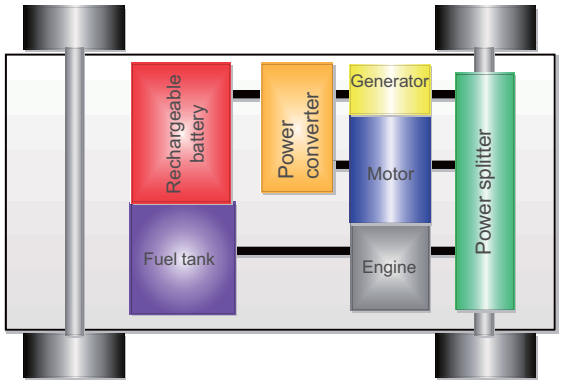
Research and development of a high-speed switched reluctance motor

- Technological opportunities

1. Design of high output power machine which is used at limited space
2. Efficiency improvement
3. Disadvantage such as driver configuration, vibration, and noise.

Development of low cost and compact size driver for SRM which can apply higher voltage than the battery voltage to the motor coils

Configuration example of hybrid electric vehicles

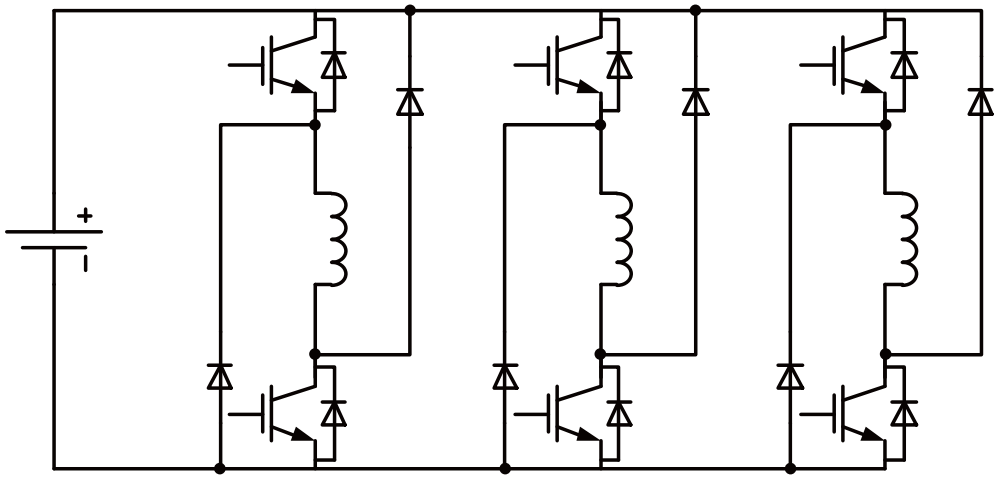


- Limited battery voltage
- Actualizing higher applied voltage to the motor at high-speed driving

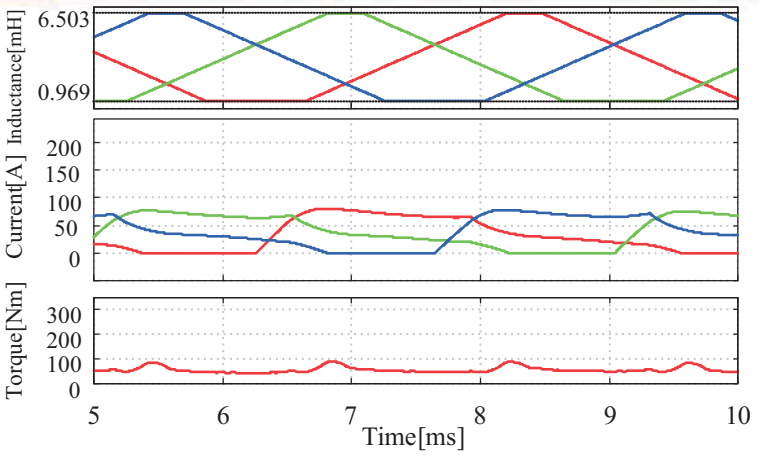
Boost converter
+
Inverter

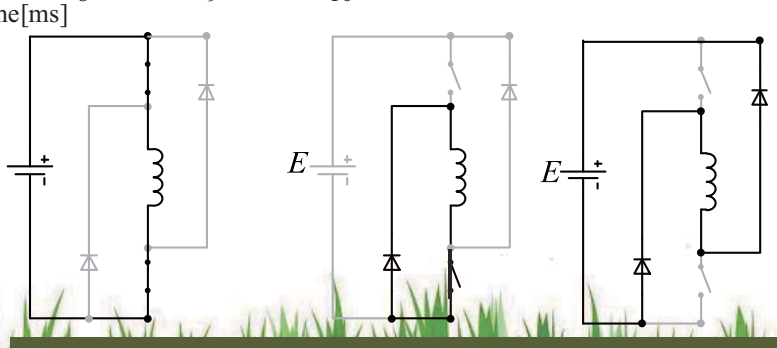
Several kinds of drive circuits for switched reluctance motor

Conventional SRM drive circuit



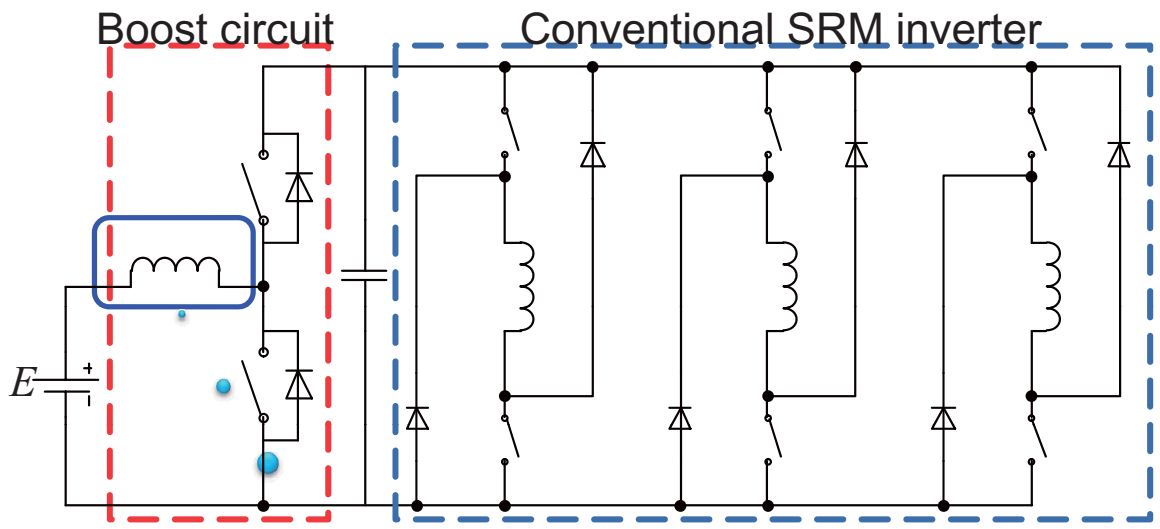
Operation mode of conventional circuit





Positive voltage mode Zero voltage mode Negative voltage mode

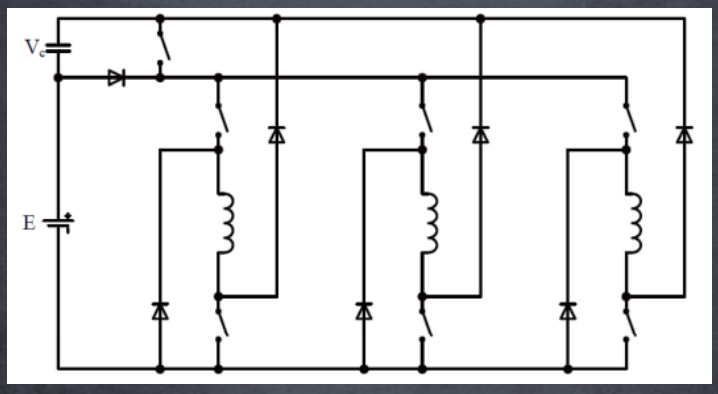
Conventional circuit with a boost converter



Boost reactor is required, which increases weight and size.

Torque ripple reduction circuit

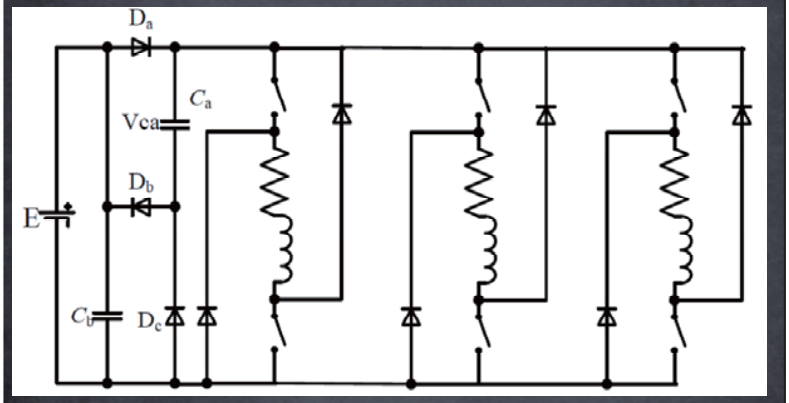
- A circuit that can reduce torque ripple by storing regenerative energy in the capacitor
- Regenerating electric power to the voltage source is difficult.



CHON Chea-Duck, Hiroki Goto, Osamu Ichinokura: "Torque ripple reduction of SRM for electric vehicles using regenerative energy," Conference record of annual conference of I.E.E of Japan, No. 4, p.328, 2009.

Passive Boost Converter

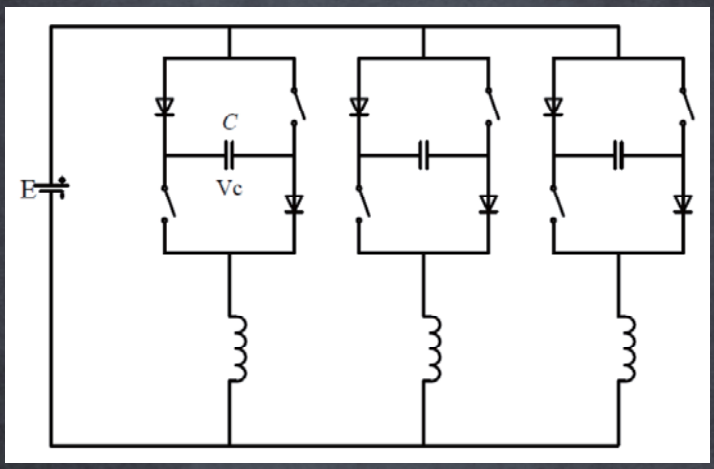
- A circuit that can reduce torque ripple by storing regenerative energy in the capacitor.
- The boost voltage in positive voltage mode is small.



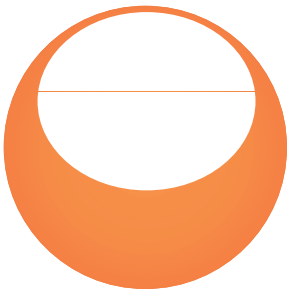
Dong-Hee Lee, Seung-Hun Seok, Jin-Woo Ahn: "SR Driver for Hydraulic Pump using a Novel Passive Boost Converter," *Conference Proceedings on Energy Conversion Congress and Exposition 2009*, pp. 282-287, 2009

Bidirectional magnetic energy and regeneration switch

- Charging regeneration energy in the capacitor accelerates a current rise and fall of current.
- Controls of the motor and the capacitor voltage are difficult because the circuit does not have zero voltage mode.



Taku Takaku, Jun Narushima, Takanori Isobe, Tadayuki Kitahara, and Ryuichi Shimada: Power Factor Correction of Single-Phase Induction Motor Using Magnetic Energy Recovery Switch, IEEJ Trans. on IA, Vol. 126, No. 9, pp.1214-1219, 2006.



Proposed drive circuit

Aim of this research

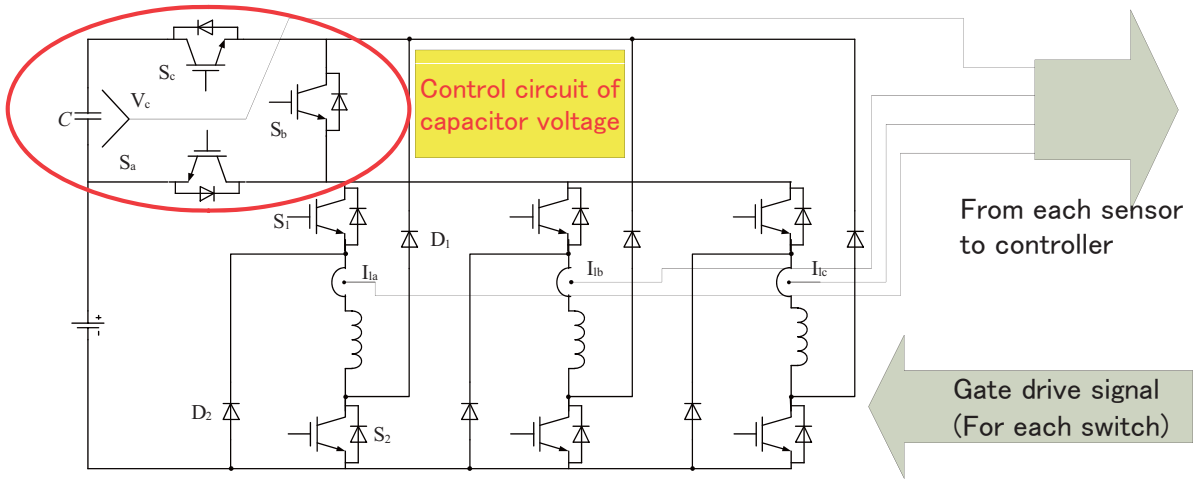
- To propose a new drive circuit for switched reluctance motors (SRMs) that does not use rare earths.
- The circuit that achieves a boost function by using the SRM coil without additional reactor.
- The circuit allows to regenerate the energy to batteries.

Comparison with conventional circuits

- Conventional circuits with voltage boost function
  - A circuit that improves the rise and fall time in a winding current of the SRM.
  - Torque ripple reduction circuit

  - They have some problems such as lack of ability of regenerative operation to the power source.

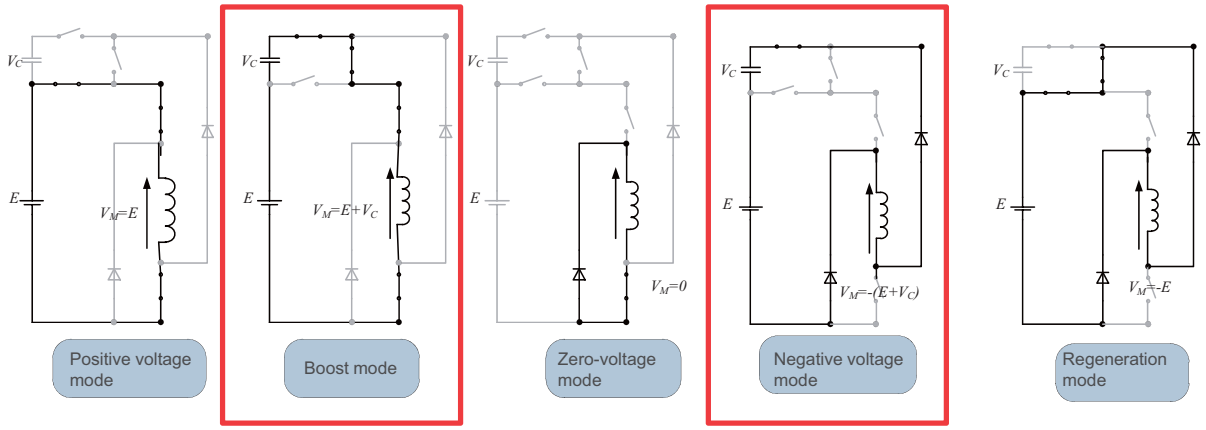
Configuration of the proposed circuit



Feature comparison of each SRM drive circuit

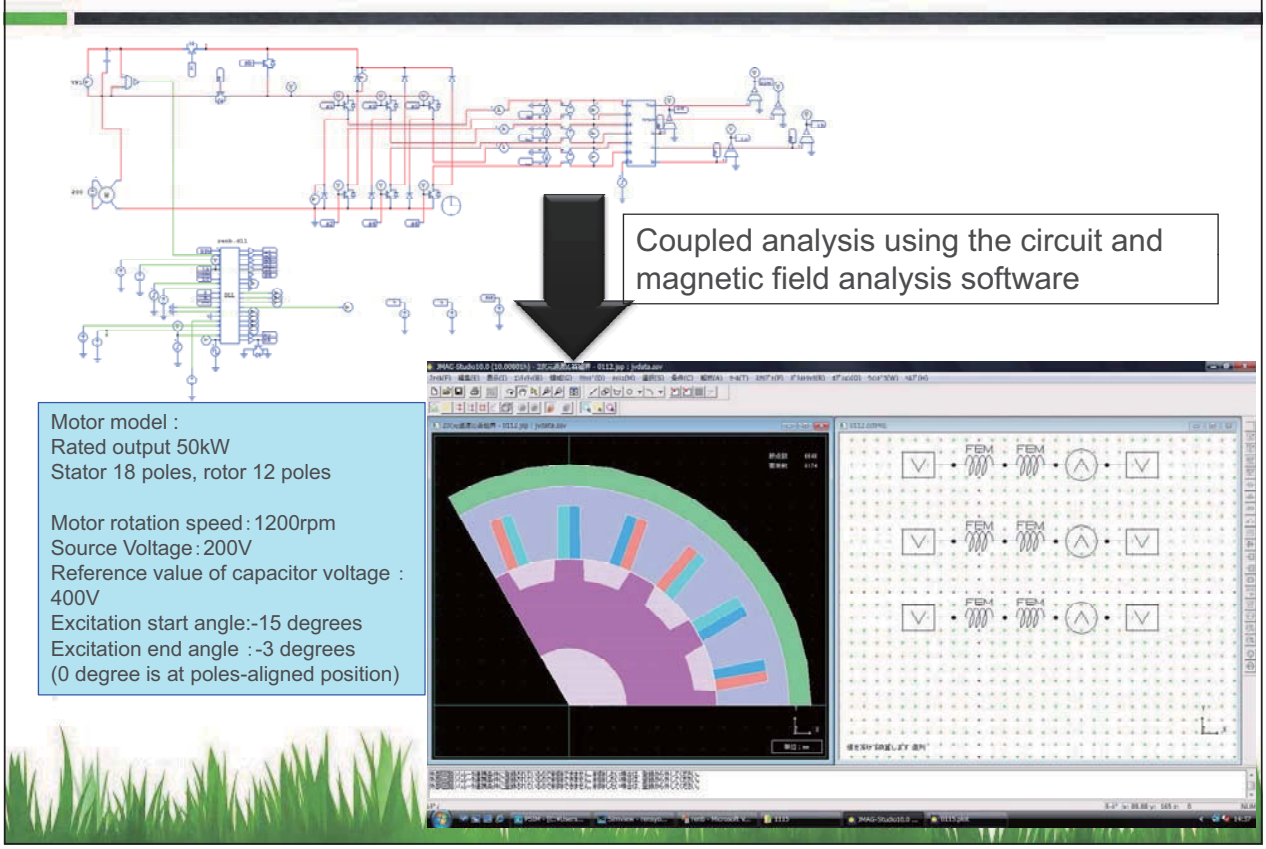
Item	Proposed circuit	Conventional circuit	Conventional +Boost circuit	Torque ripple reduction	Passive Boost	Magnetic energy regeneration switch
Boost	Possible	Impossible	Possible	Possible	Possible	Possible
Regeneration of power	Possible	Possible	Possible	Impossible	Possible	Impossible
Number of switches	9	6	8	7	6	6
Number of diodes	6	6	6	7	9	6
Number of devices	15	12	14	14	15	12
Adding reactors	Non-necessity	Non-necessity	Necessity	Non-necessity	Non-necessity	Non-necessity

Operation mode of the proposed circuit



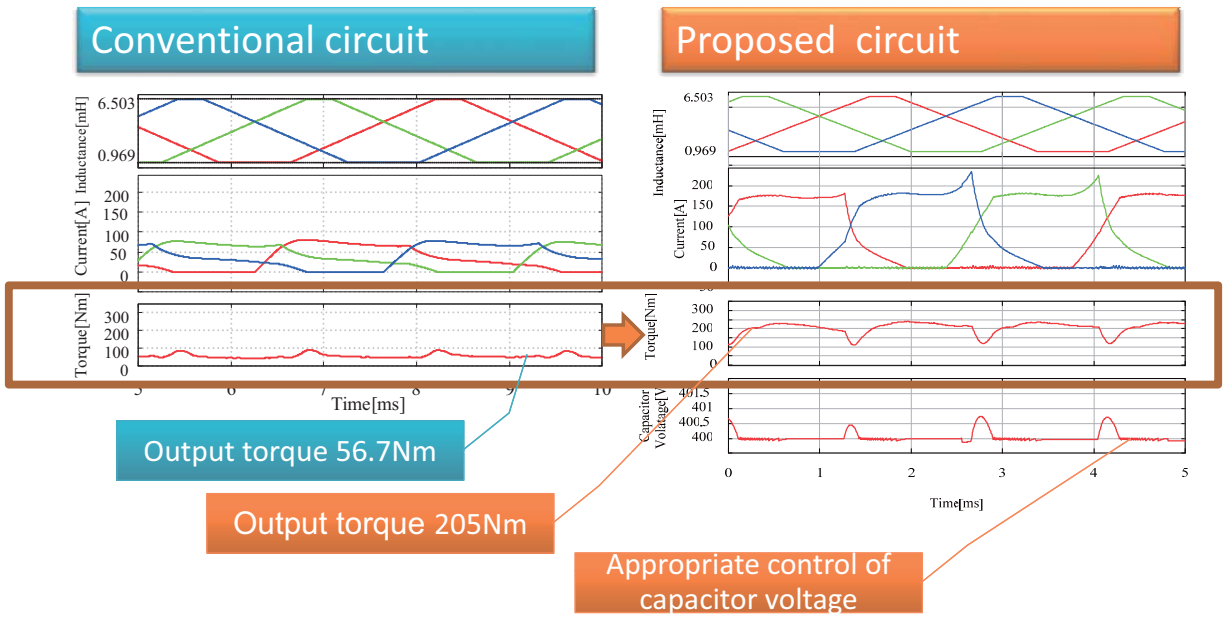
- Control of the capacitor and the torque is performed by use of the above five modes.

Effectiveness verification by simulation of the proposed circuit



Effectiveness of the proposed circuit (output torque improvement)

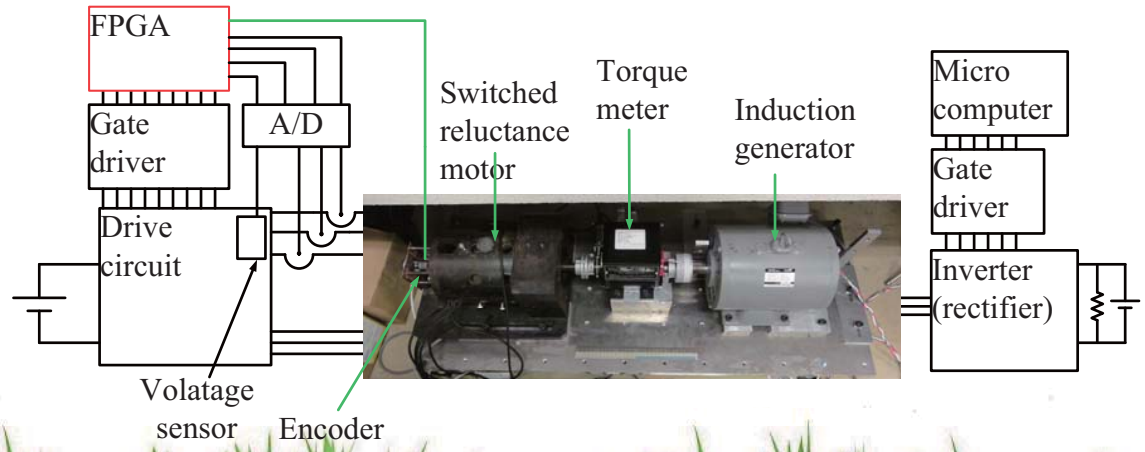
Simulation



The proposed circuit has achieved 3.5 times higher output torque than conventional circuit.

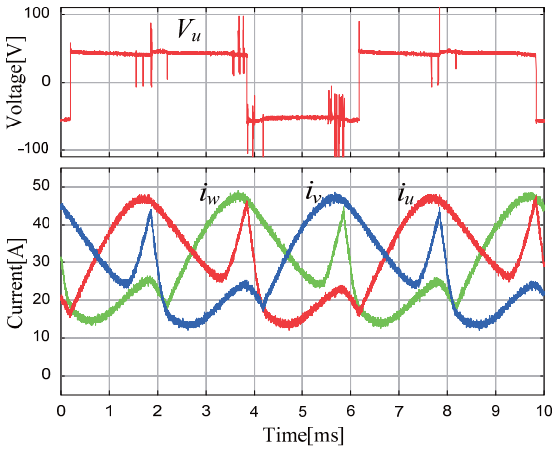
Effectiveness verification with an experiment of the proposed circuit

- Experimental verification using a small-scale SRM (Stator 6 poles, rotor 4 poles).
- A Controller using FPGA (Field Programmable Gate Array) was constructed.



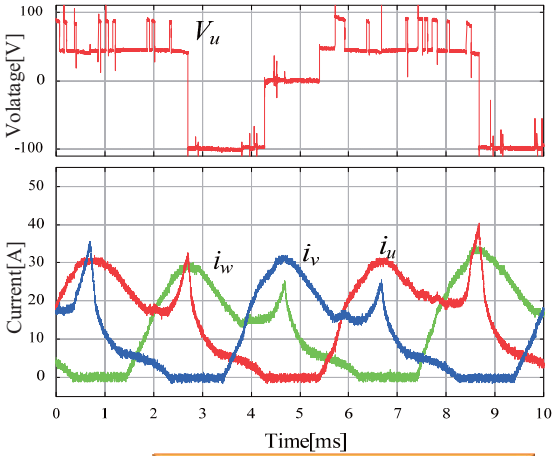
Experimental results of a small-scale SRM

Conventional circuit



RMS value of the current : 32A

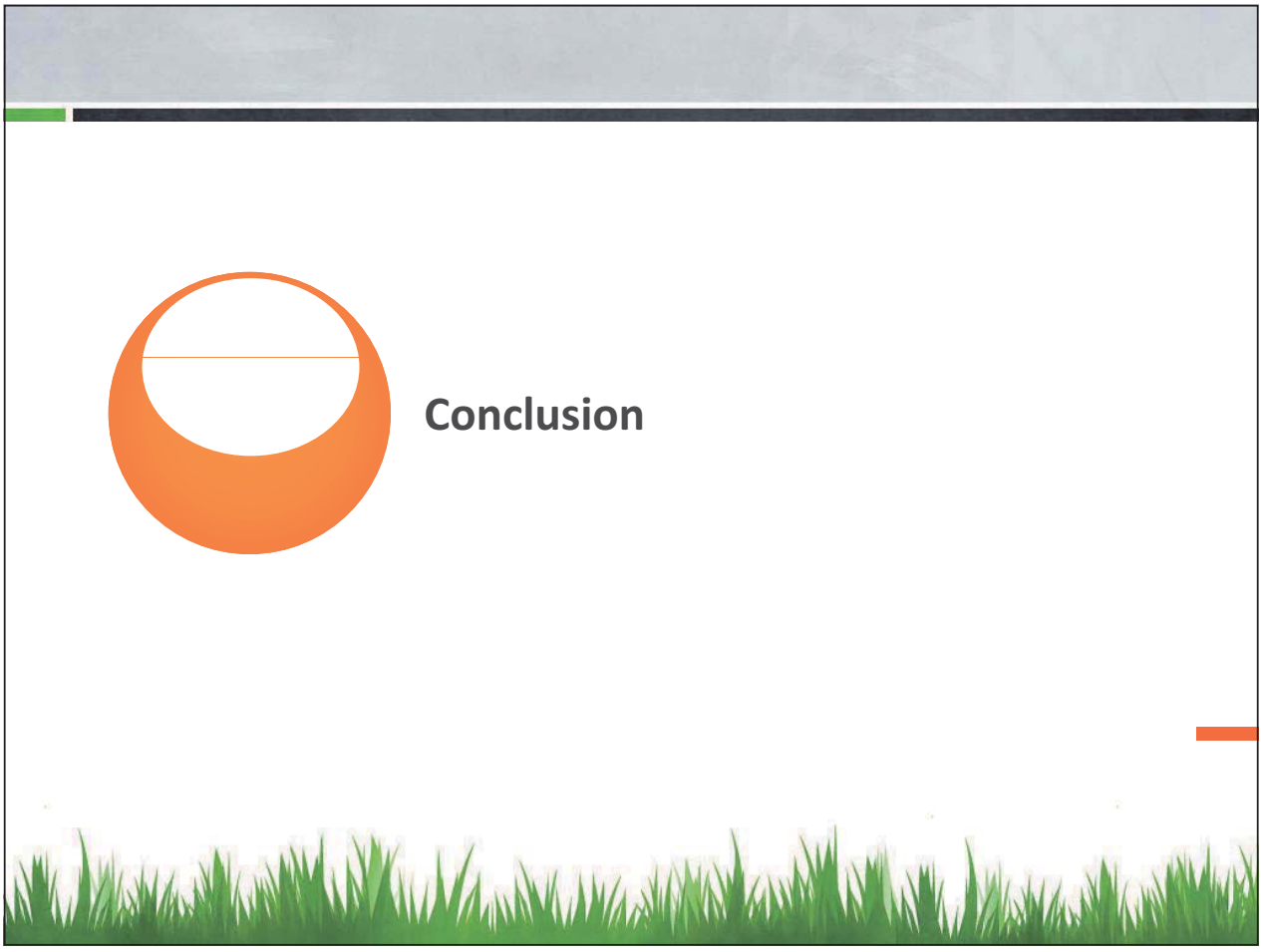
Proposed circuit



RMS value of the current : 18A

Speed	2500rpm
Torque	3.6Nm
Power	942W
Source voltage	50V
Capacitor voltage	50V

Proposed circuit achieved following point:
- Proposed circuit could apply twofold positive and negative voltage to the coil compared with source voltage.
- Proposed circuit could reduce RMS value of the SRM current than conventional circuit.



Conclusion

1. A novel SRM drive circuit with voltage boost function without additional reactors was introduced.
2. Results obtained by coupled analysis of PSIM and JMAG were shown.
3. Experimental results of a small-scale SRM were shown.

Acknowledgment

This research has been conducted as a part of the Li-EAD project supported by New Energy and Industrial Technology Development Organization (NEDO) in Japan.