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Comparison of Back-EMF Detecting Circuits for BDCM Sensorless Control

黃致愷　蔡子揚　陳鴻祺(IEEE member)　余培煜
*Chih-Kai Huang, Tzu-Yang Tsai, Hung-Chi Chen, *Pei-Yu Yu,
**Industrial Technology Research Institute, HsinChu, Taiwan.*
Department of Electrical and Control Engineering,
National Chiao Tung University, HsinChu, Taiwan.

Outline

- 1. Introduction
- 2. Sensorless Control for BDCM
- 3. Simulation results
- 4. Experimental Results
- 5. Conclusions

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Induction

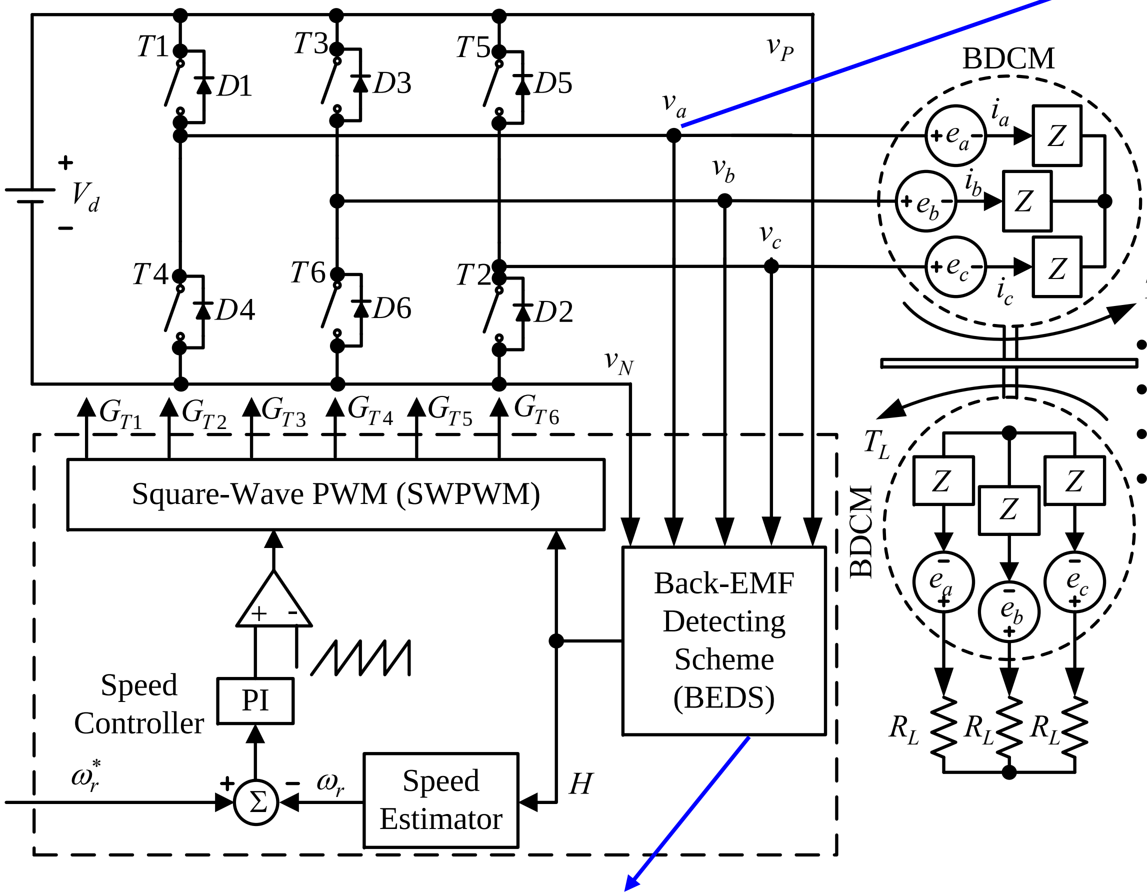
- The energy consumption of the refrigeration equipments exceed more than 20% of total power consumed in a home.
  - Improve the refrigeration efficiency

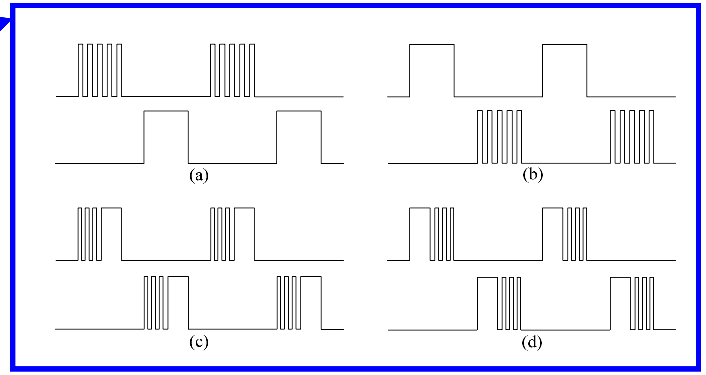
- Development of high efficiency and low cost DC inverter-fed technology including:
  - (i) Use of brushless DC motor (BDCM)
  - (ii) Variable-speed compressor & system
  - (iii) Application of rotary-type compressor

Induction

- In the normal operations of BDCMs
  - discrete rotor positions
    - should be monitored by the mounted position sensors in order to yield adequate current commutations.
  - refrigerant system
    - temperature is usually more than 90degreeC
    - would result in the failures of hall position sensors
- Groups of sensorless control
  - Continuous current (sine-wave)
  - Discontinuous current (square-wave)
    - Using terminal voltages
      - Three band-pass filters and only three terminal voltage
      - Total four input voltages including dc link voltage
    - Using fly-wheeling diode current

Sensorless Control for BDCM





- Fully upper PWM (FUPWM)
- Fully lower PWM (FLPWM)
- Alternatively leading PWM (ALeadPWM)
- Alternatively lagging PWM (ALagPWM),

- Two groups in BEDS
  – Based on frequency response of passive filters
  – A/D converter and comparators

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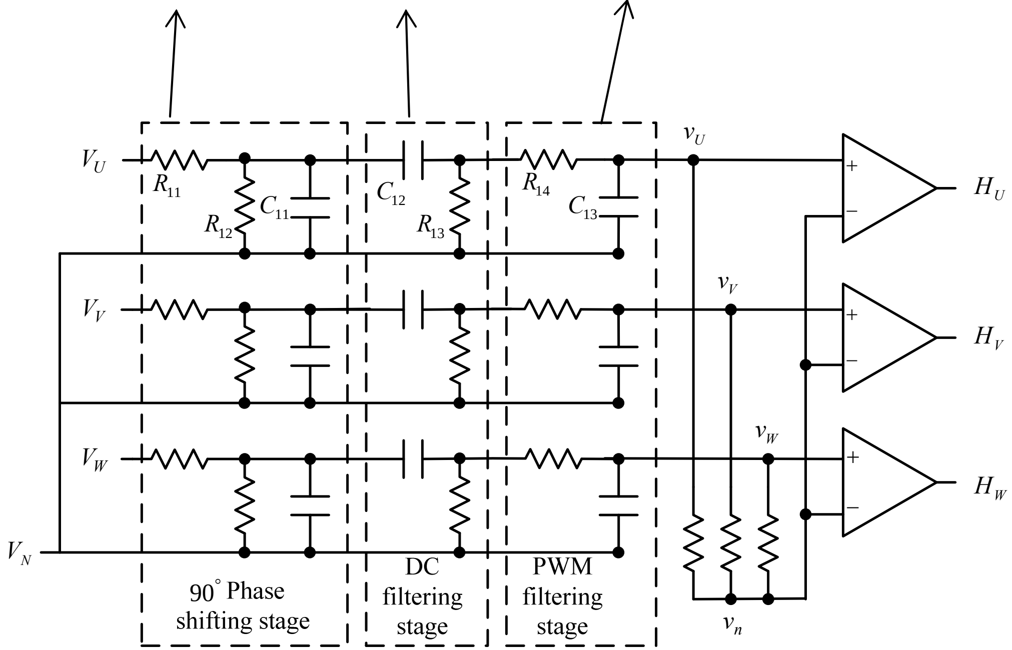
BEDC-I

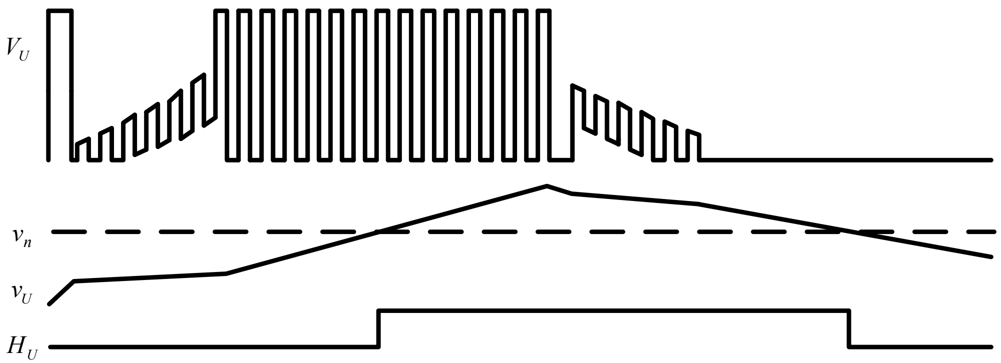
- Low pass High pass Low pass



$$f_{cut1} = \frac{R_{11} + R_{12}}{2\pi R_{11} R_{12} C_{11}} << \left(\frac{P\omega_{rLow}}{120} \right)$$

$$f_{cut2} = \frac{1}{2\pi R_{13} C_{12}} << \frac{p\omega_{rLow}}{120}$$

$$f_{PWM} > f_{cut3} = \frac{1}{2\pi R_{14} C_{13}} >> \frac{P\omega_{rHigh}}{120}$$



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BEDC-I

- The performance of BEDC-I is deeply influenced by the value accuracy of individual circuit element which implies that its performance may degrade by the value drift of circuit element along with time

BEDC-II

$R_{11} = 470k\Omega,\ R_{12} = 47k\Omega,\ R_{13} = 30k\Omega$
$R_{14} = 2k\Omega,\ \ C_{11} = C_{12} = 2.2\mu F,\ \ C_{13} = 470nF$
$R_{21} = 300k\Omega,\ R_{22} = 12k\Omega,\ R_{23} = 312k\Omega,$
$C = 330\,pF$

$$V_X = \begin{cases} \frac{V_{dc}}{2} + \frac{3}{2}E_X, & \text{PWM on} \\ \frac{3}{2}E_X, & \text{PWM off near PZCP} \\ V_{dc} + \frac{3}{2}E_X, & \text{PWM off near NZCP} \end{cases}$$

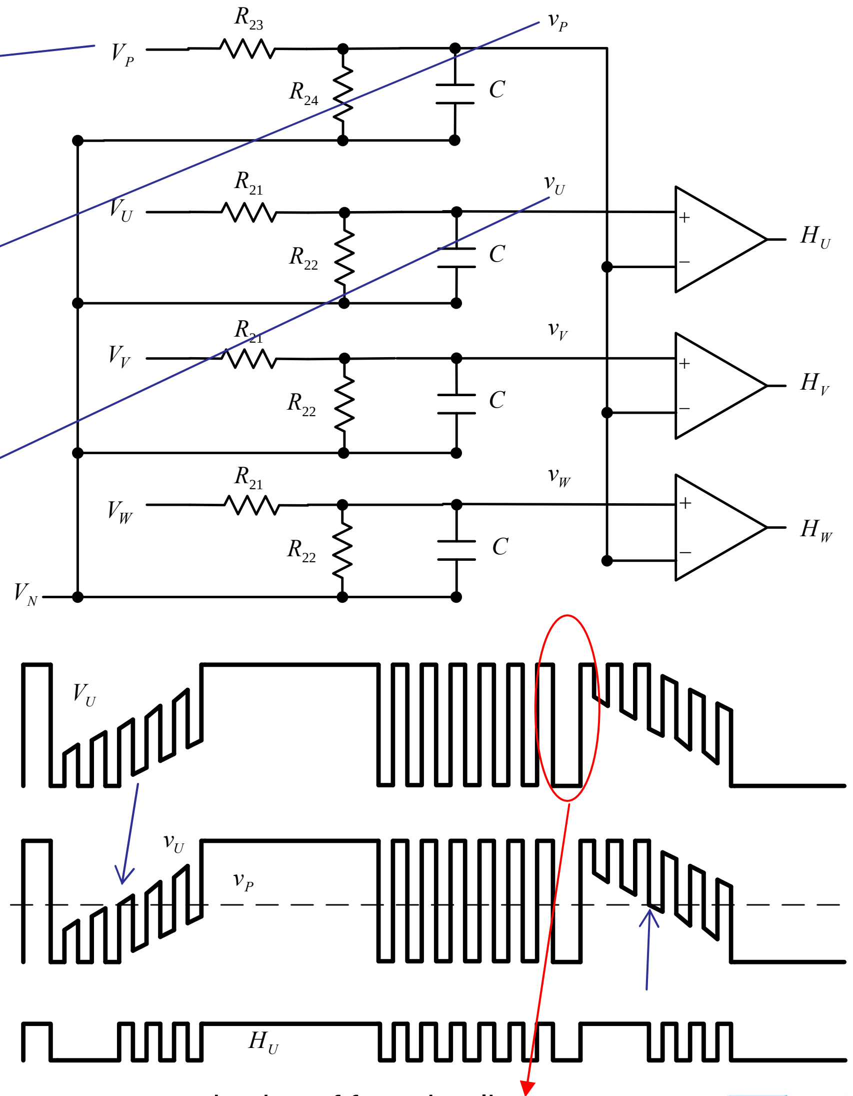
$$v_P(s) = \frac{\frac{R_{24}}{R_{23}+R_{24}}}{1+\frac{sCR_{23}R_{24}}{R_{23}+R_{24}}} V_{PN}$$

$$v_{X2}(s) = \frac{\frac{R_{22}}{R_{21}+R_{22}}}{1+\frac{sCR_{21}R_{22}}{R_{21}+R_{22}}} V_{XN}$$

$$\frac{R_{23}+R_{24}}{sCR_{23}R_{24}} >> f_{PWM}$$

$$\frac{R_{21}+R_{22}}{sCR_{21}R_{22}} >> f_{PWM}$$

$$\frac{2R_{24}}{R_{23}+R_{24}} = \frac{R_{22}}{R_{21}+R_{22}}$$



conduction of freewheeling diodes at the current

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Comparisons

	Detecting position	Implementation of sensorless control	PWM conduction method	Position-dependent load
BEDC-I	lagging positions	General function	All can be used	Not robust
BEDC-II	ZCPs	Specific function	ALagPWM	Robust

- The comparisons between the two BEDCs are tabulated in Table where we can find that the implementation of sensorless control for BEDC-I is easier than that for BEDC-II.

Simulation results

Simulated parameters

Stator resistance	0.7Ω
Stator inductance	$Ld = 4mH$ $Lq = 10.5mH$
Voltage constant (Line-to-Line)	$23.63\, mV_{rms} / rpm$
Pole number	4 pole
Motor inertia	$0.0004\, kg - m^2$
DC link voltage	$300\, V$
PWM frequency	$5\, kHz$
DC load torque	$1\, N - m$
AC load torque	$0.5\, N - m$ (peak)

- BEDC-I
  - FUPWM
- BEDC-II
  - ALagPWM

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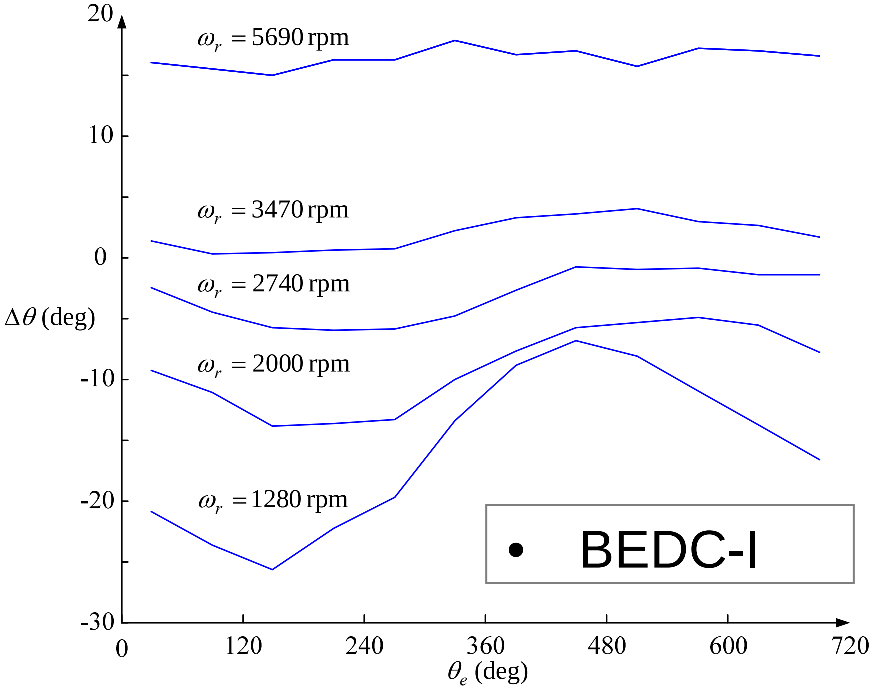
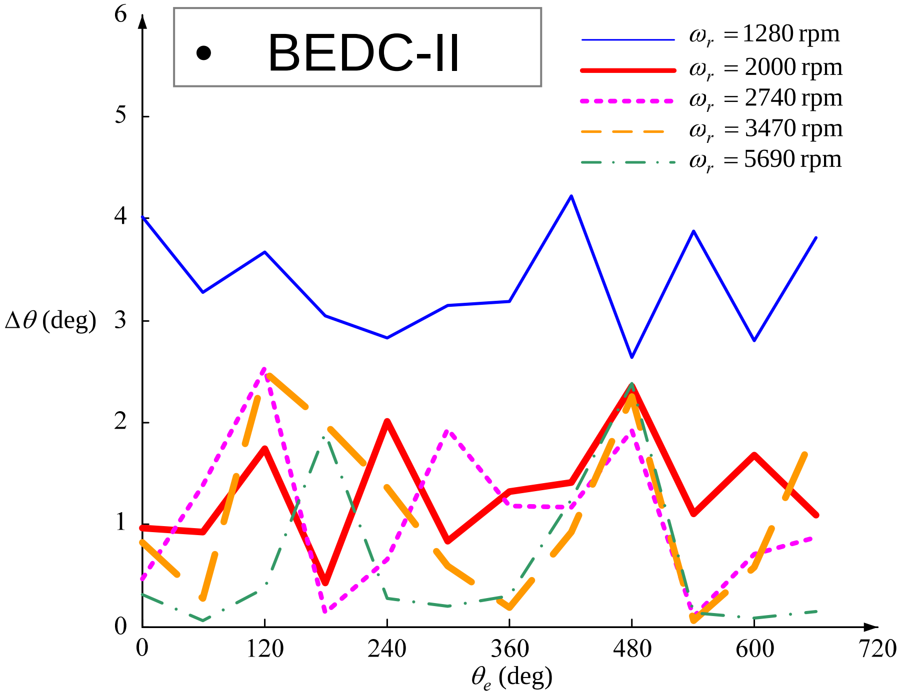
Simulation results





Duty(%)	20	30	40	50	60	70	80
ω_r (rpm)	1280	2000	2740	3470	4210	4940	5690
$\Delta\theta$ of BEDC-I	-16.5	-9.17	-3.12	2.155	6.685	11.99	16.43
$\Delta\theta$ of BEDC-II	3.426	0.29	1.074	1.01	0.894	1.082	0.66

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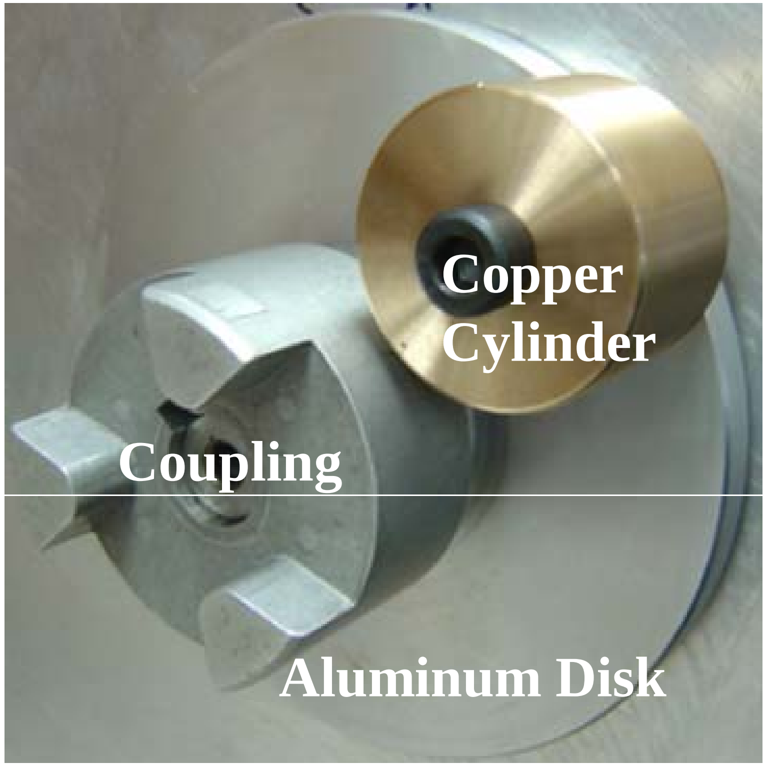
Experimental Results

- **Position-Dependent Torque**
  - It is not easy to sense the actual speed in the hermetic compressors.
    - An experimental system is set up.
    - Two BDCMs and one disk are coupled together.
    - Copper cylinder on disk will contribute to the position-dependent load.



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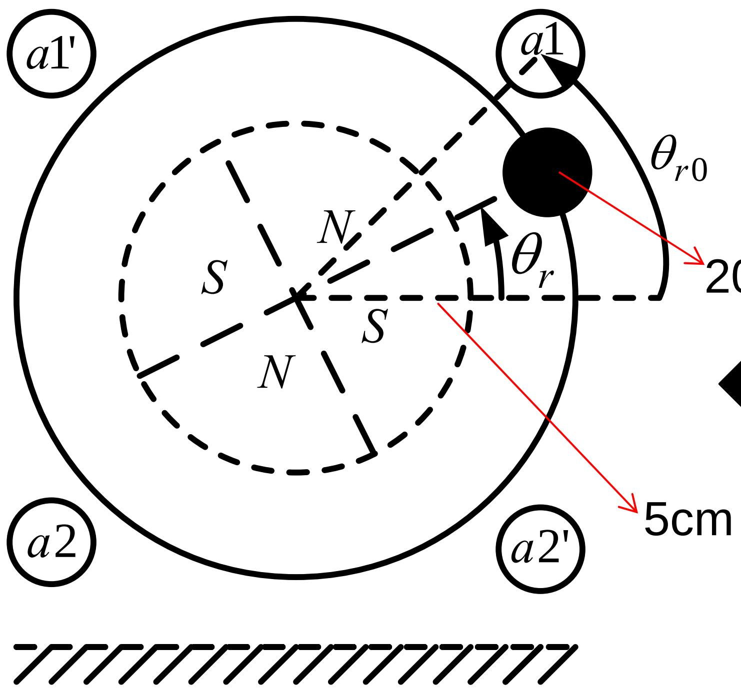
Experimental Results

- **a1, a1', a2, a2' are the phase-a windings at the stator of the 4-P BDCM.**
- **S, N are the rotor positions.**



- **Copper cylinder contributes to the position-dependent load torque**

$$T_{L,ac}(\theta_r) = MgR\cos\theta_r$$

- **Three electromotive forces are functions of rotor position**

$$\begin{cases} e_{as} = E\sin(2\theta_r - 2\theta_{r0}) \\ e_{bs} = E\sin(2\theta_r + 2\pi/3 - 2\theta_{r0}) \\ e_{cs} = E\sin(2\theta_r + 4\pi/3 - 2\theta_{r0}) \end{cases}$$

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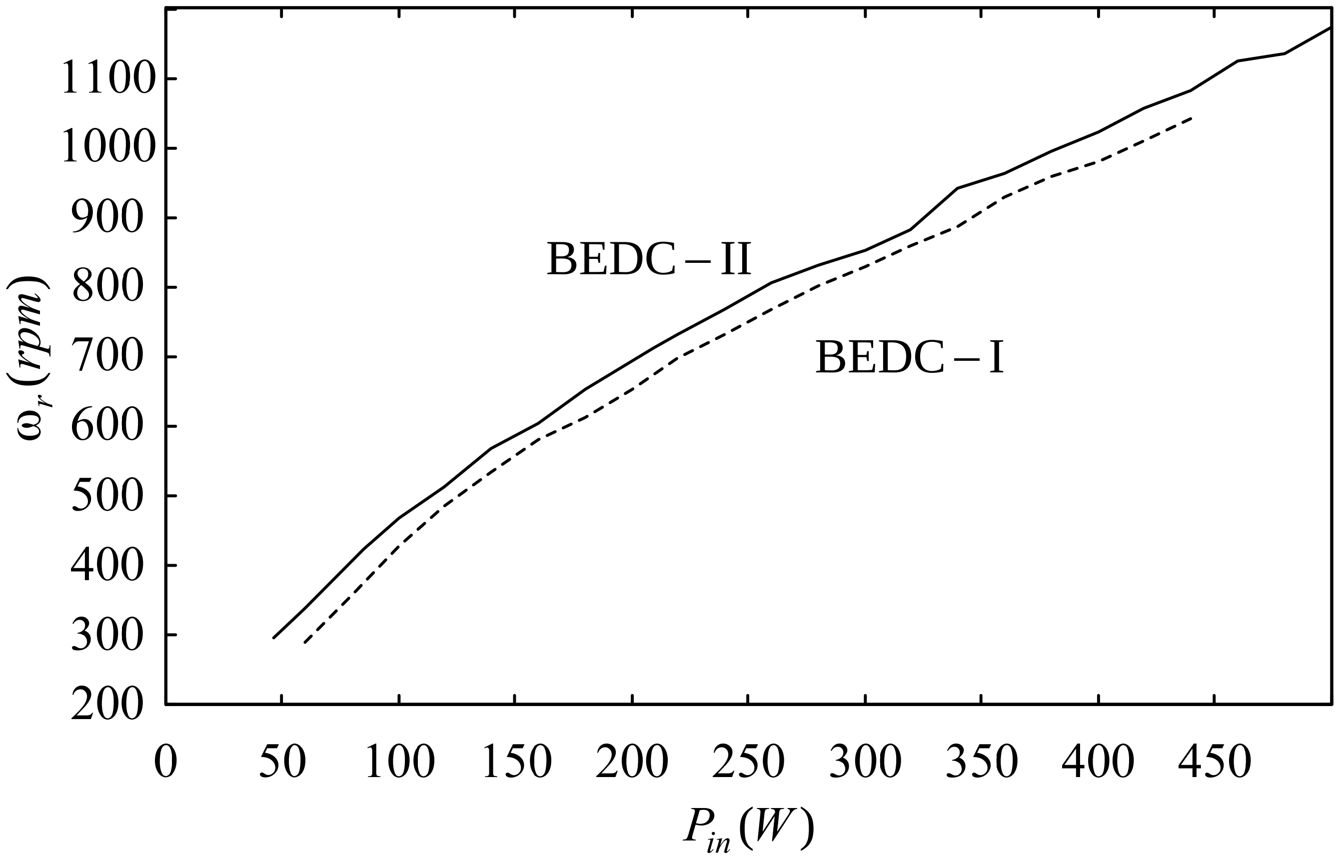
Experimental Results



$$\omega_r = \frac{1}{6T_H}\times\frac{60}{P/2} = \frac{20}{PT_H}(rpm)$$

- The Generator-end terminals are connected to three 5 Ω resistors in order to run at relatively low speed

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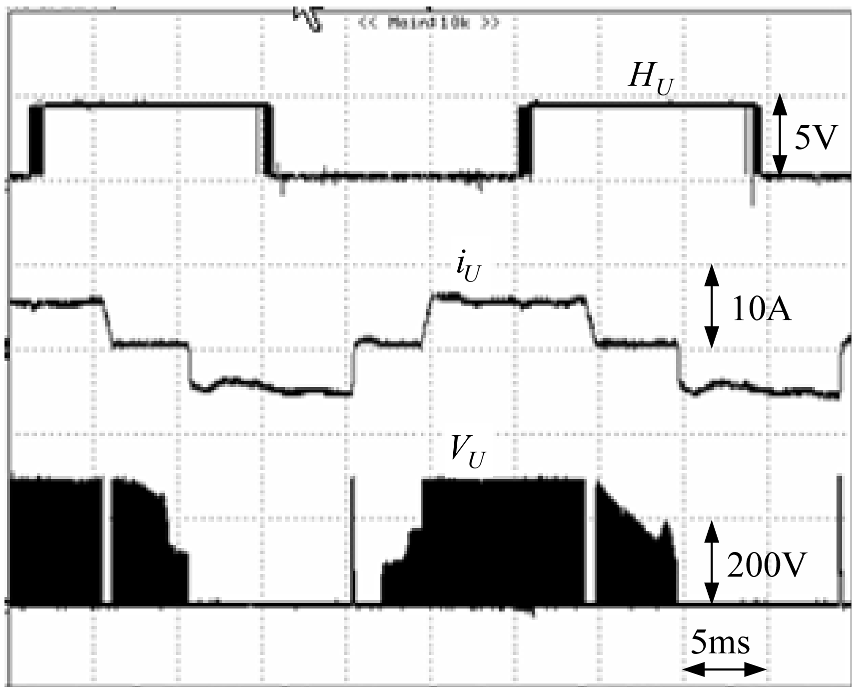
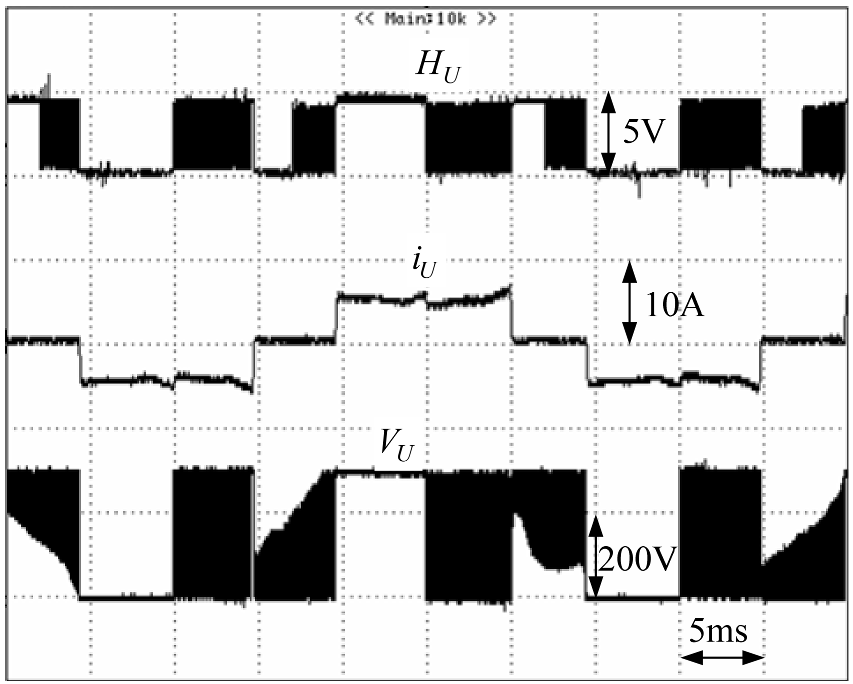
Experimental Results





- BEDC-I with FUPWM and BEDC-II with FLagPWM at near 1000rpm
- Simulated position error (BEDC-I) is about at 16° about 1000rpm

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Conclusions

- The implementation of sensorless control for BEDC-I is simpler than that for BEDC-II.
- The detection performance of BEDC-II is better than that of BEDC-I.
- This paper can help us to use two BEDCs correctly.

Thanks for your listening

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