International Appliance Technical Conference 2005

Sensorless Motor Control Method for Compressor Applications

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March 29, 2005

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Presentation Outline

- BLDC motor control methods
- Compressor requirements
- Performance vs. requirements
- Development of OSCD method
- Motor Timer & algorithm
- Test results
- Summary

BLDC Motor Control Methods

- 120 Deg control vs. Vector Control
  - Low performance low cost vs. high performance high cost

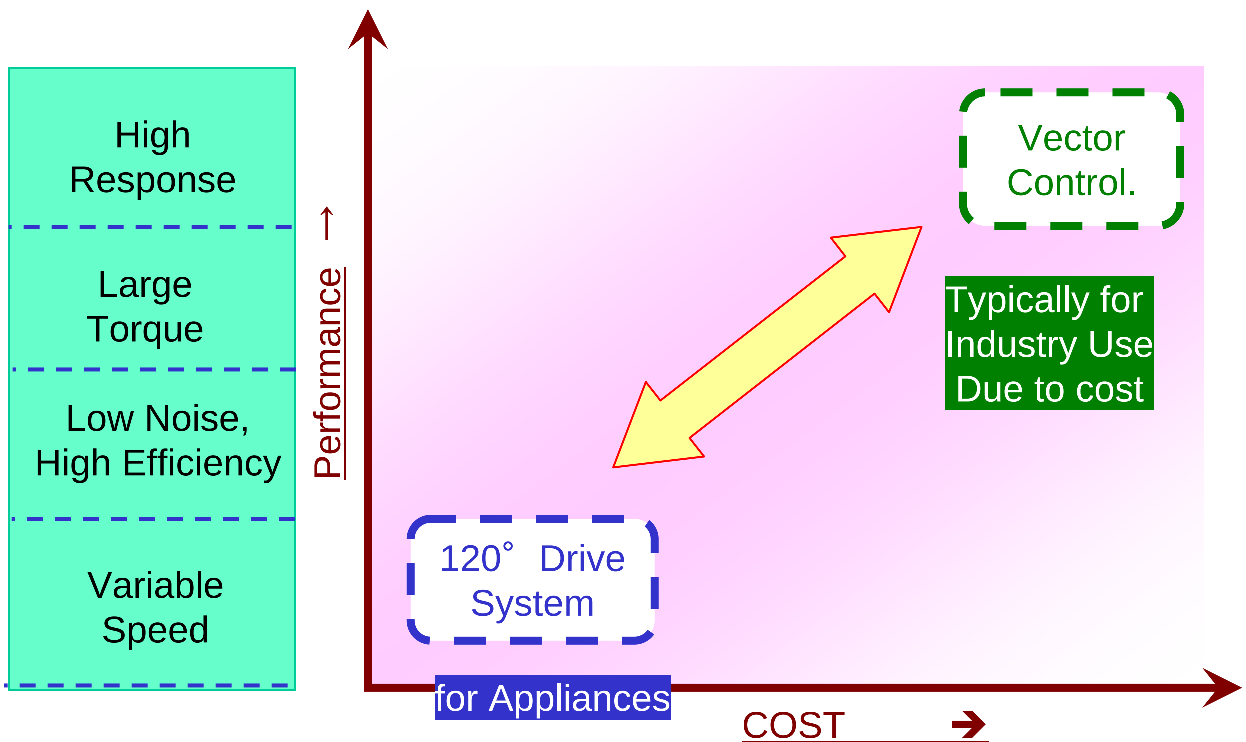


Figure 1 Cost performance trade-off for Vector & 120 Deg control

Vector Control

- Uses position sensor plus DCCT as feedback information
  - Torque & flux control, high response, high efficiency
  - Sensors add cost to the Bill Of Material (BOM)

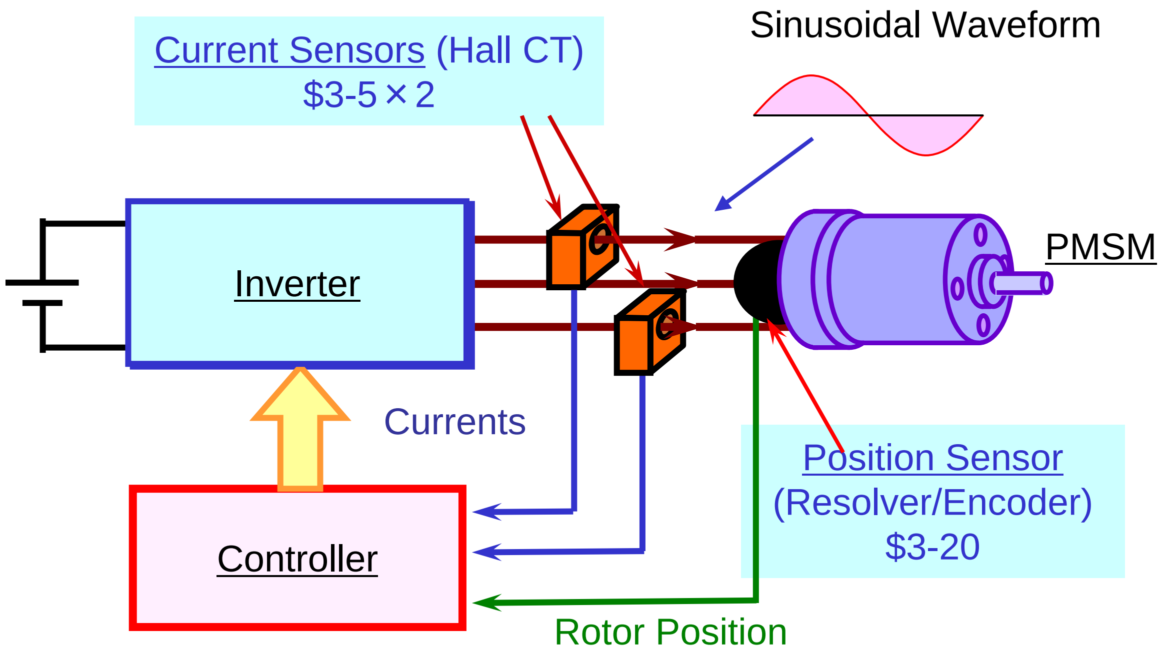


Figure 2a. Full vector control with position sensor and two current transducers adds cost to the BOM

Vector Control Algorithm

- 3 PI regulators plus several coordinate transformations required

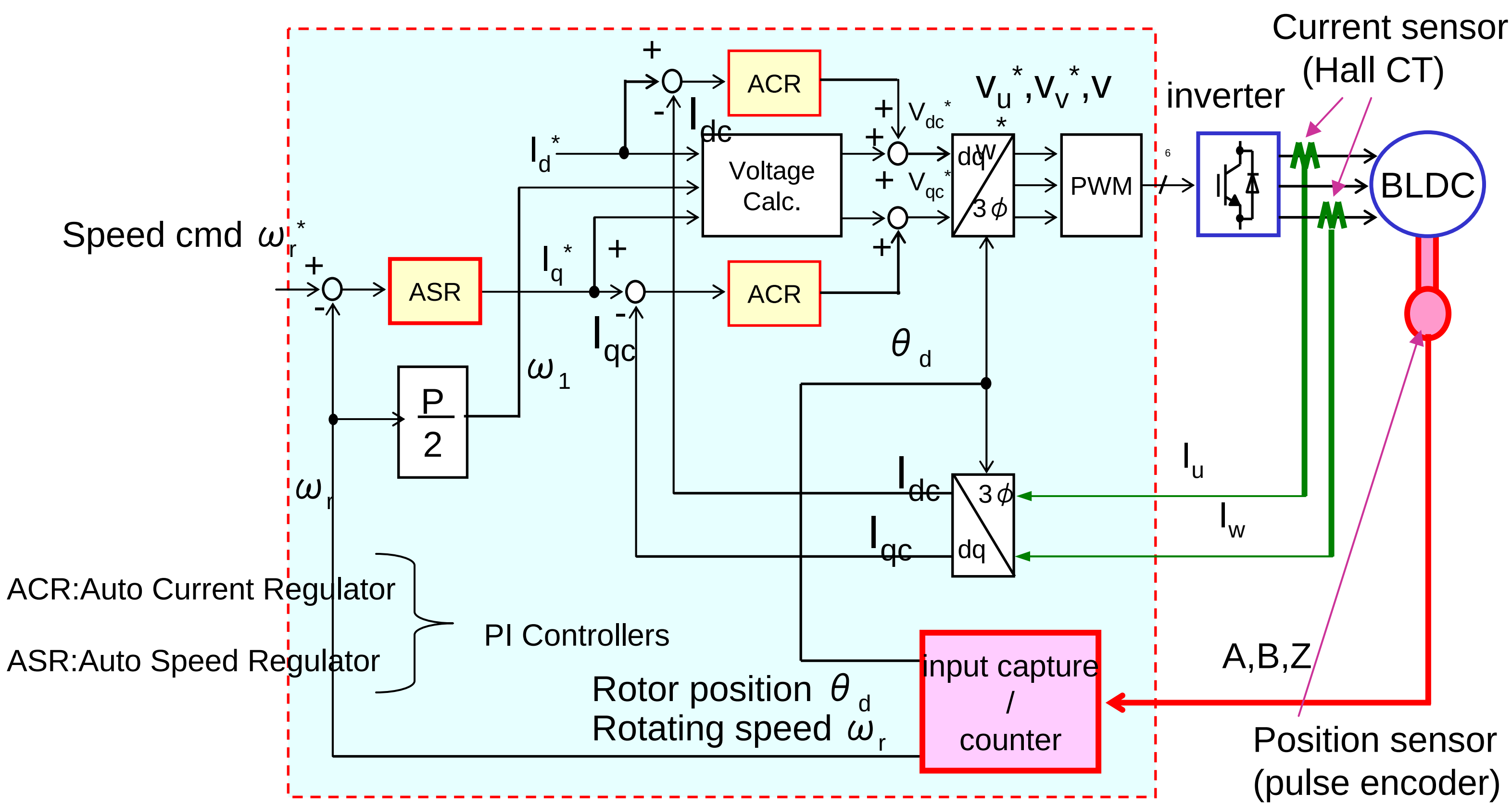


Figure 2b. Vector control algorithm executed in MCU to control torque and flux

120 Deg Sensorless Control

- Implements rectangular modulation 6-step state change
- Back EMF signals help measure rotor position and speed
- Simple proportional or proportional-integral regulator for control

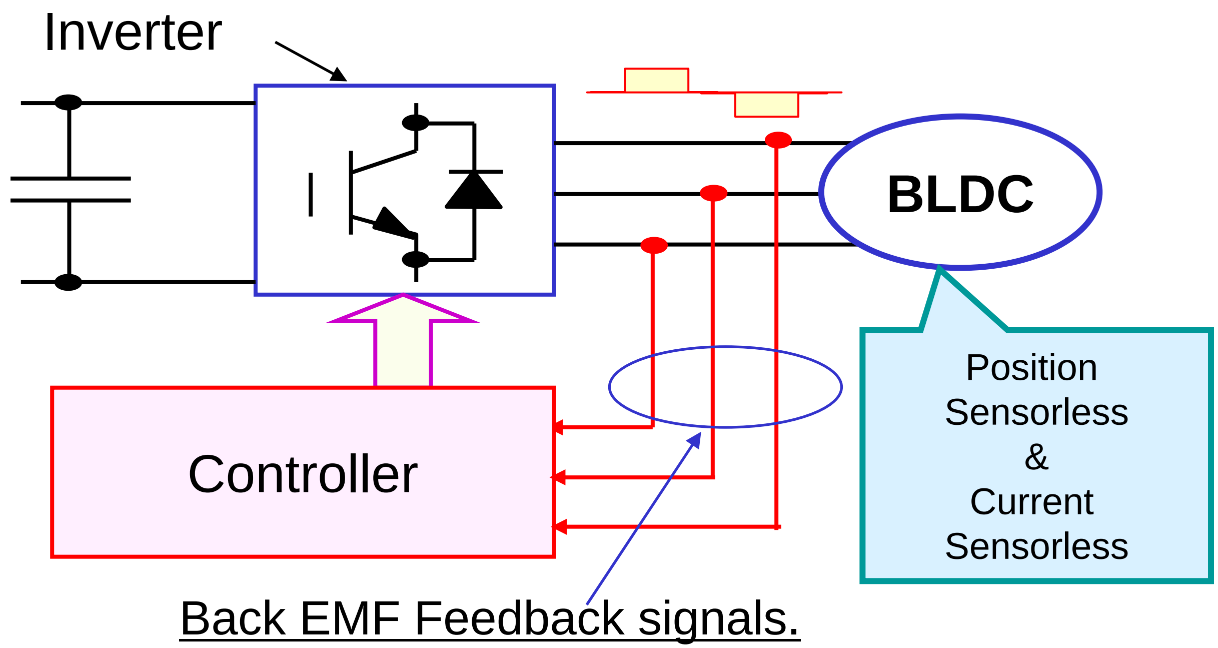


Figure 3. Sensorless 120^0 6-step control method

Performance Criteria

- We evaluated performance of vector, 120 deg sensor and sensorless, all three control algorithms using 8 criteria
  - High speed drive
  - Large torque at low speed
  - Large torque at high speed
  - Torque accuracy at low speed
  - Torque accuracy at high speed
  - Response
  - Efficiency
  - Low noise
- We used vector control as a reference point

Controller Performance

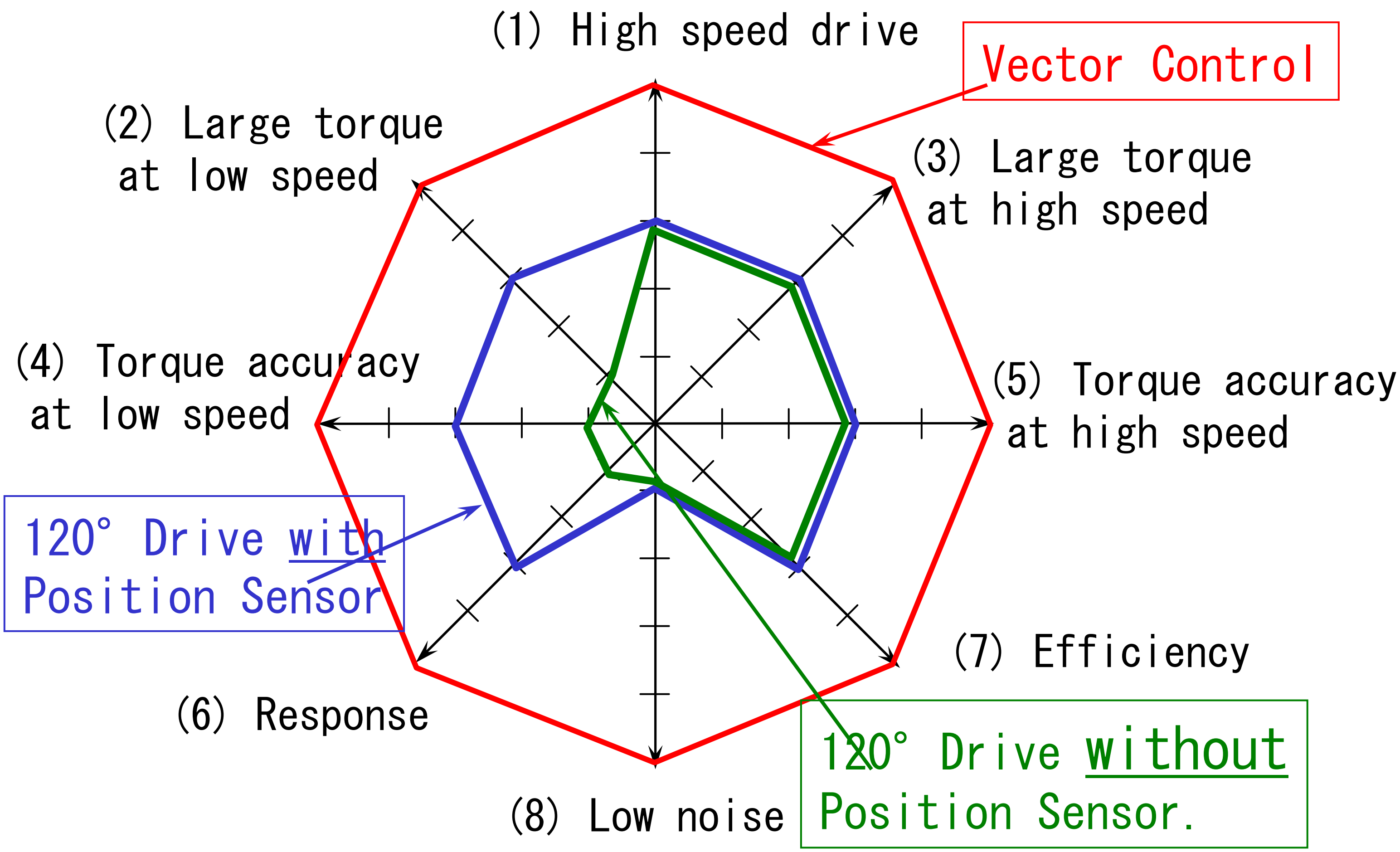
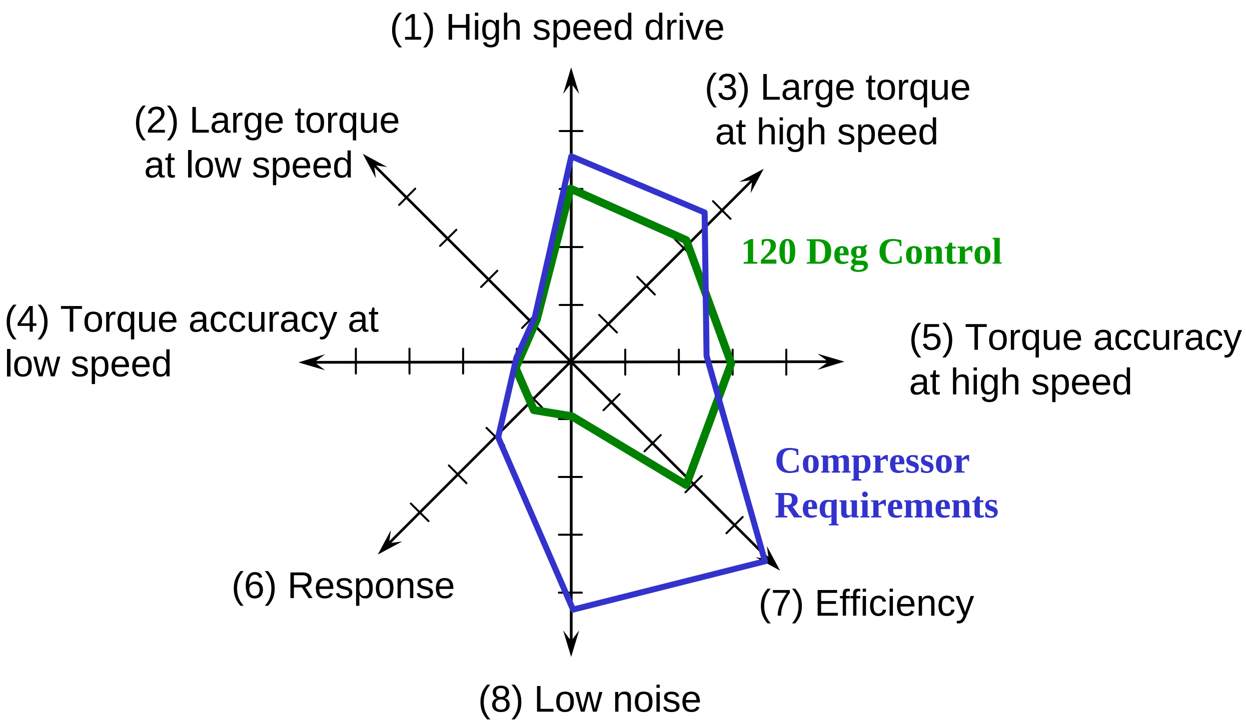


Figure 4. Comparison of 120^0 sensor and sensorless control with vector control.

Compressor Performance Requirements

- **We developed compressor requirements for the same 8 criteria as shown**
- **120 deg sensorless control is deficient in five criteria**

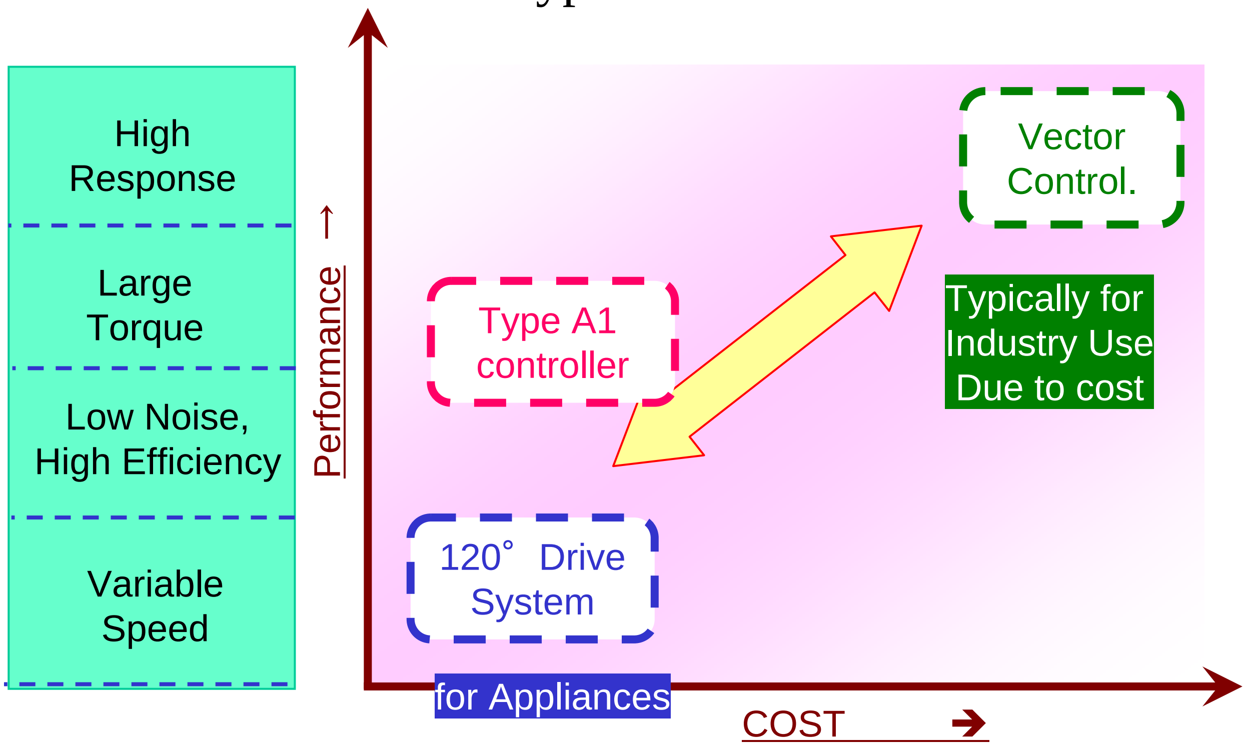


Note: 120^0 control is deficient in all but two criteria which has low importance.

Figure 5. Comparison of 120^0 sensorless control and compressor performance requirements.

Our Research Area

- A new method is needed to satisfy compressor requirements
- Goal is to develop a new method that provides more performance with the same cost as the 120 deg sensorless control
  - Our internal code name is Type A1 control method



Type A1 Control

- Two significant changes implemented to improve the performance and still keep the same cost
  - Sinusoidal modulation
  - One shunt current sensor (No DCCT)

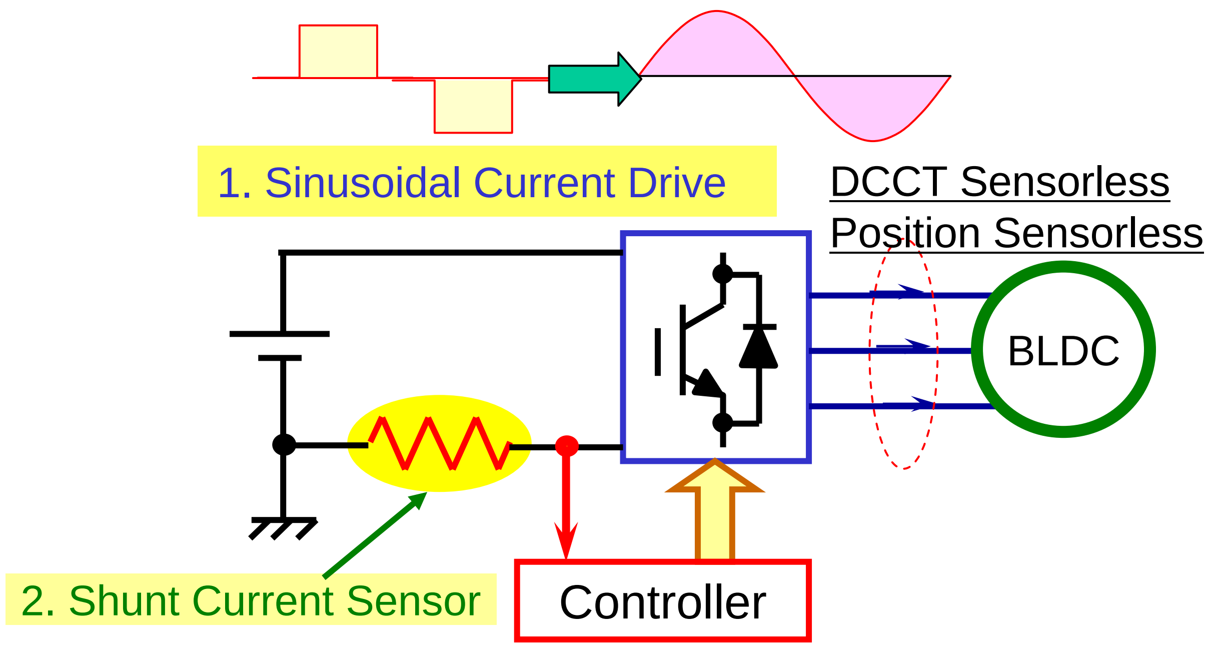


Figure 6a. Two significant changes to 120^0 control method

Sinusoidal Modulation

- 180 deg sinusoidal modulation is effective in reducing noise and increasing efficiency

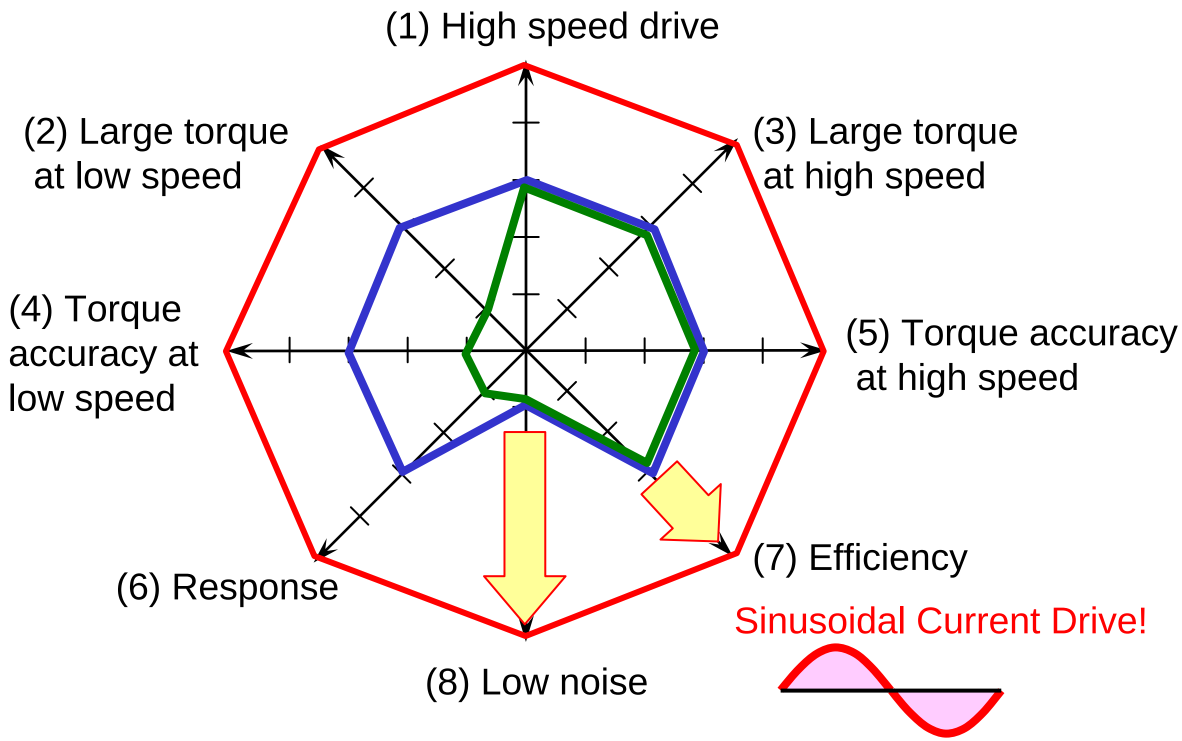


Figure 7. 180^0 sinusoidal modulation reduces noise and increases efficiency.

Multifunctional Timer Unit

- Easy to create three sine waves using accurate and large sine tables
- It has built in dead time protection in PWM output
- Back EMF voltage can not be detected because all three phases are active

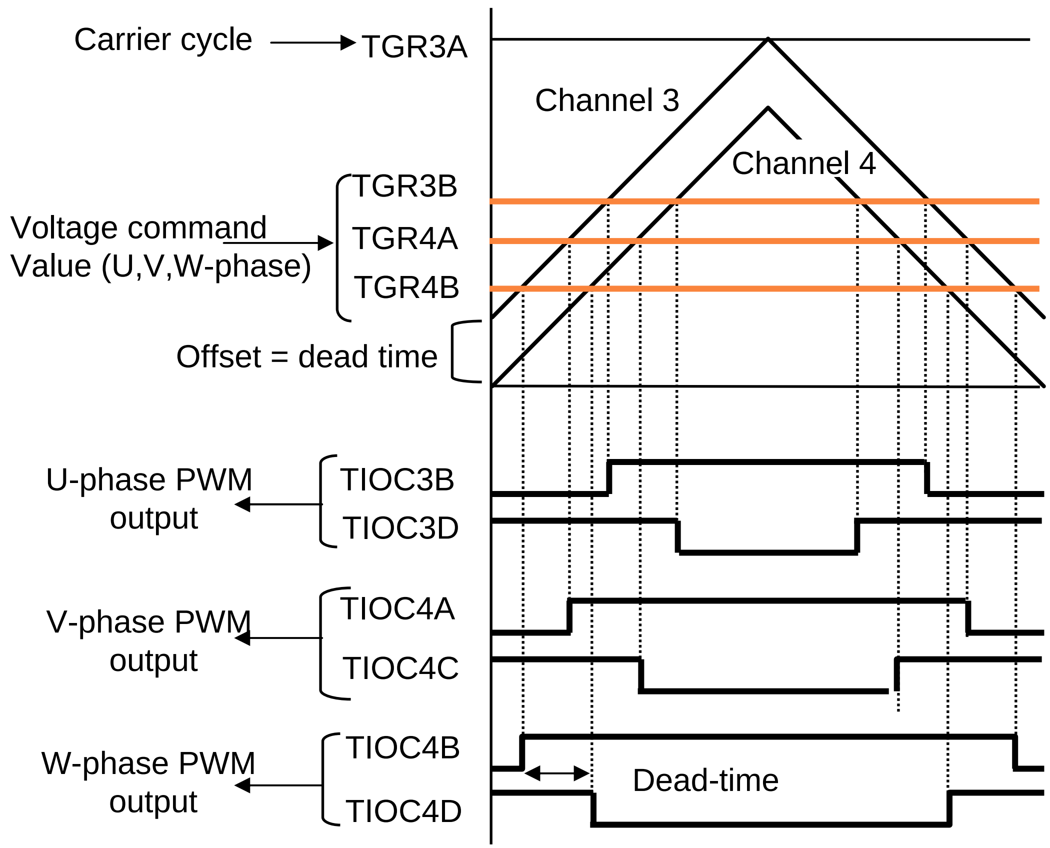


Figure 8a. MTU channels 3 and 4 create six independent pwm signals that can be used to generate three sine waves with dead time.

One Shunt Current Detection Method

- Key is to measure current at a precise time during PWM cycle
- Two current measurements give all three values because of sum of current is zero

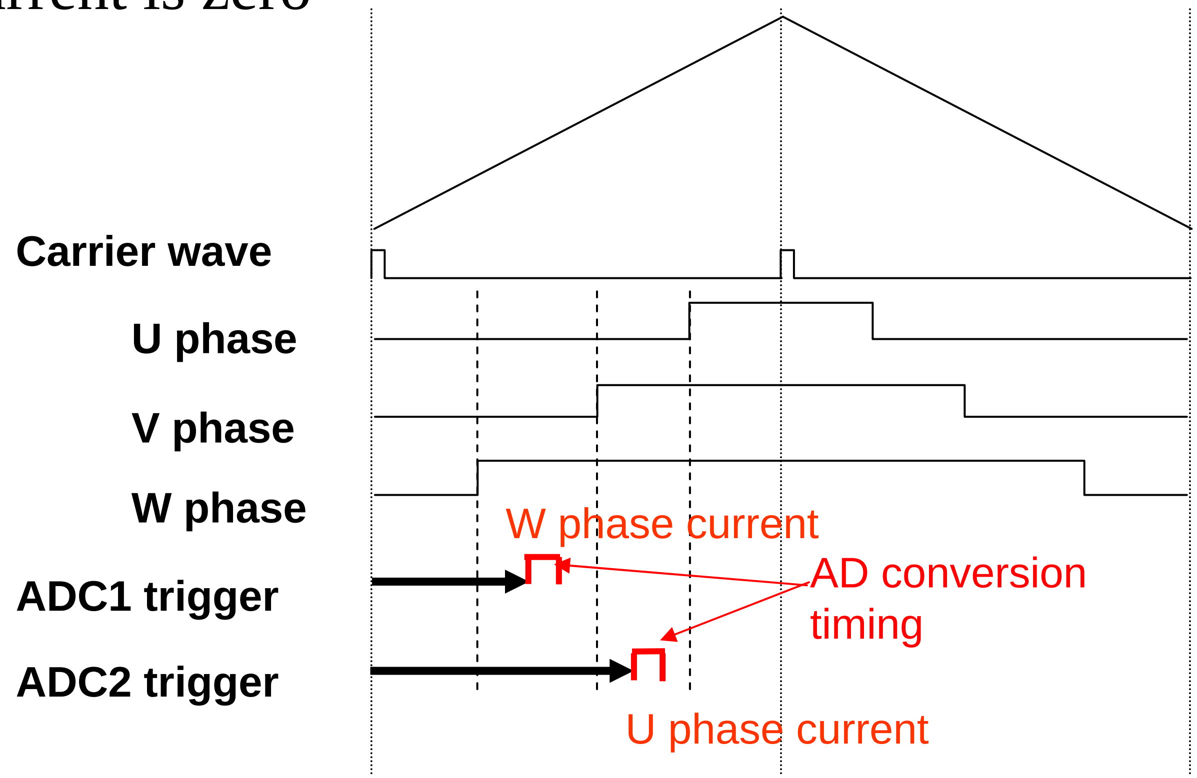


Figure 8c. Δt1 and Δt2 are set so that ADC1 measures w current and ADC2 measures u current.

MTU Triggers ADC

- Firmware internally computes ADC trigger time based on the ON time for each PWM signals and sets up the channels
- MTU triggers ADC at precise counts

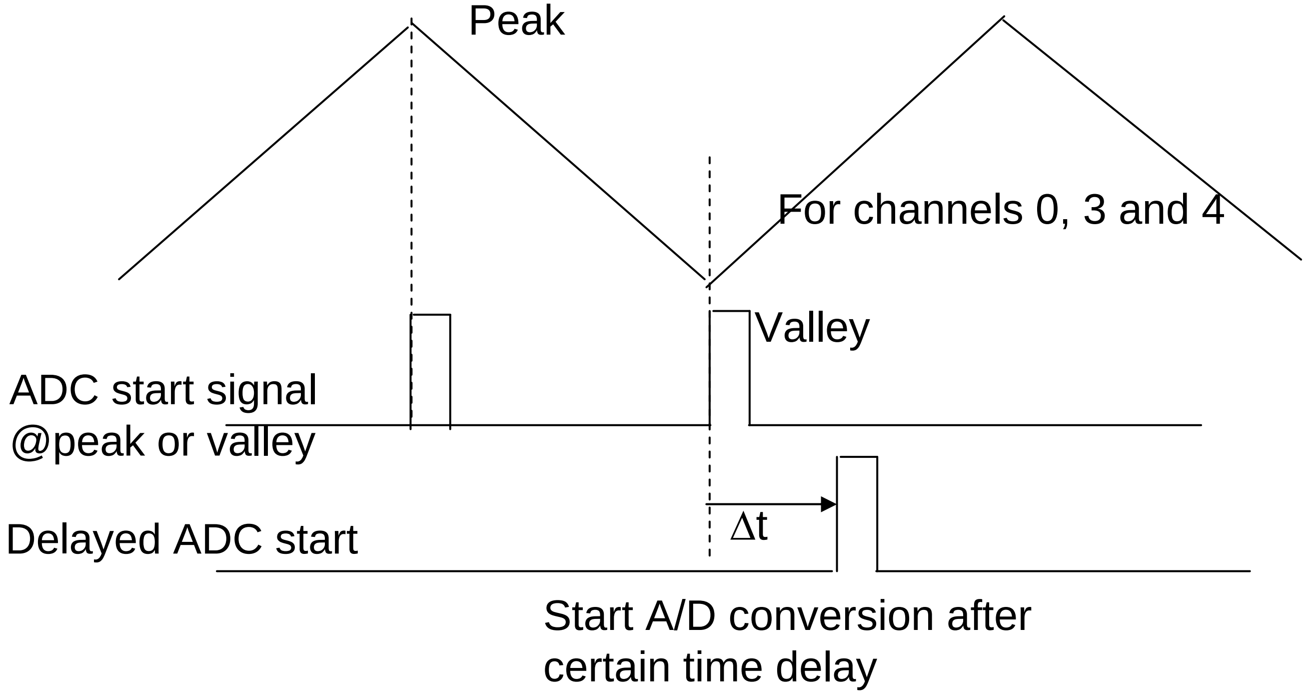


Figure 8b. MTU channels 0, 3 and 4 can issue ADC start triggers at peak or valley or on a delayed count.

Type A1 Control Algorithm

- Estimate speed error from two current measurements and applied voltage

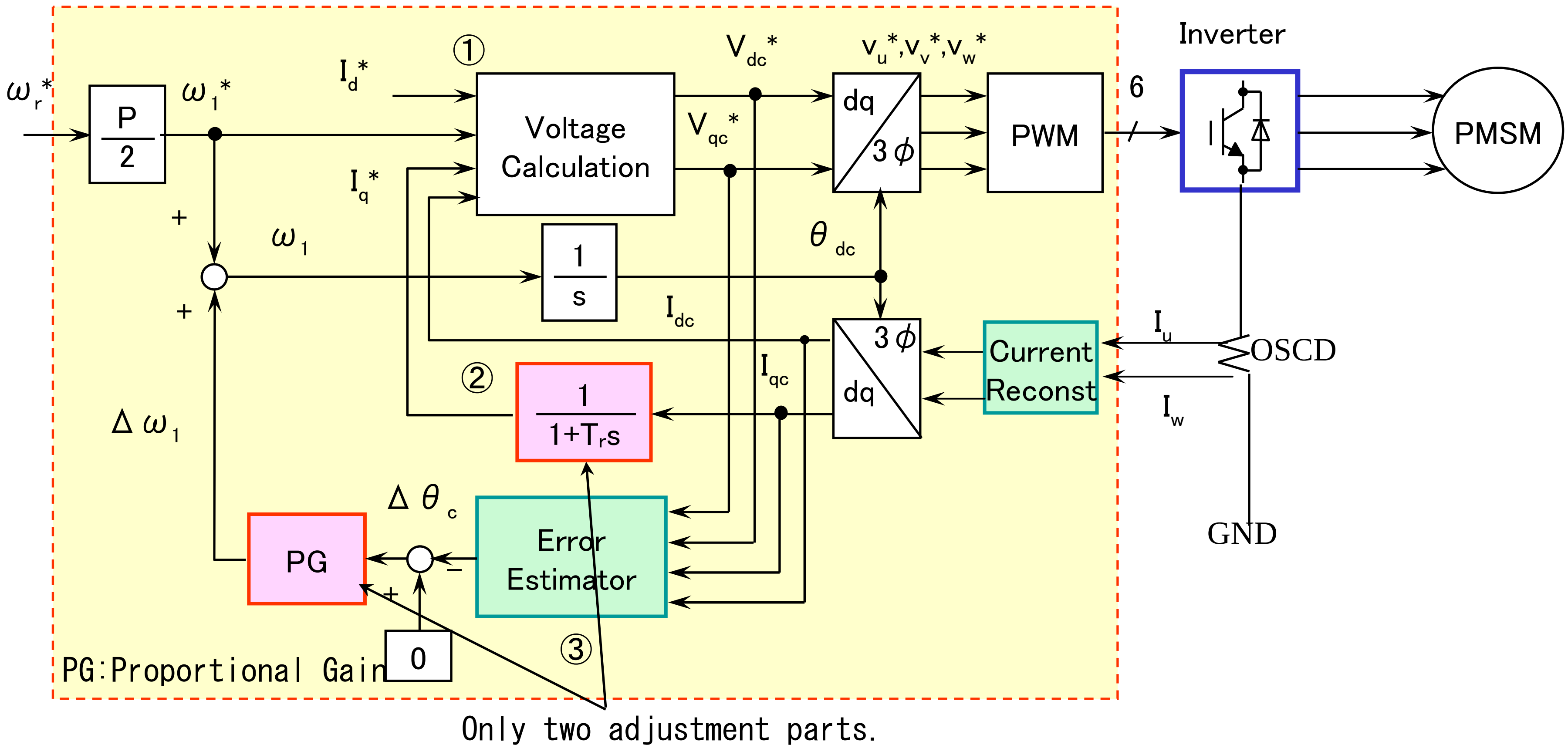


Figure 10. Type A1 closed-loop BLDC motor controller.

Type A1 Performance vs. Compressor Requirements

- **Our type A1 controller satisfies 5 criteria (1,2,3,5,7) very well**
- **We need further investigation in other three criteria (4,6,8)**

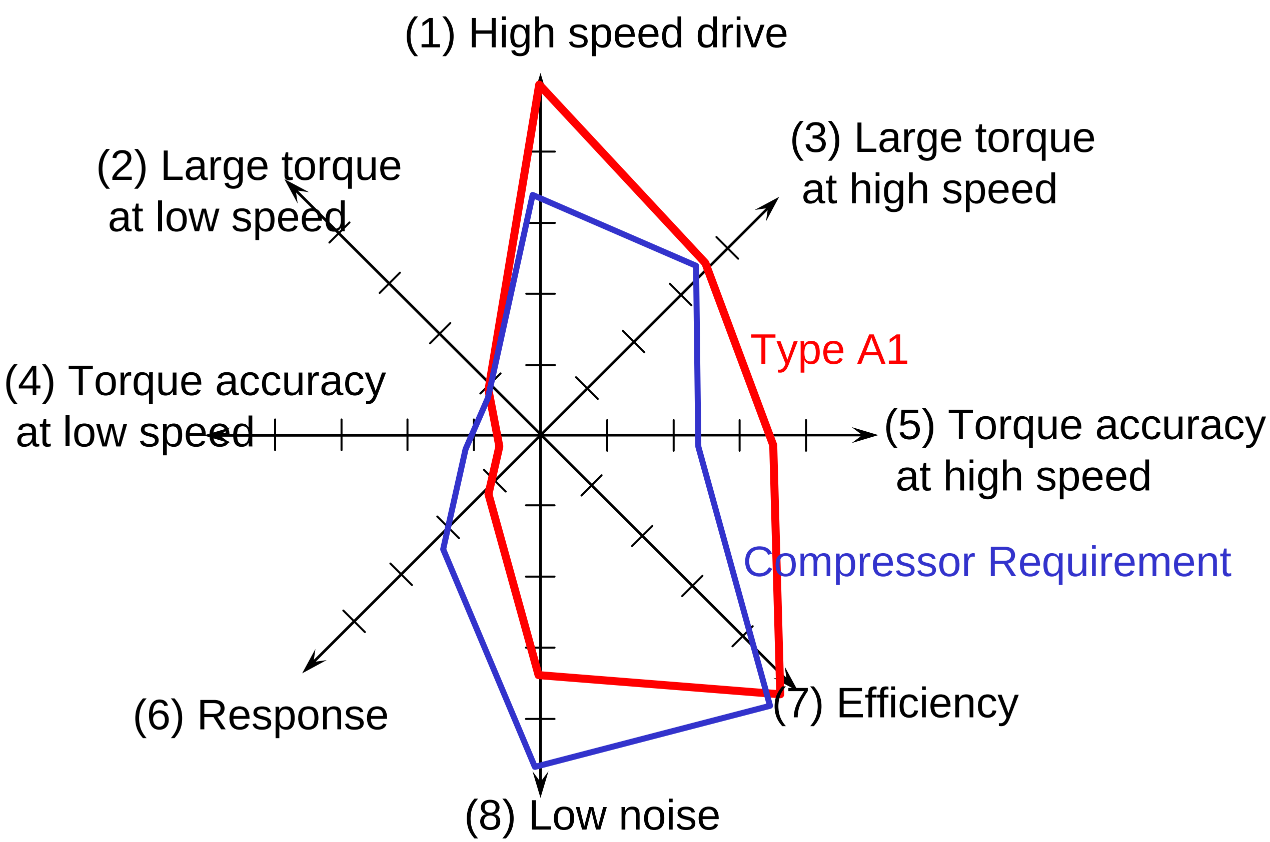


Figure 11. Performance of type A1controller vs. the compressor requirements.

Type A1 Performance vs. Compressor Requirements (contd.)

• All 8 criteria evaluated	**Requirement**	**Performance**	
High speed drive	(3.5)	(5)	Exceeds>
Large torque at low speed	(1)	(1)	Same =
Large torque at high speed	(3.5)	(3.5)	Same =
Torque accuracy at low speed	(1)	(0.5)	< Less ***
Torque accuracy at high speed	(2.5)	(3.5)	Exceeds >
Response	(2)	(1)	< Less ***
Efficiency	(5)	(5)	Same =
Low noise	(4.5)	(3)	< Less ***

Type A1 vs. 120 deg Performance

- **Much improvement on noise & efficiency criteria**

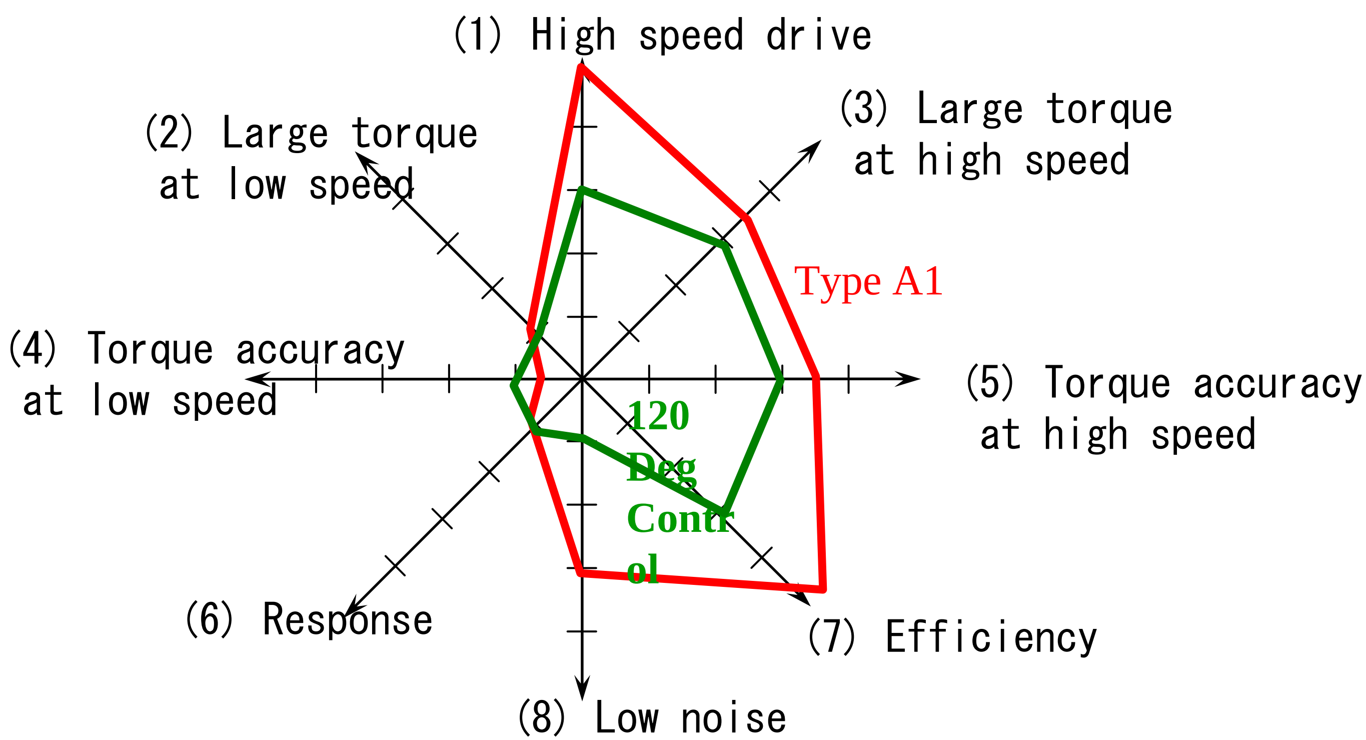


Figure 12. Type A1 control improves in all criteria except one – torque accuracy at low speeds. This criteria has very low importance.

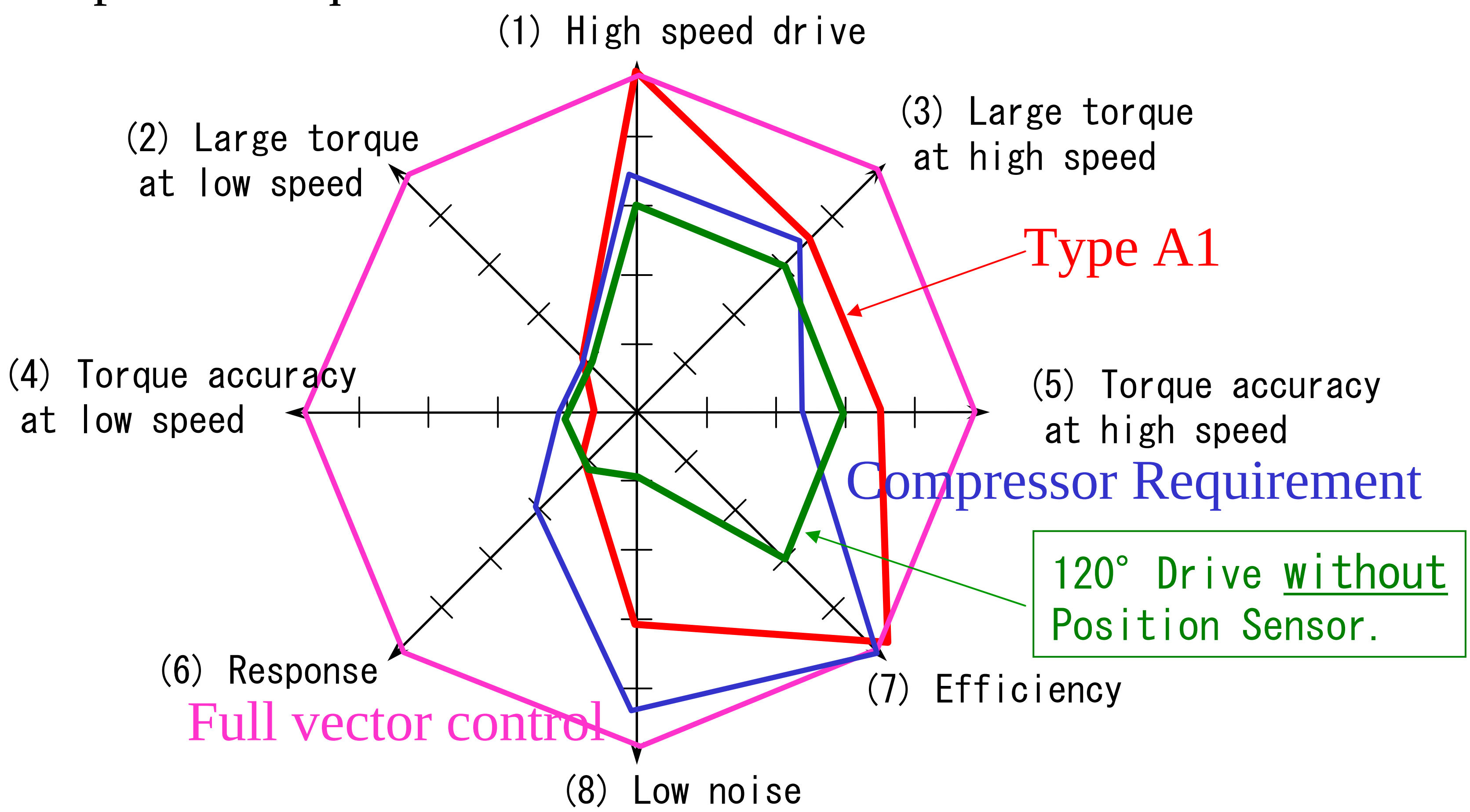
Type A1 vs. 120 Deg Performance (contd.)

All 8 criteria evaluated	**120 Deg**	**Type A1**	
High speed drive	(3)	(5)	Exceeds>
Large torque at low speed	(1)	(1)	Same =
Large torque at high speed	(3)	(3.5)	Exceeds>
Torque accuracy at low speed	(1)	(0.5)	Less ***
Torque accuracy at high speed	(3)	(3.5)	Exceeds>
Response	(1)	(1)	Same =
Efficiency	(3)	(5)	Exceeds>
Low noise	(1)	(3)	Exceeds

- Only one criteria is not improved by type A1 control method

Performance vs. Requirements

- Type A1, 120 deg and vector control performance is shown with compressor requirements



Type A1 & 120 deg vs. Compressor Requirements

Table 1. Comparison of Type A1 with 120 Deg control and performance requirements.

Criteria	**RQMTS**	**Type A1 control**	**Comments**	**120 deg control**	**Comments for A1**
High speed drive	3.5	5	exceeds	3	Better
Large torque at low speed	1	1	Meets	1	Same
Large torque at high speed	3.5	3.5	Meets	3	Better
Torque accuracy at low speed	1	0.5	<	1	Less
Torque accuracy at high speed	2.5	3.5	exceeds	3	Better
Response	2	1	<	1	Same
Efficiency	5	5	Meets	3	Better
Low noise	4.5	3	<	1	Better

Summary

- One shunt current detection method is a very low cost current measurement method
  - It does not increase BOM cost for home appliances
- Type A1 controller uses
  - sinusoidal modulation and
  - OSCD measurements
- Type A1 controller improves the performance over 120 deg control
  - Better efficiency
  - Less noise
  - Improved high speed