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Drive Module Testing Method Comparison for Drive Service Workshop

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Alkulause

Tämä insinööriyö on tehty ABB Oy:n Drives Service -yksikölle. Työn valvojana toimi Development manager Juha Alamäki ja ohjaajana lehtori Jari Ijäs Metropolia ammattikorkeakoulusta, joille haluan antaa suuret kiitokset aktiivisesta opastuksesta.

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<p>Tämä insinöörityö on tehty ABB Oy:n Drives Service -yksikölle. Työssä tutkitaan taajuusmuuttajamoduulien koestusta korjaamoympäristössä. Työssä on keskitytty ABB:n ACS800-104 R8i -invertterimoduulin testaukseen. Huolellinen ja hyvin suunniteltu koestus on tärkeää, sillä hyvällä testauksella varmistetaan huollettujen taajuusmuuttajamoduulien laatu ja turvallisuus. Erilaisten testausmenetelmien hyviä ja huonoja puolia vertaillaan ja näiden ominaisuuksien perusteella muodostetaan vertailutaulukko.</p> <p>Työn alussa on selvitetty ABB Oy:n historiaa ja nykypäivää, jonka jälkeen esitetään taajuusmuuttajan rakenne ja toimintaperiaate sekä ohjaustavat. Tämän jälkeen on esitetty testauksen tavoitteita, erilaisia koestusmenetelmiä sekä mahdollista syklisyyden lisäämistä testeihin.</p> <p>Lopputulokset on koottu vertailutaulukkoon, jossa eri testausmenetelmien hyvät ja huonot puolet tulevat ilmi. Taulukossa olevat kriteerit on pisteytetty niiden tärkeyden mukaan. ABB:n globaali korjaamoverkosto voi hyödyntää tätä vertailutaulukkoa, sopivaa koestusmenetelmää valitessaan.</p>	
Avainsanat	Koestusmenetelmä, vertailu, ALT, ACS800-104, taajuusmuuttaja

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<p>This Bachelor's thesis was made for ABB, Drives Service. The thesis explains different drive module testing methods in Drive Service Workshop environment. This thesis focuses on testing of the ACS800-104 R8i inverter module. Well planned testing procedure ensures that serviced modules are high quality and safe to use. Different testing methods are introduced and compared. The comparison chart is given as a result.</p> <p>First, ABB is briefly introduced, and then the structure, the principle and the control of AC drives are described. Then, the targets of testing and different testing methods are explained and also the possibility for cyclicity in the testing is taken into consideration.</p> <p>As a result, the table form testing method comparison chart is given. The chart reveals the pros and cons of different testing methods. The comparison criteria are rated based on their importance. The comparison chart is useful tool for the global Drives Service Workshop network, when suitable testing method is pondered.</p>	
Keywords	Testing method, comparison, ALT, ACS800-104, AC drive

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Abbreviations and Acronyms

ABB	Asea Brown Boveri. Company that was formed in a merger of ASEA and Brown, Boveri & Cie.
AC	Alternating current. The flow of electrons that periodically changes direction.
DSW	Drive Service Workshop. Workshop where AC drives are repaired and tested.
LV	Low voltage. Voltage level not exceeding 3~690 VAC.
LBU	Local business unit. Divisions of ABB are divided into business units. The business units are divided further on into local business units.
DC	Direct current. The flow of electrons that goes in one direction.
IGBT	Insulated-gate bipolar transistor. Power semiconductor with three terminals: emitter, collector and gate.
PWM	Pulse width modulation. Method that creates series of voltage pulses with variable width.
PI	Proportional-integral controller. Controller that integrates the error between the feedback and reference current to generate a variable voltage value.
DTC	Direct torque control. AC drive control method developed by ABB. Allows the torque to be controlled directly.
PCBA	Printed circuit board assembly. Used to mechanically support and electrically connect electronic components.
DUT	Device under test. The drive unit currently being tested.

ISU	IGBT supply unit. Rectifier that is made out of IGBTs.
LCL	Inductor-capacitor-inductor. Filter type made of two inductors and one capacitor.
ALT	Accelerated life test. Testing method that creates a stress higher than in the product's normal use.
HALT	Highly accelerated life test. Testing method that creates a stress much higher than in the product's normal use. In HALT the device under test eventually has to fail.
SAC	SnAgCu. Tin, silver and copper alloy for soldering.
PLC	Programmable logic controller. Simple computer that is used in automation.

1 Introduction

This bachelor's thesis deals with ABB's ACS800-104 R8i inverter module testing methods in service workshop environment. Thesis explains the current testing method used in the Drive Service Workshop, and also three other possible ways to test drive modules. The main target of the thesis is to survey the differences in various testing methods.

Proper testing of the AC drive modules is crucial to guarantee the quality and safety of the module. The testing procedure should reveal any faults in the module. The module may even have hidden faults that have occurred during the repair process or have existed before. If the test reveals these faults, they can be repaired during the test, before possibly inoperable unit is shipped to a customer from DSW.

Current testing method for drive modules is rather slow and it limits the growth of capacity. Drive module testing nowadays takes over two hours because the module must be heated up by loading it with motor. However, e.g. flaws in the solder joints are better exposed when the temperature is changing cyclically. Another current testing method's weakness is that the module is only run with constant load while in normal use the load is more or less cyclic.

There are many other possible ways to test the drive modules. The testing methods covered in this thesis are: testing drive modules using current method of DSW, loading with reactive power, Accelerated Life Testing and testing without load.

First, ABB is briefly introduced as a company. Then, the structure, the principle and the control of AC drives are described. Then, the targets of testing and different testing methods are explained and also the possibility for cyclicity in the testing is taken into consideration. Finally, as a result, a comparison chart is given.

2 ABB Group

2.1 ABB Ltd.

ABB was born in 1988 from the merger of the Swiss BBC Brown Boveri and the Swedish ASEA. The new company Asea Brown Boveri started operating on the 5th January 1988. [1] Nowadays ABB Group is world leader in power and automation solutions that both improve performance and also lower strain for the environment. ABB has operations in over 100 countries employing around 135,000. [2]

ABB is headquartered in Zürich and its shares are traded in the stock markets of Zürich, Stockholm and New York. The group is divided in five divisions: Power Products, Power Systems, Discrete Automation and Motion, Low Voltage Products, and Process Automation. [3]

ABB invests a lot in research and development. In 2009 investment in R&D was \$1.3 billion which was 4.1% of the revenue. In 2009 ABB launched several new products e.g. a new solar inverter, drives for water industry, rail converters, a compact robot, circuit breakers and a new product family for solar applications. [3]

ABB has R&D personnel of 6 000 in seven research centers. The group cooperates with 70 universities and manages about 20 000 active patent applications. [3]

2.2 ABB in Finland

A story of ABB in Finland began in 1988 when ASEA acquired Finnish Oy Strömberg AB, one year before merging with BBC Brown Boveri. [4]

Strömberg was established in 1889 and it produced for example electric motors, drives, small power plants and protective relays. [5]

In Finland ABB has operations e.g. in Helsinki, Vaasa, Oulu and Porvoo. [6]

2.3 BU Drives and Service Product and Network Management

Business Unit Low Voltage Drives is part of ABB's Discrete Automation and Motion division. LV Drives management is located in Helsinki where the Local Business Unit Drives Service also is. LBU Drives Service is responsible for developing global after sales services for LV Drives. These services include spare parts, training, and repair and maintenance services. Service Product and Network Management department's main responsibility is to develop these kinds of services and also network management of global service network. Department is located in Pitäjänmäki, Helsinki. [7]

3 Principles of AC Drives

In this section the AC drive is introduced and explained. It is important to have certain knowledge of drives before thinking about the testing methods.

AC drive or variable frequency drive is an electronic device for controlling e.g. electric motor. AC drive has many advantages compared to use of an AC motor when the motor needs to be controlled. Operating speed is fast and because the process can be controlled precisely, AC drive is more energy efficient. AC drive also enables soft start which reduces mechanical stress. [8, p. 380]

3.1 Structure

This part explains the structure of an AC drive. The single drive consists of two converter modules: the first one is called rectifier which converts AC voltage to DC, and the second one is inverter which then converts DC voltage to AC with different frequency and amplitude. [8, p. 414] Between the inverter and the rectifier are the DC voltage intermediate circuit and control electronics. [9] The next image illustrates the AC drive structure (Fig. 1).

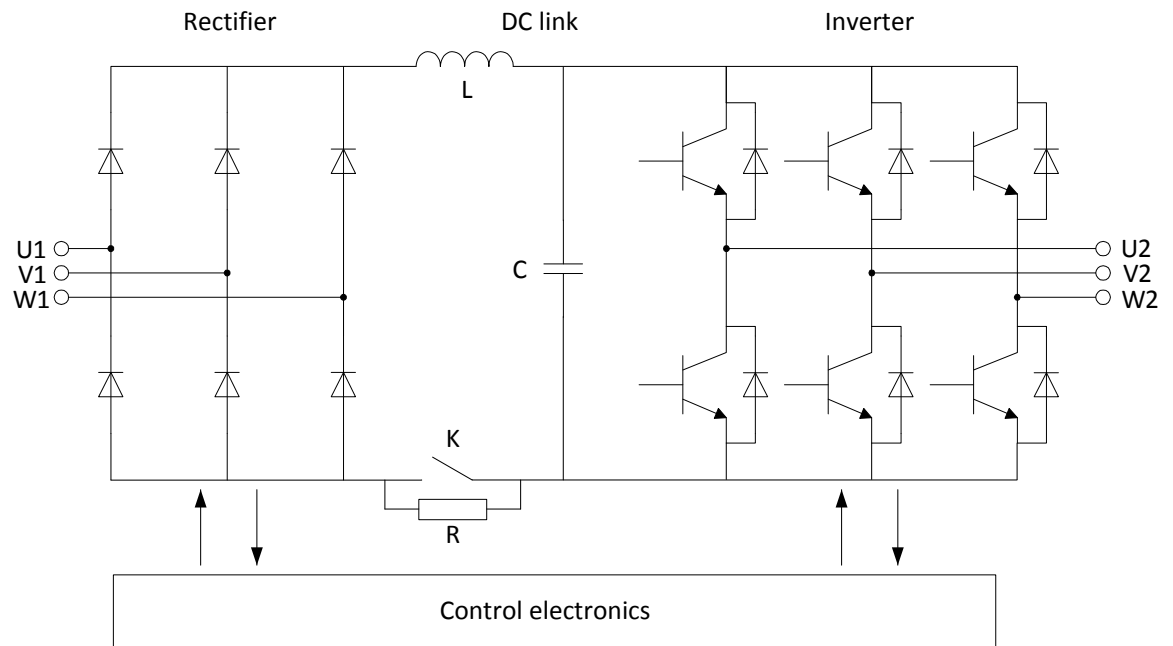


Fig. 1 AC drive with diode rectifier and IGBT inverter

The mains are connected to terminals U1, V1 and W1 and the motor to terminals U2, V2 and W2. This particular drive has diode rectifier and IGBT inverter.

The voltage waveforms in different parts of an AC drive are shown in the next image (Fig. 2).

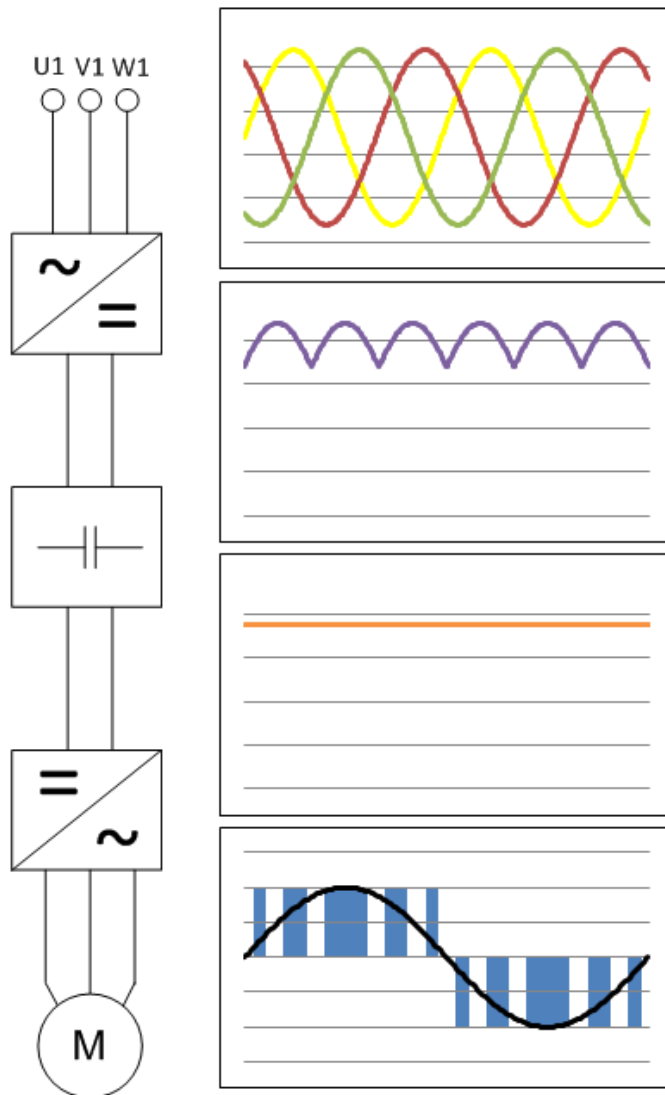


Fig. 2 Voltage wave forms of the AC drive

After the rectifier, the three phase sine wave (yellow, green and red waveforms) has turned into a pulsating DC voltage (purple) which is filtered in the DC voltage intermediate circuit before it is fed to an inverter unit. When using PWM, the inverter chops the filtered DC voltage (orange) and creates a series of voltage pulses (blue) with desired frequency. The amplitude of the pulses is kept as constant as possible but the width of the pulses is changed. The sinusoidal component (black) represents the current in the motor. The impedance of the motor creates current and also filters it to a sine wave. If demanded, it is also possible to filter the voltage of the inverter output into a sinusoidal form using sine filters. [10, p. 62]

The AC drives can be either single drives or multidrives. Single drives contain the rectifier and one inverter module while the multidrives contain more than one inverter (Fig. 3).

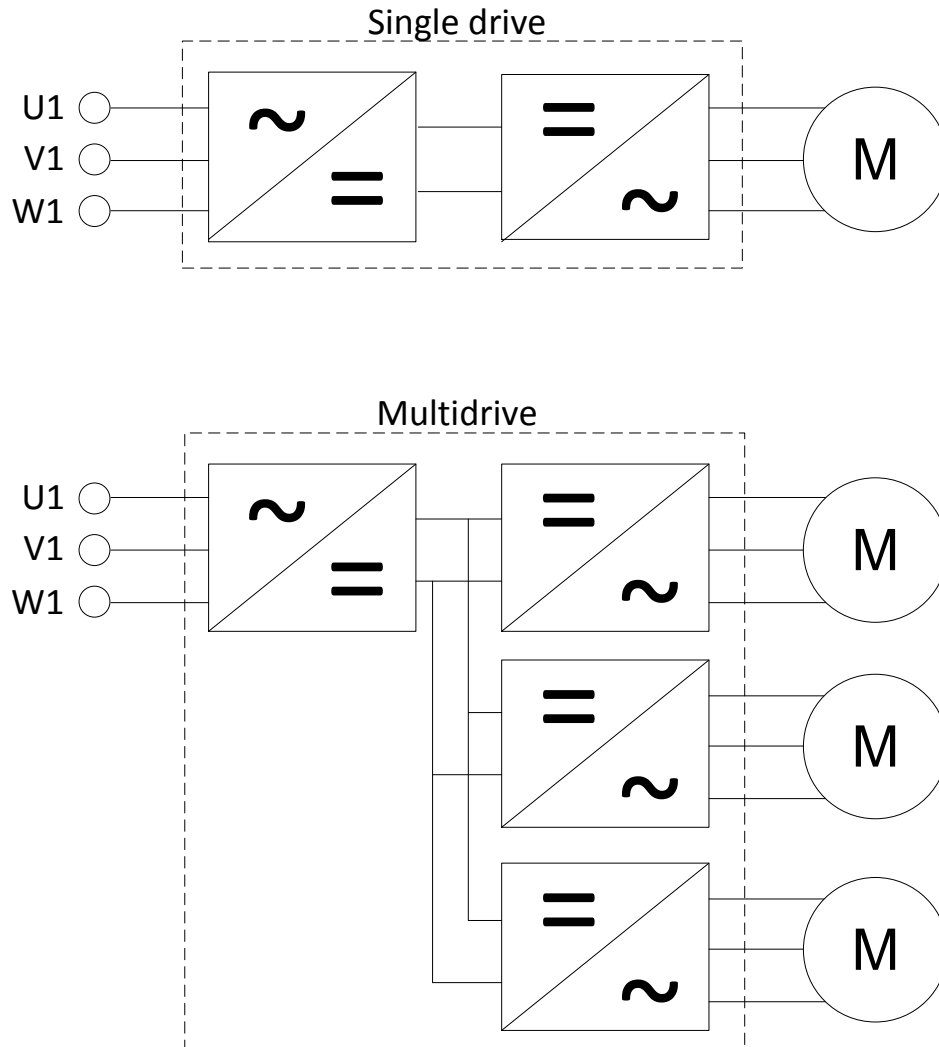


Fig. 3 Difference between a single drive and a multidrive

Multidrives need only one common DC link for number of inverters and motors. This simplifies the connections and maximizes the floor space when the process requires more than one controlled motor. It is also possible to add more rectifiers to the multidrive if there are a lot of inverters and more needed power. [9]

3.1.1 Rectifier

The rectifier converts AC voltage into DC voltage. The rectifier can be made using different kinds of components, such as diodes, thyristors or IGBTs. Diode rectifier (Fig. 4) is the most common and simplest solution. It typically consists of six or twelve diodes and it only allows the energy (E) to flow from network to DC voltage intermediate circuit. [9]

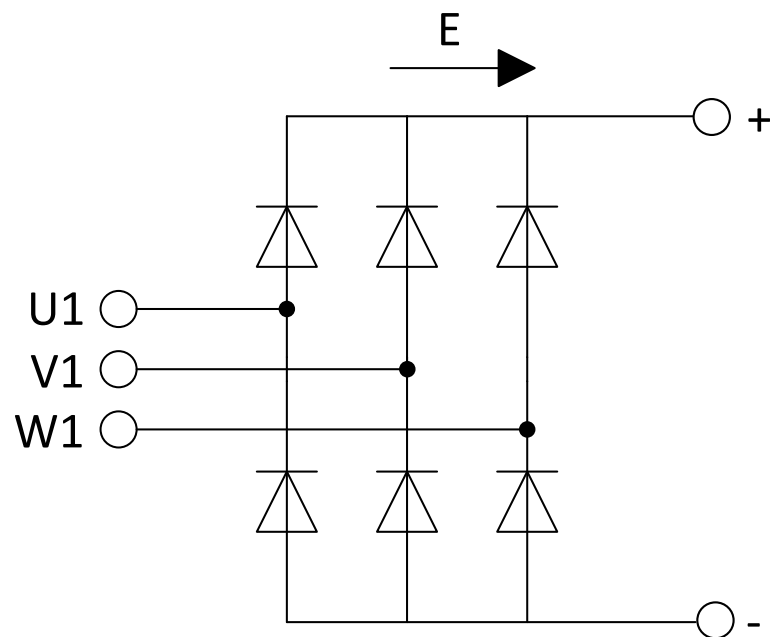


Fig. 4 6-pulse diode bridge rectifier

A thyristor and IGBT rectifiers allow the energy to flow in both directions so that the braking energy can be fed back into the network. When using thyristors, two bridges are needed because the first one is working as motoring and the second one as regenerative bridge (Fig. 5). [9]

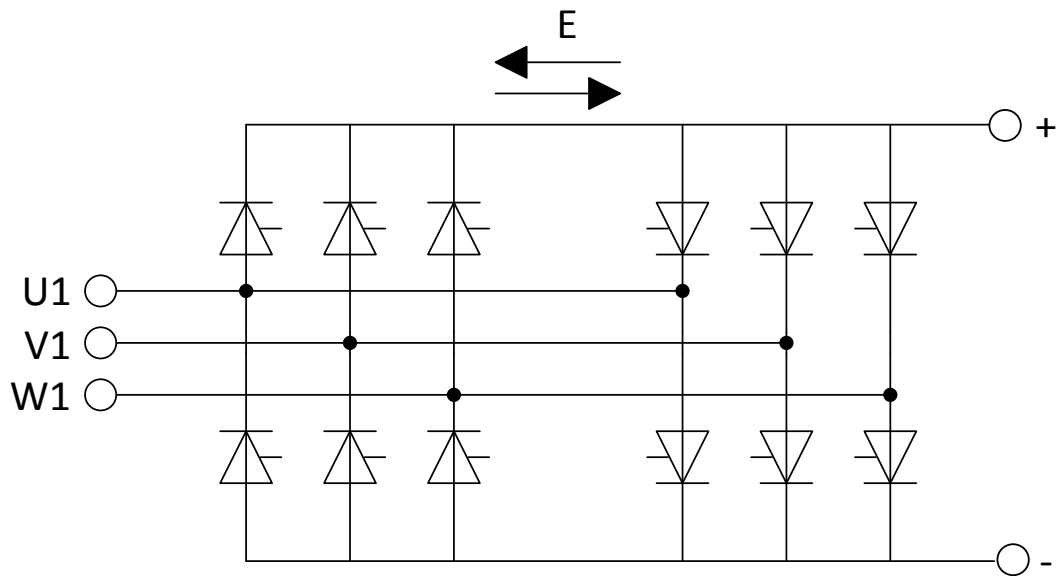


Fig. 5 Regenerative thyristor rectifier

When feeding energy back to the network, the current has to be limited so that the energy in the DC link does not drop too low. This is why the thyristors are needed both, in motoring and regenerative bridges. [9]

The IGBT rectifier (Fig. 6) consists of six IGBTs and six freewheeling diodes which protect the IGBTs and allow the energy to flow in two directions. [9]

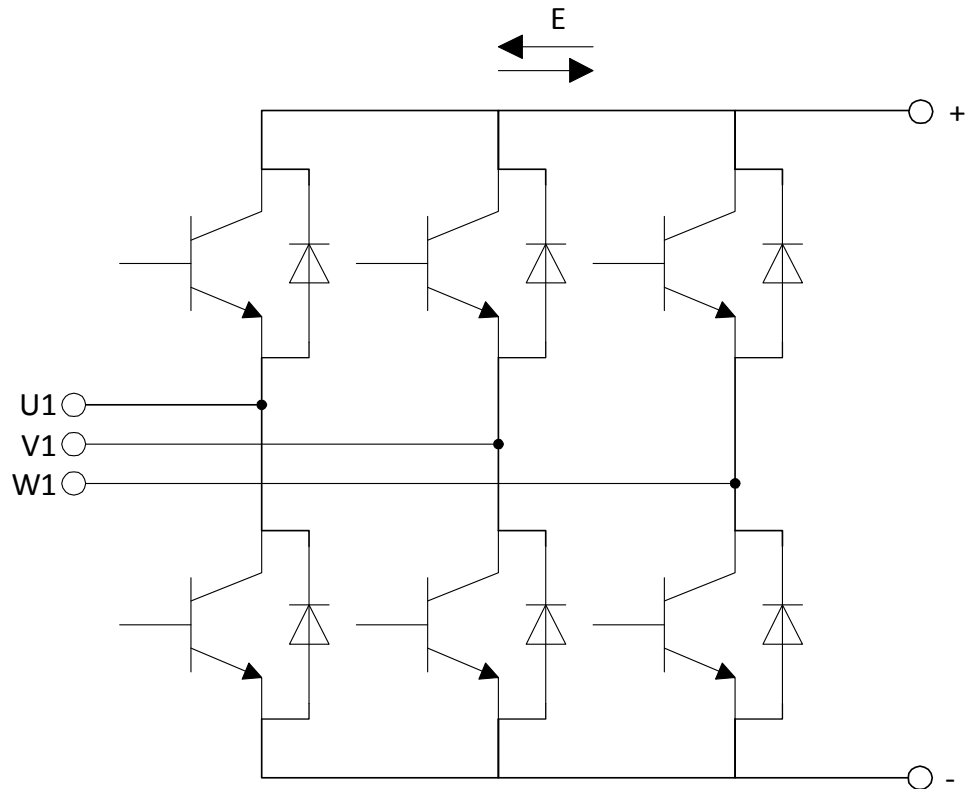


Fig. 6 IGBT rectifier

A rectifier creates a pulsating DC voltage which must be filtered before feeding it to the inverter unit. The number of the pulses is dependent on the number of power semiconductor components in the rectifier. A rectifier with six power semiconductor components creates a DC wave with six pulses per period, and a rectifier with 12 components creates 12-pulse DC voltage. The pulsating DC voltage is then filtered and clean DC comes as a result. [10, p. 52]

3.1.2 DC Voltage Intermediate Circuit

The main purpose of the DC voltage intermediate circuit or DC link is to operate as energy storage and to filter the pulsating DC voltage from the rectifier. Usually the energy is stored into a capacitor and a choke levels the pulsating DC voltage of the rectifier. It also includes a charging circuit for the capacitor and may include a braking chopper and a resistor (Fig. 7). [9]

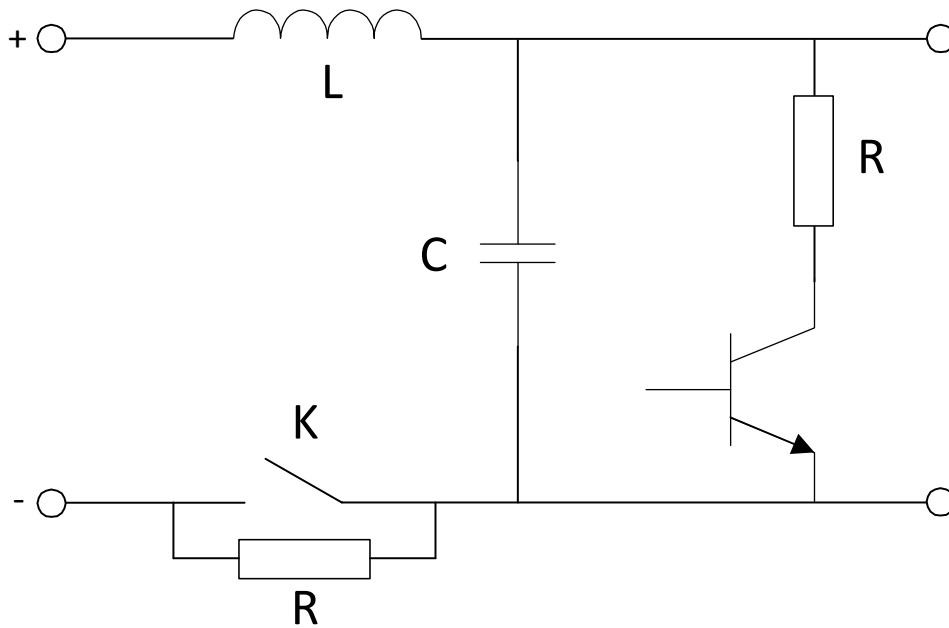


Fig. 7 DC voltage intermediate circuit with braking chopper and resistor

It is important that the capacitance of the storage capacitor is high enough so that the voltage of the intermediate circuit is kept as constant as possible. This allows the inverter unit to operate precisely. [11, p. 608]

3.1.3 Inverter

The inverter is the last module of the AC drive. The next image illustrates the construction of the IGBT inverter (Fig. 8).

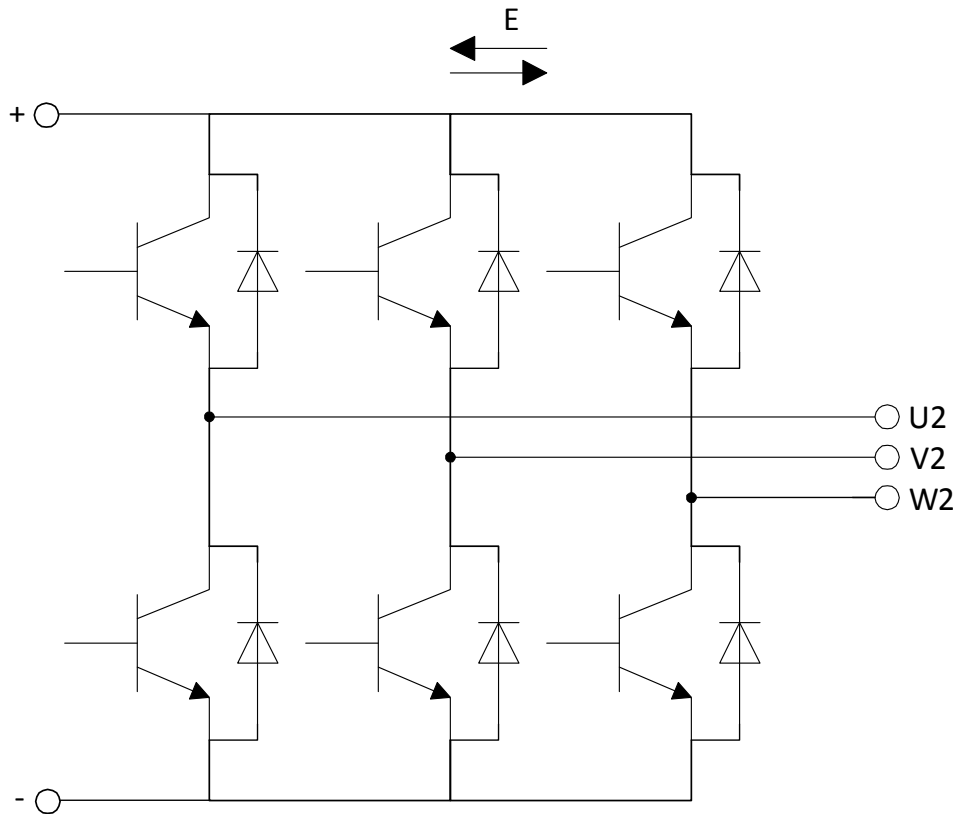


Fig. 8 Three phase 6-pulse IGBT inverter

The IGBT inverter converts DC voltage from DC voltage intermediate circuit into AC voltage with variable frequency and amplitude. It can also be made of thyristors or other semi-conductors but IGBTs are the most common nowadays. [9]

Inverter chops DC voltage of the intermediate circuit and creates a series of voltage pulses which are fed to a motor. [8, p. 415]

This thesis focuses on converter module ACS800-104, frame size R8i (Fig. 9) which is the biggest both in power and physical size of all the ACS800 converter modules of ABB. The nominal power of ACS800-104, R8i is up to 2800 kW.



Fig. 9 ACS800-104, frame size R8i

ACS800-104, R8i stands on a pedestal with wheels so it is easy to slide into a cabinet. The DC connection bars are located on the top of the module and quick connectors for AC are in the back. Optical fibers for communication with the main circuit interface are connected to front. Cooling is done with a fan that is located under the module.

3.2 Control

The electric motors are controlled by using various control methods, which must be comprehended to understand the actual operation of the AC drives. Also different control methods are used in different parts of the test. The next image illustrates why and how the drives are controlled (Fig. 10).

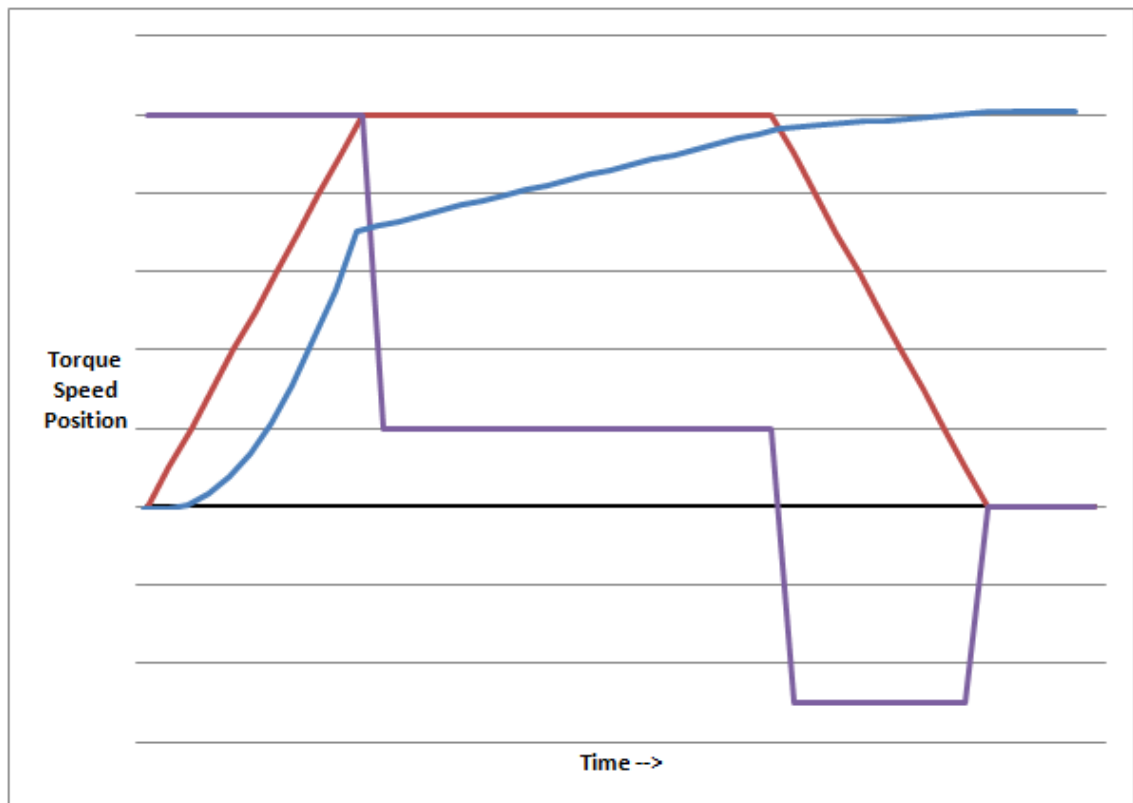


Fig. 10 Control

This graph could be about the control of e.g. an elevator. These three lines represent the speed (red), position (blue) and torque (purple) of the elevator and time is in the X-axis. First, the elevator must start softly and then its speed is accelerated to a full using maximum torque all the time. When the elevator has reached its full speed the torque can be lowered. At the deceleration part, the torque turns negative which slows down the elevator. As this example shows the key measures in the drive control are torque and speed. [10, p. 8]

Scalar and vector controls are based on PWM, unlike the Direct Torque Control which allows controlling the torque and the speed directly. These methods are explained in the following chapters. It is important to understand the difference of various control methods because different kinds of controls are used in different testing practices.

3.2.1 Scalar Control

In the scalar control or open-loop control, neither the position nor the direction of the speed is considered. The scalar control is used in applications such as pumps and ventilators where exact precision is not needed. Motion sensors are not used and the control is done by changing the voltage amplitude and frequency. The V/f ratio is kept constant when not exceeding the nominal speed. The image below explains the principle of scalar control (Fig. 11).

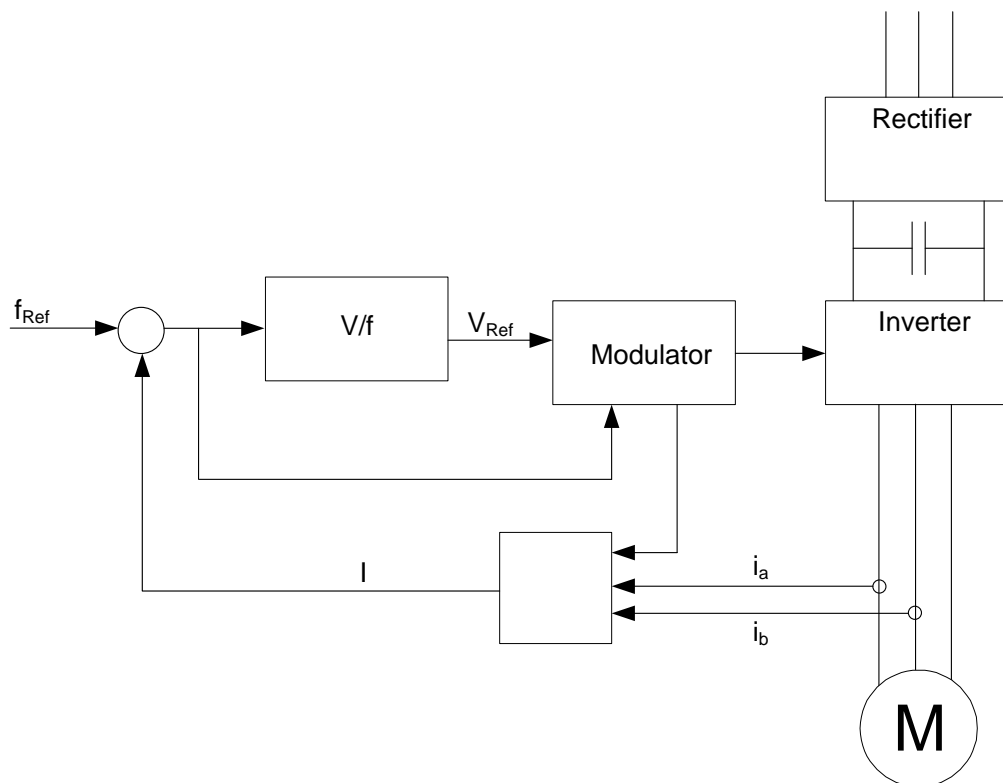


Fig. 11 Scalar control

Speed is controlled by changing the frequency reference. Voltage and frequency reference values are fed to a modulator. The inverter uses PWM, and based on the modulator values it creates a series of voltage pulses. The pulses are then fed to a motor. The impedance of the motor creates a current and also filters it into the sinusoidal form. The scalar control does not take motor values into account. Only the currents of the motor are measured and considered.

This practice is cheap to implement since the position sensors tend to be expensive, but the control is not precise because the actual speed of the motor is unknown. This means that the slip cannot be compensated and that the motor speed is dependent on the load. The other downside is that the modulator is needed. Use of the modulator slows down the control. [10, p. 271]

3.2.2 Vector Control

Unlike in the scalar control, in the flux vector control also the actual position and the speed of the motor are taken into account. The purpose of the vector control is to control the motor correctly at all situations. This is why the actual speed and position of the motor are measured by using motion sensors, so that the torque can be controlled indirectly. See picture below (Fig 12).

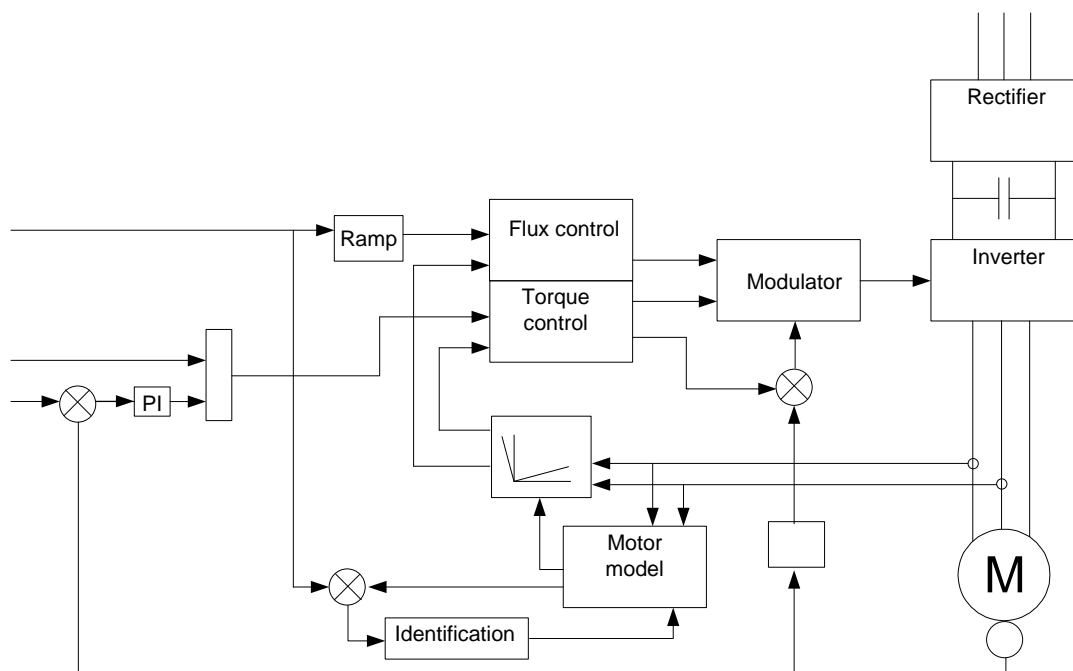


Fig. 12 Vector control

Flux and speed are controlled separately. The actual speed is measured using speed sensor.

Measures such as voltage, current and frequency are produced in a microprocessor, which also contains the mathematical model of the motor. The microprocessor calculates the magnetic flux of the motor. The flux and the torque are controlled separately. The measures created by the microprocessor's flux and torque control, are fed to the modulator which gives commands to the inverter. The inverter then generates the voltage pulses using PWM. The impedance of the motor creates and filters the current.

The actual speed and motor currents are measured. The actual speed of the motor is fed to PI controller that determines the speed reference so that the slip is compensated.

The vector control is very precise but difficult to implement because the motion sensors are needed. As in the scalar control, in the vector control the modulator is needed which limits the dynamic performance. [10, p. 270]

3.2.3 Direct Torque Control

By using Direct Torque Control or DTC instead of PWM, it is possible to directly control the torque and speed without using motion sensors (Fig. 13). Torque is calculated precisely in the microprocessor which also holds the mathematical model of the motor. Since there is no need of modulator, the DTC is much faster than scalar or vector control methods.

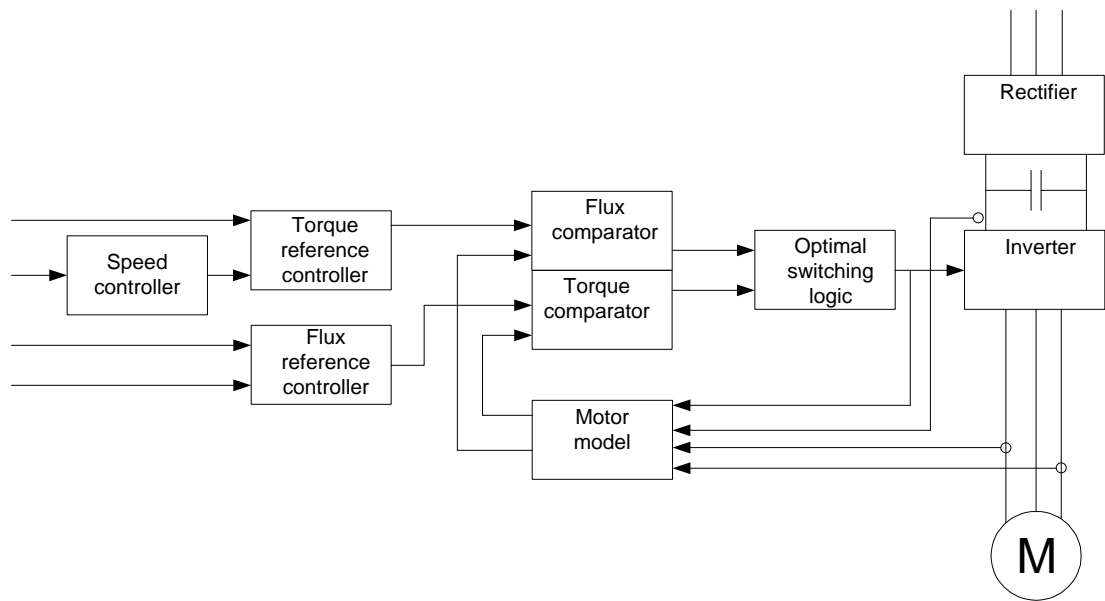


Fig. 13 DTC

The motor currents and DC voltage are measured and fed to the motor model. The microprocessor calculates the optimal switching of the IGBTs so that there is no unnecessary switching.

Quick torque response keeps the speed of the motor constant despite the change in the load. DTC also provides full torque at minimum speed. [12]

4 Targets of Testing

The power modules are tested to ensure that the service was carried out properly and that the module operates duly. Hidden faults that may have occurred during the service or existed before are cleared up. If the testing procedure is done right and by the standards, the product is durable and safe to use. One year warranty is given for the serviced products and it is vital that the product can operate for at least one year, preferably for two years after the service.

Failure rate is dependent on life time and it follows the so-called bathtub curve (Fig. 14).

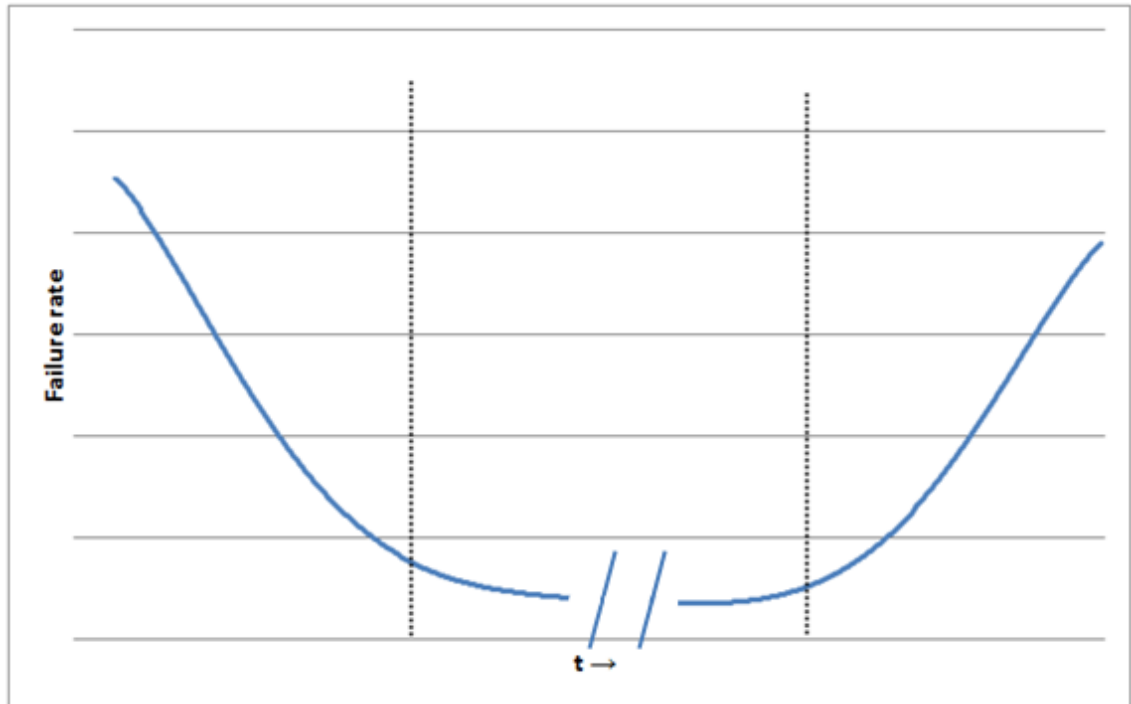


Fig. 14 Bathtub curve

Failure rate is on Y-axis and X-axis represents the operating time of the module. The first sector represents the infancy period, the middle part is the useful life of the product and the last part is wear-out period. [15, p. 182]

If the serviced modules are not properly tested, there is a possibility that a module with hidden faults is shipped to a customer and will fail after short time of use. New parts such as PCBAs and IGBTs may have weak solder joints that are only revealed when all the parts have heated up. If the modules that would otherwise fail during the infancy period can be found and re-repaired, the testing procedure is successful.

After the useful life time has expired the modules start to break down one by one.

5 Current Testing Methods in Workshop

This part explains the testing procedures done nowadays in ABB drive service workshop.

5.1 Visual Inspection

The purpose of the visual inspection is to check that all the critical connections are connected properly. Also the cleanliness is checked and that there are not any visible damages in the module.

There are five steps in the visual inspection which are introduced in the next table (Table 1).

Table 1. Visual inspection procedure

Step 1: Visual inspection of the heat sink	Check that the heat sink of the frequency converter is clean.
Step 2: Visual inspection of fans	Check that the fans are properly installed.
Step 3: Visual inspection of quick connectors	Check and clean the contact surfaces at the quick connector.
Step 4: Check the tightening of power semiconductor module	Check that the IGBT modules have been tightened to the correct torque.
Step 5: Check the circuit boards and the main circuit connections	In the visual inspection of the boards and the main circuit connections, it is important to ensure that all electrical connections are properly tightened.

If all the steps are checked over and everything appears to be as it should be, the tester can move on to basic measurement.

5.2 Basic Measurement

Some basic measurements must be done using a multimeter before power can be applied to the drive module.

There are five steps in the basic measurement procedure, which are explained in the next table (Table 2).

Table 2. Basic measurement procedure

Step 1: Motor IGBT freewheeling diode measurement	Use a multimeter to make sure that the measurements for the output bridge freewheeling diodes are OK.
Step 2: IGBT gate measurement	Use a multimeter to measure the condition of the IGBT gates.
Step 3: Temperature sensor measurement	Use a multimeter to measure the condition of the negative temperature coefficient thermistor on the IGBT module.
Step 4: Discharging resistor measurement	Use a multimeter to measure the resistance of the discharging resistors.
Step 5: Voltage reducing module; Thick-film hybrid measurement	Use a multimeter with high voltage probe and an external DC power supply to measure the condition of the Thick-film hybrid.

Insulation resistance measurement test can be done if all of the steps of the basic measurement are carried out and everything is ok.

5.3 Insulation Resistance Measurement and Capacitor Reforming

The insulation resistance measurement is done by using measuring device capable of producing 1000 VDC for 15 seconds. In the test, the main circuit terminals are short-circuited and the insulation resistance is measured between the main circuit and the frame.

If the module has been in storage for over a year, the capacitors must be reformed before the actual test run. This is done by increasing the DC link voltage step by step.

An appropriate reforming voltage is $1.35 \cdot U_{\text{Nominal}}$ (AC) and maximum current is 500 mA. When the capacitors are reformed and external voltage source turned off, the discharging resistors, if working properly, should discharge the capacitors.

5.4 Testing the Main Circuit

First the module is tested without a motor to make sure that any faults do not occur and that the fans are working correctly. In this test the control mode is set to scalar and the frequency reference should be at 25 Hz. If no faults occur and the fans are working, the module can be tested with a light load.

The drive modules are tested with back-to-back coupled motors where two similar motors are used. (Fig. 15)



Fig. 15 Back-to-back coupled motors in workshop

The picture above shows two 500 kW motors in ABB drive service workshop in Kiitorantie Vantaa, Finland. The next figure illustrates how this testing method works (Fig. 16).

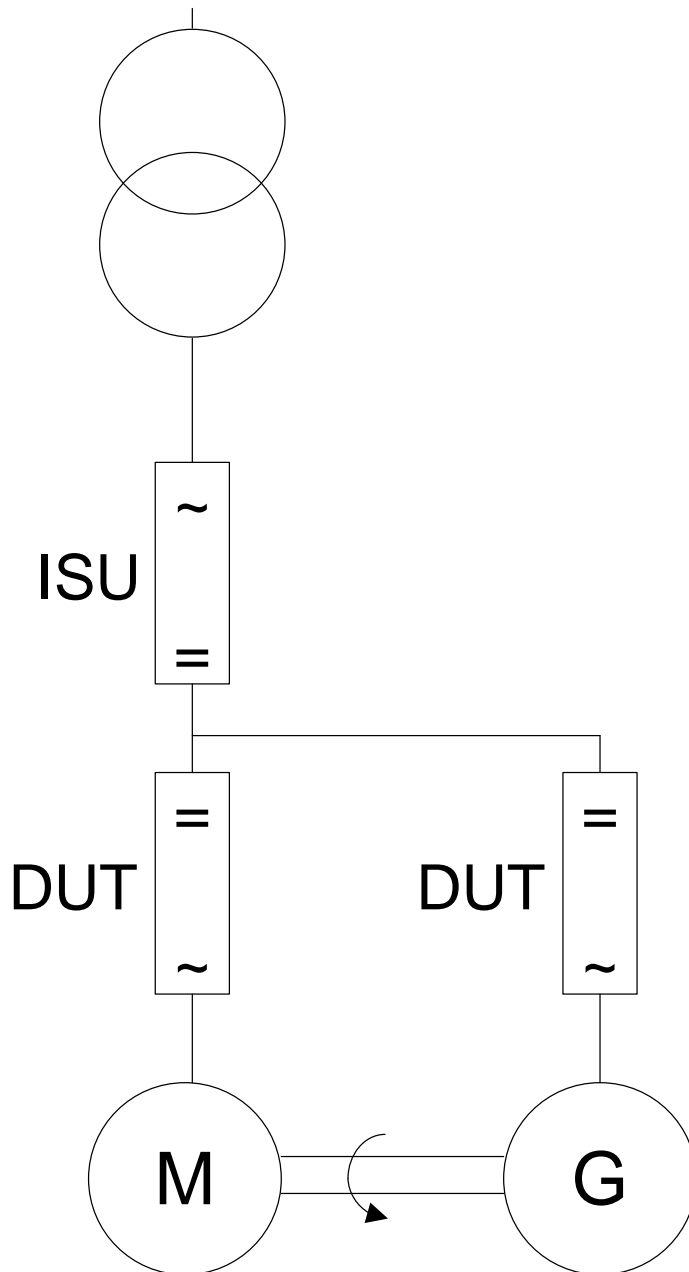


Fig. 16 Back-to-back coupled motors

First, the AC voltage is rectified in ISU. In this case two ACS800-104 modules are tested. The first DUT converts the voltage of the ISU to AC for the motor. Because the shafts of the machines are attached together, the generator starts generating AC power, which is then rectified in another DUT, which again feeds the first module. So, actually the power is cycling between these two modules and machines and when the system is running, only the losses are taken from the grid. When two modules are

tested simultaneously, both of them must be tested in both sides: the motor and the generator side.

In the first test no other load is used but the motors' free rolling shaft load. The module control mode is set to DTC, the correct motor data is set and ID run is performed. If using four pole synchronous motors the speed reference is set to 1500 rpm / 50 Hz, and 20 sec after the start the output currents and voltages are measured. Output currents should be symmetrical and the output voltages should have the same value as defined in the motor data set. Then the direction is changed by setting the speed reference to -1500 rpm. If everything is correct and there are no faults, the module can be tested with nominal load.

Testing time on nominal load must be one hour. The load motor has to be run in motor and in generator use. The drive must be run continuously so that the drive temperature is stabilized. The actual temperature is then checked from the control panel. The testing is successful if DC voltage has the same value as in parameters, the output currents are symmetrical, output voltages have the same value as defined in the motor data set and there are no faults detected.

The losses of the motors are calculated below (F1, F2)

$$P_{Electric} = \sqrt{3} * U_N * I_N * \cos \varphi_N = \sqrt{3} * 690 \text{ V} * 505 \text{ A} * 0,86 = 519 \text{ kW} \quad (F1)$$

$$P_{Loss} = 2 * (P_{Electric} - P_N) = 2 * (519 \text{ kW} - 500 \text{ kW}) = 38 \text{ kW} \quad (F2)$$

Power loss of the motors is 38 kW. When they are used for 8 hours a day, the need of energy is 304 kWh/d. The drive modules also have internal losses from e.g. power dissipation of IGBTs and internal fans but they are not taken into consideration because they remain the same no matter which testing method is used.

The downsides of this method are big size and high price of the motors and inefficiency which leads to high losses. Testing time is also quite long because the drive must be run so long that it will heat up.

6 Other Testing Possibilities

In this part of the thesis other kind of test methods are introduced and explained.

6.1 Loading with Reactive Power

Loading with reactive power is a testing method that requires less space than traditional method since there are no motors used. The idea of this method is to run one converter at capacitive load and the other at inductive load with LCL-filters and transformer (ratio of 690 V / 0,9*690 V). The picture below visualizes the procedure (Fig. 17).

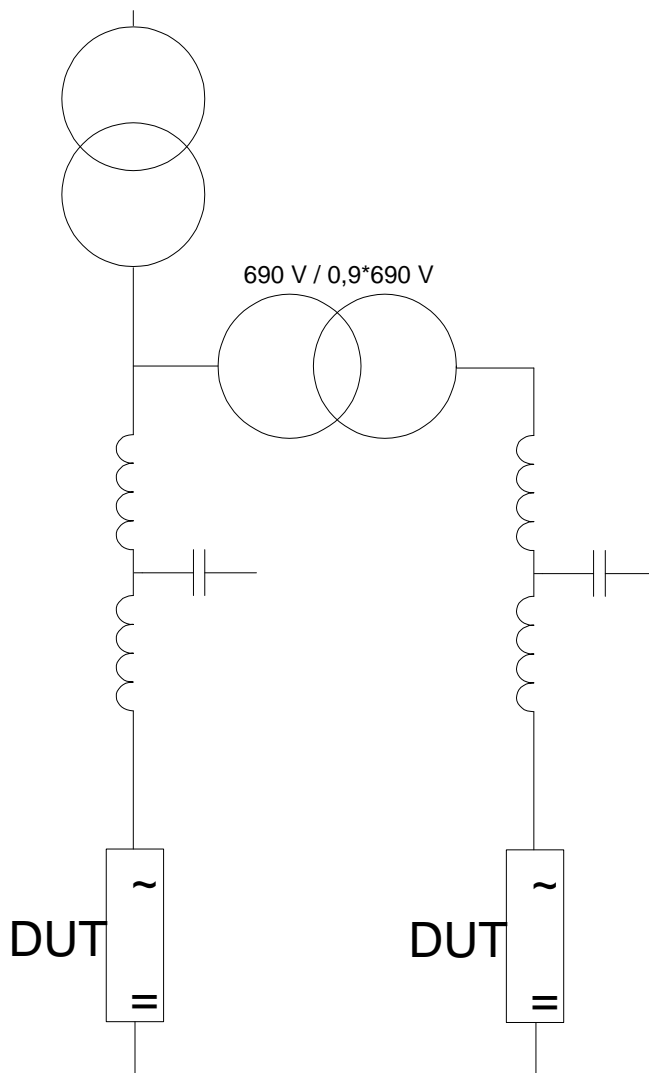


Fig. 17 Loading without motors

The losses of the transformer are calculated below (F3)

$$P_{Loss} = (1 - \eta) * P_N = (1 - 0.985) * 500 \text{ kW} = 7.5 \text{ kW} \quad (\text{F3})$$

This calculation is only valid if the nominal values of the transformer are not exceeded. The power loss of the transformer in nominal load is a lot less than when using motor package. With use of 8 h/d, the daily need of energy is 60 kWh. Besides this, the drive modules also have internal losses.

The failure of one of the DUTs causes reactive power to get out of balance, which can be a problem and brings testing to a halt.

6.2 Accelerated Life Testing

Accelerated Life Testing or ALT is a testing system that can be used to prove design and production reliability to the end user, which will create stress equivalent to products normal use in a shorter time. ALT is best for finding out hidden faults in the product. [14]

Accelerated ageing test platform is one possible way of testing drive modules using ALT. As in the previous method, in the platform, there are also no motors used (Fig. 18).

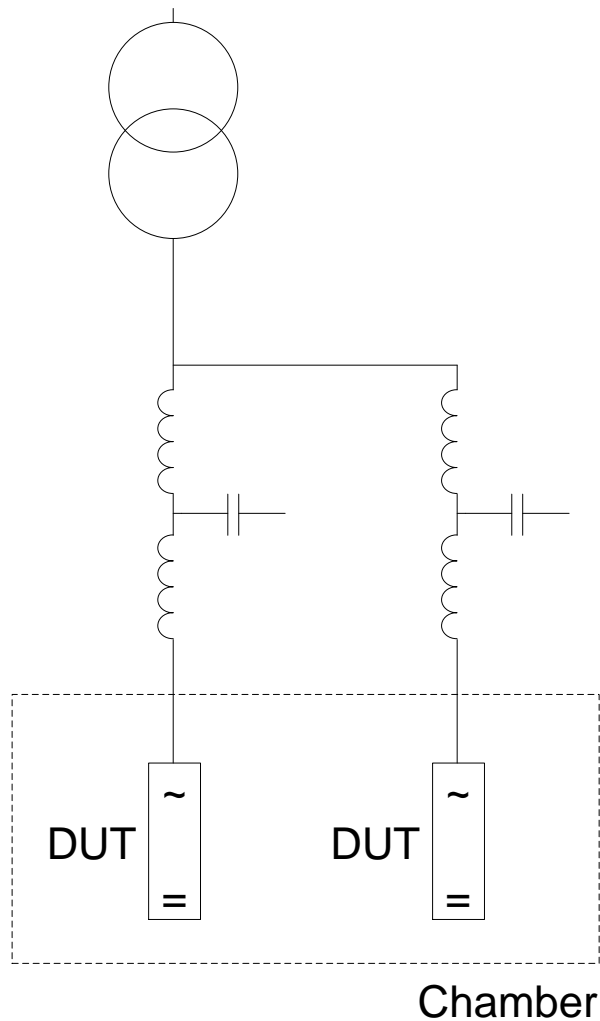


Fig. 18 Accelerated ageing test platform

The first module is run at capacitive load and the other at inductive load with LCL filters. In this solution there is no isolation transformer, and due to that the losses are even smaller than in the previous method. Unlike in HALT, which is more suitable for serial production testing, the product is not allowed to fail during this test.

In this given platform the ageing is done by using temperature cycling as accelerator. The testing platform is situated inside a chamber, in which the temperature is cycling from 20°C to 90°C. The chamber is capable of creating two temperature cycles per hour. The temperature cycles are done by electric heaters and fans. First the heaters are turned on and cooling is blocked. When the highest desired maximum temperature

is achieved, the cooling vents are opened and fans are turned on. The eligible number of cycles is performed while modules are loaded with reactive power.

Acceleration factor is based on Coffin-Manson formula (F4).

$$AF = \left(\frac{\Delta T_{test}}{\Delta T_{oper}} \right)^m \quad (F4)$$

ΔT_{test} is testing chamber temperature change, ΔT_{oper} normal operation temperature variation and m constant which is characteristic to a metal. For the value of m, 2.65 is commonly used when trying to find out flaws in the solder joints when using SAC solder. [15]

In this case the acceleration factor is:

$$AF = \left(\frac{70 \text{ }^\circ\text{C}}{20 \text{ }^\circ\text{C}} \right)^{2.65} = 27.66$$

The acceleration factor means that one cycle in the cabinet represents 28 cycles in the normal use. This should be more than enough for exposing flaws in solder joints before the serviced module is shipped back to customer.

The losses of the ALT platform are caused by internal losses of the drive modules and also the fans and electric heaters of the chamber.

Also in this case, the failure of one of the DUTs causes reactive power to get out of balance.

6.3 Testing Without Load

In this test method there are no motors used and the drive is not loaded at all. Only basic measurement and insulation resistance measurement tests are carried out.

This method is cheap to implement and requires only a little space. Still, it is questionable if this method is reliable and that the quality of the product can be verified if the module is not loaded at all.

7 Cyclic Testing

Most of the drive modules experience cyclic loads in their lifetime. All of the testing methods presented above lack the feature to cyclically load the drive. This is a serious issue and needs further examination.

Cyclic loading is possible on every mentioned testing method but it requires a lot of parameterization or PC/PLC with parameterization macros. If the parameters are not adjusted just right there is possibility that the need of reactive power increases which leads to high expenses. If there is no necessity to test the module with the customer's software, there could be module specified test softwares that include all the parameterization.

For example in motor use, the drive, after it is warmed, could accelerate and decelerate repeatedly and run the motor in both directions.

When using reactive power as a load, the modules could swap roles repeatedly and operate on inductive and capacitive load in turns. With ALT platform that is preheated the module is already warm and there is no need for warming up.

One example of cyclicity is presented in the next image (Fig. 19).

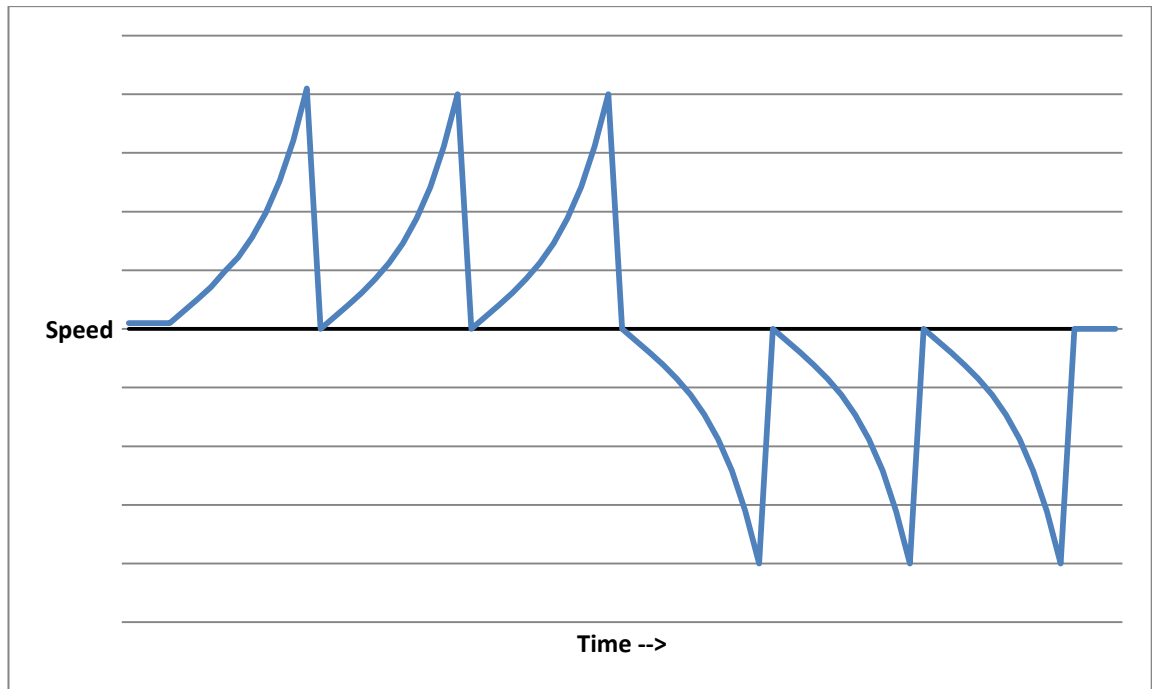


Fig. 19 Cyclic loading with speed

In this example the module is started with relatively quick start ramp and then accelerated to full speed. After that it decelerates and has to perform two quick acceleration-deceleration ramps. Then the module modulates same patterns on different rotation direction.

Also the torque can be changed cyclically (Fig 20).

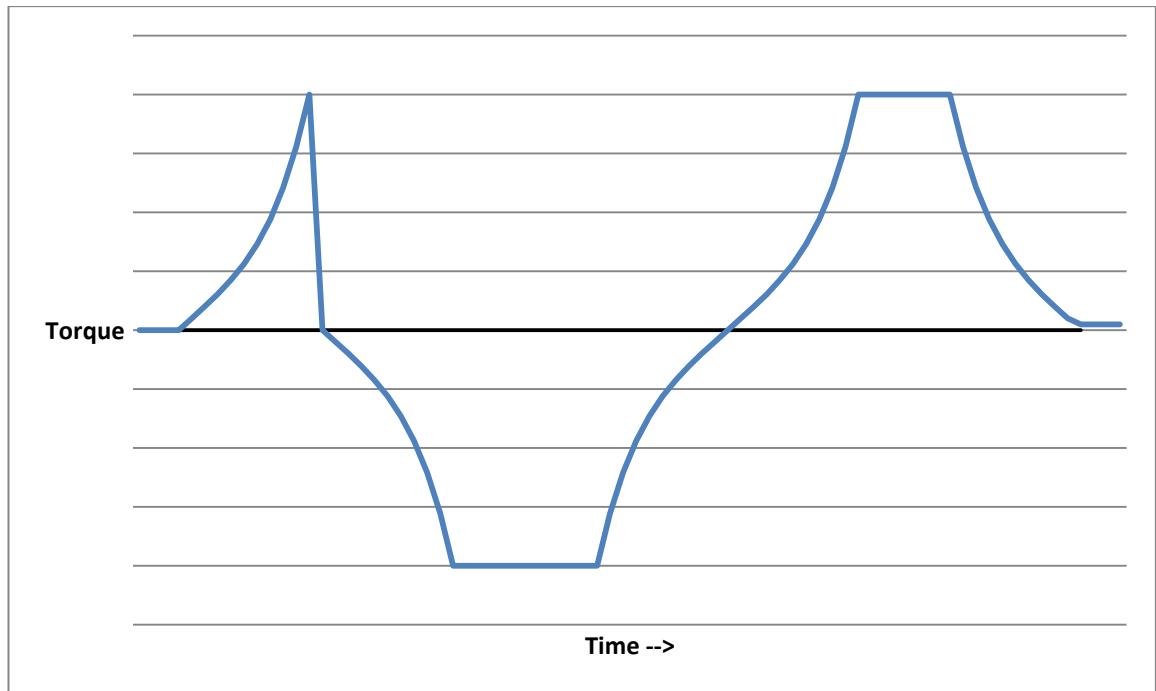


Fig. 20 Cyclic loading with changing torque

There is unlimited number of possible ways to make the testing cyclic. Also the combinations of these different curves can be used so that the torque and speed are working on different directions. In this case the module operates on both the motor side and generator side. In the last example (Fig. 21) the two curves are put to a same scale.

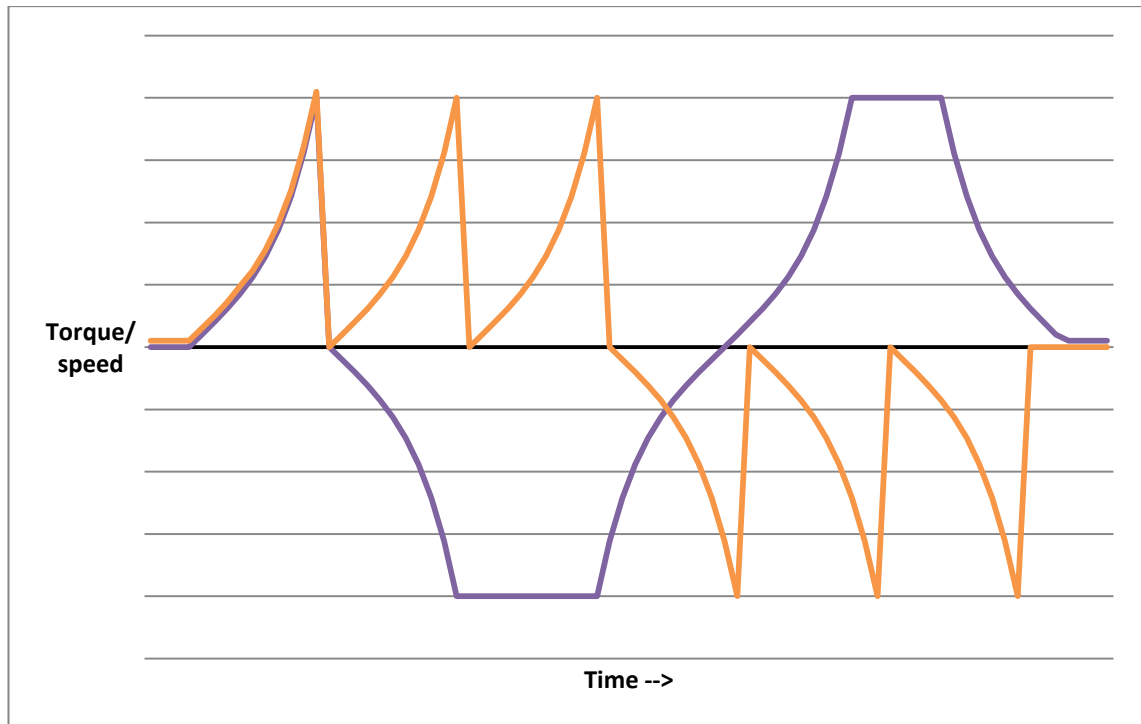


Fig. 21 Cyclic torque and speed

In this case when torque (purple) and speed (orange) operate in different directions, other module's parameters must be set inversely. The modules operate in generator and motor side in turns.

It is also possible to add rotational inertia to motors' shafts in the current testing method. This way the accelerations and decelerations can be done with big torque but relatively slow speed. This decreases the needed testing power.

This issue needs research and testing in lab environment and very precise parameterization and programming.

8 Comparison Chart

In this section the evaluation and the scoring criteria are described and the final comparison chart is presented.

Different comparison criteria are:

- *Price* is the actual total investment of the testing method

The method where no actual loading is done obviously costs the least. Current testing method is expensive to put together because motors are very expensive and require a separate room which costs extra. ALT platform is more expensive than the 'Loading with reactive power' because of the testing chamber, electric heaters and fans.

- *Required floor space* means the actual space needed for the testing equipment

Without load testing method does not require floor space, because the module is not actually loaded. A transformer that requires some floor space is needed when testing with reactive power. ALT platform's chamber is bigger than the normal testing cabinet but the current testing method requires an entire room for big motors.

- *Actual usage equivalence* means how well does the testing procedure reflects field conditions

Current testing method naturally represents the normal field conditions the best because the module actually rotates motor. Without loading represents field conditions the worst. ALT platform and loading with reactive power are on same line, but ALT gets more points because in the field conditions the temperature may also vary.

- *Energy efficiency* takes into account the electrical energy needed for the test

Two hours of motors running for nothing puts the current testing method on the bottom of this criterion but even worse is if the modules are not tested well and have to be shipped back and forth between drive service workshop and customer. ALT platform narrowly loses to loading with reactive power because of the electric heaters and extra fans in the testing chamber.

- *Trustworthy* means how reliable the testing method is

Overall every other testing method but the testing without load, is quite trustworthy. ALT platform wins because of its ability to reveal hidden faults.

- *Testing time* is the total time of the whole testing process

The testing time for the testing without load method is naturally the shortest. The reactive power testing and current testing method both take around two hours. The ALT platform only needs one hour to test the modules.

- *Ability to reveal solder joint fatigue* means how well does the testing method expose the weaknesses in the solder joints

The faults in the solder joints are mostly revealed in cyclic loading. This is why the ALT platform, by creating thermal cycles wins this criterion. Loading with reactive power and the current testing method of DSW expose solder joint fatigue equally well. If the modules are not tested with load, there is no possibility to reveal any weaknesses in the solder joints.

- *Extensibility* means how easy it is to extend the testing line for more modules

All the mentioned methods are extendable but ALT platform's problem is that the chamber has fixed walls which may complicate the addition of the modules.

- *Multi-use* takes into account how well the test line adapts to different kinds of modules (e.g. ACS800 → ACS880)

All the mentioned methods are extendable but ALT platform's problem is that the chamber may have quite tight construction which makes the modification difficult.

- *Image issue* means how the customers react to different testing methods (e.g. some may think that it is necessary to load modules with motors etc.)

If the modules are not loaded at all, the customers probably will not be satisfied and the image of the company may weaken. Some customers may think that the current testing method is one and only possible way to reliably test serviced modules and that is why the current method wins this criterion. ALT platform is more plausible than loading with reactive power because the advantages of accelerated testing are well-known among customers.

Different testing methods are at the top row of the table and comparison criteria are on the left column. Each comparison criterion has its own scoring rate based on the significance in the testing procedure. The score is presented in brackets. The sum of the scores is shown in the last row.

Table 3. Comparison chart

	Current testing method	Loading with reactive power	ALT platform	Without load
Price (0-5)	1	3	4	5
Required floor space (0-4)	1	3	2	4
Actual usage equivalence (0-7)	7	4	6	0
Energy efficiency (0-6)	1	4	3	0
Trustworthy (0-8)	6	6	8	0
Testing time (0-3)	1	1	2	3
Ability to reveal solder joint fatigue (0-7)	4	4	7	0
Extensibility (0-2)	2	2	1	2
Multi-use (0-4)	4	4	2	4
Image issue (0-3)	3	1	2	0
SUM	30	32	37	18

The ALT platform seems to be the best testing method, and as expected, testing without load seems to be the worst. Loading with reactive power seems to be a narrower better way to test drive modules than the current testing method.

9 Summary

The purpose of this bachelor's thesis was to compare different testing methods in Drive Service Workshop environment. After the AC drive and the current testing methods were introduced, new possibilities were considered. Also the possibility of cyclicity was briefly taken into account. As a result, the comparison chart was given.

It was found that the differences between various testing methods were significant. In some cases the rating of the methods was fairly difficult because of the diversity. Also it was challenging to give each criterion its maximum score, and by this accentuate the most and least important criteria. Due to the fact that others but the current testing method are not tested in a workshop environment, the pros and cons mainly are based on opinions of individuals.

The ALT platform became the first in the comparison chart and it is important that it is researched further and that the pilot platform is built. Also the current testing method and the method where the loading is done with reactive power can be very good if the cyclicity in loading is introduced to the testing procedure. Testing without load seems to be very unreliable method and should not be taken into consideration at the ABB DSW.

This thesis actually seems to be just a peek to this rather big subject. It would be important to build pilot testing platforms for different testing methods and collect data of drive module faults, both during test and in use. This way it would be possible to track the reliability of each method. There would also be possibilities for an IT-orientated thesis worker to study the cyclicity and to produce the parameter settings for it.

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