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SGEM Research Report D2.2.4
Helsinki 2011

Juho Farin, Kari Mäki, Marja-Leena Pykälä

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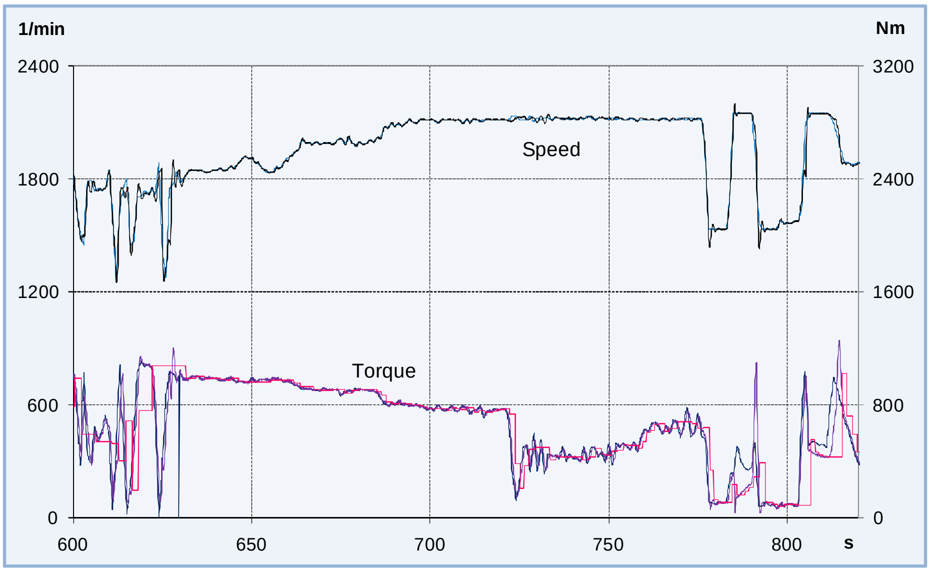

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SGEM - Smart Grids and Energy Markets

Theme 2 - Future infrastructure of power distribution

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Key words: active or universal dynamometer, induction machine dynamometer, frequency converter, prime mover, PSCAD model, simulation

Abstract

This report has been done within the Task 2.2.2 of the SGEM work package WP 2.2. The work has been done in the research program Smart Grids and Energy Marketing (SGEM) of Cluster of Energy and Environment (CLEEN) financed by Finnish Funding Agency for Technology and Innovation (Tekes), industrial partners, universities, and research institutes. The focus is in measurements done on the drive consisting of a diesel engine, an induction machine, a frequency converter and a distribution transformer and in the modelling of the dynamometer with a converter.

Helsinki, March 2011

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Abbreviations

ACS	AC Standard, ABB standard frequency converter family, e.g. ACS 600
AC	Alternative current
ACU	Auxiliary Control Unit
DC	Direct current
DDCS	ABB Distributed Drives Communication System
DTC	Direct Torque Control
f	Frequency
FIU	Filter Unit
flux	Magnetizing flux of the induction machine
I	Current
IGBT	Insulated Gate Bipolar Transistor
ICU	Incoming Unit
INU	Inverter Unit
ISU	IGBT Supply
J	Moment of inertia
n	Rotational speed (RPM)
NAMC	NAMC Board is Motor and inverter control board of ACS 600
NDBU	DDCS Branching Unit. Type of optical branching boards for fibre links
P	Real or active power
PQ	Power Quality
Q	Reactive power
U	Voltage
S	Apparent power
T	Torque
ø	Phase angle difference between voltage and current
ω	Angular velocity

Preface

The work done for this report is part of Smart Grids and Energy Marketing (SGEM) of Cluster of Energy and Environment (CLEEN) financed by Finnish Funding Agency for Technology and Innovation, industrial partners, universities, and research institutes.

We wish to thank the funding organizations and the steering group of SGEM programme for making this work possible to carry out.

This work has been done in cooperation with VTT Energy Systems and VTT Emission Control. Thanks to the dynamometer operators Mårten Westerholm and Christer Söderström for their sympathy at the measurement arrangement.

The PSCAD model used as a basis for the studies belongs to the Helib-library of PSCAD simulation models.

The authors

INTRODUCTION

This report has been done within the Task 2.2.2 of the work package 2.2 in the research program SGEM, Smart Grids and Energy Marketing work package. The focus is in the measurements done on the drive called universal dynamometer, which is normally used for loading diesel engines.

A PSCAD model of the dynamometer equipment was build during the project. The model consists of diesel engine, induction generator and DTC-controlled converter. Connection to the public network through distribution transformer has also been modelled. The model is based on the existing model of DTC-controlled induction generator which is available at the Helib-library of PSCAD simulation models owned by VTT and University of Vaasa. The measuring and simulation results will be compared to assess their validity.

1 BACKGROUND OF THE DRIVE

A dynamometer (dyno) is a device for measuring force, moment = moment of force = torque, or power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed.

A dynamometer can also be used to determine the torque and power required to operate a driven machine such as a pump. In that case, motoring or driving dynamometer is used. A dynamometer that is designed to be driven is called an absorption or passive dynamometer. On the other hand the dynamometer used both for absorption and driving is known as active or universal dynamometer.

A DC dynamometer is simply a direct current motor or generator that converts the energy created by the crankshaft of an engine into electricity. An AC dynamometer is simply an alternating current motor or generator. Both are universal dynamometers as they can both absorb power and power the engine.

Electric motor/generator dynamometers are a specialized type of adjustable-speed drives. An AC motor can operate as a generator which is driven by the unit under test or a motor which drives the unit under test. When equipped with appropriate control units, electric motor/generator dynamometers can be configured as universal dynamometers. The control unit for an AC motor is a variable-frequency drive. Regenerative control unit can transfer power from the unit under test to the electric utility.

The dynamometer's Power Absorption Unit absorbs the power developed by the prime mover. Regenerative dynamometers, in which the prime mover drives an AC induction motor as a generator to create load, make excess AC power and potentially, using a frequency converter, can feed AC power back into the commercial electrical power grid.

Control mode at Constant Force

The dynamometer has a "braking" torque controller; the Power Absorption Unit is configured to provide a set braking force torque load while the prime mover is configured to operate at whatever throttle opening, fuel delivery rate or any other variable it is desired to test. The prime mover is then allowed to accelerate the engine through the desired speed or RPM range. Constant Force test routines require the Power Absorption Unit to be set slightly torque deficient as referenced to prime mover output to allow some rate of acceleration. - Power is calculated based on torque (T) x angular velocity (ω) + calculated power required for the acceleration rate that occurred.

Control mode at Constant Speed

If the dynamometer has a speed regulator (human or computer), the Power Absorption Unit provides a variable mount of braking force (torque) that is necessary to cause the prime mover to operate at the desired single test rotational speed (rpm). The Power Absorption Unit braking load applied to the prime mover to can be manually controlled or determined by a computer. Most systems employ eddy current, oil hydraulic or DC as well as AC motor produced loads because of their linear and quick load change ability. - Power is calculated based on torque (T) x angular velocity (ω).

2 DYNAMOMETER SYSTEM

“AC Dynamometer for Engine Testing” at VTT is an induction machine made by Schorch and a frequency converter named “ACS 600 MultiDrive”. ACS 600 was made by ABB. This dynamometer was installed at 2001 at VTT Biologinkuja 5, Espoo. The external control system was procured from Froude Consine Inc. and its name was Texcel.

The dynamometer system has two major component assemblies. The first assembly is a three phase induction machine fastened to a shaft of a diesel motor (MUT, motor under test, prime mover). The second major component assembly is the dynamometer controller cabinet, here a frequency converter “MultiDrive”, air-cooled drive for multimotor applications, although here used with a single motor.

2.1 Dynamometer Specifications

A diesel engine (a prime mover) under test is loaded by the 3~ induction machine (a dyno machine) manufactured by Schorch, type LN7355Y-BT83P-Z, serial number 27062101/1, year 2001. Rated values of the induction machine are:

Motor	590 kW	59 Hz	400 V Δ	1050 A	1755 rpm	3110 Nm
Generator	581 kW	59 Hz	400 V Δ	1020 A	1785 rpm	3108 Nm

In the converter operation the running cooling fan is compulsory. See below the examples of the rated values in converter operation:

f	*5*	*59*	*80*	*132,5*	*Hz*
U	*37*	*400*	*400*	*400*	*V D*
P	*44,5*	*581*	*582*	*564*	*kW*
T	*3210*	*3210*	*2365*	*1385*	*Nm*
I	*1020*	*1020*	*950*	*920*	*A*
n	*165*	*1785*	*2420*	*4000*	*1/min*

The frequency converter is of type ACS 600, U_2 = 400 V, I_2 = 1094 A, 755 kVA. The converter has the following modules or units:

- ACU = (Auxiliary Control Unit I/O board and control board)
- ICU (Incoming Unit, Supply section, main breaker) 400 V, 1006 A, 50 Hz
- FIU (Filter Unit + charging resistors)
- ISU (IGBT Supply Unit)
- MOTOR CABLES (cables to the 3~ induction machine)
- INU (Drive inverter unit) ACA610-0765-3, in this case a “Single Drive” solution.

Connection to the 20 kV local distribution network was made through a 1000 kVA, 400 V/20 kV, 50 Hz distribution transformer. Figure 1 presents the main components.

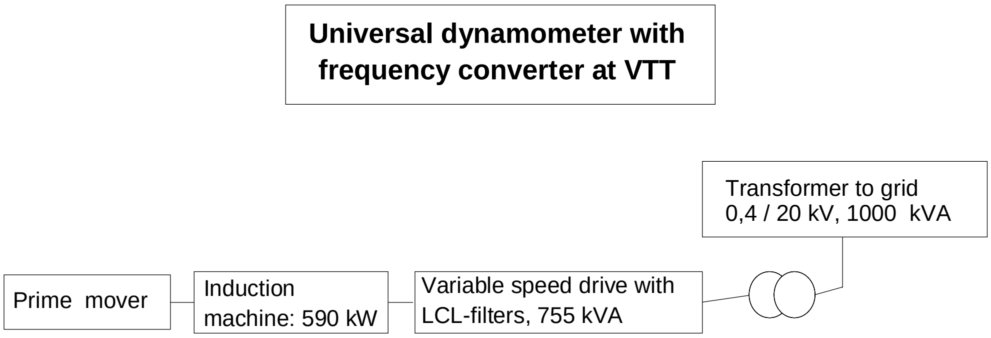


Figure 1. Universal Dynamometer for Engine Testing

Citation from Reference /1/ for the description of the direct torque control DTC:

"The motor control of ACS 600 frequency converter is based on the direct control of motor torque (DTC) by means of the stator flux. The inverter power semiconductors (switches) are regulated to achieve the required stator flux and torque of the motor. The power module "switching reference" is changed only if the values of the actual torque and the stator flux differ from their reference values more than the allowed hysteresis. The reference value for the torque controller comes either from the speed controller or directly from an external source.

The motor control requires the measurements of the intermediate circuit voltage and two phase currents of the motor. The stator flux is calculated by integrating the motor voltage in vector space. The torque of the motor is calculated as a cross product of the stator flux and rotor current. By utilising the identified motor model, the stator flux estimate is improved. The measurement of the shaft speed is not needed for the motor control. Good dynamic control performance is achieved providing the identification run is done during the commissioning.

The main difference between traditional control and the DTC is that the torque control is made at the same time level as the control of power switches (25 microseconds). There is no separate voltage and frequency controlled PWM modulator. All selections of the switches are based on the electromagnetic state of the motor."

Further in the same manual /1/ ABB tells:

"The DTC can only be applied by using high speed signal processing technology. Digital signal processors (MOTOROLA 560xx) are used in ACS 600 products to achieve this performance. Each ACS 600 product has a product specific loading package, which contains all necessary software files to be downloaded to the NAMC board. The loading packages define for example the inverter ratings which are different for AC and DC supplied inverters.

The speed control is executed every 2 ms in the fixed part of the software.”

On the dynamometer controller, the operator sets the counter-torque that he wants to force against his motor. The operator can see if his controller and motor combination are strong enough to keep the motor spinning at the assigned speed against the dyno counter-torque. The operator can also set the speed or torque to which the motor under test can be driven to, and test the motor speed torque capabilities.

3 DIESEL MOTOR (prime mover)

During the 28.9.2010 drives the type of the diesel motor was AGCO SISU POWER 84AWI, ser. number V00700. Its rated power was 250 kW/2100 rpm and the maximum torque 1660 Nm/1500 rpm. The measurement with designation NRTC10350FAC was so called NonRoadTransientCycle.

The mass moment of inertia of the whole drive train consist of the moment of inertia 0.15 kgm^2 of the diesel engine and that of the flywheel J=0.45 kgm^2. The type of the flexible coupling is of VULKAN HERNE VKD L-2K3411. its moment of inertia is 0.4 kgm^2 and the shaft is of type Uni-Cardan, the moment of inertia depends on the flanges, a typical value in this case is 0.1 kgm^2. The dynamometer (motor/generator) manufactured by Schorch type LN7355Y-BT83P-Z has the mass moment of inertia 10.49 kgm^2.

4 MEASUREMENTS

The measurements were performed on September, 28th 2010 during the normal test run of dyno. The system was controlled by Texcel software.

The measuring location inside section MOTOR CABLES, between the frequency converter and the induction machine, was selected because of the possibility to compare electrical and mechanical measuring results of three individual measuring systems: Drive Window, Fluke 1760 and Texcel.

4.1 DriveWindow software and DDCS adapter

DriveWindow software is a PC tool for locally operating, controlling, parametrising and monitoring ABB drives (ACS 600). DriveWindow is designed to support the daily operation of ABB low and medium voltage industrial drives. The tool provides users with capabilities to view, edit, and set drive parameters, as well as advanced functions like drive backup and data logger views. PC can be connected to the high speed DDCS network using the RUSB-02 adapter. The adapter connects a free USB port on the PC to the DDCS network. The DDCS Fibre Optical communication Link of the converter has a protocol DDCS (ABB Distributed Drives Communication System).

The measurement connections were made in the frequency converter inside ACU SECTION (Control) BA02 +01.2. At the lower optical Branching Unit NDBU-95 there was a free measurement channel “MSTR” where an ABB RUSB-02 DDCS adapter could connect the data acquiring PC onto DDCS link.

Normal recording interval was 100 ms. At the fast monitoring mode the interval may be 10 ms. With this fast mode the measurements were, however, not tried to execute, because the measurements ware said to be risky in fear of jamming.

From the parameter or signal groups one can select for DriveWindow measurements at a time not more than six channels: reference values and measured or calculated actual values e. g.: T, n, flux, I, P and U.

About the actual signal markings of the following figures 2, 4 and 6:

01.03: SPEED MEASURED [rpm]#19	Measured actual speed from the encoder.
01.06: MOTOR CURRENT [A]#19	Measured motor current absolute value (RMS)
01.08: MOTOR TORQUE [%]#19	Motor torque in percent of the rated motor torque
02.01: SPEED REF2 [rpm]#19	Limited speed reference.
02.09: TORQUE REF2 [%]#19	Final torque reference from the speed control chain.
02.15: FLUX ACT [%]#19	Flux actual value

4.2 Fluke 1760, Power quality recorder/analyzer

The measurement connections for Fluke 1760 were made inside section MOTOR CABLES = BA03 +11.1 between the frequency converter and the induction machine. Three phase voltages were measured from the cabinet busbars U2, V2, W2 versus PE, because no neutral line existed. The 1000 V voltage probes were connected on the channels ch1, ch2 and ch3 of the recorder. With the flexible current sensors TPS Flex 24 the line currents from the busbars U2, V2, W2 were measured on the recorder channels ch5, ch6 and ch7, respectively. The positive direction of the currents was from the converter towards machine. The recorder adds up to eight channels.

The measured quantities were frequency (f), voltage (U), current (I), harmonics and interharmonics, real power (P), reactive power (Q), apparent power (S), power factor (PF = P/S), displacement power factor (cos ø of the fundamental components), events, flicker and unbalance.

The device samples measurement signals at a nominal frequency of 10.24 kHz. The time aggregation of the measurement values is according to IEC6100-4-30 class A section 4.5 based on 10/12 cycle values (10 cycles for 50 Hz and 12 cycles for 60 Hz nominal frequency, 200 ms). So the 10/12 cycle values are aggregated from 2048 samples synchronized to the power frequency. Other time aggregations are half cycle, full cycle, 3 s, 10 min, 2 h and a free interval aggregation that can be set between 10 s and 1 d. Half cycle and full cycle values are based on the zero crossings of the fundamental (synchronization). The recorder can measure the fundamental frequency at the range 50 Hz ±15 % or 42.5 Hz … 57.5 Hz for 50 Hz systems.

For transient recordings one can enter sampling frequencies between 100 kHz and 10 MHz. Fluke 1760 recorder is mainly a device to measure power quality quantities according to IEC6100-4-30 and EN 50160, so because the recorder has only a limited memory volume a great deal of the countless events including transients may escape if the triggering settings for the measurement allowing are too low.

The overall uncertainty of Fluke 1760 recorder was

- TPS Flex 24: 10 A…1000 A, 45 Hz to 3.0 kHz, Intrinsic error < ±1 %, Phase error < ± 0.5°
- TPS Voltprobe 1 kV: 10 V...1000 V, DC to 5.0 kHz, uncertainty 0.1 %
- Intrinsic uncertainty for harmonics: Class I, EN 61000-4-7 (2002) /3/ and /4/.

Used settings of Fluke 1760 recorder

For the measurements the recorder got the usual power quality settings:

- nominal phase voltage 230.00 V (phase to phase voltage 398.37 V) ±10 %
- nominal frequency 50.00 Hz.

The averaging time was 10 ms for RMS values, 3 s for harmonics, 200 ms for the ripple control and 15 min for the quantity of “Free interval”.

Half cycle RMS measurements had the following trigger settings or limits at RMS and oscilloscope measurements:

- maximum phase voltage 253 V
- minimum phase voltage 207 V
- the trigger limit of 11.50 V fires if the difference between consecutive phase voltage values exceeds this limit; this describes the steepness of the phase voltage change
- no other limits were set e.g. for currents, real powers and frequency

The transient settings were 500 kHz for sampling and 1250 V for the minimum limit of a peak voltage. So no transient phenomenon was registered.

4.3 Texcel – control

There are many different modes to control the dynamometer. Here it is presented two of them. At **one mode** (SPEED – TORQUE control) an operator gives a rotational speed reference (throttle is in speed mode) for the diesel engine in which case the brake program Texcel gives a torque reference and the frequency converter deals with the rest (dynamometer is in torque mode).

At the **other mode** (TORQUE – SPEED control) the operator gives a torque reference for the diesel engine (torque control on the throttle) and Texcel gives the rotational speed reference for the frequency converter. From this speed *reference the converter governs the torque required (speed control on the* converter).

The Texcel gets current speed and torque values from the motor and torque hub respectively, it uses these values and compares against the demanded values from the operator, the Texcel then decides if it needs to increase or decrease the load on the motor and adjusts its output to the frequency converter. The converter which is running in torque control, takes this value and applies more or less current to achieve the desired outcome. The converter reads the rotational speed from the same encorder as the Texcel, but uses the current draw to determine the torque being applied to/by motor, then applies the updated demand to the motor.

The stability is controlled via PID’s within the Texcel; however the converter/motor is inherently stable using its control algorithms to maintain a controlled torque level /2/. Recording interval at the Texcel measurements was 100 ms.

4.4 Measurement results

The following figures 2 to 7 present the dynamometer results measured with DriveWindow and Texcel. The duration of the measurement interval at figures 2 and 3 was about 3 min 20 s.

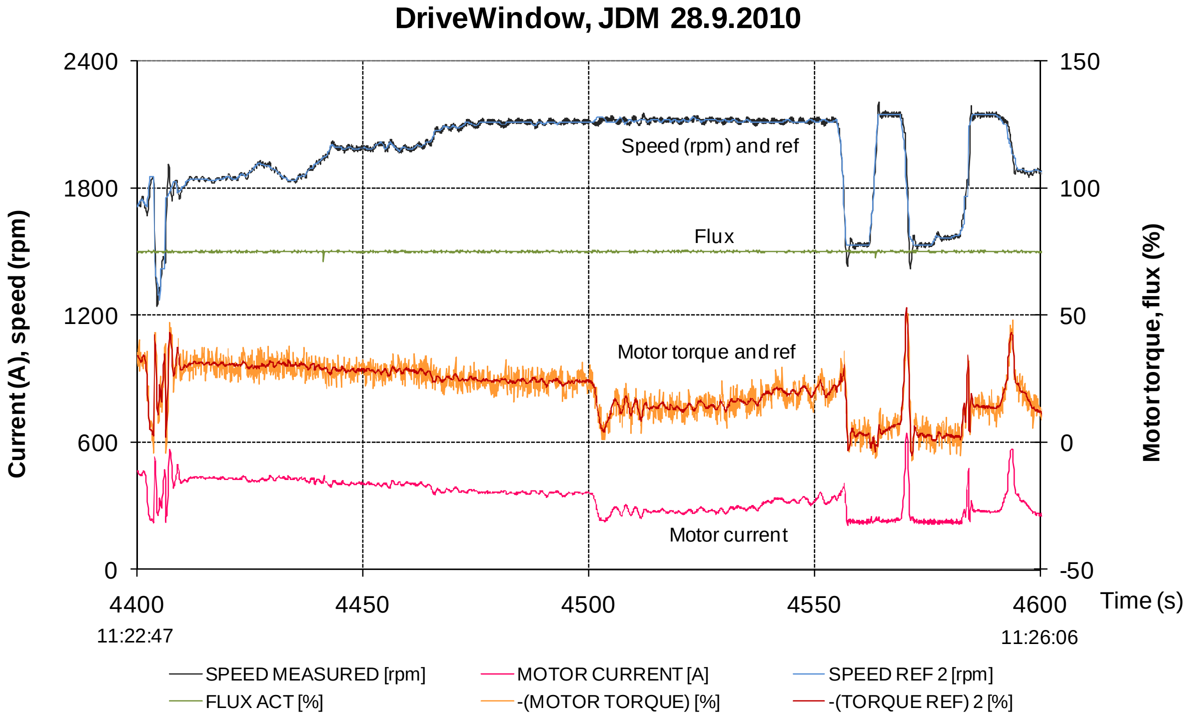


Figure 2. DriveWindow results at 11:22:47 … 11:26:06, duration 3 min 20s.

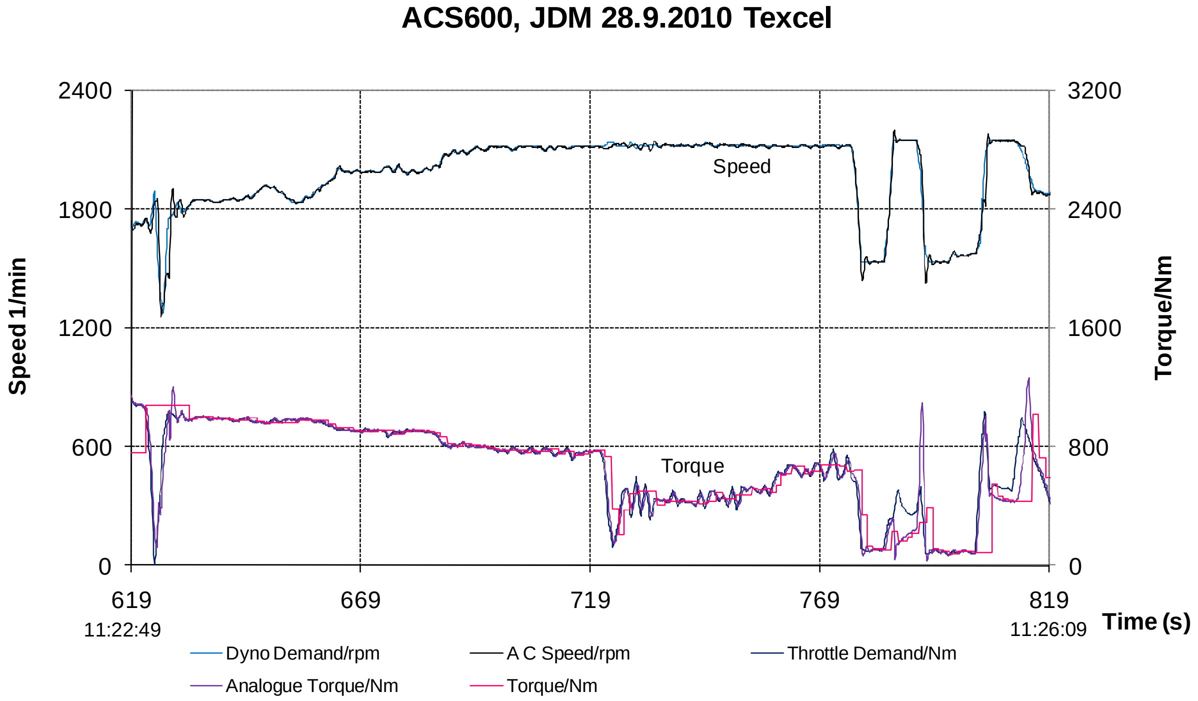


Figure 3. Texcel results at 11:22:50 … 11:26:10.

The shape of the torques “TORQUE REF2 [%]” and “Analogue Torque/Nm” in these figures are alike. At Figure 2 a curve “MOTOR TORQUE [%]” swings on the both side of the “TORQUE REF2 [%]”. At DriveWindow figure 2 the torque signs are changed. The “FLUX ACT [%]” of the induction machine (generator or brake) was all the time almost constant. The speed curves “SPEED MEASURED [rpm]”, “SPEED REF2 [rpm]”, “Dyno Demand/rpm” and “A C Speed/rpm” in figures 2 and 3 are very alike.

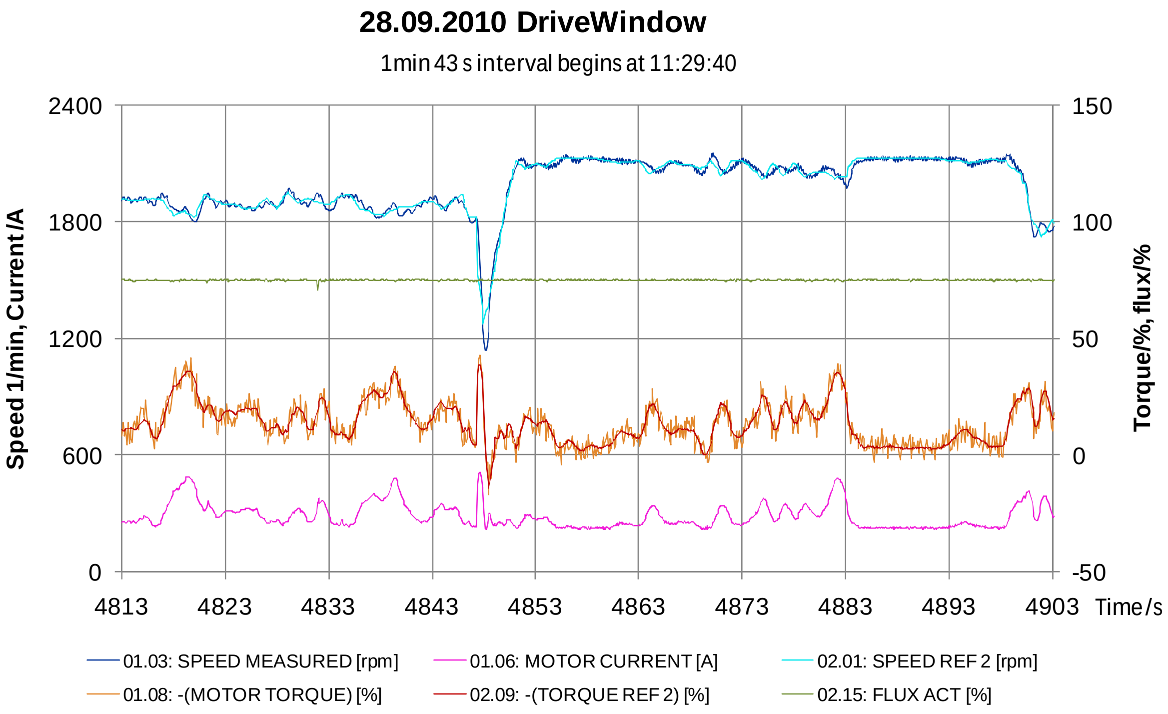


Figure 4. DriveWindow interval 1 min 30 s begins at 11:29:40.

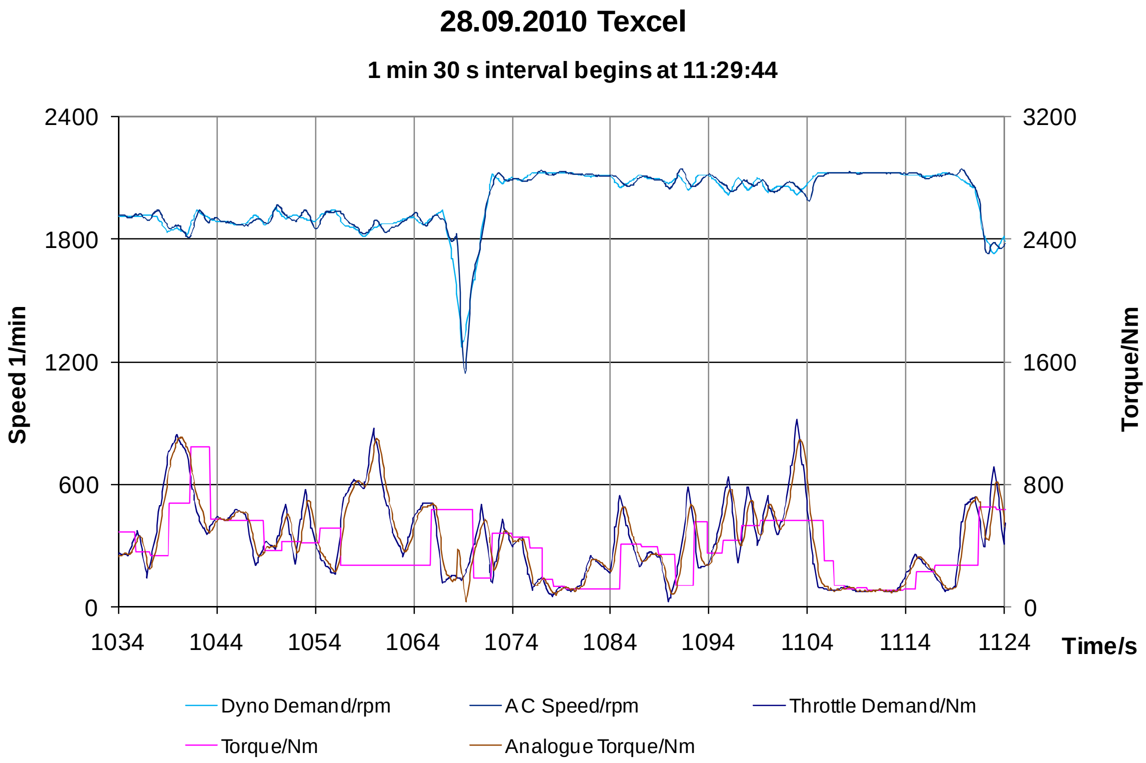


Figure 5. Texcel interval 1 min 30 s begins at 11:29:44

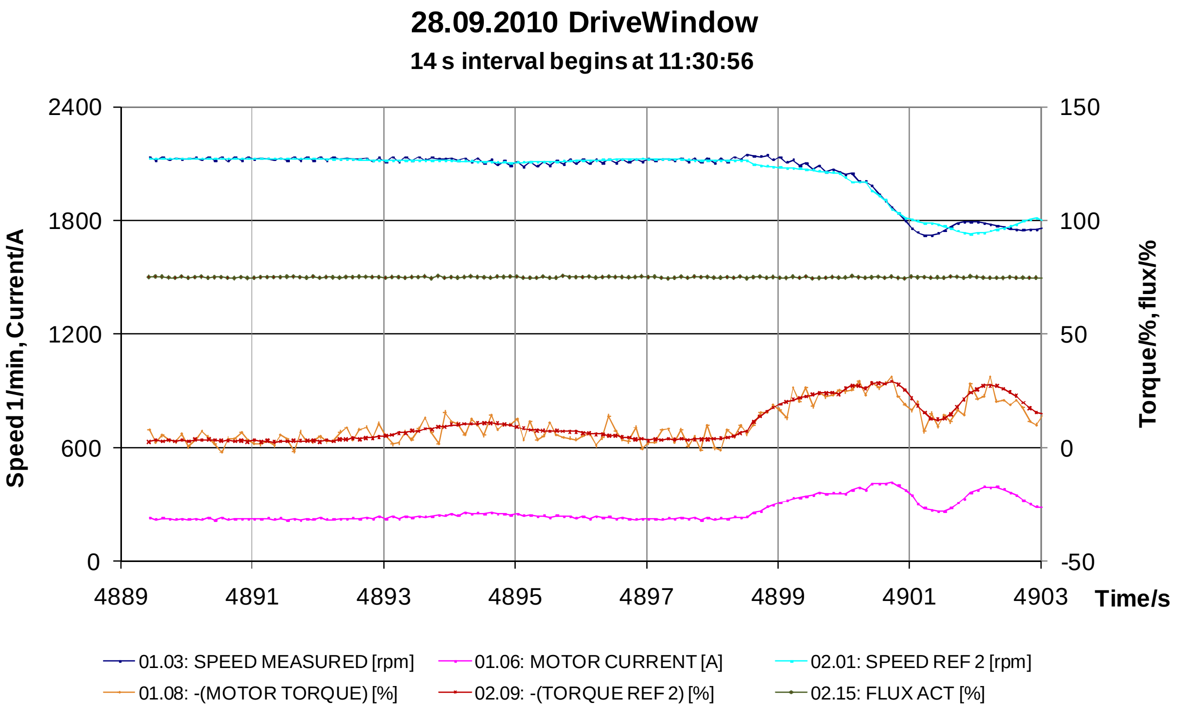


Figure 6. DriveWindow interval 14 s begins on 11:30:56.

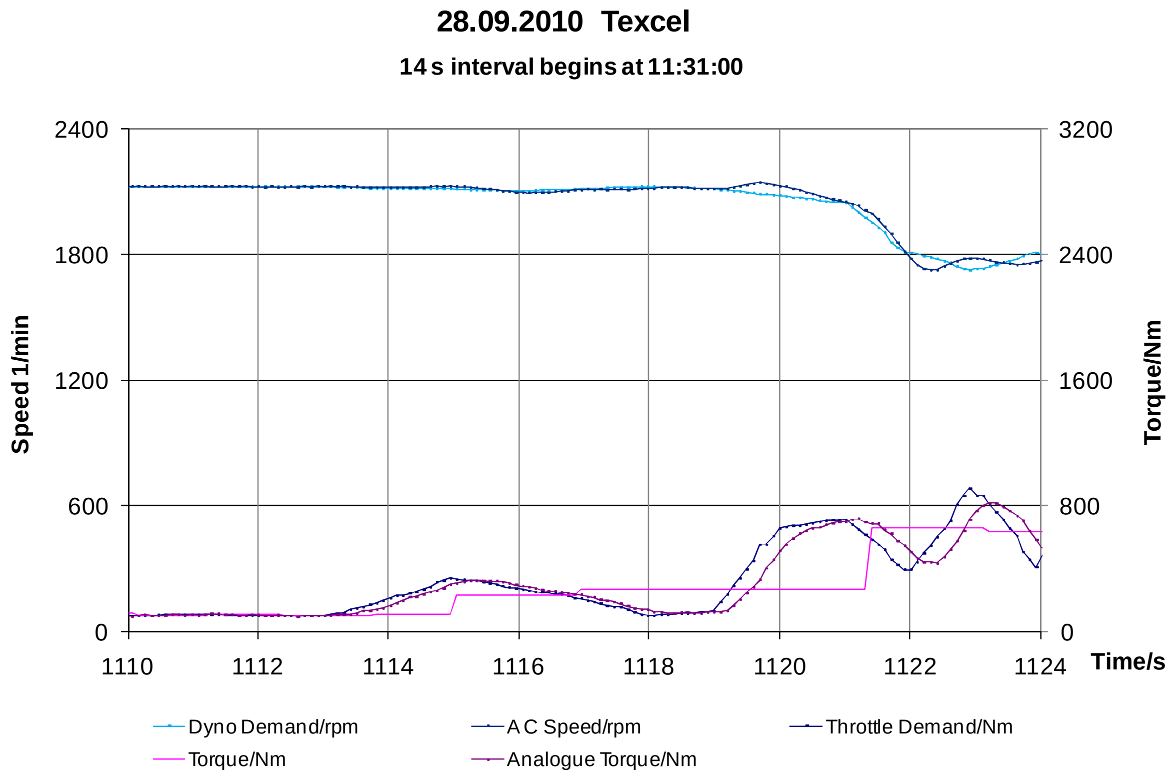


Figure 7. Texcel interval 14 s begins on 11:31:00.

Figures 4 to 7 describe a shorter interval later on the same day. At DriveWindow figures 4 and 6 the torque signs are changed. This way the torques and currents change to the same direction. “Analogue torque/Nm” follows rather well “Throttle demand/Nm” when the rotational speed variations are small (Figures 3, 5 and 7). The curve named “Torque/Nm” changes in the figures by jumps approximately 1-second intervals. The values seem to be some kind of 1-second moving average values with a delay. The flux curves of the machine are in every figure amazingly constant. The machine current (root mean square) curves of the figures 2, 4 and 6 appear to be very smooth compared to the momentarily swinging motor torque. Either the flux value is updated seldom (it is averaged) or the flux is very successfully kept constant all the time by the frequency converter. In reality the oscillations of the motor torque may be even larger than the measured values because the recording interval was 100 ms when the frequency converter plays the speed control in 2 ms intervals and the torque control switches the IGBTs even faster in 25-microseconds intervals).

The results of Fluke 1760 recorder are depicted at figures 8 and 9. Figure 8 presents 10 min intervals of voltage (V RMS p-p), machine current (I RMS), real power (P [kW]), power factor cos ø and frequency (f). The former measurements in figures 2 to 7 occurred at the right part of Figure 8 between 11:20 and 11.30.

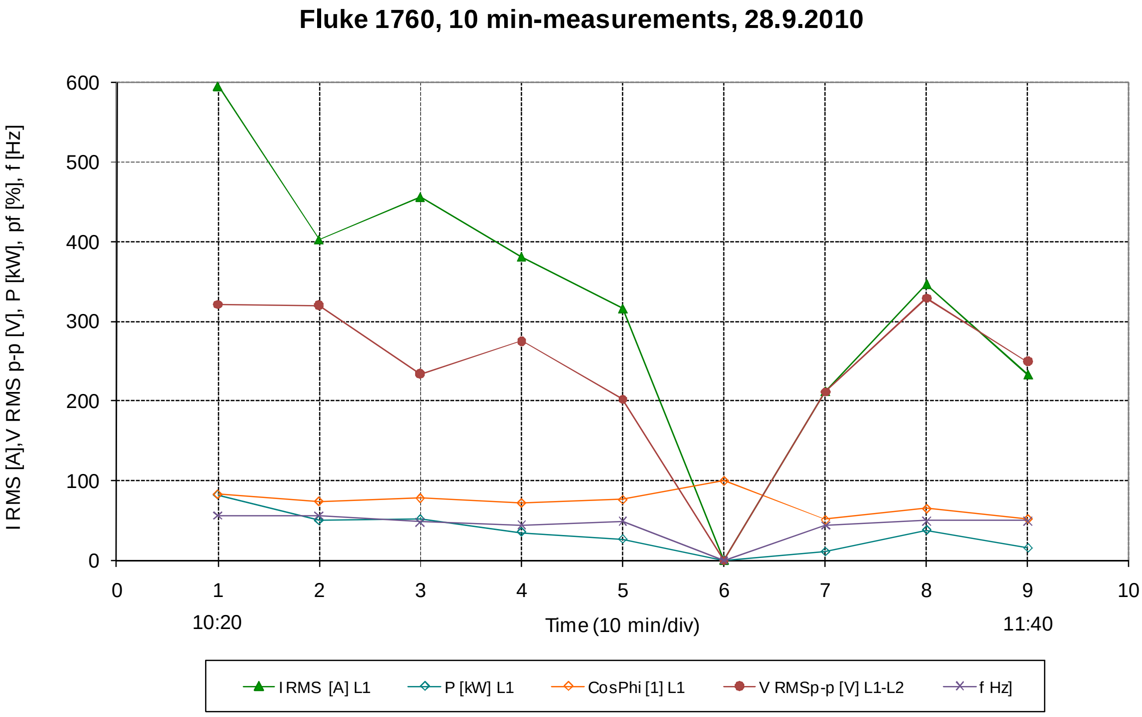


Figure 8. The average values of 10 min intervals measured by Fluke 1760 recorder.

Figure 9 is an example of the waveforms of a phase-to-phase voltage L1-L2 and a phase L1 current, the exact operating point is not possible to define as the different measurements were not synchronised. 10-minute values between the time 11:20 and 11:30 are shown in Figure 8. Both quantities measured have no filtering between the very fast switching IGBT inverter and the induction machine. The voltage and currents waveforms show that the sampling frequency 10.24 kHz in use was inadequate to follow the fast changes. The current curve is smoother than the voltage record due to the winding inductances.

In Appendix A there are half cycle RMS results measured by Fluke 1760 recorder.

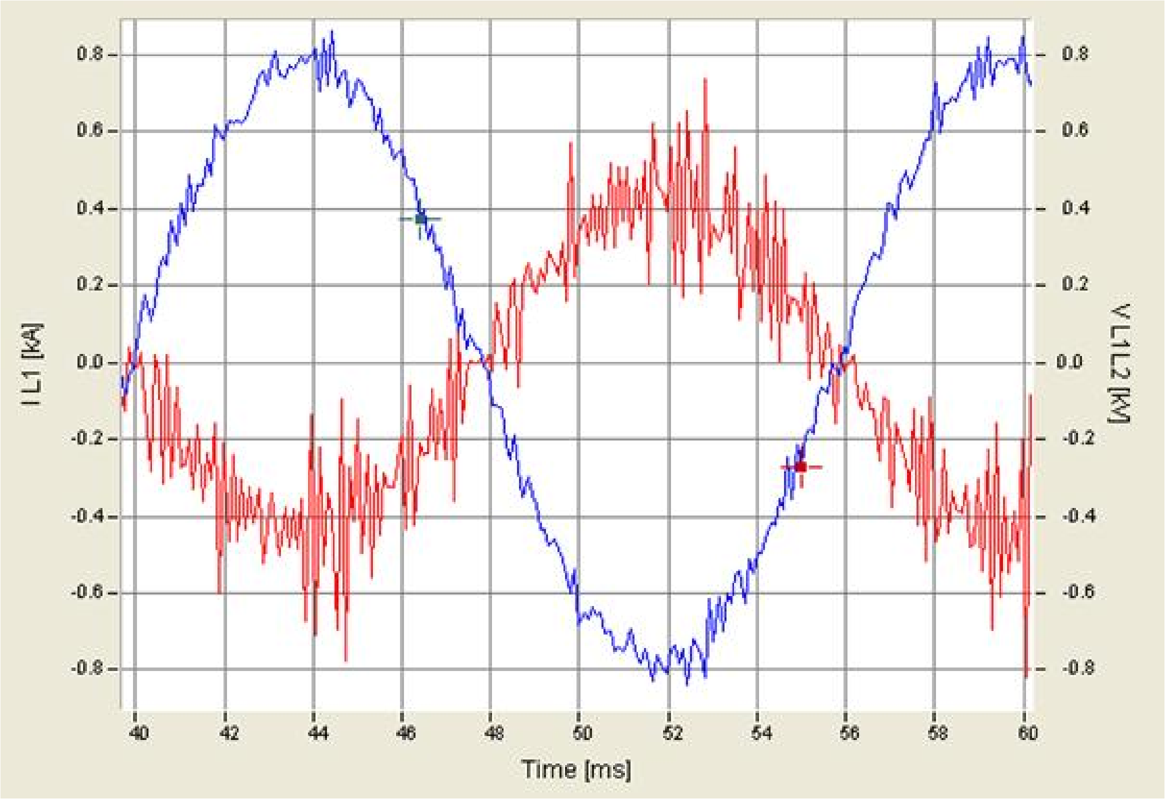


Figure 9. The phase-to-phase voltage L1-L2 (red curve) and a phase current L1 (blue) measured 28.09.2010 11:24:52 by Fluke 1760 recorder. NOTE The positive direction of the currents is from the converter to machine.

5 PSCAD SIMULATIONS

5.1 Model

A PSCAD model of the dynamometer equipment has been build during the project. The model consists of diesel engine, induction generator and DTC-controlled converter. The connection to the public network through distribution transformer has also been modelled.

The model is based on the existing model of DTC-controlled induction generator which is available at the Helib-library of PSCAD simulation models. The original model has been described in /5/. For the purposes of this project, most of the parameters were modified to represent the actual situation. Generator values were modified according to the information obtained from the manufacturer. The datasheet with the values is given in appendix B. Some converter parameters were also changed according to available information. Some adjustments were made in the converter control parameters to make the operation stable with new equipment values. The basic principles of DTC-control were not altered.

Regarding the network connection, realistic data for network short circuit values as well as for transformer were available and they were used in the model.

Following figure shows the basic structure of the model. Distribution transformer and the feeding network are outside the model block and thereby not visible. Appendix C gives a picture of the whole simulation model.

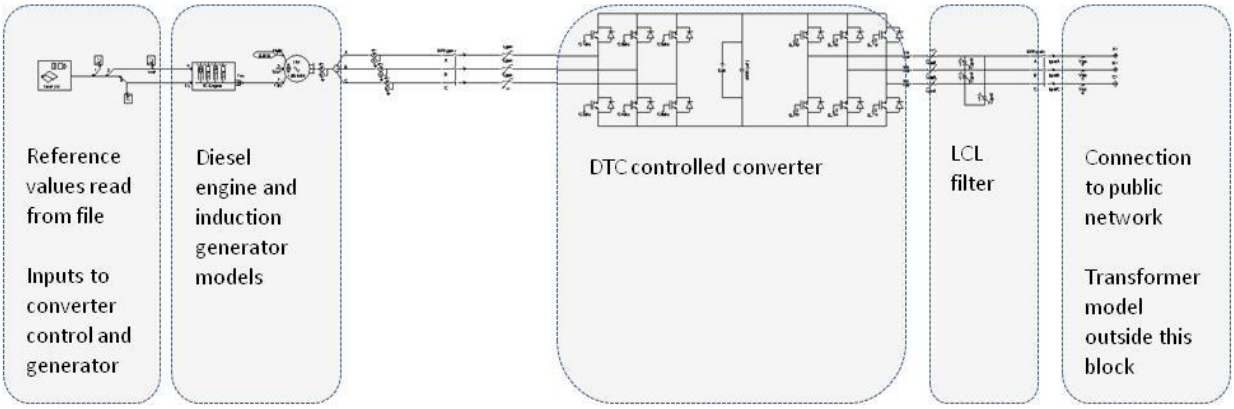


Figure 10. The basic structure of the model. For simplicity, control and measurement blocks have been left out.

5.2 Model drives compared with the real drives

The results given by the simulation model were compared to the measurements made during test runs. The purpose was to validate the accuracy of model in different situations.

As the reference values used during the test runs were available, a quite natural way of testing the model was using the same reference value as an input to the model. Since the inputs were exactly same, the outputs could be compared with accuracy.

The operation of the model compared to the measurements has been presented in following figures.

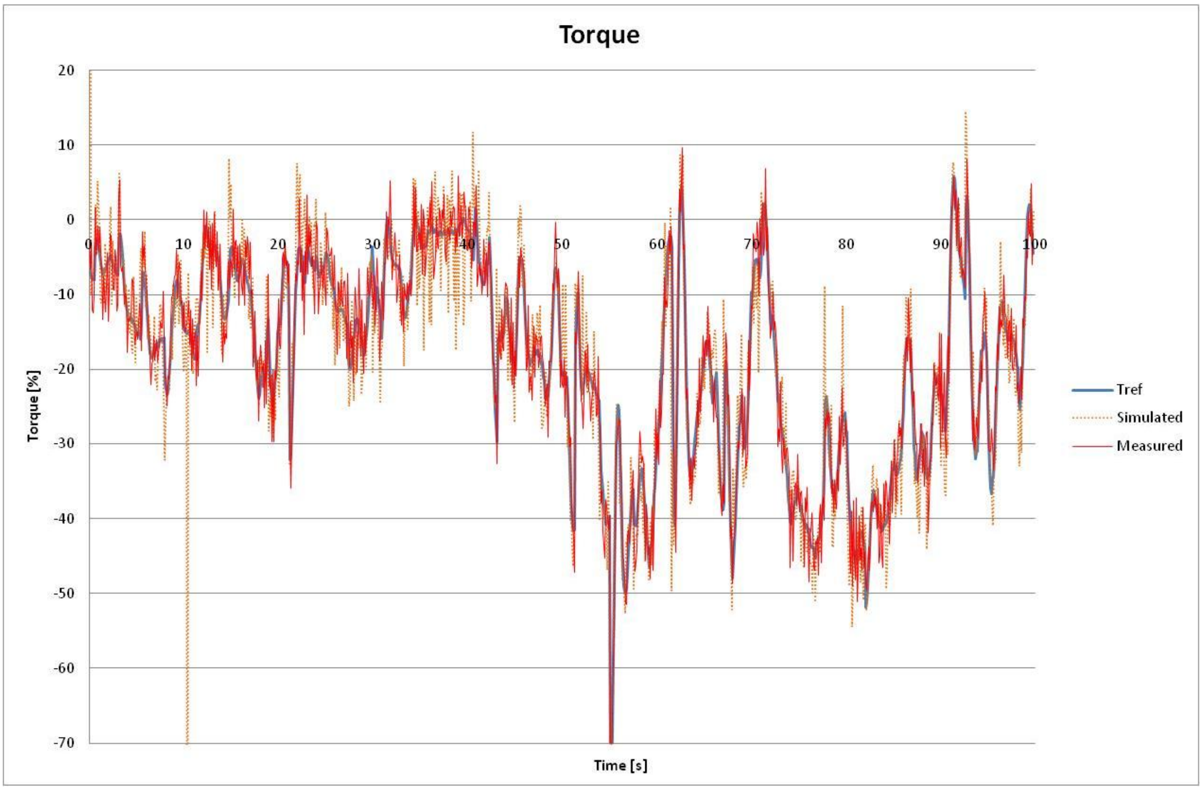


Figure 11. Torque curves for the complete test run. Simulated torque (yellow dotted line) matches the measured one (solid red line) relatively well. Some peaks can be observed for instance at times 10 s and 80 s.

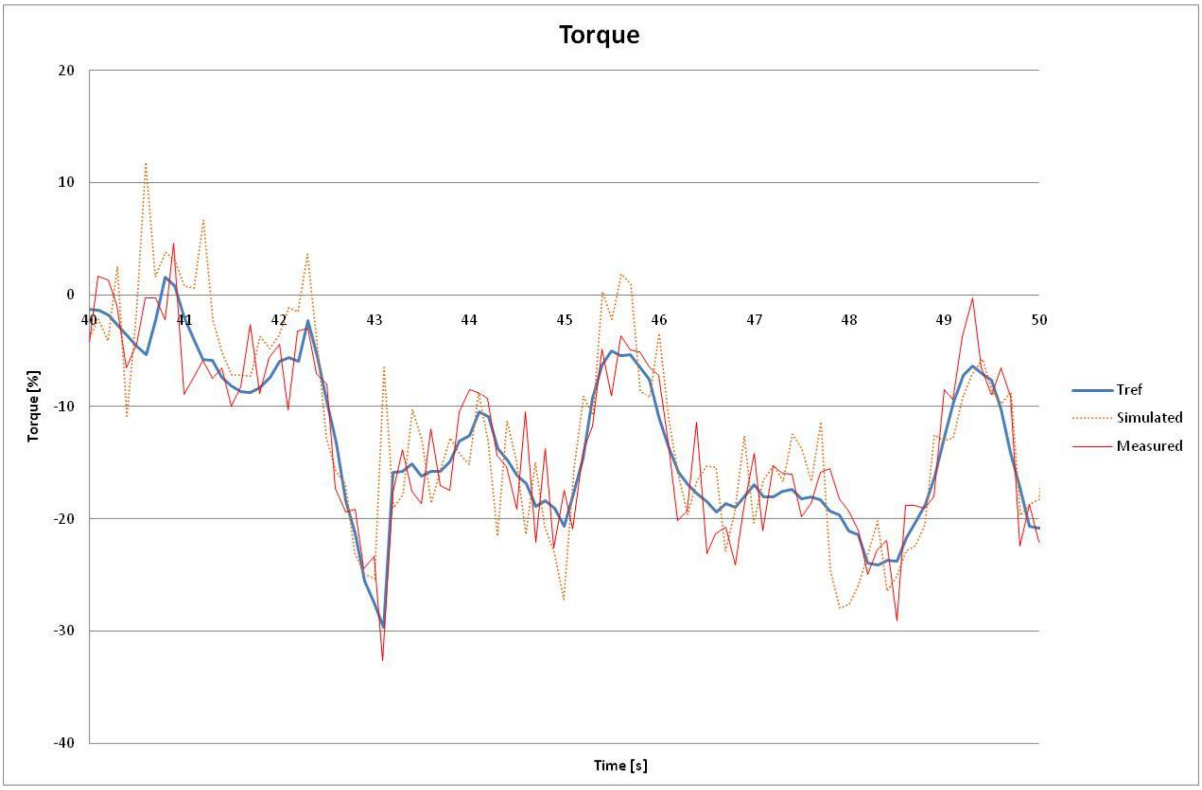


Figure 12. Enlargement of torque curves between 40 and 50 s. Simulated and measured values behave similarly, although some difference can be seen.

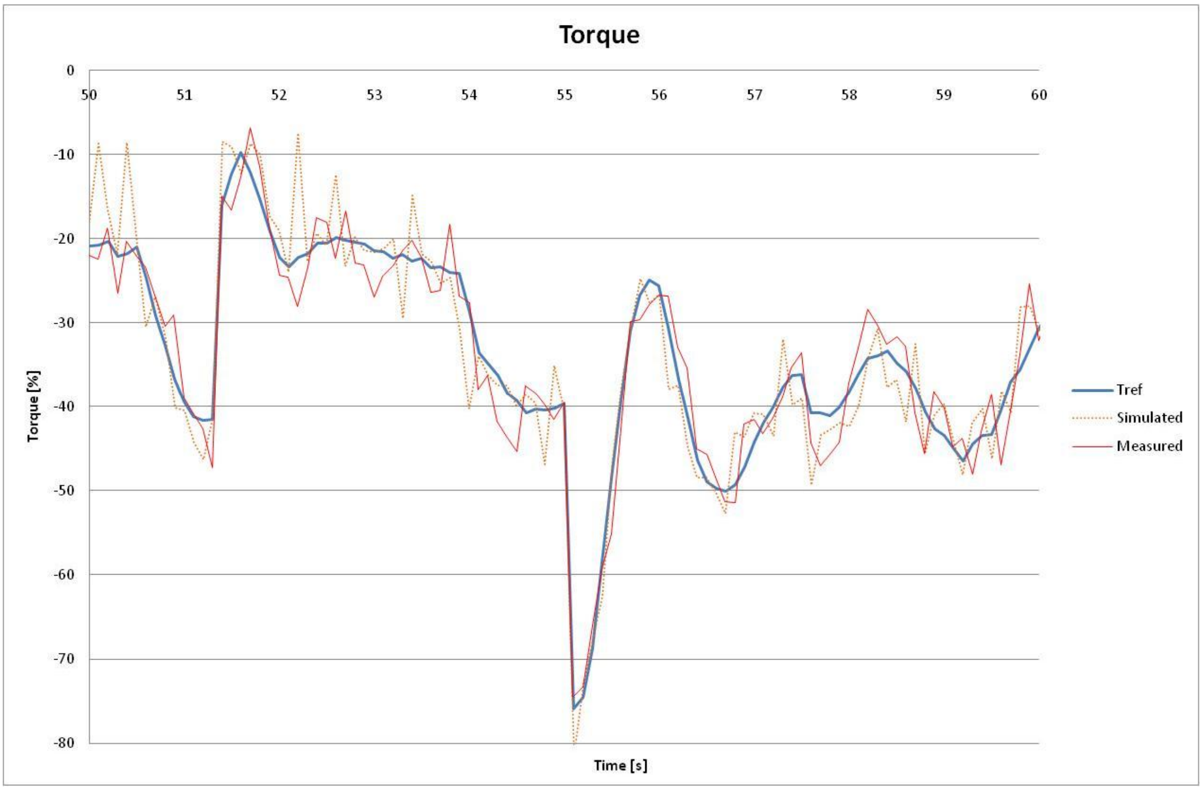


Figure 13. Another enlargement of torque curves between 50 and 60 s. The response to reference value peak at 55 seconds is similar for measured and simulated cases.

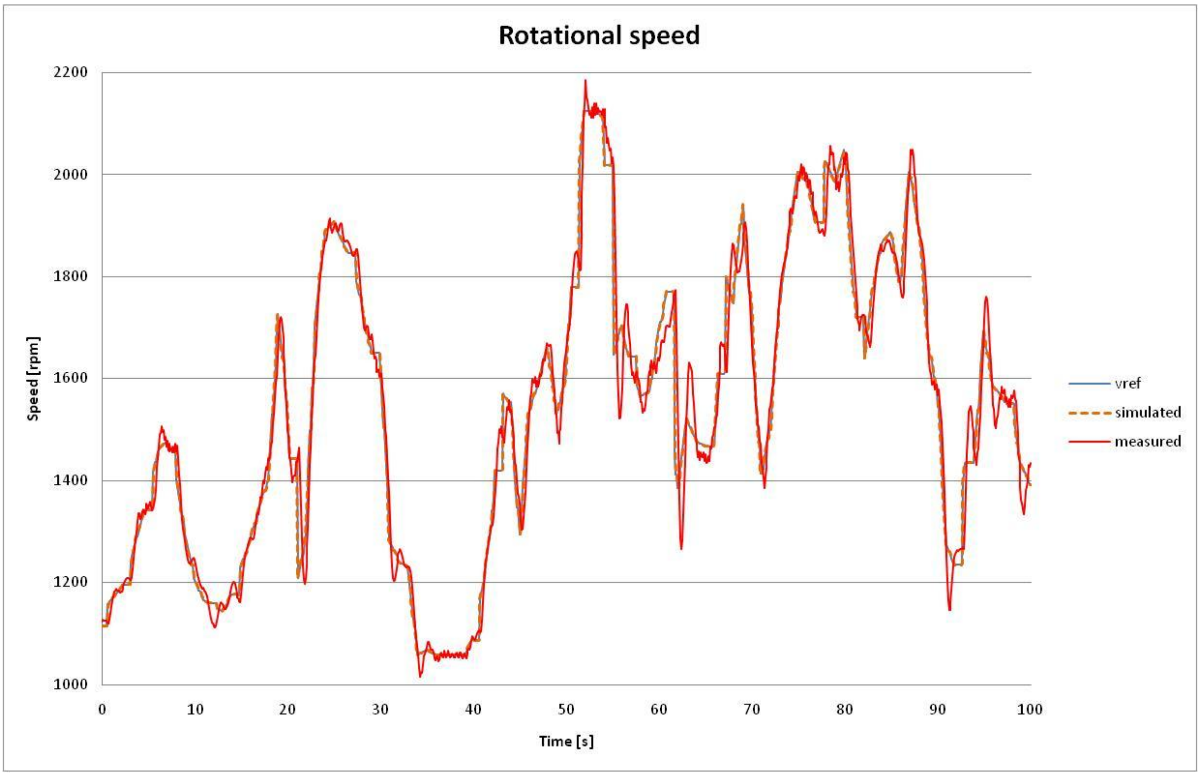


Figure 14. Generator rotational speed during the test run. Simulated value follows the reference even too strictly, which may be considered in further development of the model. Behaviour similar to the measured one would be more realistic.

The first results indicate that the torque behaves as expected with similarity to the measured values. The rotational speed also behaves correctly, however the simulated value follows the given reference even too strictly. For instance there should be some slowness when ramping the reference value rapidly. In the further work, the control parameters and the inertia values of engines could be checked. However, the behaviour as such is correct but a bit more deviation from the reference would make it look more realistic.

One aspect affecting the simulation results is the resolution applied for simulation time step and result plotting. In the previous example figures, the values comparable to measurement were used. This means that the simulation time step was 25 µs and recording interval was 100 ms. This is reasonable when the purpose is to compare the results with same input.

However, the simulation environment is able to perform much more accurate simulations. Thereby some of the tests were repeated with a time step of 5 µs and recording interval of 1 ms. The general behaviour remains similar, but some differences can be seen. In the torque curve, there is a ripple around the reference value. Some more transients can also be seen. These results have been presented in following figures.

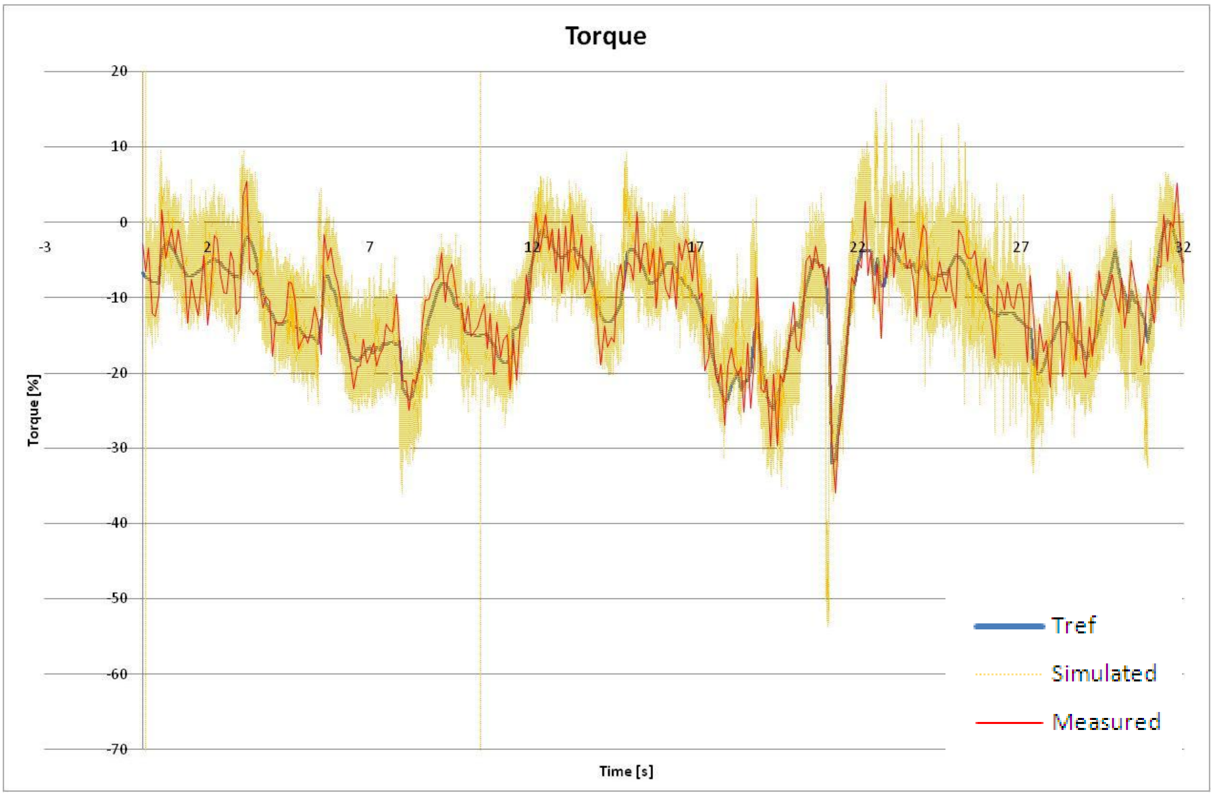


Figure 15. Generator torque simulated with more accurate resolution. Torque output follows the reference and behaves similarly to measurements, but some ripple is clearly seen. (blue line: reference, red line: measured and yellow line: simulated)

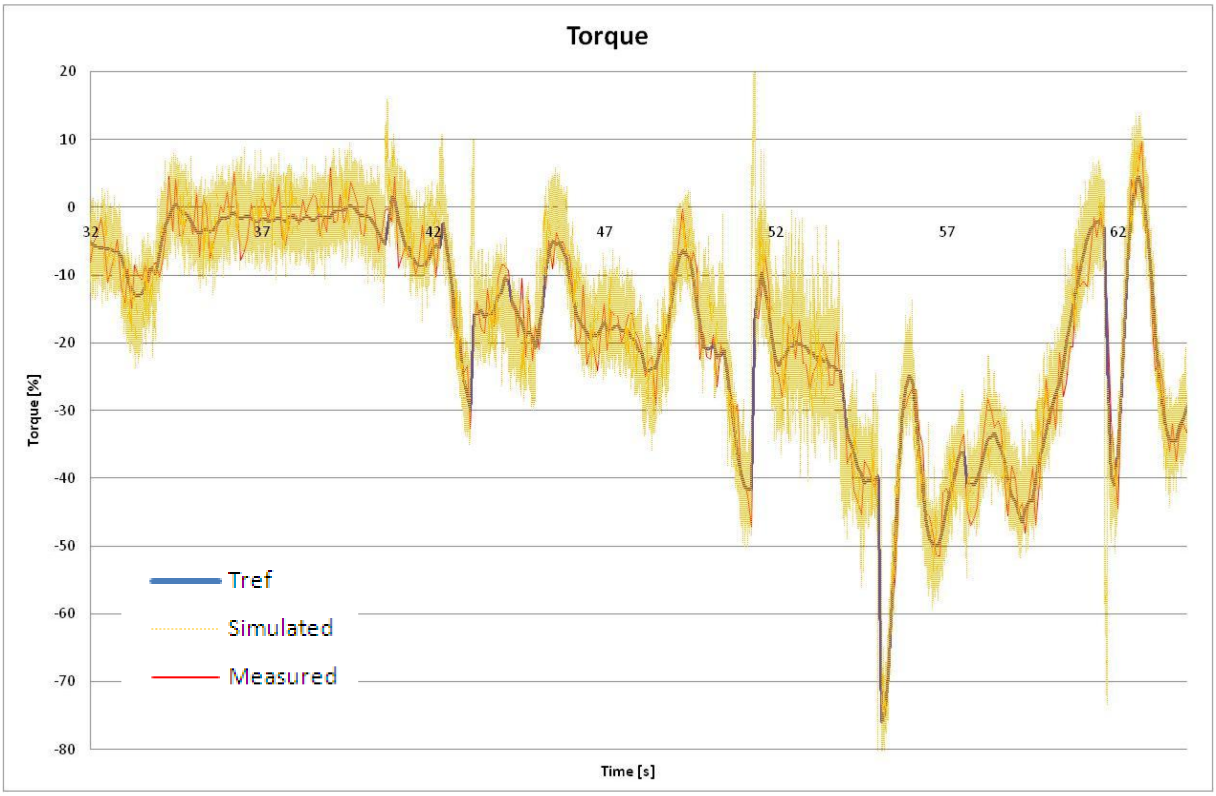


Figure 16. Another example of high-accuracy simulations. For instance the operation around 55 s with rapid changes in the reference seems correct. Ripple is still present.

At this point of the studies, it remains unsure whether the ripple is caused by a wrong operation of the simulation model. For instance control parameters were adjusted during the simulations to reduce the ripple. Some improvements were made for instance by reducing the gain of a PI-controller. Thereby it is possible that the ripple is only related to the simulation model.

However, it is also possible that some of the quick transients were simply not observed by the measurements made with slower interval. This means that the results given by the simulation could be more accurate. For the reliability of measuring the results, the initial analysis was based on using same resolutions for both measurements and simulations.

6 CONCLUSIONS

Generally the modelling of the combination of dynamometer and converter has been done successfully. Some improvements can be made in further work. Most uncertainties relating to the validation of the model are caused by the resolutions of measurements and simulation.

In the current version the parameters are based on the Helib-library of PSCAD simulation models. Modifications were made where data for the real equipment was available. Performance of the model is dependent on many internal control parameters that are difficult to obtain for existing devices. Increasing the accuracy of the model by adjusting the parameters might be possible in co-operation with the real device manufacturers.

The model is also intended to be used as a part of a larger simulation model for MultiPower laboratory environment. Simulation results regarding the values at the network connection point indicate that model should operate well as a part of a larger system. However, integrating to a larger simulation model requires some work and testing.

One challenge is that the diesel engine used during the dynamometer runs depends on the requirements of motor testing. Thereby it may be necessary to model different engines in the future. On the other hand, for power system studies, changing parameters such as output power and inertia should be adequate when the engine type changes.

Measurements have been a compromise between the resolution and the record length. The resolution of the Texcel measurements cannot be changed, but the power quantities can be measured at higher frequency range. Additionally, the quantities of the network end can be measured. Other control cases are in principle possible beyond the diesel engine test run sequences.

7 REFERENCES

/1/ ABB: ACS 600 Firmware Manual, System Application Program 5.2 for ACS 600 Frequency Converters. ©2000 ABB Industry Oy

/2/ E-mails 10 June … 19 July 2010 between Lasse Peltonen from VTT and Kevin from support@freudehofmann.com, Froude Hofmann Limited, Blackpole Road, Worcester. England

/3/ Fluke 1760 Power Quality Recorder, Users Manual. June 2006 Rev. 1, 6/07. 2006, 2007 Fluke Corporation

/4/ Fluke 1760 PQ Analyze Software, Reference Manual. July 2006 Rev. 1 6/07. 2006 Fluke Corporation

/5/ DTC-ohjatun epätahtikoneen malli, User Manual for the Helib-library of PSCAD simulation models. Rev. 11/2007. (in Finnish)

A. Appendix

Half cycle aggregations of RMS values measured by Fluke 1760 power quality recorder /3/ and /4/

The power quality recorder had the following setting values: the nominal phase voltage of 230.00 V and the nominal frequency of 50.00 Hz.

Interpolation for the RMS cycle values happens with 10.24 kHz = 10.24 kHz/(50 Hz) = 204,8 samples/cycle for 50 Hz systems and 10.24 kHz/(60 Hz) = 170.7 samples/cycle for 60 Hz.

Half cycle RMS measurements had the following trigger settings:

- maximum phase voltage 253 V
- minimum phase voltage 207 V

The trigger limit of 11.50 V fires if the difference between consecutive phase voltages exceeds this 11.50 V limit. There was set no difference limit for the phase to phase voltages. Even currents, powers and frequency had no trigger limits.

The detection of events (dips, swells, interruptions, rapid voltage changes) is based on half cycle rms values or full cycle rms values updated every half cycle (whatever is configured with the settings).

Flagging means that in case of dips, swells and interruptions, all other influenced quantities like frequency, harmonic or flicker are suppressed in statistic evaluation to avoid multiple counting. According to IEC 61000-4-30 the purpose of the flagging concept is to avoid counting an event more than once. *After recording, the flagging concept cannot be changed, which means flagged data are not recorded, only events.*

The event settings:

- Dip threshold 90 % of the nominal phase voltage
- Swell threshold 110 % of the nominal phase voltage
- Interruption threshold 1 % of the nominal phase voltage
- Hysteresis 2 % of the nominal phase voltage

The voltages and currents had the same flagging times (light brown areas on the following figures), the powers had their own areas and the frequency also its own ones. It seems that the recorder does not flag if the recorder cannot measure the desired quantity, for instance the frequency illustration has no colouring of the flagging (area remains in white) if the frequency is out of the measurement range. According to the measured values the recorder can measure at a slightly larger range than promised by the manufacturer of the recorder.

The brown area of the phase voltages and the brown area of the phase to phase voltages may differ from each other due to the different half cycle RMS settings.

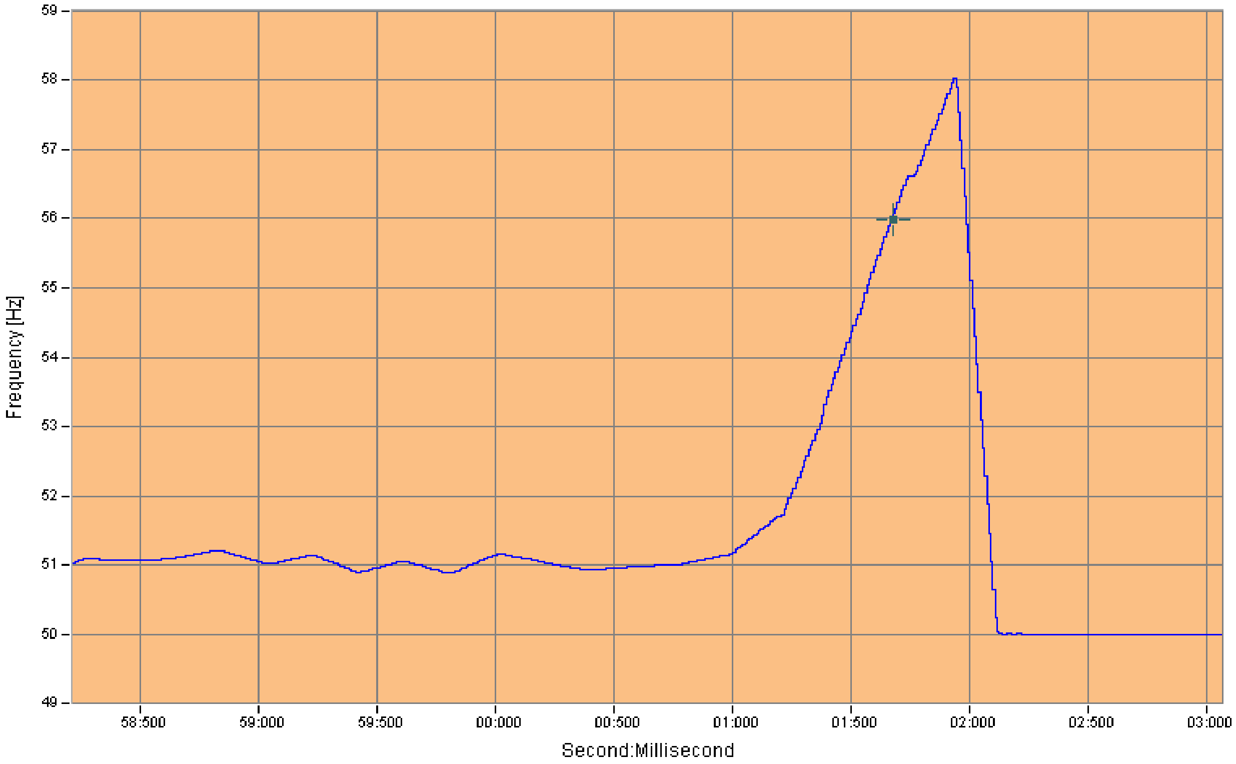


Figure 17. The RMS frequency/Hz 28.09.2010 11:27:58 - 11:28:03 with a measurement time of 5 s. The recorder has coloured the whole area of the figure in light brown whenever the recorder recorded the measurable frequency.

The synchronization range is for 50 Hz systems 42.5 Hz … 57.5 Hz and for 60 Hz systems 51 Hz … 69 Hz. Here the nominal frequency was set 50 Hz. A special calculation method is used related to the 10 ms and 20 ms (half/full cycle) rms values. The measured frequency is the sync frequency of the Phase Locked Loop which is refreshed every 200 ms (based on the FFT evaluation) /3/.

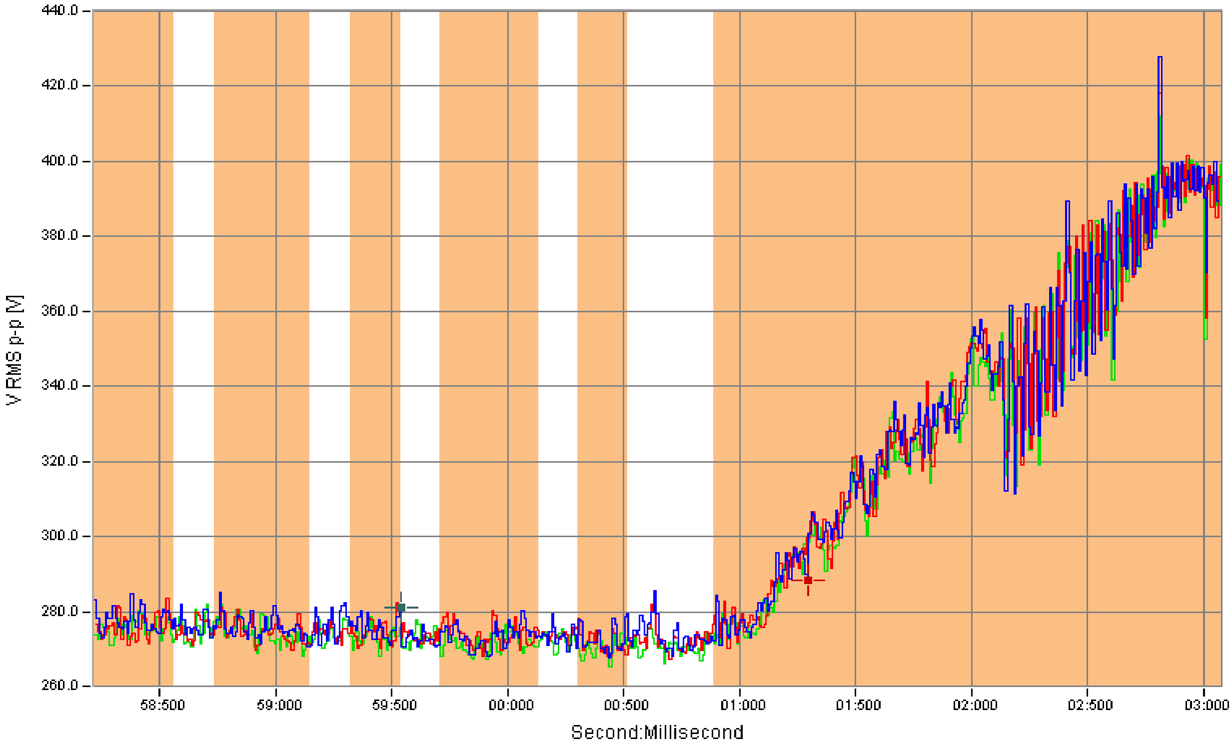


Figure 18. The phase-to-phase RMS voltages/V 28.09.2010 11:27:58 - 11:28:03 with a measurement time of 5 s; L1-L2 = blue, L2-L3 = red and L3-L1 = green. The recorder has flagged the brown areas.

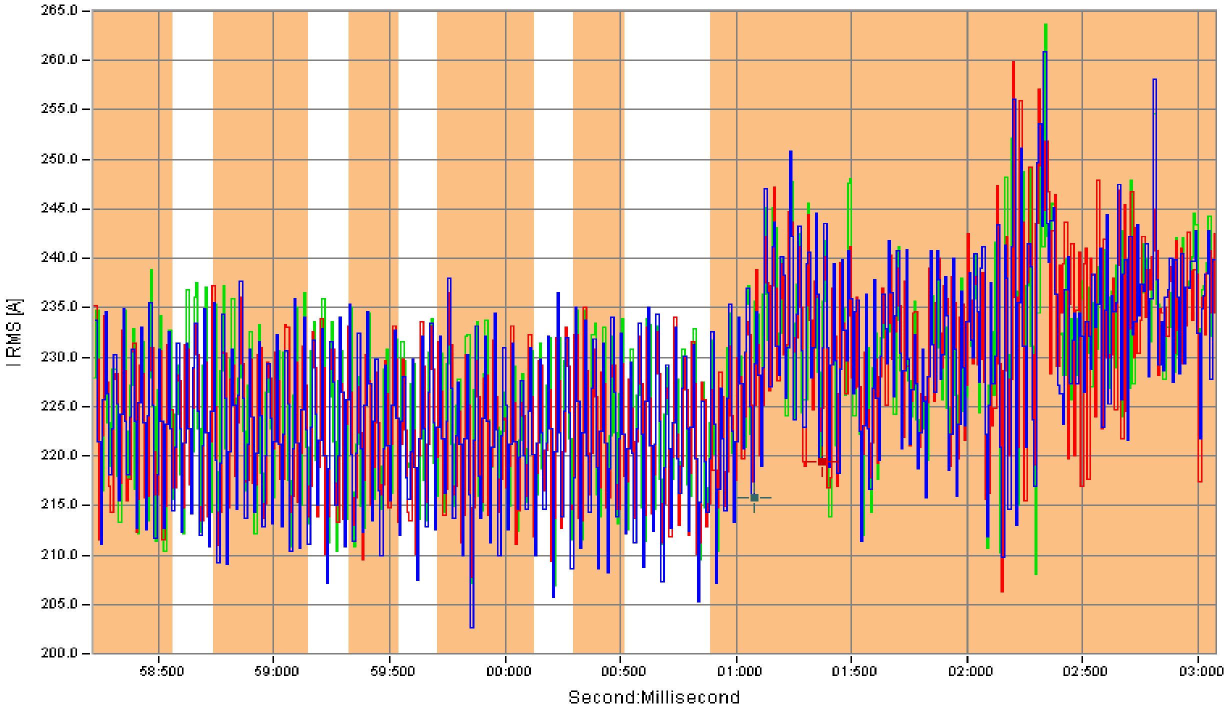


Figure 19.The phase RMS currents/A 28.09.2010 11:27:58 - 11:28:03 with a measurement time of 5 s; L1 = blue, L2 = red and L3 = green. The recorder has flagged the brown areas of the figure.

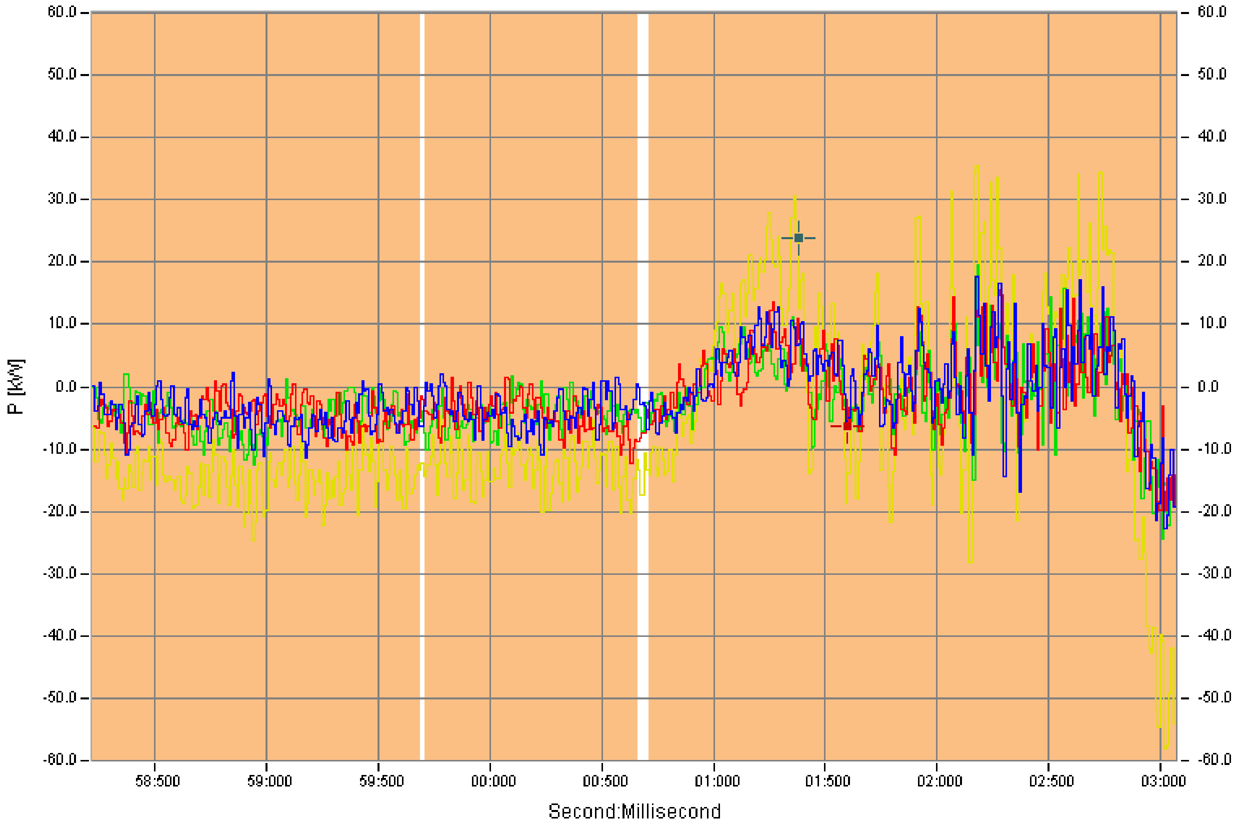


Figure 20. The phase RMS real powers/kW 28.09.2010 11:27:58 - 11:28:03 with a measurement time of 5 s; L1 = blue, L2 = red and L3 = green and sum of the formers = yellow. The recorder has flagged the brown areas of the figure.

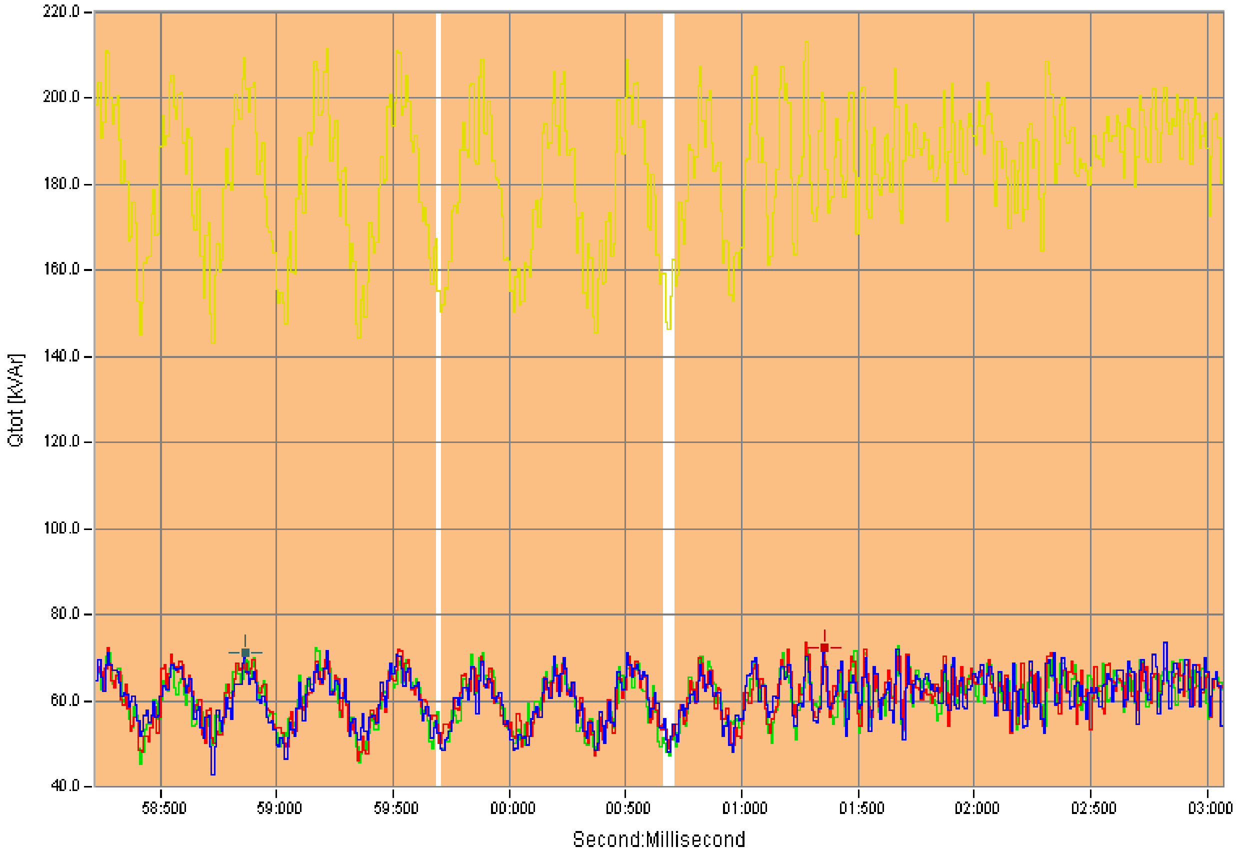


Figure 21. The phase RMS reactive powers/kVAr 28.09.2010 11:27:58 - 11:28:03 with a measurement time of 5 s; L1 = blue, L2 = red and L3 = green and sum of the formers = yellow. The recorder has flagged the brown areas of the figure.

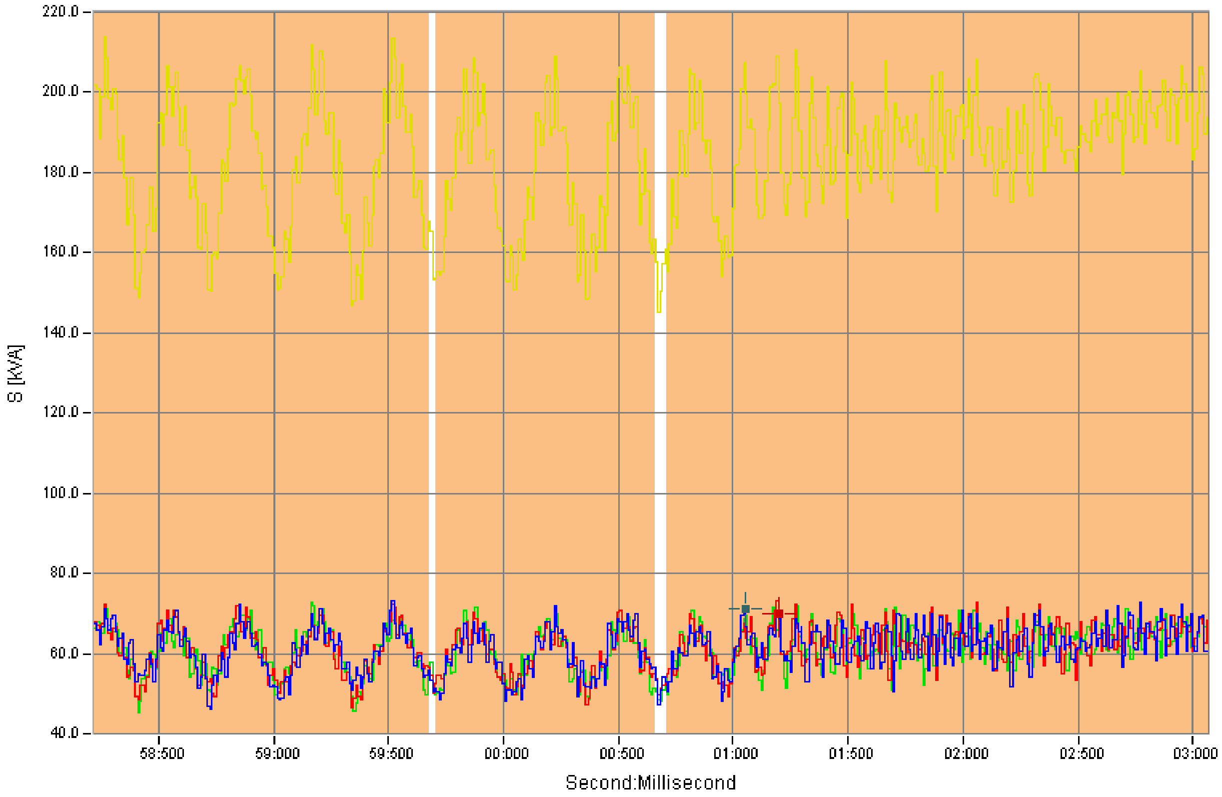


Figure 22. The RMS apparent powers/kVA 28.09.2010 11:27:58 - 11:28:03 with a measurement time of 5 s; L1 = blue, L2 = red and L3 = green and sum of the formers = yellow The recorder has flagged the brown areas of the figure.

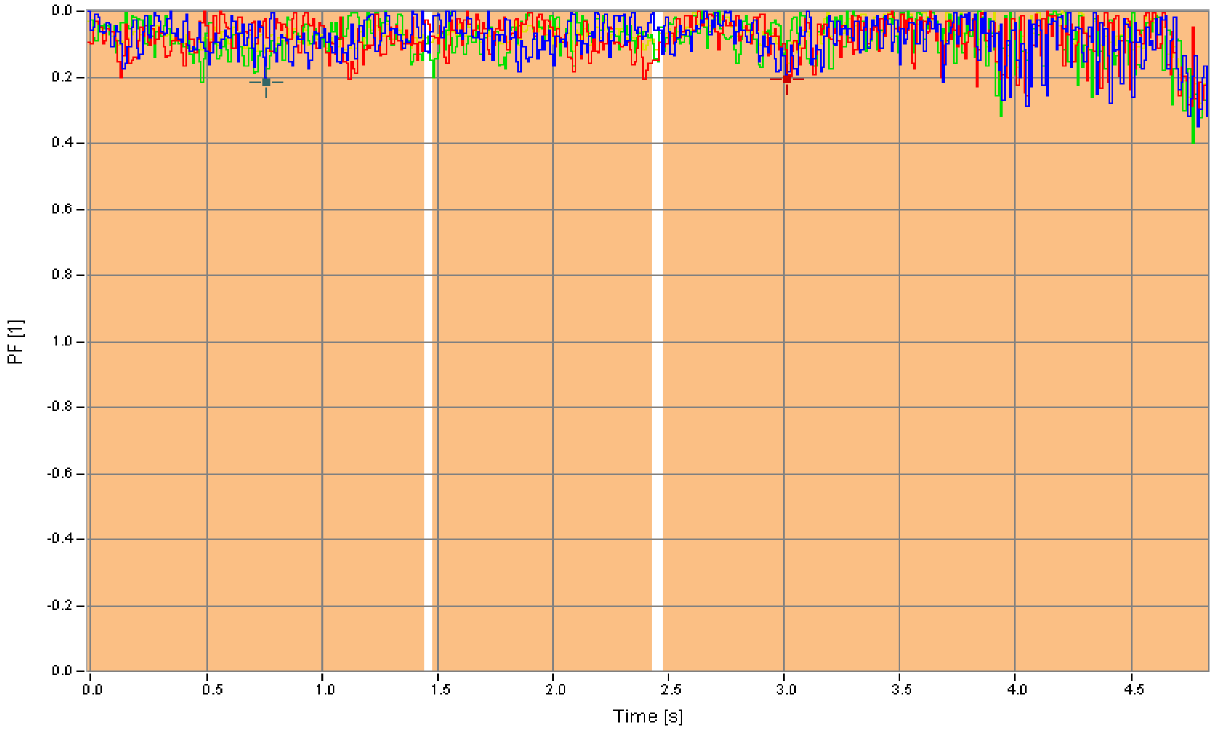
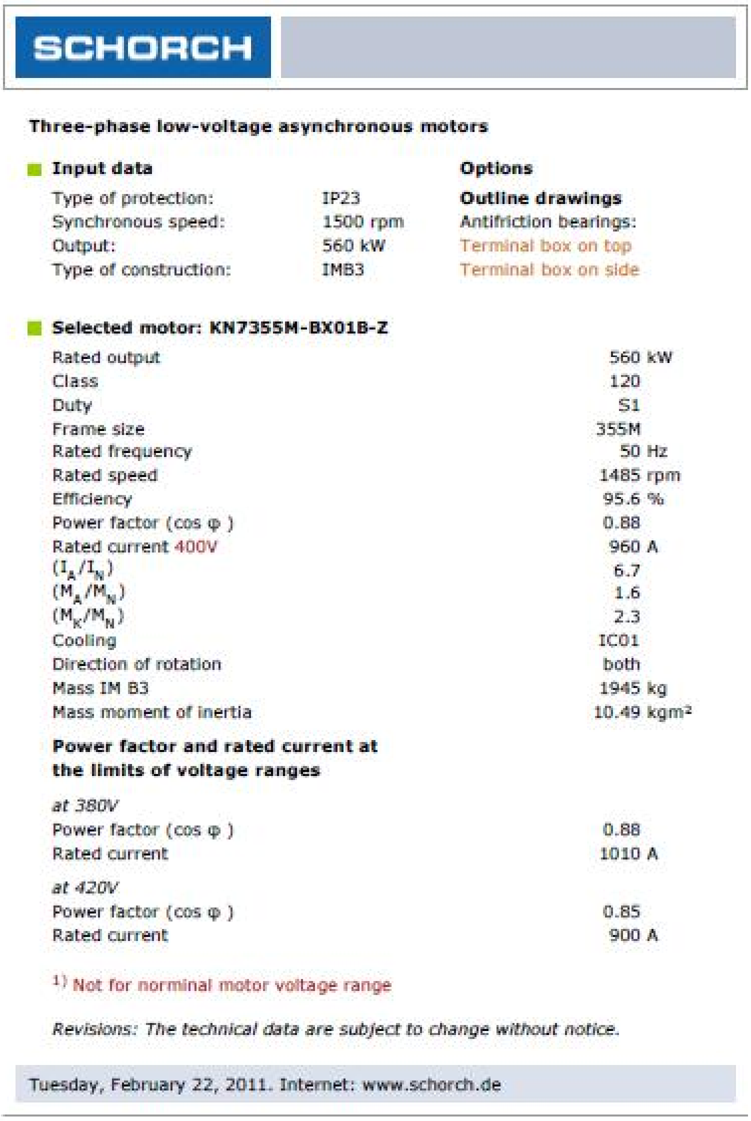


Figure 23. The phase RMS power factors (= P/S) 28.09.2010 11:27:58 - 11:28:03 with a measurement time of 5 s; L1 = blue, L2 = red and L3 = green and an average of the formers = yellow. The recorder has flagged the brown areas of the figure. Horizontal axis is the same as in the preceding figures. Here the scale is in seconds instead of the timestamp Second:Millisecond presentation. The powers measured have a different flagging method compared with the method of the voltages and currents or the frequency.

B. Appendix

Generator datasheet (f=50Hz).



SCHORCH

Three-phase low-voltage asynchronous motors

Input data

Type of protection:	IP23
Synchronous speed:	1500 rpm
Output:	560 kW
Type of construction:	IMB3

Options

Outline drawings

Antifriction bearings:

Terminal box on top

Terminal box on side

Selected motor: KN7355M-BX01B-Z

Rated output	560 kW
Class	120
Duty	S1
Frame size	355M
Rated frequency	50 Hz
Rated speed	1485 rpm
Efficiency	95.6 %
Power factor (cos φ)	0.88
Rated current 400V	960 A
(I_A/I_N)	6.7
(M_A/M_N)	1.6
(M_K/M_N)	2.3
Cooling	IC01
Direction of rotation	both
Mass IM B3	1945 kg
Mass moment of inertia	10.49 kgm²

Power factor and rated current at the limits of voltage ranges

at 380V	
Power factor (cos φ)	0.88
Rated current	1010 A
at 420V	
Power factor (cos φ)	0.85
Rated current	900 A

(1) Not for norminal motor voltage range

Revisions: The technical data are subject to change without notice.

Tuesday, February 22, 2011. Internet: www.schorch.de

C. Appendix

Overall picture of the simulation model.