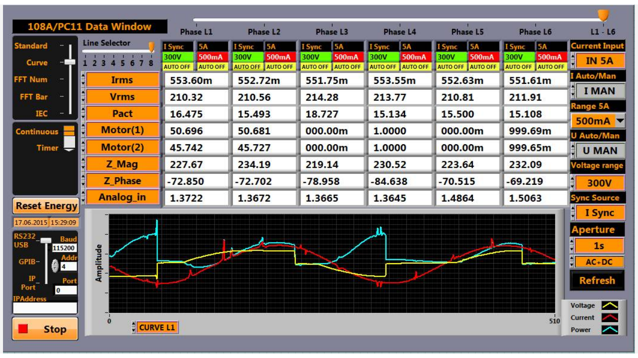
Electric Motor Testing Using Infratek 108A-6 High Precision Power Analyzer

The 108A-6 equipped with Option 03, (6 analog inputs, 2 digital inputs, and 12 outputs) performs all required measurements for motor testing.

Use the Infratek operating Software to perform motor tests in ***STANDARD*** measure mode. Values at different motor operating points can be stored and viewed when done.

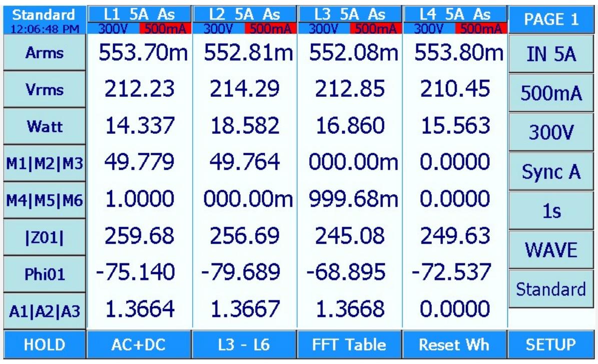


108A Computer Software

The 108A scalable analog inputs can be used for torque-, temperature- and vibration measurements. Two scalable TTL-inputs are for speed- or torque measurement. An external synchronization input per phase from an encoder can be used to synchronize measurements to the pole position.

The 108A-6 measures two motors simultaneously: input power, output power, torque, slip, speed, and efficiency of every motor, as well as harmonics of current, voltage, power, impedance, and phase angle. For none sinusoidal signals (trapezoidal wave-forms or frequency inverters), we recommend to use the fundamental of impedance and fundamental of phase. From these values the motor inductances L, L_d, L_q and the motor resistances $R = R_m + R_{dc}$ can be determined.

The motor DC-resistance is obtained by applying a DC-current: $R_{dc} = P_{dc} / I^2_{dc}$. R_m is a magnetization dependent loss.



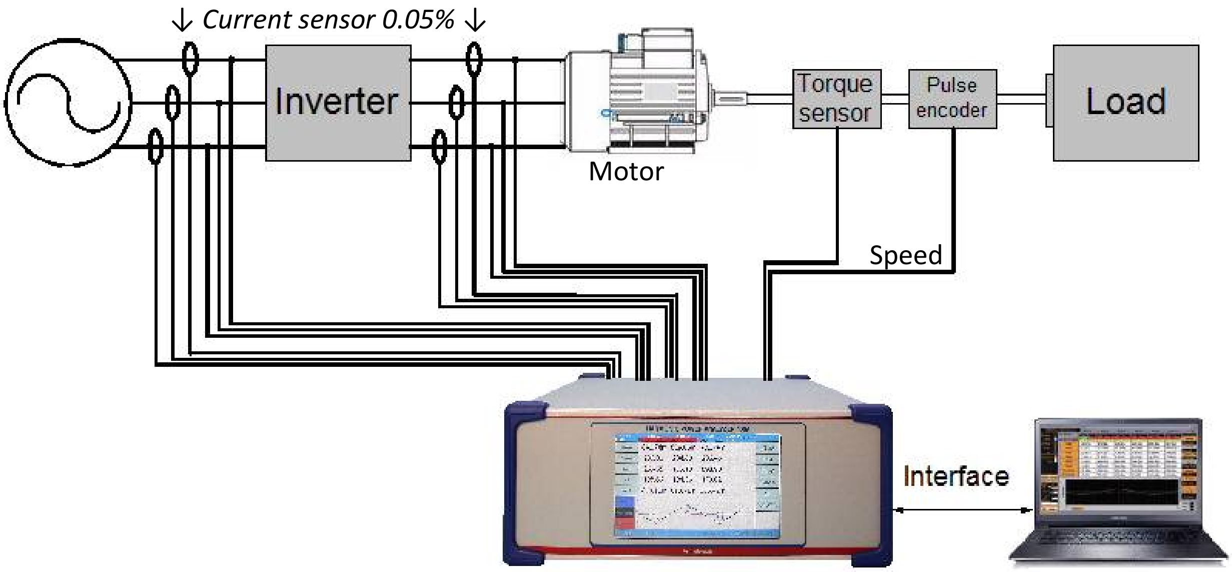
Standard 12:06:48 PM	L1 5A As 300V 500mA	L2 5A As 300V 500mA	L3 5A As 300V 500mA	L4 5A As 300V 500mA	PAGE 1
Arms	553.70m	552.81m	552.08m	553.80m	IN 5A
Vrms	212.23	214.29	212.85	210.45	500mA
Watt	14.337	18.582	16.860	15.563	300V
M1|M2|M3	49.779	49.764	000.00m	0.0000	Sync A
M4|M5|M6	1.0000	000.00m	999.68m	0.0000	1s
|Z01|	259.68	256.69	245.08	249.63	WAVE
Phi01	-75.140	-79.689	-68.895	-72.537	Standard
A1|A2|A3	1.3664	1.3667	1.3668	0.0000	
HOLD	AC+DC	L3 - L6	FFT Table	Reset Wh	SETUP

The 108A display and the computer software screen can be configured to the user's needs.

M1| M2| M3| = Input power, output power, torque
M4| M5| M6| = Slip, rpm, efficiency
Phi01 = Phase angle of fundamental
A1| A2| A3| = Analog inputs 1, 2, 3

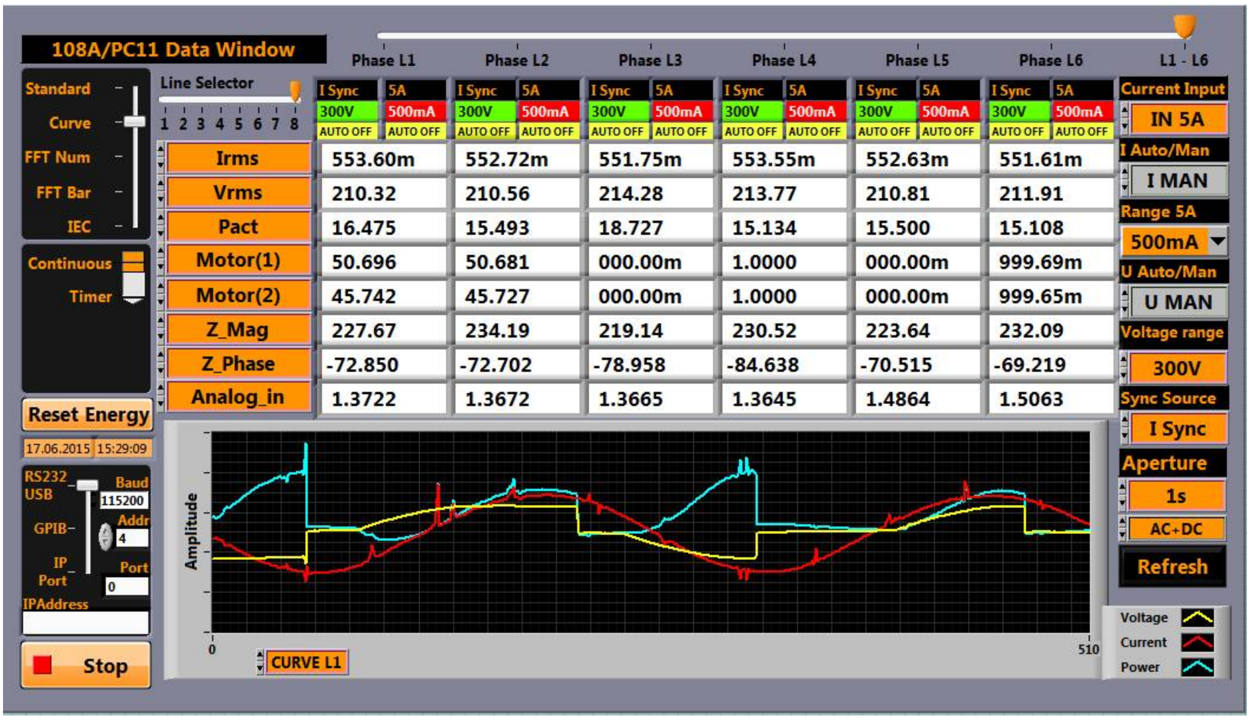
108A Display Screen

Efficiency Measurement of an Inverter driven Induction Motor in Steady State



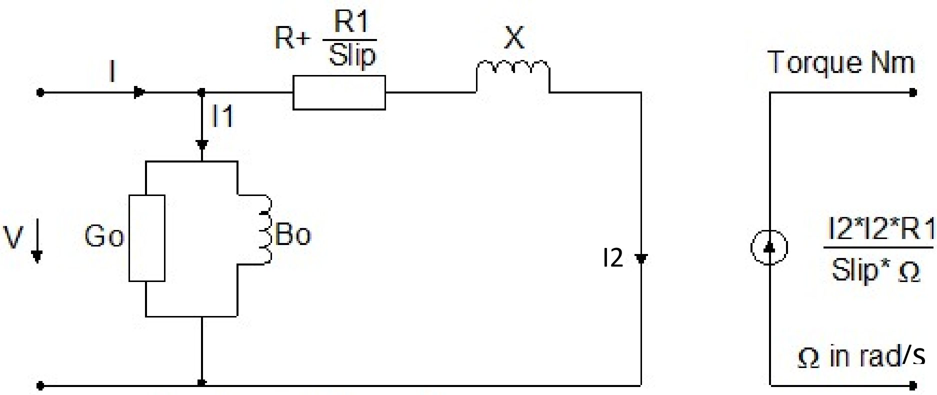
Overall Efficiency = 4π* rotation per second*torque/(nr_poles)*(P1+P2+P3)

First, run a no load motor test. The interface command “**COMP:MOT1_Loss?**” stores the motor loss. For tests on loaded motor this loss is subtracted to compute motor output power. With the command “**COMP:MOTOR1?**” all motor values: input power, output power, torque, slip, speed (rpm), and efficiency are sent to the PC.



The external torque- and temperature inputs are transferred to the PC by the command "COMP:ANIN?". Run tests at different loads to obtain graphs of slip versus torque, input power versus torque, and efficiency versus torque. Remember, the speed- and torque inputs can be scaled to read actual rpm and Nm.

Circuit Model of an Asynchronous Induction Motor



Circuit model of one phase

Perform a no-load test and a blocked-rotor test.

The circuit elements can be determined.

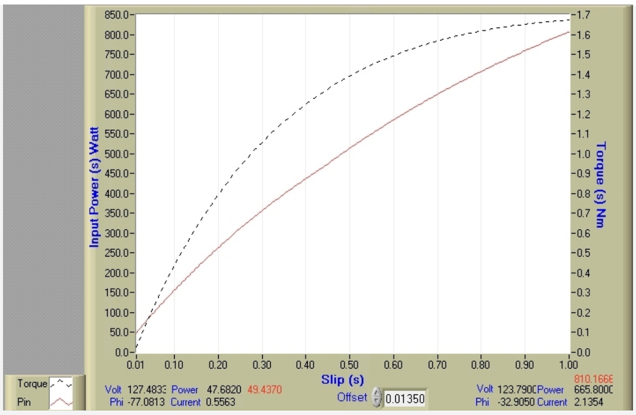
No-load test
Measure the fundamental of voltage, current, impedance and phase angle. Calculate Go and Bo.

Blocked-rotor test:
Measure the fundamental of voltage, current, impedance, and phase angle. From a DC measurement obtain the ohmic resistance Rdc. Approximate R = 0.5Rdc. Calculate R1 and X from fundamental of impedance and phase.

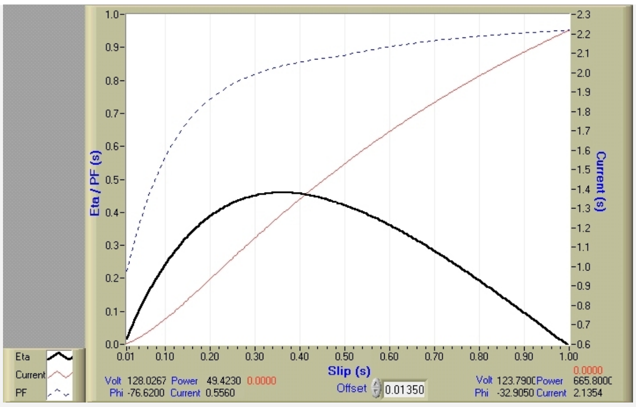
Once the elements of the equivalent circuit are determined various motor characteristics can be plotted, such as: torque / power / power-factor versus slip.

Measurements on loaded Motor

Operate the motor at various load points. Store the measurements using the PC Operating Software, alternatively store the measurements on the Power Analyzer in Excel. Plots like torque versus slip, input power versus slip, and many more graphs can be obtained.

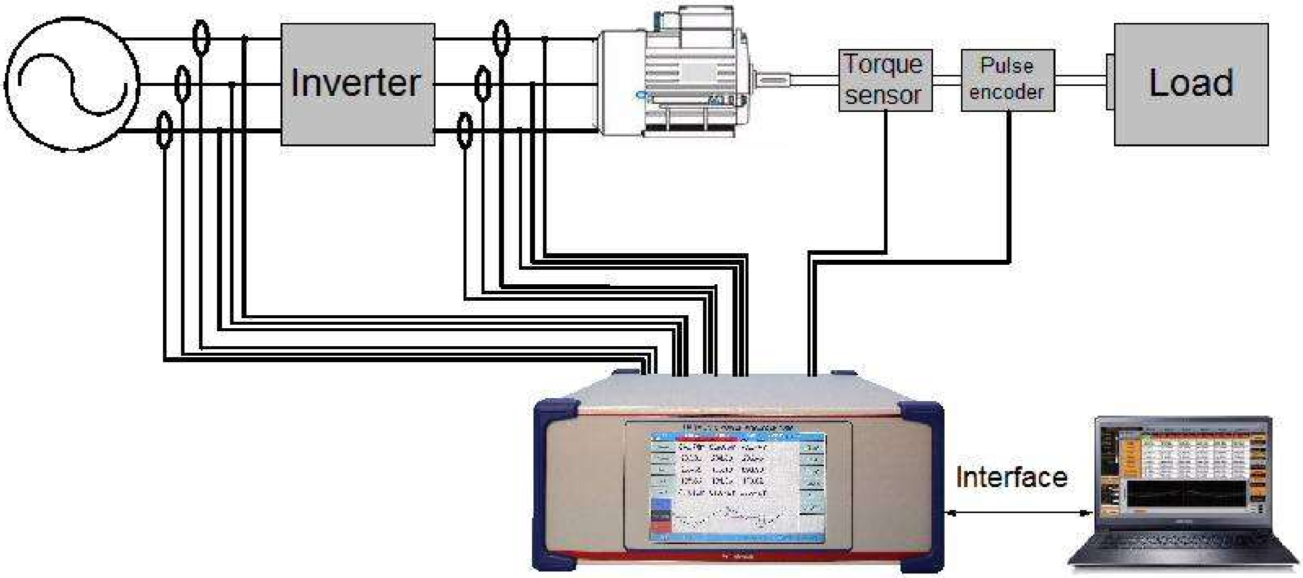


Torque and power versus slip. Motor is star connected. It is operated by 50Hz power line.



Power Factor, efficiency, and phase current versus slip.

Measurement of Start-up Behaviors of Inverter Driven Induction Motor

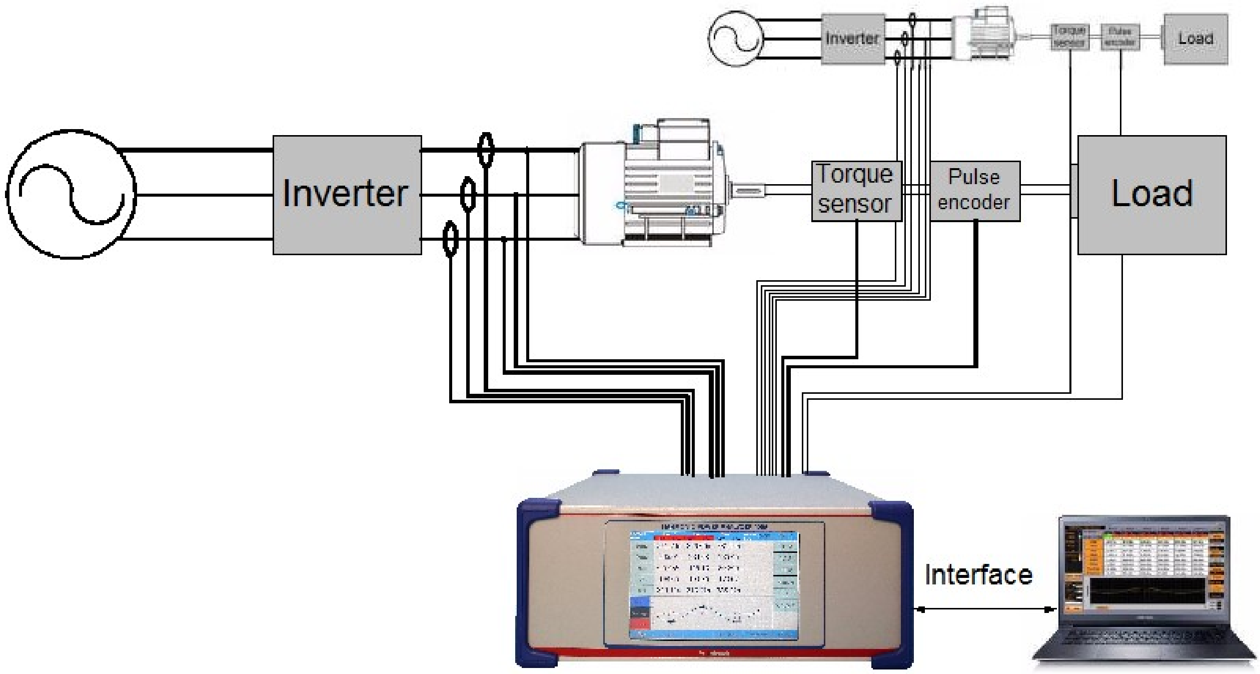


Select *LOGGING Mode*

Select voltage- and current ranges such that at start-up no range overload occurs. Select current- or external synchronization **to all installed phases on the 108A**, set “CYCLE” to 1, 2, 3, or any other value. Apply the synchronization to all phases installed in the Power Analyzer. Finally start the system.

If you selected DYCLE = 1 the 108A sends every period one data set per phase to the PC. A 6-phase instrument sends 6 data sets to the PC, phase 1 first. Each data set contains: Frequency, A, V, W, PF, VA, Wh, and VAh. A 6-phase 108A transmits 6 data sets per 20ms (maximum speed). Stop the measurement when the system is in steady state and analyze the data using EXCEL.

Simultaneous Measurement of 2 Synchronous Motors (PMSM, BLDC)



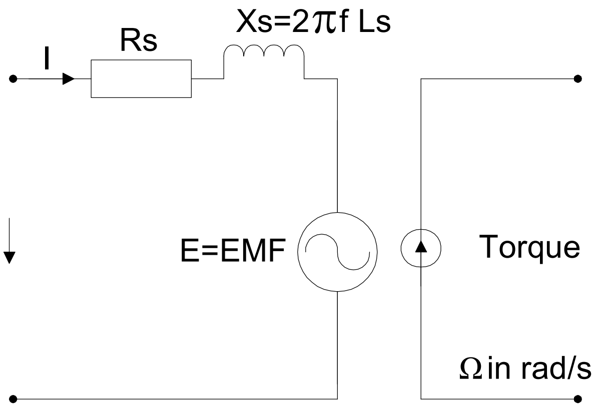
A wide range of synchronous motors are on the market (PMSM, IPMSM, BLDC). The power consumption ranges from mW to 500kW. Many different constructions are in use. They all have in common that the magnetic field rotation (2 phase or 3 phase) is electronically generated. A wide range of speeds (rpm) are available.

Advantage of the 108A Power Analyzer

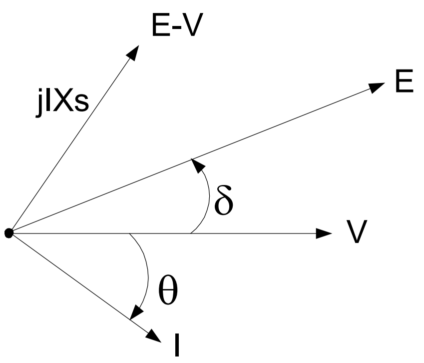
For medium size-, small-, and very small motors the 108A provides per phase 3 direct current inputs: 1mA-2A, (for small motors) 15mA-7A, and 1A to 40A (for medium size motors). For very large motors high precision (0.004 %) broad band current sensors up to 700A are available.

The sensor output is simply connected to the 1mA-2A input on the 108A. To display actual currents, scaling per phase is available. Also, analog inputs and speed inputs can be scaled. The 108A measure all motor parameters, current, voltage, power, and their harmonics, impedance, and phase angles simultaneously. This is important because electronically generated waves include harmonics (BLDC) and noise (PMSM).

Circuit Model of a Synchronous Motor



Synchroneous Motor Circuit Model of one phase



Phasor representation neglecting Rs.

Normally, in a synchronous motor R_s is much smaller than X_s.

From a blocked rotor test

Rs + Xs can be determined (Rs and Xs are somewhat current dependent). Measure impedance and phase angle θ: $Z = Rs + j2\pi f\, Ls$. From this simple model the electromotive force E and power angle δ can be calculated.

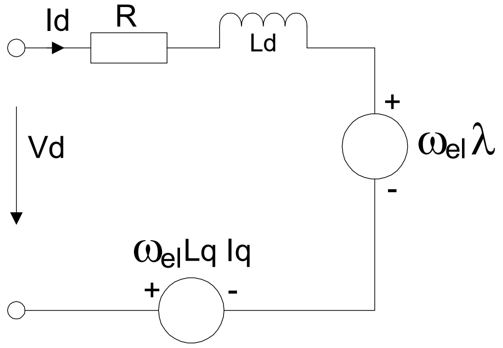
Maximum torque developed by a PMSM-, IPMSM, or BLDC-motor depends very much on its construction. The torque is a function of power angle δ. Their main advantages are low loss and the ability to run at very high speeds (IPMSM).

(There is no need to go through the trouble to perform the mathematics of Clark Transformation followed by the Park Transformation to get to the d, q - coordinates. It remains the proof that $Ls = \frac{1}{3}\sqrt{Ld^2+Lq^2}$. For PMSM Ld = Lq, high speed motors IPMSM Ld < Lq).

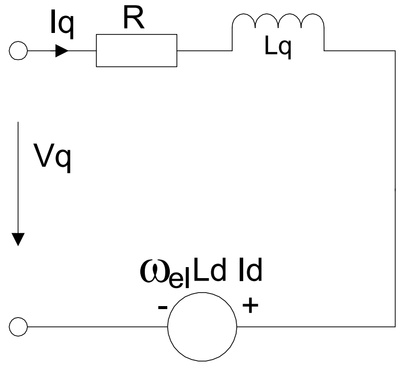
PMSM = Permanent magnet synchronous motor
IPMSM = Interior permanent magnet synchronous motor
BLDC = Brushless DC electric motor

Determination of synchronous inductances Ld and Lq of IPMSM and PMSM

The equivalent phase model of PMSM and IPMSM are shown below (PSPM = permanent magnet synchronous motors). R represents the sum of ohmic losses (R_{ohm}) plus magnetic losses (Rm). Ld and Lq are the equivalent inductances along the d-axis (direct axis) and the q-axis (quadrature axis).



d-axis circuit

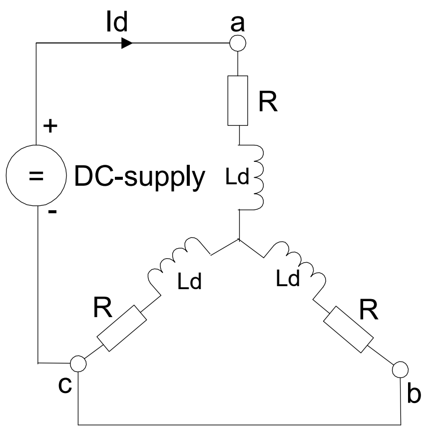


q-axis circuit

The ohmic losses are temperature dependent $R_{ohm} = R_o(1+\alpha\Delta t)$, the magnetic losses are magnetization dependent due to non-linearity.

Ld and Lq are measured in a locked motor shaft test. This implies ωel = 0, or the voltage sources of the equivalent circuits are zero.
Lq, and mainly Ld are somewhat current dependent.

Measure d-axis inductance Ld



Alignment into d-axis

Step 1: Align the rotor to phase a. Connect DC-supply as shown. The current Id aligns the rotor into the d-axis, electrical angle = 0°.

Step 2: Lock the rotor shaft.

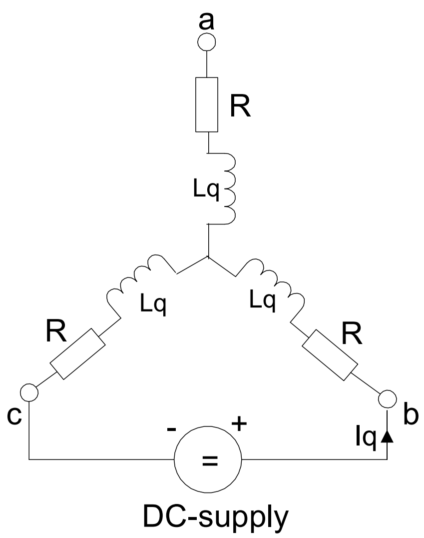
Step 3: Replace the DC-supply by a variable frequency AC-Source. Apply current Id.

Step 4: From the 108A display read frequency f, |Z01|, Phi01, (use current synchronization).

Step 5: Calculate: R = 0.667 • |Z01|cos (Phi01)
Xd = 0.667 · |Z01| sin (Phi01)
Ld = Xd / 2πf

Step 6: Repeat Step 5 at different current levels. Plot R and Ld versus current.

Measure q-axis inductance Lq



Alignment into q-axis

Step 1: Current Iq aligns the rotor into the q-axis, electrical angle = 90°.

Step 2: Lock the rotor shaft firmly, Iq generates torque.

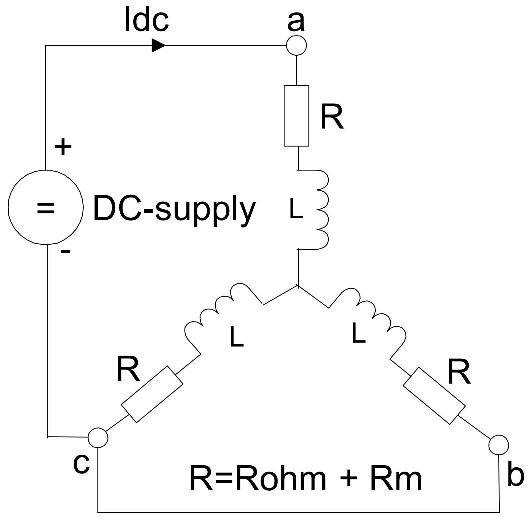
Step 3: Replace the DC-Supply by a variable frequency AC-Source. Apply current Iq.

Step 4: From the 108A display read frequency, |Z01|, Phi01, (use current synchronization).

Step 5: Calculate: R = 0.5 |Z01|cos (Phi01)
Xq = 0.5 |Z01| sin (Phi01)
Lq = Xq / 2πf

Step 6: Repeat step 5 at different current levels. Plot Lq versus current.

Measure Ohmic component of Loss Resistance R = Rohm + Rm



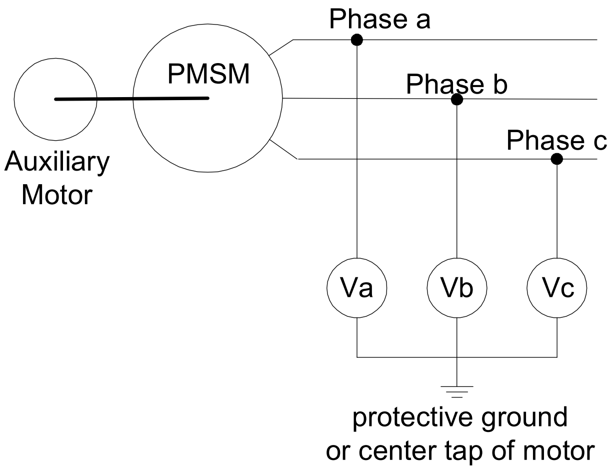
Step 1: Connect DC power supply.

Step 2: Measure Vdc, Idc, and Pdc using 108A.

Step 3: Calculate Rohm = Pdc / I^2dc

Back – EMF (BEMF)

To measure the BEMF the shaft of a PMSM / IPMSM is turned by an auxiliary motor at constant speed ω_{el}.



Step 1: Connect Va, Vb, Vc to phase 1, 2, 3 of the 108A. (use voltage synchronization).

Step 2: Display V01a, V01b, V01c the fundamental of voltage and frequency.

Step 3: Calculate the BEMF peak value.

Vapeak = 1.41 · V01a
Vbpeak = 1.41 · V01b
Vcpeak = 1.41 · V01c

Calculate k= Vpeak / 2πf [Vs / rad].
k is a constant used for motor control.

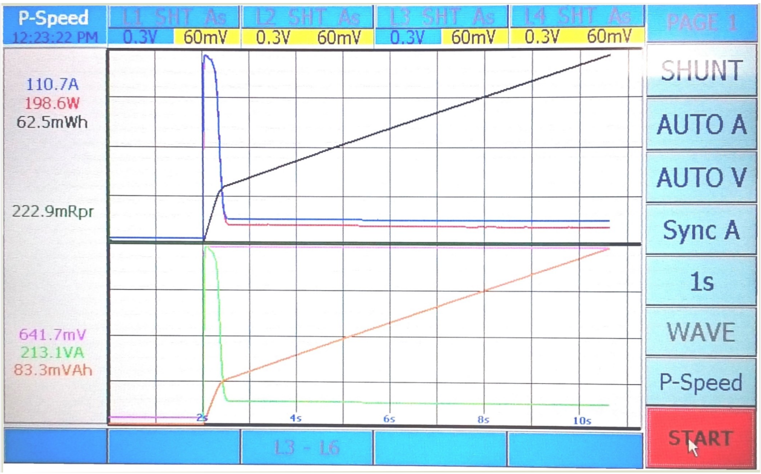
Transient Performance of Synchronous Motors

The 108A also measures motors in transient state (start-up, speed change, load change) using the **Logging measure mode** or the **Power-Speed measure mode**.

Logging Mode

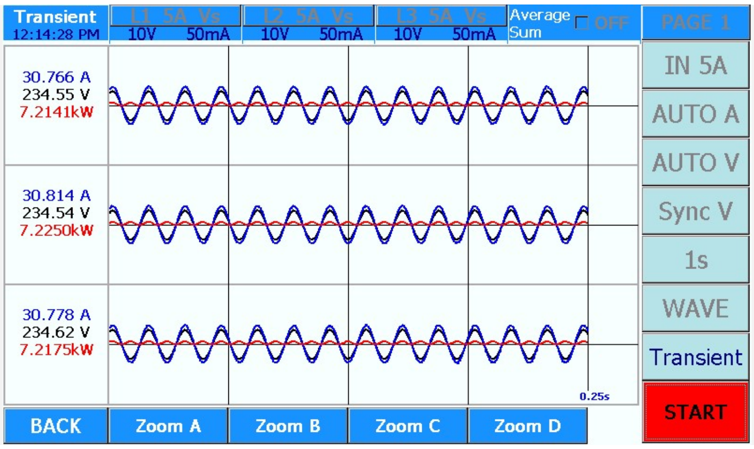
At end of programmed time interval (1, 2, 3, … periods), frequency, A, V, PF, VA, Wh, and VAh of each phase are transmitted to the PC. Data are stored. In EXCEL graphs can be generated.

Power Speed Mode



Use it for high speed IPMSM with fast changing signal frequency. In 20ms intervals averaged current and voltage, 3-phase power, 3-phase apparent power, and speed (rpm) are sent to PC. In EXCEL graphs like power versus rpm can be drawn. Plots on the 108A display are drawn.

Transient wave



At operating points of interest the simultaneous wave forms of all 6 phases can be viewed (current, voltage and power). To view details sectors of wave forms A, B, C, or D can be expanded.

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