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ACCURATE ESTIMATION OF START-UP PULSATING TORQUE OF DIRECT ON LINE SYNCHRONOUS MOTORS DRIVING COMPRESSOR TRAINS

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Presenter/Author bios

Francesco Meucci
Is working as Electrical System Design Engineer at BHGE, Florence, Italy.

He joined GE in 2012 through a technical leadership program gaining cross functional background on electrical and mechanical area of concern. From 2014 he's working on multiple projects with special focus on rotordynamic analyses and troubleshooting linked with electrical machines and structures. He graduated in Electrical and Automation Engineering at University of Florence, Italy in 2011.

Niccolò Spolveri
Is currently working as Lead Electrical System Design Engineer at BHGE, Florence, Italy.

He joined GE in 2012 as Lead Electrical System Engineer working in requisition projects. He is responsible for the integration of VSDS (Variable Speed Drive System) for complex projects mainly for LNG (Liquefaction Natural Gas) applications. He got Master Degree in Electric Engineering at University of Bologna, Italy in 2009.

David Donati
Is currently working as Senior Mechanical Design Engineer at BHGE, Florence, Italy

12 years experience in Engineering with deep expertise in mechanical design (including skill on Static Structural FEM analysis) especially on Gearboxes/Coupling and turbomachinery rotor-dynamics. With the additional role of Productivity Leader he follows all relevant cost out activities (SC, DTC, Standardizations, CRC programs) expanding this activity to PT (Power Transmission) business

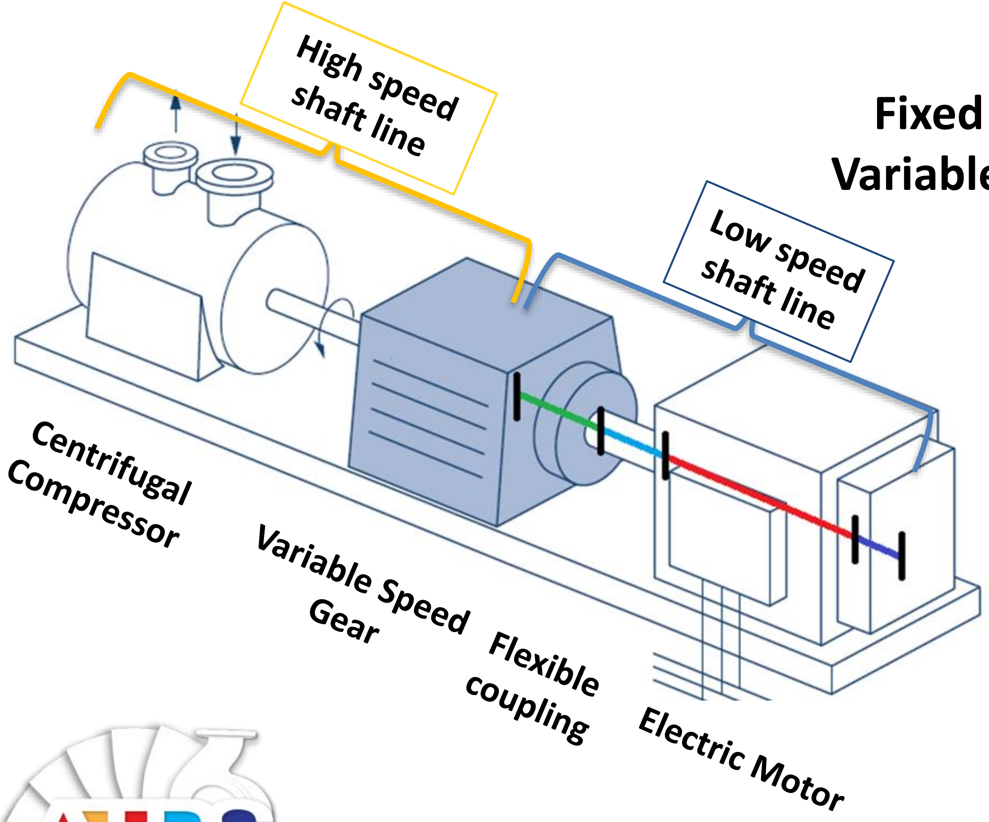
Stefano Del Puglia
Is an Engineer Manager in the Electrical Department of BHGE, Florence, Italy.

He joined GE in 2005 as electrical design engineer working as responsible of system integration of electrical items for Oil & Gas applications. Stefano Del Puglia received Master Degree in electrical engineering from the University of Florence. Before joining GE, he worked as design engineer for power electronics and motor inverter in Florence, Italy

Abstract

In a compressor train driven by fixed speed synchronous motor (>17MW) was discovered a potential torsional problem on the input shaft of the hydraulic variable speed gear during the start-up phase when only low speed shaft line is engaged. It was due to high motor excitation torque crossing the 1st torsional critical speed during startup causing a very limited numbers of train startups (1400) versus project requirements (5000). Supported by API 617 (8th edition), the motor excitation air-gap torque during startup has been analyzed considering electrical system characteristics that influence the effective voltage drop at motor terminals. A more realistic analysis of the excitation confirmed the correctness of the shaft line design avoiding any redesign and impacts in the projects execution.

Compressor Train Composition



Fixed Speed Synchronous Motor + Hydraulic Variable Speed Gear + Centrifugal Compressor

- Direct On Line 4-poles Motor
- Rated Power 17.5 MW
- Rated Speed 1500 rpm

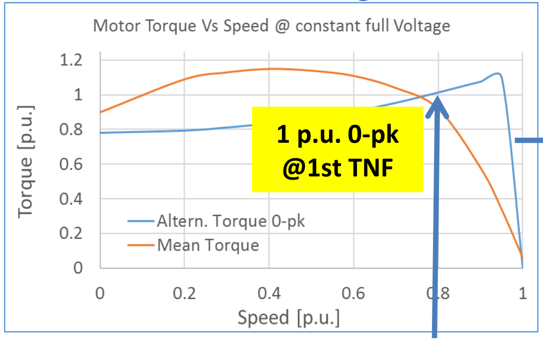
During compressor train startup
Only low speed shaft line of the compressor train is engaged.

Note: this system is flexible and has a torsional frequency below motor operating speed

Problem Statement

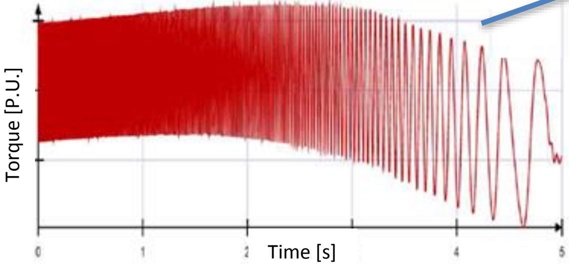
EM Start-Up torques curves vs Speed

100% voltage



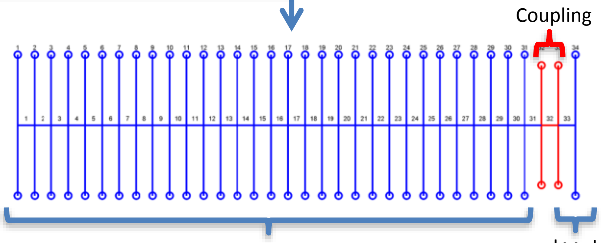
EM Start-Up torques Torque Vs Time

100% voltage



In a synchronous motor, the torque produced typically sweeps the frequency range from zero to twice the line frequency as it accelerates from rest during starting. [IEEE 1255]

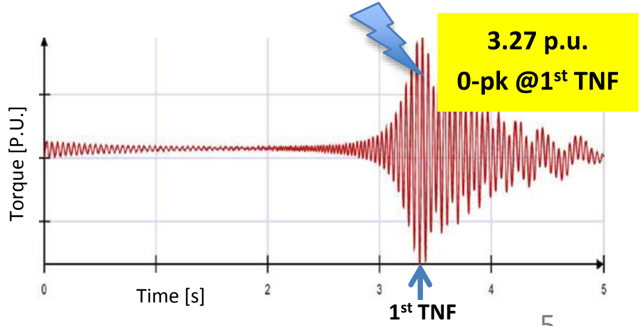
Mass elastic torsional model



These systems are inherently flexible and have relatively low resonant frequencies. [IEEE 1255]

Torsional analysis on low speed shaft of the compressor train indicated potential problem of high stress on the input shaft of the hydraulic variable speed gear due to electric motor excitation torque when crossing the 1st torsional critical speed during compressor train startup.

Torque Response @ Input Shaft

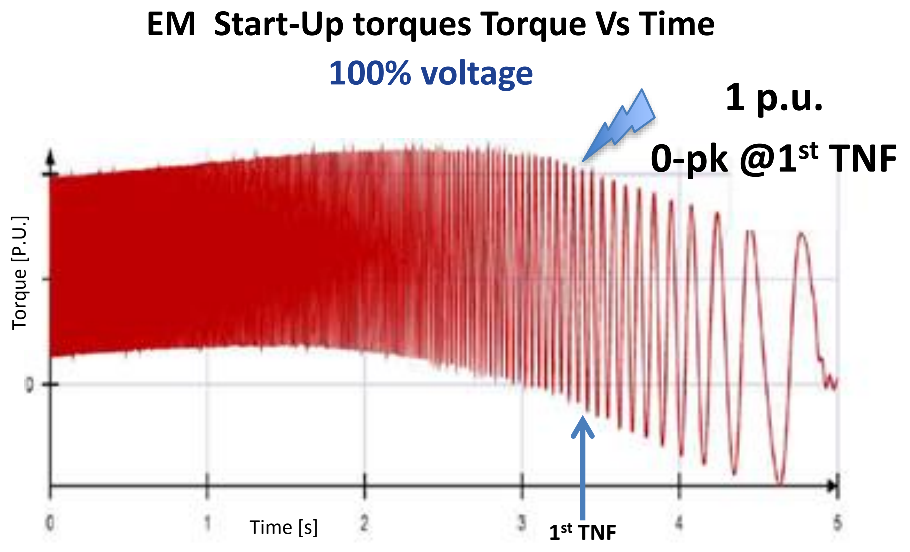


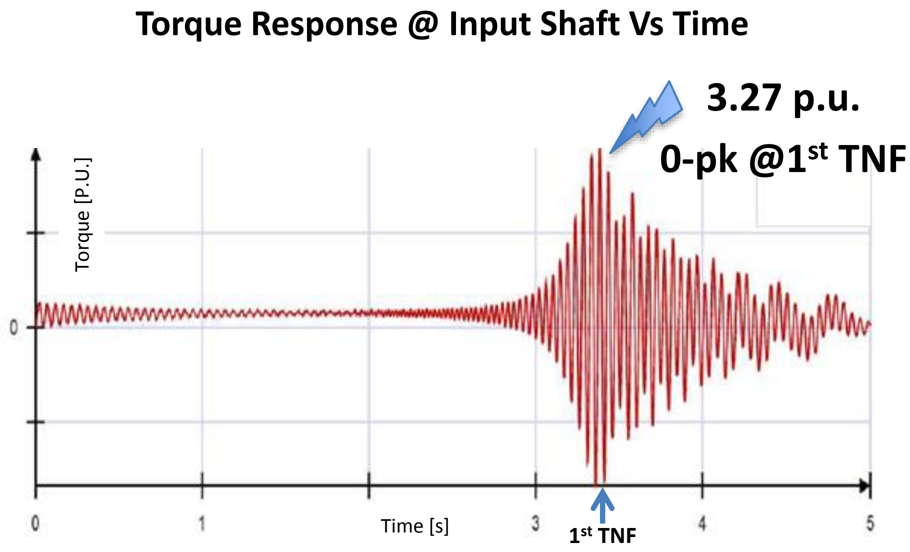
Legend:

EM: Electric Motor
TNF: Torsional Natural Frequency
P.U.: Per Unit (i.e. 1p.u. of torque = Rated Torque)
0-pk: mean to peak values

Note: all values are normalized and therefore relative.

Problem Statement





For this project, canonical air-gap torque evaluation method (without any motor voltage transient effects), gives an high resultant torque allowing a very limited number of startups due to high fatigue stress on the input shaft.

Legend:

EM: Electric Motor

TNF: Torsional Natural Frequency

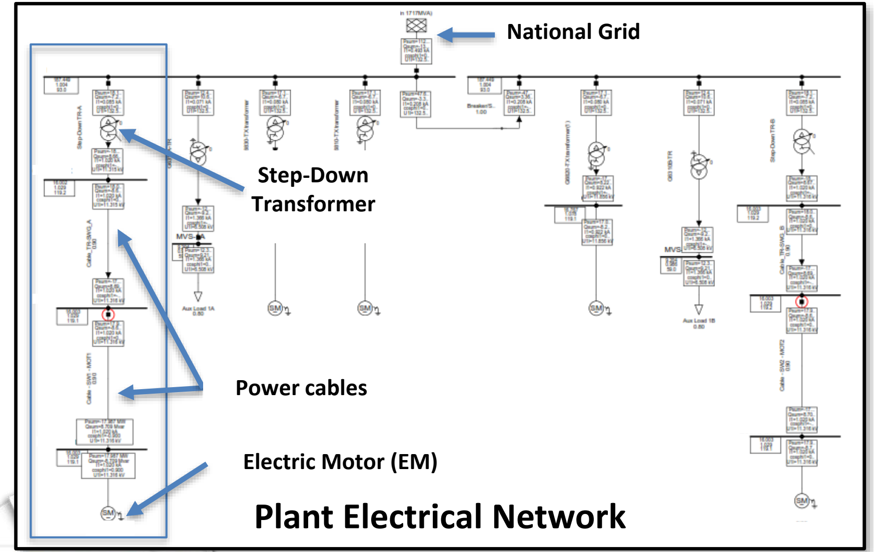
P.U.: Per Unit (i.e. 1p.u. of torque = Rated Torque)

0-pk: mean to peak values

Note: all values are normalized and therefore relative.

Analysis of the Problem

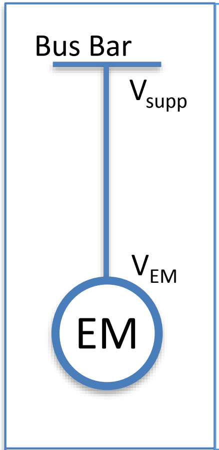
For a more accurate transient torsional analysis, the effect of motor voltage drop and voltage recovery is considered for a more realistic electric motor air-gap estimation (as suggested by API 617) by simulating the electrical system behaviors during motor startup.

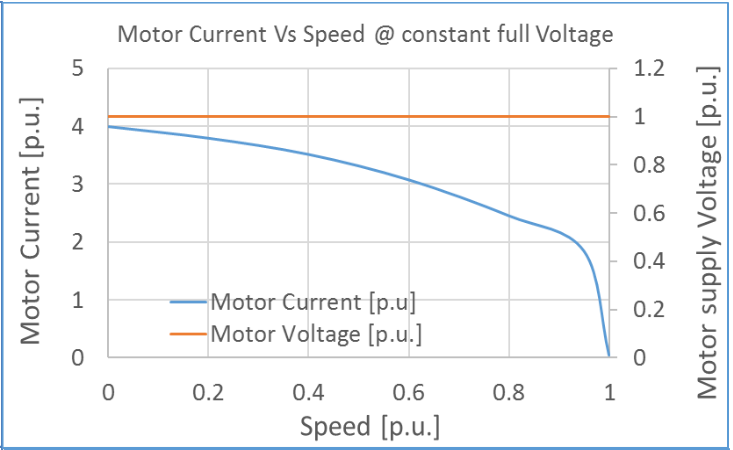


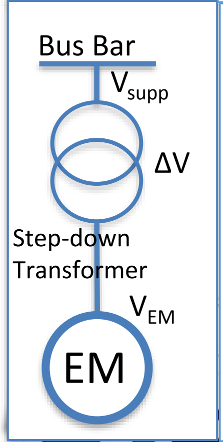
- Assumptions on Network key data;
- Evaluation of electrical items impacting voltage drop;
- Motor electrical equivalent model;

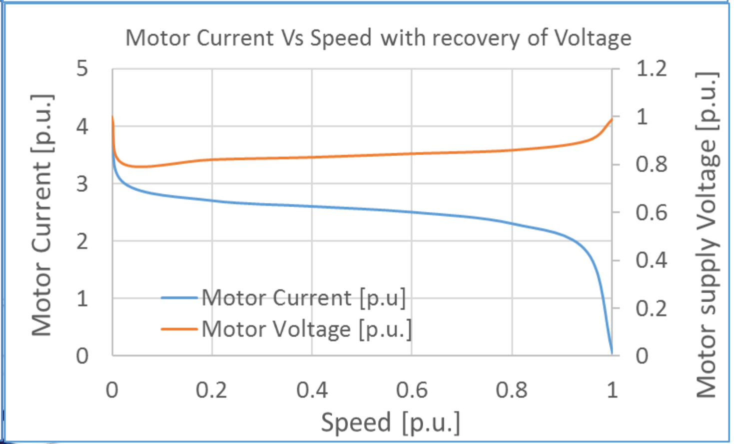
$$Torque_{EM} \propto (Voltage_{EM})^2$$

Analysis of the Problem









$$Torque_{EM} \propto (Voltage_{EM})^2$$

$$V_{EM}(\omega, I_{EM}) = V_{supp} - \Delta V(\omega, I_{EM})$$

The voltage drop is $\Delta V = Z_{eq} \cdot I_{EM}$
Where $I_{EM}(\omega, V_{EM})$

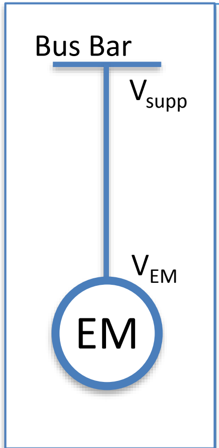
Assumption for a **"conservative"** approach:

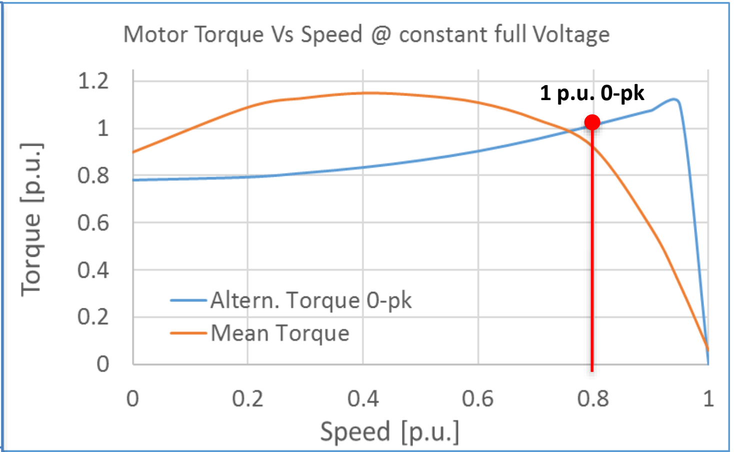
- Short circuit power → Assumed infinite $Z_{sc} = 0$
- MV Power Cables → Assumed $Z_{pc} = 0$
- Step-Down Transformer → $Z_{tr} = 9\%$ (proj. Value)

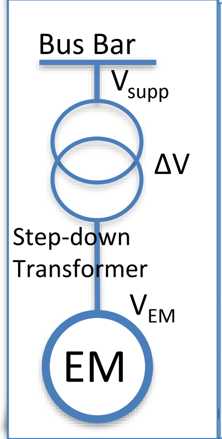
So what is $Z_{eq} = Z_{sc} + Z_{PC} + Z_{TR}$?

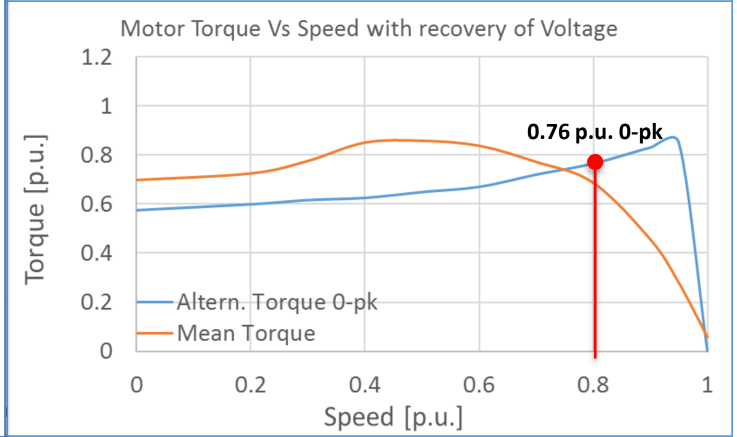
Due to uncertainty on network short circuit power and power cables, motor voltage drop is evaluated with step-down transformer contribution only, so $Z_{eq} = Z_{TR}$

Analysis of the Problem









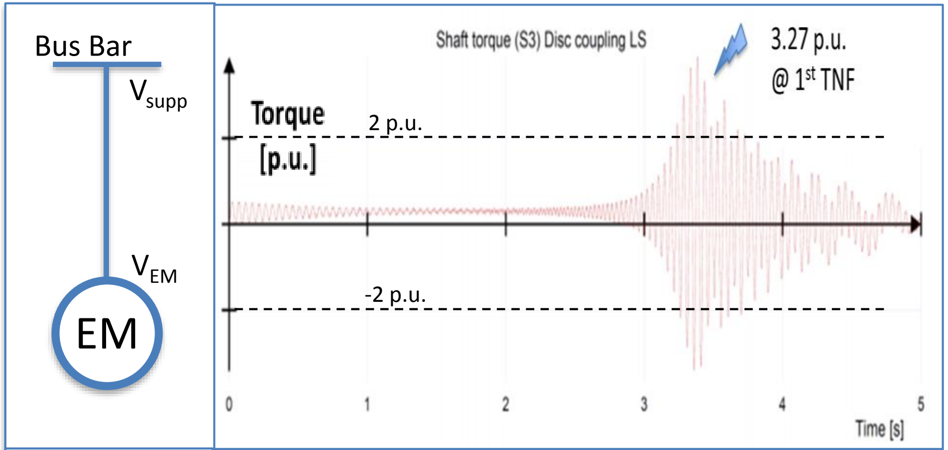
$$Torque_{EM} \propto (Voltage_{EM})^2$$

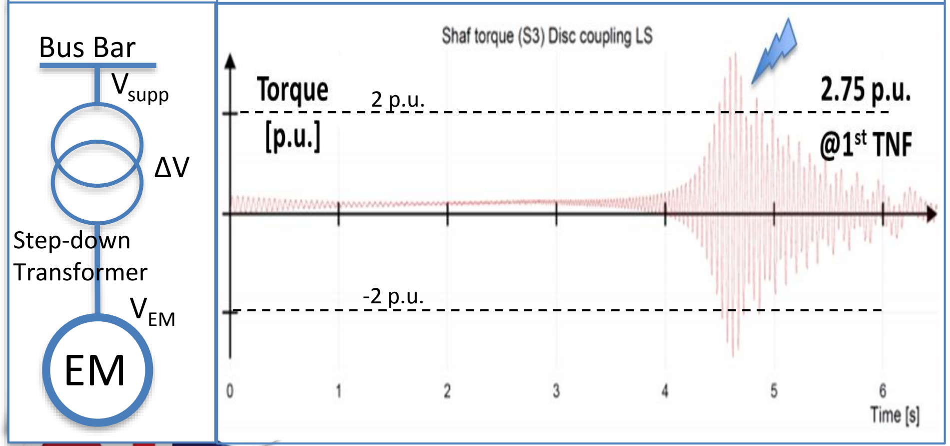
Canonical approach results in 1 p.u. 0-pk of alternating torque exciting 1st TNF, while with some smart considerations (in this case the effect of voltage drop due to step-down transformer) the resultant alternating torque is 0.76 p.u. 0-pk.

- 24 % of Alternating Excitation toque @ 1st TNF

And what about torsional mechanical response?

Analysis of the Problem





And what about torsional mechanical response?

Canonical approach: 3.27 p.u. 0-pk

More accurate approach: 2.75 p.u. 0-pk

- 16 % of Alternating Resultant toque @ 1st TNF

LCF Analysis for Number of Start-up Evaluation

Number of start-up increases from about 1400 to 5000 times

Conclusion and Recommendations

- In such kind of application the startup could be more critical than the short circuit event because of torsional frequency is always crossed and could become the main driver for the sizing of the shaft line.

- It is demonstrated how some simple considerations on how the motor is fed and behave in the reality should be a key point for the sizing of the shaft line.

- It was evident that, with the canonical approach, the fatigue analysis predicted 1400 number of train startup, while with this more accurate approach the numbers of train startup are around 5000.

Bear in mind that for this project, with the target of 5000 startup, the canonical approach would lead to an oversize of the shaft-line.

Field test results are currently not available but further comparisons between simulation results and field measures will take place later.

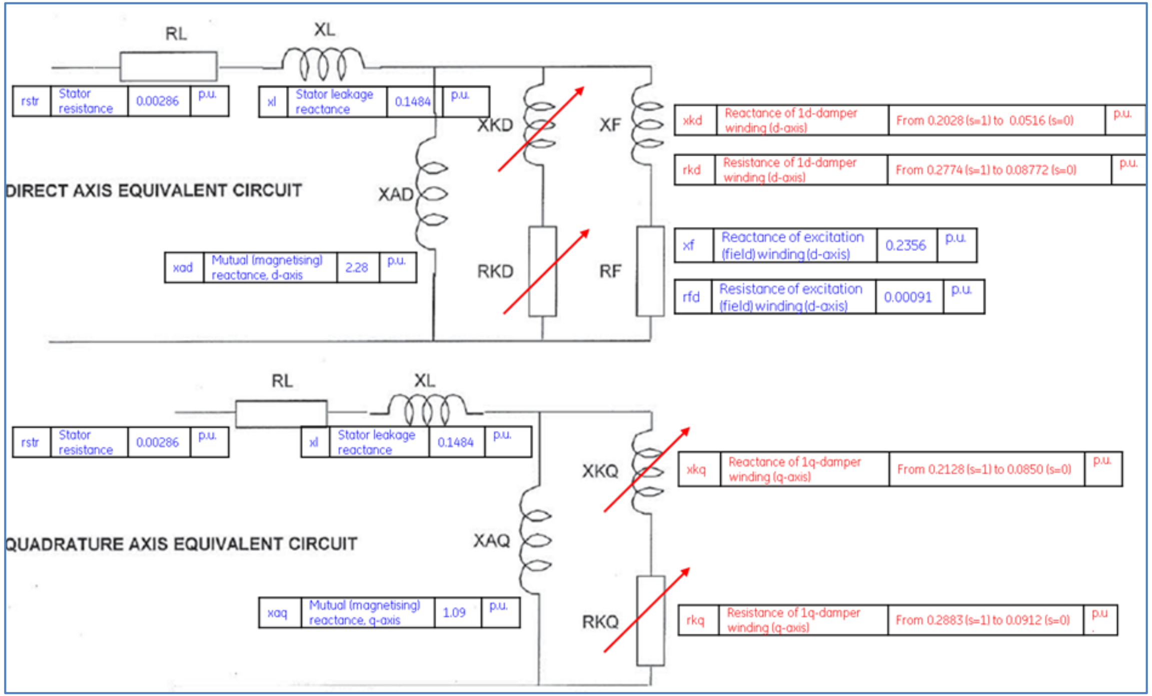
Back Up

DETAILS OF MOTOR CIRCUIT FOR STARTUP

The Synchronous motor started direct on line as the same behaviors of an Induction motor.

Then the model for Asynchronous startup needs 12 circuit parameters that are all constant in speed (frequency) apart of damper circuits rkd, xkd, rkq and xkq that varying with the speed/slip.

Where slip is the difference between the stator rotating field (at network frequency) and the speed of the rotor that it is accelerating. So, slip varies from 1 to 0

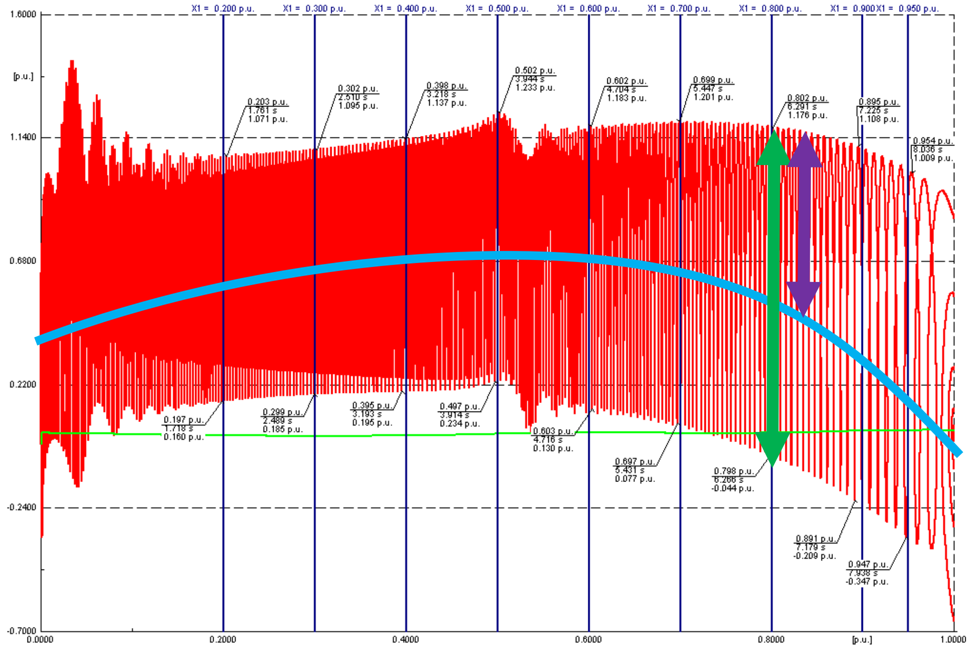


AIR-GAP TORQUE: “ALTERNATING TORQUE” AND “MEAN TORQUE”

During the Direct on Line start-up of a synchronous motor, the resulting air gap torque contain a pulsating component respect to the mean torque value.

In this way the motor air-gap torque during the start-up (in **red** in the image) is composed by:

- **Mean torque**: **blue line**
- **Alternating torque**: is superimposed the mean torque with a frequency two times the slip frequency and the amplitude (peak-to-pack) is represented with the **green arrow.**



The amplitude of the Alternating torque can be express as 0-peak value respect the mean torque (**blue line**):

- **ALTERNATING TORQUE 0-pk**: **violet arrow**