A tool to optimize motor management: Benchmarking EcoStruxure Motor Management Design with ETAP

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Executive summary

In the engineering sphere, there are several expert software for the simulation of power systems. However, these software solutions are not always easy for non-experts to use and often require specialized training. This paper analyzes the capabilities of the EcoStruxure Motor Management Design (MMD) web application dedicated to power systems with motor applications. It has a simple and intuitive interface for the average user, with a holistic approach to analysis. The paper provides a description of the MMD calculation methods as well as a comparison of the results with ETAP, one of the references among experts.

Introduction

Motor starting, power quality, and short circuit calculations are some of the key studies conducted for the successful integration of large motors into an electrical system, as well as to ensure that financial and mechanical expectations are met.

Computer simulation is the most efficient means of conducting this kind of analysis. The ability to study a system's reactions in various situations makes it possible to design more reliable systems and avoid common issues. Currently, such analyses are handled exclusively by technical experts using dedicated software and can be time consuming and labor intensive.

In this paper, the authors examine the various calculations integrated in the EcoStruxure Motor Management Design (MMD) web application dedicated to the analyses of motor applications in power systems. The MMD application is benchmarked against ETAP, a reference software in the field, and its accuracy is evaluated. The aim is to provide a reference for comparison and to demonstrate that most power system studies around motors can be handled in a relatively simple yet efficient way. This extends the possibilities for analysis and optimization, even by non-experts, in an cost-efficient manner. In the early project phase, when such calculations need to be run multiple times to compare scenarios of power system versus motor, the ease of performing the analyses and the holistic approach integrated in the application make it possible to design better systems with significantly less effort. This paper also addresses the accuracy of the provided calculations.

Motor starting in industrial systems

Generally, in motor application analyses, we are interested in the following characteristics:

- Feasibility of the motor start from a mechanical standpoint
- Electric stress on the system related to the start and operation of the motor
- Energy consumption of the motor application

Electric stress can present in several ways:

- Short circuit current contribution of the motor, affecting the busbar and protection equipment size
- Voltage drops during start, impacting the parallel loads on the busbar
- Harmonic disturbances, reducing the quality of energy and increasing losses in circuit components

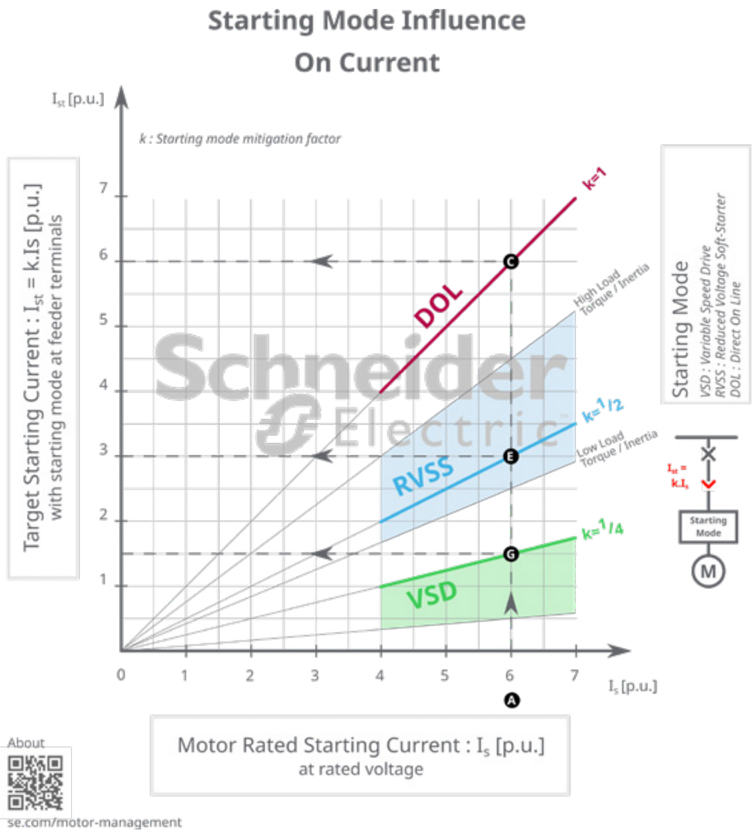
These issues may vary depending on the motor starting mode as multiple pieces of equipment can be resized or added to address them.

Figure 1

The impact of starting mode on inrush current. Direct online (DOL), soft starter (RVSS), variable speed drive (VSD)

Reference:
[How to estimate electrical network stress during large motor starting in pre-design phase]

As an example, the motor starting current is dependent on the starting mode ***(Figure 1)***



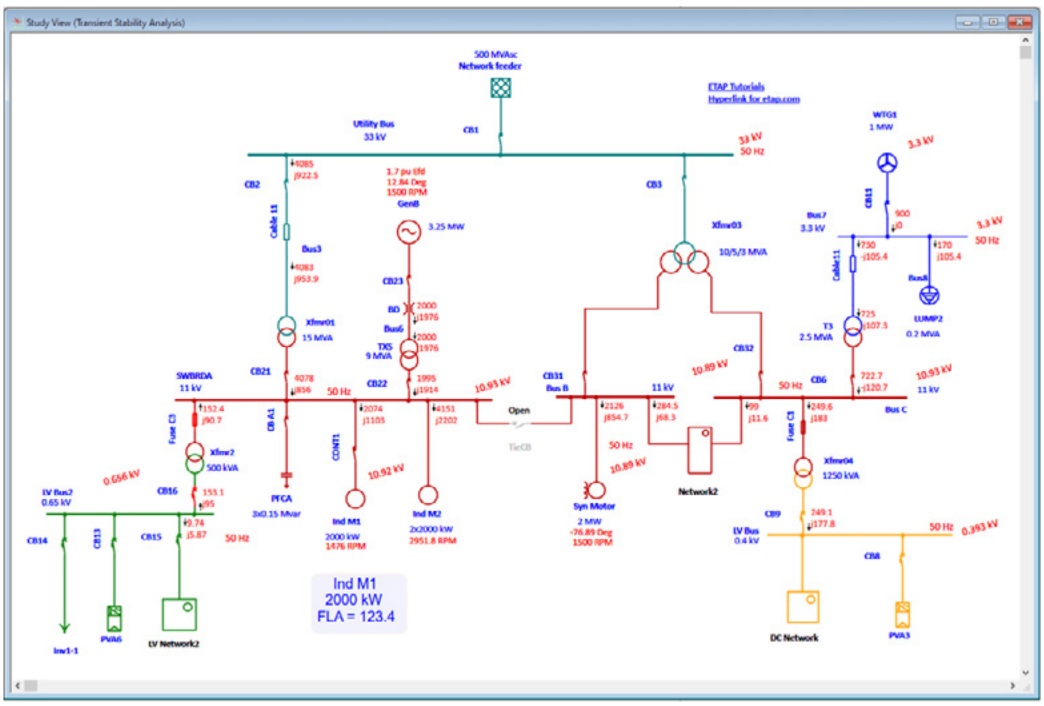
ETAP software presentation

ETAP® is a leading software platform for electrical power systems modeling and simulation, optimizing customer electricity power systems based on their digital twin equivalents.

Electrical Transient Analyzer Program (product of ETAP®) is an electrical network modeling and simulation software tool used by power systems engineers to analyze electrical power system, dynamics, transients, and protection.

Figure 2

ETAP diagram screenshot



ETAP facilitates the simulation and control of wide AC and DC networks with multiple elements. The software includes many modules that extend design capabilities by allowing the design of circuit protection, cable sizing, motor starting simulation, or system stability evaluation[1].

Since we are interested in motor related calculations, the following modules are used to provide a comparative analysis:

- **Short circuit analysis** – performs fault current calculations with the ability to automatically compare obtained values with the short circuit current ratings
- **Harmonic analysis** – modeling harmonic current and voltage sources to identify problems related to harmonics, reduce unwanted triggers, design and test filters, and report disturbances in voltage and current harmonic limits
- **Transient stability analysis** – to model and analyze power system dynamics and transients

EcoStruxure Motor Management Design

EcoStruxure Motor Management Design (MMD)[2] is a web application for analyzing motor integration in industrial power systems. The application uses simplified electrical models to facilitate the analysis and significantly reduces the time required for such analysis. Unlike ETAP, MMD does not have the option to create extended customized circuits. Therefore, it uses a predefined single load bus radial diagram.

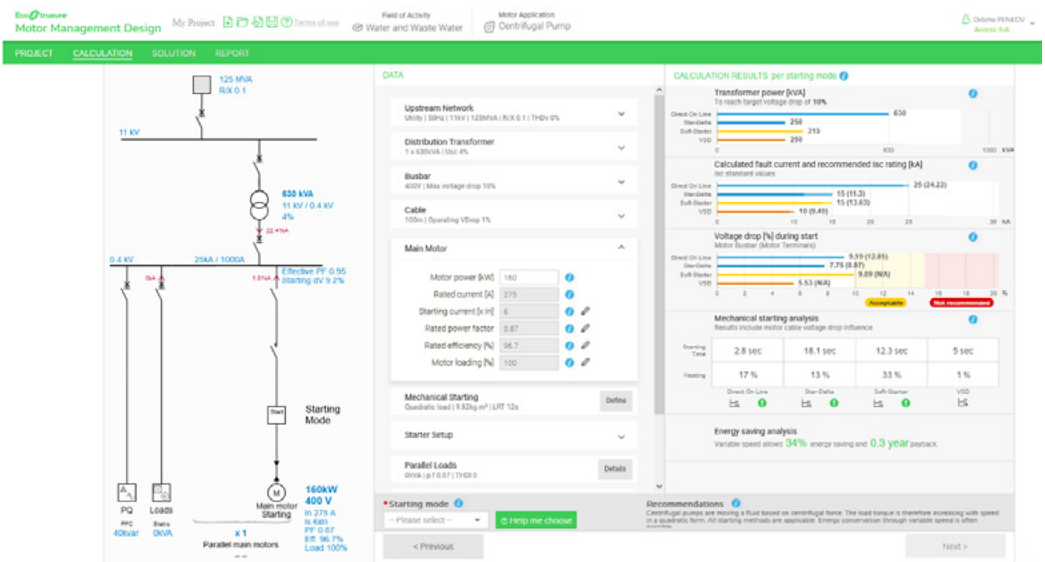


Figure 3

MMD layout of the calculation part

[1] https://etap.com/packages/

[2] https://ecostruxure-motor-management.se.app/design

The functionality of the application includes the calculation of the following parameters:

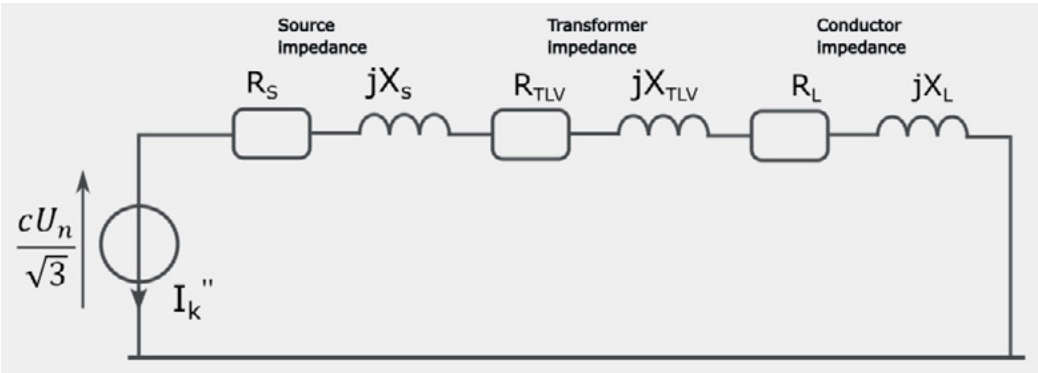
- **Transformer or generator sizing** – proposing transformer or generator size to maintain the voltage drop during start under the set limit and to supply all indicated loads respecting the engineering practices and margins
- **3-phase symmetrical short circuit currents** – including transformer and motor contribution to fault
- **Starting voltage drop** – considering parallel loads and motor starting current
- **Mechanical starting analysis** – calculating starting time and heating during start
- **Power quality analysis** – calculating voltage and current harmonic distortion when using a frequency converter; sizing the active filter; calculating harmonic distortion on the feeder bus and compliance to the IEEE 519 standard
- **Energy savings analysis** – calculating energy savings and investment payback on the use of a VSD instead of a constant speed with flow control for pumps and fans
- **Sizing and selection of suitable equipment** – for the calculated system

Comparison of short circuit current analysis

ETAP and MMD both use the IEC 60909 standard for short circuit analysis. This standard is based on the introduction of an equivalent voltage source at the short circuit location. The equivalent voltage source is the only active voltage of the system. All network feeders, synchronous and asynchronous machines are replaced by their internal impedances.

Figure 4

Equivalent circuit diagram for utility-fed fault



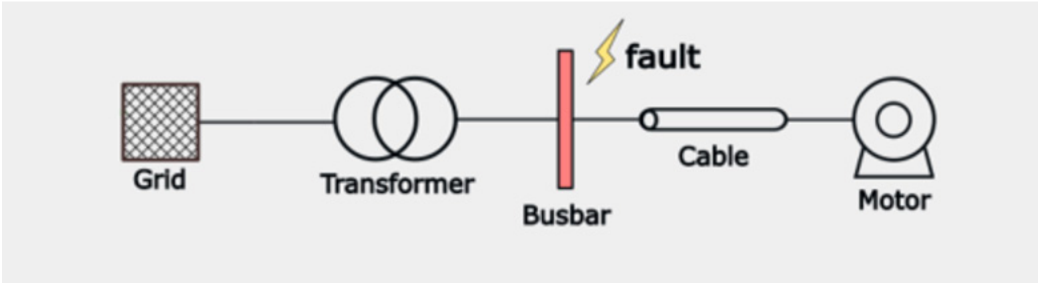
3-phase initial symmetrical short circuit current is calculated by using voltage source $cU_n\sqrt{3}$ at the short circuit location, short circuit impedance $Z_k=|R_{total}+ jX_{total}|$ and voltage correction coefficient c = 1,1.

$$I''_k = \frac{c \cdot U_n}{\sqrt{3} \cdot Z_k}$$

Utility-powered system analysis

Figure 5

Short circuit analysis case study



For a simple comparison, a radial circuit single-transformer power supply is used as a case study.

The IEC 60909 standard gives the following impedance correction to be applied to the transformer impedance:

Table 1

Short circuit analysis case studies with utility-powered circuit

Utility-powered systems analysis										
	Utility		Transformer			Motor				
№	V	S_{sc}	Number	U_{sc}	Power	Voltage	Number	P	LRC	cos φ
	kV	%		%	MVA	kV		MW	XI_n	%
1	34.5	640	1	7	10	3.3	1	2.5	6.5	93
2	34.5	640	1	10	15	3.3	4	3.3	6.5	93
3	220	720	2	10	15	11	7	5	6.5	93
4	11	640	1	8.3	10	3.3	3	0.8	7	92
5	11	640	1	8.3	10	3.3	3	0.8	7	92

$$K_T=0.95 \frac{c_{max}}{1+0.6 \cdot x_T}$$

X_T – Transformer impedance

K_T – Correction coefficient

$$c_{max} = 1.1$$

Transformer impedance:

$$Z_{Transformer} = K_T \cdot Z_T$$

We assume that the short circuit occurs on the busbar supplying the motor ***(Figure 5)***. The parameters of the case studies are presented in ***Table 1***.

The results in ***Table 2*** show that the transformer fault contribution in MMD is slightly higher than the one obtained by the ETAP software.

The results are compared in relative or absolute values. The following formulas are used for that:

$$Absolute\ error = Value_{ETAP} - Value_{MMD}$$

$$Relative\ error = \frac{Value_{ETAP} - Value_{MMD}}{Value_{ETAP}} \cdot 100\%$$

Table 2

Short circuit analysis results

Utility-powered case studies results									
	ETAP			MMD			Error		
№	Motor contribution	*Transfo I_{sc}*	*Total I_{sc}*	Motor contribution	*Transfo I_{Tsc}*	*Total I_{sc}*	*Motor I_{sc} error*	*Total I_{Tsc} error*	Total current error
	kA	kA	kA	kA	kA	kA	%	%	%
1	3.58	22.00	25.6	3.58	22.54	26	0	-2.45	-1.56
2	2.16	23.22	31.8	2.16	23.4	32	0	-0.80	-0.63
3	2.13	6.00	26.9	2.13	6.12	27	0	-2.03	-0.27
4	1.25	19.19	22.9	1.25	19.44	23	0	-1.31	-0.34
5	1.07	19.19	22.4	1.07	19.44	23	0	-1.31	-2.73

The reason of higher short-circuit current with MMD compared to ETAP in utility-cases is the introduction of a more pessimistic transformer impedance correction coefficient K_T in MMD. Limited at 1.00, the impedance is equal or lower corrected and the fault current is maximized. This ensures that even if the case is remodeled in ETAP as part of a more extended analysis, the basic results will be compliant.

The calculation of the motor short circuit current contribution is the same for ETAP and MMD because the corrections required in accordance with the IEC60909 standard are simple and straightforward. Therefore, we will not compare these values in the following examples.

Generator-powered system analysis

In the case of a generator supply, its impedance is calculated according to the formula:

$$Z_{KG} = Z_G \cdot K_G$$

$$Z_G = R_G + i \cdot X_d''$$

Where K_G is the impedance correction factor:

$$K_G = \frac{c}{1 + x_d'' \cdot \sin\varphi_{rG}}$$

The case studies for generator-fed systems are given in *Table 3*:

Table 3

Generator-powered system case studies

Utility-powered case studies results							
№	Upstream voltage	Number of generators	Apparent power	Power factor	Xd"	Transformer Usc	Transformer power
	kV		MVA	pu	pu	%	MVA
1	34.5	1	20	0.8	0.13	8.35	10
2	34.5	2	25	0.75	0.19	8.35	10
3	34.5	3	10	0.85	0.16	8.35	10
4	11	1	23	0.87	0.19	10	15
5	11	1	5	0.87	0.185	8	10

After performing the short circuit current calculations, results obtained in MMD are 1-3% higher than in ETAP *(Table 4)*. As for the utility / transformer above, the calculations have assumed a slightly more pessimistic correction of the impedance in order to guarantee the results if the case is transferred to ETAP.

Table 4

Generator-powered system analysis results

Generator-powered cases			
№	ETAP	MMD	Error
	Calculated fault current	Calculated fault current	Transformer currents error
	kA	kA	%
1	106.19	107.43	-1.17%
2	4.8	4.78	0.42%
3	4.206	4.24	-0.81%
4	106.61	106.74	-0.12%
5	34.085	35.12	-3.04%

Comparison of motor starting analyses

Motor starting is a complex dynamic process in which the values of current, voltage, speed, and torque vary non-linearly over time. This process can be described by dynamic or static models.

A static model only defines the voltage drop in a worst case scenario by using motor nameplate data, and does not determine parameters such as starting capability or starting time.

The dynamic model gives more information about the starting capability and provides starting curves. However, it requires the dynamic characteristics of the motor and the load.

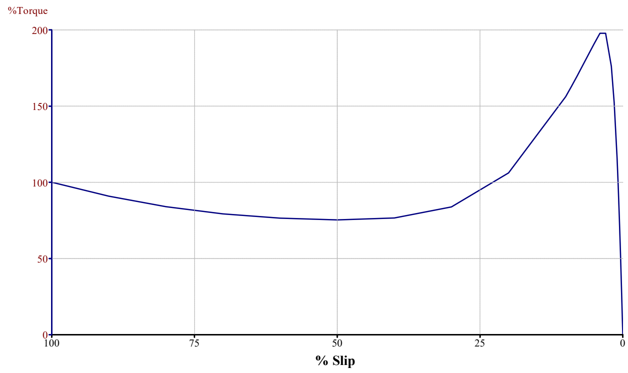
MMD combines static and dynamic types of modeling, using nameplate data to calculate the worst-case voltage drop and the motor-load curves to calculate the starting time, starting capability, and heating.

Motor modeling

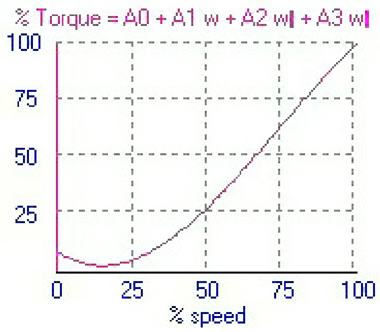
To compare the starting analysis, the Transient stability module in ETAP is used. For the comparison, it is necessary to define the motor, load, and generator dynamic models.

Motor and load parameters selected from the ETAP library implemented to MMD:

Figure 6
ETAP library motor and load curves

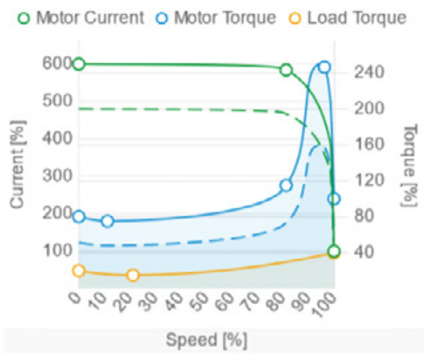


CKT model

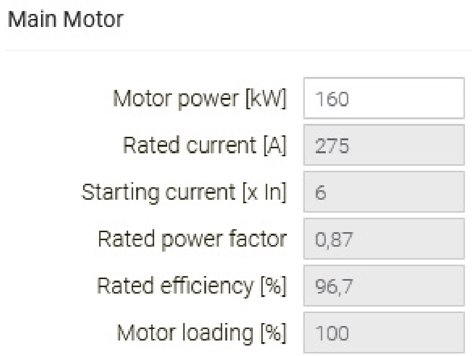


Load curve

Figure 7
Motor model definition in MMD



MMD motor dynamic model presentation

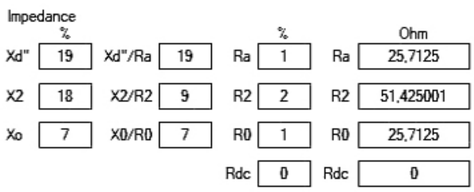


Example MMD motor input data

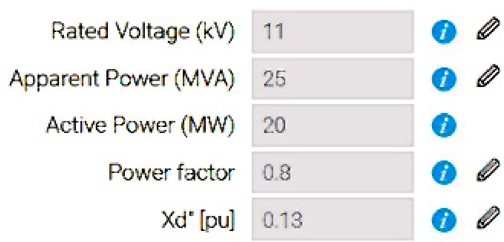
Generator model

ETAP generator models require a detailed impedance dataset *(Figure 8)*, where MMD only needs sub-transient reactance - Xd" value. The generator model was defined by the typical values proposed by ETAP. These values are taken as a reference and used in MMD.

Figure 8
Differences between required generator input data



ETAP



MMD

In the case of a generator-powered system, the MMD model does not include the excitation of the generator and the governor control. Consequently, the results of the voltage drop and motor starting time are expected to be more pessimistic.

Generator excitation system

To analyze the generator supplied circuits in the Transient Stability module in ETAP, it is necessary to select the excitation system. For this purpose, a widely used AC8B system is chosen. *(Annex A, Figure 17 and Figure 18)*

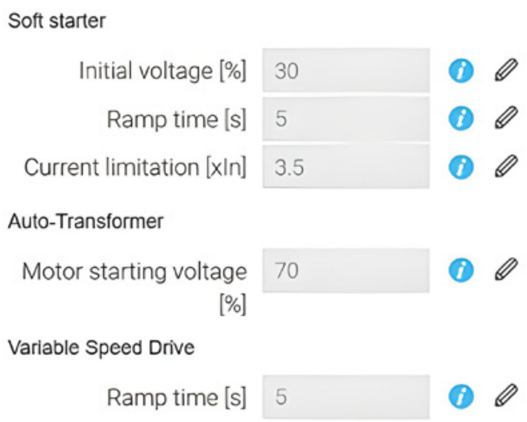
Starting mode

MMD includes five types of starting: Direct online (DOL), autotransformer (in MV), star/ delta (in LV), soft starter, and variable frequency drive (VFD).

With the exception of starting with a VFD, the other methods are easily modelled with ETAP. ETAP uses U/f as the control method for motor drives, while MMD assumes vector control. This difference in starter settings makes it impossible to compare starting with a variable frequency drive.

Figure 9

MMD motor starter window

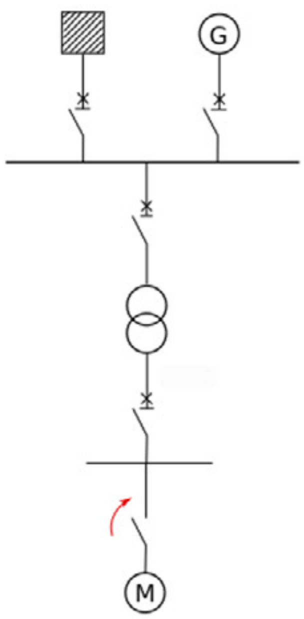


Case study presentation

The case study data is as follows:

Figure 10

Voltage drop analysis case study



Case studies for this analysis are shown in *Table 7 in Appendix A*.

Voltage drop analysis

The difference in calculations is presented in absolute values.

Figure 11

Absolute error of voltage drop comparison analysis

	1 case	2 case	3 case	4 case	5 case	6 case	7 case	8 case	9 case	10 case	11 case	12 case
Dol	-1.9%	3.0%	-1.9%	0.7%	-1.8%	-1.9%	-1.2%	-4.4%	-0.6%	-0.9%	-0.1%	1.1%
Autotransform/YD	-2.0%	-0.3%	-2.0%	-0.6%	-2.0%	-2.2%	-1.3%	-3.3%	-0.4%	-2.0%	1.3%	-0.3%
Soft starter	-1.6%	-11.7	-1.9%	-6.7%	-1.3%	0.0%	1.0%	-2.2%	-3.6%	-0.2%	-7.9%	-6.3%

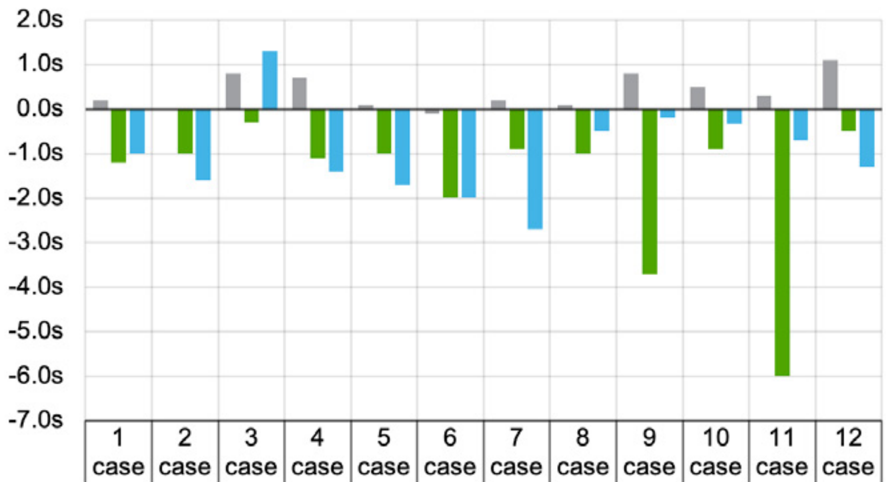
The results show that the MMD application has a very constant excess of estimation of the voltage drop, thus securing the feasibility from this standpoint. In fact, if it were underestimated, it may result in wrong conclusions and recommendations. Therefore, an excess in the calculated voltage drop means that if the analyses conclude about the convenience of a starting mode, it will also be confirmed with ETAP and can be further optimized, if necessary. In the opposite case, if a desired starting mode is not confirmed with MMD, it means that a further, more detailed calculation with ETAP may lead to a different conclusion. In such case, the analyses are made by an experienced expert and probably require additional data.

Starting time comparison

Starting time is compared in absolute values, as was the voltage drop. We can again see an excess of the calculation of the starting time with MMD. Similar conclusions for the voltage drop can also be drawn.

Figure 12

Absolute error of starting time calculations



	1 case	2 case	3 case	4 case	5 case	6 case	7 case	8 case	9 case	10 case	11 case	12 case
DOL	0.2s	0.0s	0.8s	0.7s	0.1s	-0.1s	0.2s	0.1s	0.8s	0.5s	0.3s	1.1s
Autotransform/YD	-1.2s	-1.0s	-0.3s	-1.1s	-1.0s	-2.0s	-0.9s	-1.0s	-3.7s	-0.9s	-6.0s	-0.5s
Soft starter	-1.0s	-1.6s	1.3s	-1.4s	-1.7s	-2.0s	-2.7s	-0.5s	-0.2s	-0.3s	-0.7s	-1.3s

Power quality analysis

With the widespread use of non-linear loads, harmonic analysis is one of the essential components of application design. Therefore, harmonic analysis and filter sizing are increasingly being implemented in all modern computer-aided design programs.

Total harmonic distortion (THD) is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the quadratic sum of all harmonic components to the fundamental:

$$THD_i = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \qquad THD_u = \frac{\sqrt{\sum_{h=2}^{\infty} U_h^2}}{U_1}$$

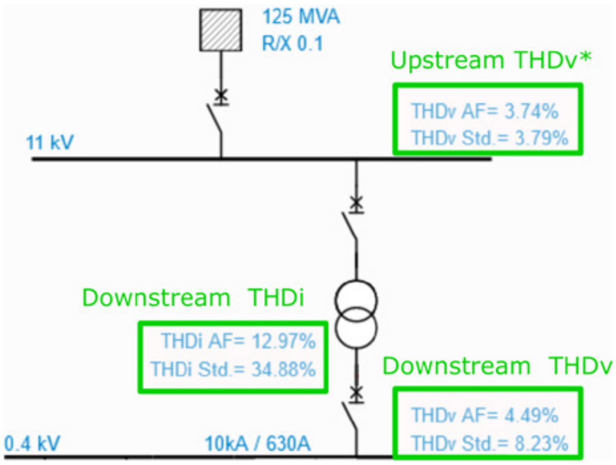
Harmonic analysis in ETAP is implemented through the Harmonics module which allows harmonic load flow and frequency scanning.

MMD automatically calculates the total harmonic voltage distortion THDv if the main motor or other parallel running motors use a variable speed drive. The user can also specify predefined mains harmonics. The result can be seen in the interactive window. *(Figure 13)*

Figure 13

Example of THDv calculation in MMD

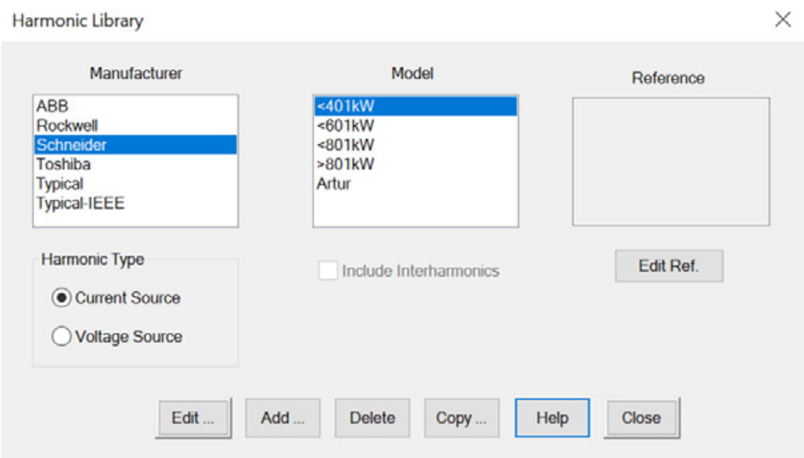
Std = before filtering with standard 6-pulse drive
AF = after filtering



To analyze the harmonic load flow in ETAP, it is necessary to specify the sources of distortion in the circuit. In our case, this is the VSD. When selecting a distortion source, we have the option of choosing a harmonic spectrum from the ETAP library or creating our own spectrum. *(Figure 14)*

Figure 14

ETAP harmonic library



MMD uses typical Schneider Electric VSD harmonic spectrums, a function of the VSD power. *(Table 5)*

Table 5

Approximate values of harmonic current distortion and spectrum of Schneider Electric drives

VSD power	<201 kW	<401 kW	<601 kW	<801 kW	>801 kW
$THDi_{VSD}$	42%	40%	36%	33%	30%
Hcf_{5}	90	90	92	92	92
Hcf_{7}	35	35	31	31	31
Hcf_{11}	18	18	20	20	20
Hcf_{13}	12	12	10	10	10
Hcf_{17}	10	10	7	7	7
Hcf_{19}	8	8	5	5	5
Hcf_{23}	8	8	3	3	3
Hcf_{25}	6	6	3	3	3

The power supply scheme in *Figure 15* is a radial network created in ETAP to reproduce the network used in MMD. The case studies for comparative analysis are created by varying the load and power values of the motors and distortion sources in the form of VSDs. *(Appendix B, Table 8)*

Figure 15

Power quality case study principle electrical architecture

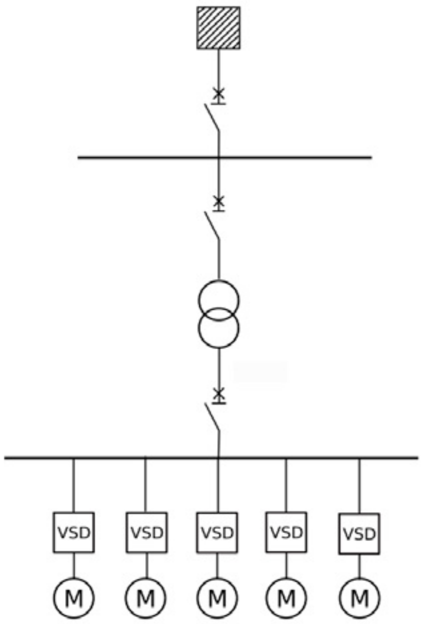
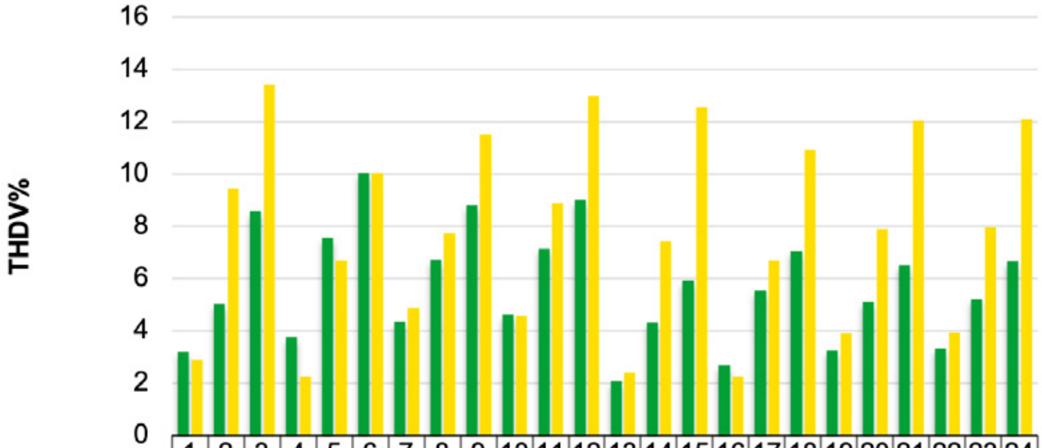


Figure 16

Power quality case study results



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MMD %	3	5	9	4	8	10	4	7	9	5	7	9	2	4	6	3	6	7	3	5	7	3	5	7
ETAP %	3	9	13	2	7	10	5	8	12	5	9	13	2	7	13	2	7	11	4	8	12	4	8	12

The results of the comparative analysis are shown in ***Figure 16***. It can be observed that the difference between the results increases with the increase of the distortion sources connected in parallel. This phenomenon can be explained by the summation exponent coefficient.

Harmonic summation coefficient α is used to express the phase shift of harmonics from different sources, according to IEC 61000-3-14:

$$D = \sqrt[\alpha]{\sum_i D_i^\alpha}$$

When the harmonics are strictly in phase, they add up to themselves. However, when the harmonics are in phase shift, some of them can subtract one from another, reducing the THD. Thus, this coefficient makes it possible to represent a case of harmonics sum when harmonics are not in phase. In addition, such a sum indirectly considers that during operation, not all motors are loaded the same or some may not be operating.

Table 6

Summation exponent for harmonics

Harmonic order	α
h < 5	1
$5 \le h \le 10$	1.4
$h > 10$	2

The summation factor varies ($1 \le \alpha \le 2$). For harmonic calculations in MMD, the α coefficient is assumed to be 1.4. The coefficient used in ETAP is equal to 1. The coefficient difference in the programs can explain the increase in the difference between results with the increase of sources to sum.

Conclusion

A comparative analysis of MMD and ETAP shows that all calculations are made with an acceptable deviation and can be reliably used in real projects. It also indicates that the motor management design calculation methods are more pessimistic, thus avoiding underestimation. These results can be considered entirely satisfactory, as even when comparing complex models, we obtained a small deviation in the results.

We can conclude that MMD can be advantageously used instead of complex simulation software in the context of a limited network.

Appendix A: Motor starting analysis comparison case studies

Table 7

Motor starting analysis case studies

	Supply			Transformer			Motor				
Nº	Utility	Generator kV/MVA	Xd "	Power MVA	Usc	Voltage kV	Power kW	LRC pu	Eff %	PF %	ETAP CKT Model
1	22.9 kV/ 250 MVA	-	-	2.5	6.25	0.66	300	6.25	95.63	85.24	LV100HP2P
2	-	33 kV/ 50 MVA	19	50	12.5	11	5000	6.61	92.64	85.41	LV10HP2P
3	22.9 kV/ 125 MVA	-	-	3	6.25	0.66	300	6.43	94.84	88.63	LV150HP2P
4	-	33 kV/ 75 MVA	19	30	12.5	11	5000	6.56	96.95	90.38	LV200HP2P
5	22.9 kV/ 125 MVA	-	-	2	6.25	0.66	300	5.77	96.14	79.53	LV20HP2P
6	33 kV/ 375 MVA	-	-	30	12.5	11	5000	6.44	96.65	87.65	LV250HP2P
7	-	33 kV/ 25 MVA	19	1.8	6.25	0.66	300	6.44	96.65	87.65	LV250HP2P
8	33 kV/ 375 MVA	-	-	20	10	11	5000	5.99	90.7	83.63	LV50HP2P
9	-	22.9 kV/ 15 MVA	19	3	6.25	0.66	300	6.39	95	88.43	LV75HP2P
10	33 kV/ 375 MVA	-		15	10	11	5000	6.25	95.64	85.24	LV100HP2P
11	-	22.9 kV/ 5 MVA	19	2	6.25	0.66	300	6.61	92.64	85.41	LV10HP2P
12	-	22.9 kV/ 75 MVA	19	50	12.5	11	5000	6.43	96.3	88.63	LV150HP2P

Figure 17

IEEE type AC8B exciter and AVR system representation

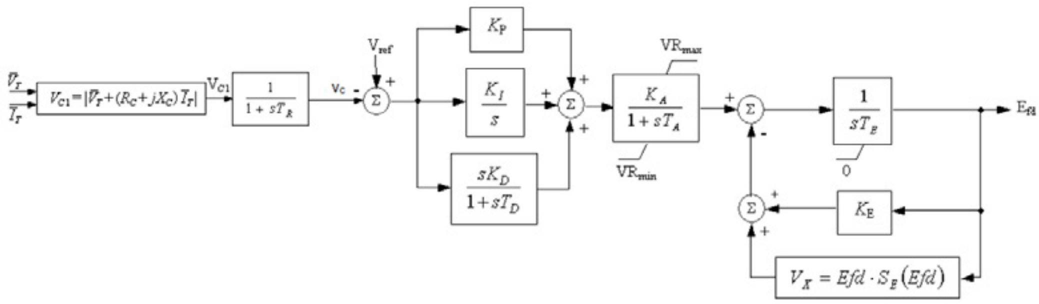
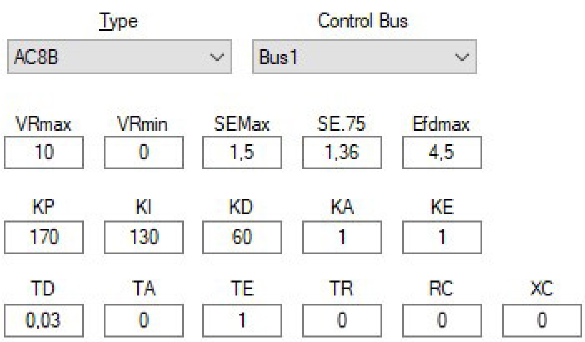


Figure 18

AC8B excitation system parameters in ETAP



Appendix B: Power quality

Table 8

Power quality analysis case studies

Case studies and harmonic pollution								
Case	Upstream Psc	Motor power	VSD power	Loading	# Motors	Transformer power	Busbar calculated THDv	
							MMD	ETAP
Nº	MVA	kW	kW	%	number	kVA	%	%
1	125	250	250	100%	1	1600	3.2	2.9
2	125	250	250	100%	3	1600	5.02	9.44
3	125	250	250	100%	5	1600	8.57	13.43
4	125	250	355	70%	1	1600	3.77	2.28
5	125	250	355	70%	3	1600	7.57	6.69
6	125	250	355	70%	5	1600	10.05	10.04
7	125	400	400	100%	1	1600	4.36	4.9
8	125	400	400	100%	2	1600	6.71	7.73
9	125	400	400	100%	3	1600	8.79	11.5
10	125	400	500	80%	1	1600	4.64	4.57
11	125	400	500	80%	2	1600	7.15	8.9
12	125	400	500	80%	3	1600	9	13.01
13	125	250	250	100%	1	2500	2.07	2.42
14	125	250	250	100%	3	2500	4.32	7.42
15	125	250	250	100%	5	2500	5.92	12.56
16	125	250	355	70%	1	2500	2.68	2.27
17	125	250	355	70%	3	2500	5.53	6.68
18	125	250	355	70%	5	2500	7.05	10.91
19	125	400	400	100%	1	2500	3.27	3.9
20	125	400	400	100%	2	2500	5.12	7.9
21	125	400	400	100%	3	2500	6.53	12.03
22	125	400	500	80%	1	2500	3.33	3.92
23	125	400	500	80%	2	2500	5.22	7.95
24	125	400	500	80%	3	2500	6.67	12.11

About the authors

Artur Almatov graduated in electrical engineering from Tashkent Polytechnic University, Uzbekistan. In 2022, he received his Master's degree from the University of Grenoble Alpes. He joined Schneider Electric as intern in 2021. He continues to work for the company as an energy systems engineer.

Jerome Guillet graduated in 2004 with a Master's degree in mechanical and industrial engineering from the Arts et Métiers ParisTech. He started his professional career in 2005 as a technical engineer at the electrolytic capacitors manufacturer, SICSAFCO. He joined Schneider Electric Power Quality as an R&D engineer in 2008. Since 2015, he has worked in the Motor Management Competency Center. He currently supports in the early stages of large motor projects and contributes to popularize motor knowledge with dedicated calculation tools and training.

Delcho Penkov graduated from the Technical University of Sofia, Bulgaria, in 2002 with a degree in engineering. In 2006, he obtained his PhD in electrical engineering from the Institut National Polytechnique in Grenoble, France. He started his career at Schneider Electric as a technical expert for transient analysis and simulation. He currently leads the Motor Management Competency Center for high-power motor applications. He has authored and co-authored several papers and patents for motor application-oriented equipment. He is a member of the IEEE.

Resources

[How to estimate electrical network stress during large motor starting in pre-design phase](#)
Blog post

5 steps for efficient motor management design
Blog post

LV or MV for large pumps and motor management in mining?
Blog post

Motor management design application
Tradeoff Tool 1

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