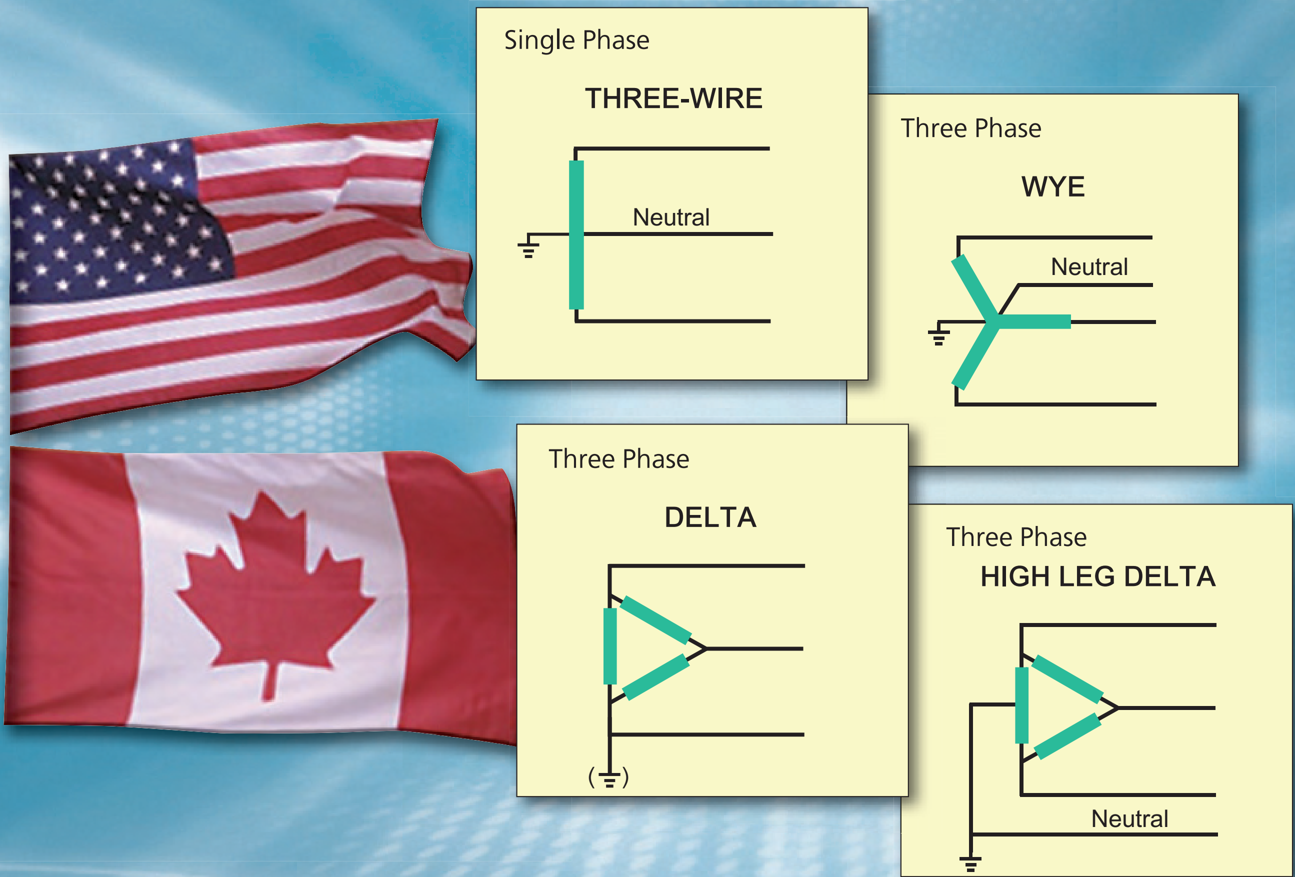
Export relevant voltage information and mains forms in North America



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Technical Paper

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MOELLER

We keep power under control.

An earlier compilation of the normal mains forms and conventional voltages in North America show a multitude of local variations. This is due to the historical structure, but also with the huge dimensions of the continent, the distances between energy resource locations and load centres and the high current demands and the individual needs of power suppliers. With such a multiplicity it is impossible to deal economically as well as technically. The standard ANSI[1] C84.1 has brought a large reduction in conventional voltages and is a clear example of the revising effects of standards. The standard had the task of coordinating the differing interests of the energy producers and distributors on the one side and the electricity consumer on the other side, e.g. by the determination of tolerances. Whereas the energy production, energy trading and distribution was in the past in one hand, today they are mostly the responsibility of various company groups each with their own business interests.

There are still today in America regional differences of energy production. The exporting supplier of machines or systems (OEM[2]) with associated electrical equipment should quickly and bindingly discuss the network conditions with the final system user. The mains system voltage as well as the mains system form have an influence on the selection and use of the switching and protection devices. Delta mains systems or unearthed star-delta mains systems exclude some modern, European solutions. Specialist as well as non-experts are dependant upon the correct voltage details.

Selection of the correct voltage in North America is not only too much for many holiday makers, but also with specialists there is often doubts with the exporting of machines and systems. This is due to the fact that different voltage details are often given *(Service Voltage or Utilization Voltage, Nominal System Voltage or Rated Voltage and finally the Motor Nameplate Voltage)*, that we do not differentiate in the IEC world. In the IEC world, from production to use, we talk about operting voltage and assume the compliance with the tolerance for voltage drop. In Germany the voltage is an electrical parameter that we do not need to think too much about.

This essay is concerned exclusively with low voltages in public and industrial mains systems and their supplied commercial and industrial equipment. It details extracts of important information for the project engineers of companies exporting to America. Binding information is detailed in „American National Standard for Electric Power Systems and Equipment – Voltage Ratings (60 Hertz), ANSI C84.1-2006" or for Canada the CSA[3] Standard „CAN-3-C235-83".

Service Voltage and Utilization Voltage

In this essay only the low voltage range is considered. In North America that includes all voltages with a value of up to 1000 V (Increased to 1200 V by ANSI C84.1-2006). Above 1000 V (1200 V) is called medium voltage and high voltage. Only AC voltages are considered that can also appear as AC systems. The rated frequency for all voltages is uniformly 60 Hz. All described voltages and tolerances are for continuous operation without consideration of short-time alterations due to switching processes or the start-up of large motors. Heavy or long start-up drives can lead in individual cases to the necessity for special starting types and conductor dimensions to maintain the specified tolerances.

Whereas in the IEC world we work with the uniform description operating voltage (comparable in America: *Nominal System Voltage* or *Rated Voltage*), in North America it is differentiated between differently named voltages in the distribution/ supply network and in the consumer system. The *Service Voltage* is the voltage in the supply network. Their tolerances must be especially maintained at the delivery points of the energy supply company´s conductors and the conductors of the end user. That is, house connection boxes *(point of connection, point of common coupling)*. The electricity supply company is responsible for the quality of this voltage. The actual *Service Voltage* is normally between 95 ... 105 % of it´s nominal voltage. When considering the voltage tolerance it must be taken into account that in large american states there are more spur conductor system instead of compact network mains systems that allow a higher supply safety and a higher voltage stability.

The *Utilization Voltage* is the voltage in the consumer´s mains system, especially the effective voltage at the connection point of the equipment. The *Utilization Voltage* can fluctuate in the worst case between 87 ... 106 % of the rated voltage. The difference between the minimum *Service Voltage* and the minimum *Utilization Voltage* is the permitted value of the *Voltage drop* inside the consumer system. The system operator and the electrical installer are responsible for the quality of this voltage by his correct dimensioning of the conductors. The permissable 5 % maximum voltage drop according to NEC[4] *(Feeder Circuit + Branch Circuit)* is normally divided between a voltage drop of 3 % up to the incomer *(Feeder Circuit)* and 2 % for the consumer installation *(Branch Circuit)*.

With the tolerance of both voltages we decide between an ideal level (Range A) and a still tolerable level (Range B). Voltages in the Range B should be limited in the frequency as well as the duration of their occurrance. There is however no binding specification for this limitation as well as for the occurrence of voltages outside Range B. The tolerances can be especially critical due to larger voltage drops or heavy load fluctuations in lightly interconnected networks with long spur connections.

With AC systems there can, as well as the tolerance of the voltage amplitude, appear a *Voltage Unbalance* between

1 ANSI = American National Standards Institute, Inc, *http://www.ansi.org/*
2 OEM = Original Equipment Manufacturer
3 CSA = Canadian Standards Association, *http://www.csa.org/*
4 NEC = National Electrical Code

the individual phases or the phases and a possibly existing neutral conductor. The voltage unbalance without load must not be more than 3 % according to ANSI C84.1. It could be considered with a derating factor for the motor capacity according to Appendix D of ANSI C84.1, that for example, a 3 % voltage unbalance is rated with 0.9. The voltage unbalance is determined:

Voltage unbalance [%] =

$$100 \times \frac{\text{(max. difference from the average voltage)}}{\text{(average voltage)}}$$

Example:
The measured voltage (phase to phase) is 230 V, 232 V and 225 V. The average is 229 V and the largest difference from the average is 4 V. In this example the voltage unbalance is 1.75 %.

	Effect of difference of operating voltage U_e from the rated voltage of the motor	
	Operation at 90 % U_n	Operation at 110 % U_n
Start and max. torque	approx. - 20 %	approx. + 20 %
Slip in %	increasing	decreasing
Full load revs	slight decrease	slight increase
Inrush current	- 10 %	+ 10 %
Full load current	Differing, according to motor size and design	Differing, according to motor size and design
No load current	decreasing (~ 10 to 30 %)	increasing (~ 10 to 30 %)
Temperate rise in motor	Differing, according to motor size and design	Differing, according to motor size and design
Full load efficiency	Differing, according to motor size and design	Differing, according to motor size and design
Full load power factor	slight increase	slight decrease
Magnetically caused noise	slight decrease	slight increase

Table 1: General effects of differences of the operating voltage from the rated voltage for AC motors. Neither undervoltage nor overvoltage has an especially positive effect, therefore smallest possible tolerances should be strived for.

With motors, a voltage unbalance leads also to a current unbalance. Here the use of a device with IEC phase-failure sensitivity for the protection of the motor is especially attractive. **Table 1** shows the principle effect of differences of the actually connected operating voltage from the rated voltage for AC motors.

A survey of the EPRI [5] shows that most typical end consumers have daily voltage fluctuations of ≤ 3 %. At the same time more than 10 % of the end consumers has a voltage fluctuation of ≥ 7 % that can be outside *Range B* [1]. In 98 % of the network the voltage unbalance is ≤ 3 % and in 66 % of the network is ≤ 1 %.

The end consumer can, other than by energy awareness, have nearly no influence over the quality of the electrical supply. Load fluctuations, long supply cables and own power generation outside the influence of the electrical supply companies make voltage regulation, also for the supply companies, to a daily challenge. Frequent and longer differences should be reported to the electricity supply company so that they can have a better overview and can react to the fluctuations. The energy supply company have their expansion planning and regulation measures aggravated by ever changing targets. Private voltage regulation equipment in consumer systems with sensitive equipment is often necessary. The normal division in America into Service Voltage and Utilization Voltage is also very much a question of competence and responsibility for the quality of the voltages.

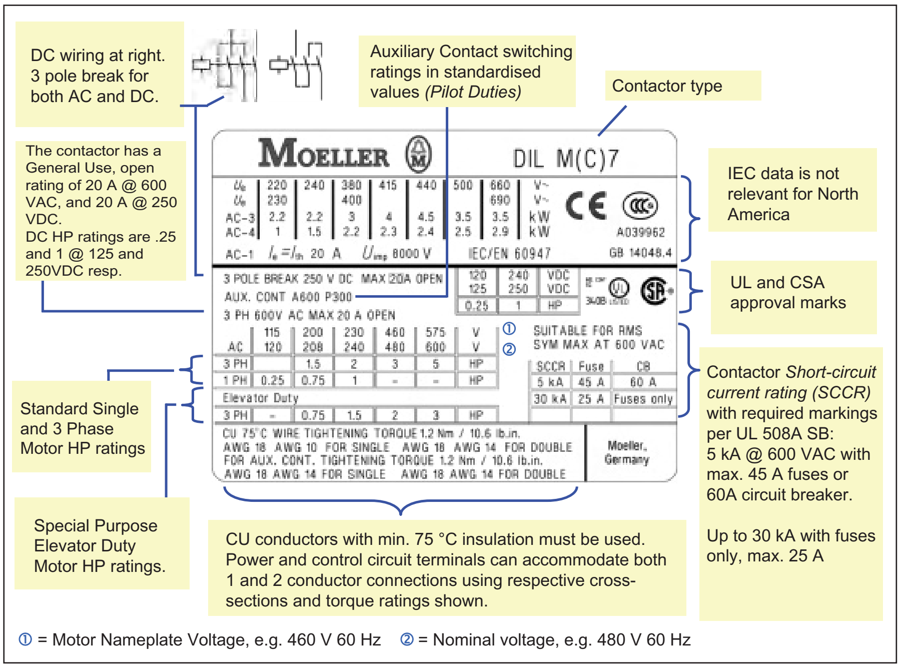
Nameplate Voltage

Also in North America it is normal that for motors and switching and protection devices for motors the operating voltage is given on the rating plate for which the equipment is designed. This operating voltage is with motors known as *Nameplate Voltage*. It is noticable and confusing that this voltage does not agree with the nominal mains voltage. The *Nameplate Voltage* is equal to the minimum service voltage, this means that the motor equiment is nearly never operated with the nominal voltage of the mains. Therefore the operating currents of the protection devices can be better determined and the permissable voltage tolerance can be better utilized. The catalogues of various switchgear manufacturers and the rating plates of switching and protection devices give inconsistantly either the *Nameplate Voltage* (simpler for the user) or the nominal system voltage (mains voltage). **Picture 1** shows a nameplate from a Moeller contactor. As well as the nominal mains voltage the Motor Nameplate Voltage is also given here. The power details correspond to the NEMA power of motors. The electrical testing of the switchgear is carried out with the higher nominal mains voltage = rated operating voltage, plus the specified tolerances. A degree of help with device selection is offered by the normal American NEMA sizes of the equipment and switchgear combinations. **Table 2** shows the tolerances of the described network voltages.

The *Utilization Voltage* (permissable voltage at the connection point of the equipment), according to **Table 3**, is not identical with the normal operating voltage of the motor (*Nameplate Voltages*), nor with NEMA[6] permissable voltage tolerances on the equipment. Especially with small and sensitive AC equipment

[5] EPRI = Electric Power Research Institute

[6] NEMA = National Electrical Manufacturers Association, *http://www.nema.org/*



Picture 1: Example of the voltage details for North America on the rating plate of a Moeller contactor. The nominal mains voltage and the motor Nameplate voltages are given.

	Range B Minimum	Range A Minimum	Nominal System Voltage	Range A Maximum	Range B Maximum
Utiliza-tion Voltage	87 %	90 %		104 %	105,8 %
	418 V	432 V	**480 V**	499 V	508 V
	85 % 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 % 101 102 103 104 105 106 %				
Service Voltage	92 %	95 %		105 %	105,8 %
	442 V	456 V	**480 V**	504 V	508 V

Table 2: Tolerances of Service Voltage and Utilization Voltage, with examples for the most important voltage in the USA, 480 V, 60 Hz.

Nominal-mains voltage *Rated voltage*	**Service Voltage**	**Utilization Voltage**		**Nameplate Voltage**	**NEMA Requirement**
		Range B	*Range A*	**Operating voltage of motor**	
Tolerance →	- 5 %, + 5 %	- 13 %, + 6 %	- 10 %, + 4 %		- 10 %, + 10 %
120 V	114 – 126 V	104.4 – 127.2 V	108 – 124.8 V	**115 V**	103.5 – 126.5 V
208 V	197.6 – 218.4 V	181 – 220.5 V	187.2 – 216.3 V	**200 V**	180 – 220 V
240 V	228 – 218.4 V	208.9 – 254.4 V	216 – 249.6 V	**230 V**	207 – 253 V
277 V	263.2 – 290.9 V	241 – 293.6 V	249.3 – 288 V	**–**	
480 V	456 – 504 V	417.6 – 508.8 V	432 – 499.2 V	**460 V**	414 – 506 V
Band width	10 %	19 %	14 %		20 %

Table 3: The most important nominal mains voltages and the allocated Nameplate Voltages (operating voltages) of the equipment. Also the tolerance band width and the permissable absolute voltage values are shown.

(electric razors, computers, etc.) wide range adapters are especially sensible. Often, uninteruptable power supplies (UPS) are necessary for data safety for computers and automation systems.

Note concerning the acceptance of European switchgear when exporting to North America:

By export motors are often used that are dimensioned in kW. The inspector may then recalculate the kW value into HP and then dimension the conductor using the current of the next largest standard HP motor. This method can lead to the use of larger cross sections than is necessary for the actual current flowing.

Short-circuit Power and Short-circuit current in North America

The north American mains networks are mostly softer as the European mains networks, as the transformers often have a higher impedance voltage of up to 7 %. With the calculation for larger consumer systems the different impedance voltage should be taken into account with the short-circuit calculations. With higher impedance voltages of the power transformer the maximum short-circuit current is less than with smaller short-circuit voltages. In the IEC area normally only the secondary short-circuit current of the transformer is found in the transformer short-circuit current tables. In american tables higher currents are given that take into account extra feedback currents from motors that are also connected to the short-circuited network. It is also normal to have details of values for differing, potential short-circuit currents that could appear on the transformor primary side. The american tables are more complex and contain more selection criteria. The **table 4** shows, from a IEC basis, reference values for short-circuit currents for american voltages and with unlimited primary-side short-circuit power.

Mains systems in North America

Normally the type of network is not so important for the electrical consumer

Reference Values for Short-circuit Currents of American 3 phase Transformers

		240 V, 60 Hz		480 V, 60 Hz		600 V, 60 Hz	
Rated power kVA	Short-circuit voltage u_k %	Rated current A	Short-circuit current I_k“ kA	Rated current A	Short-circuit current I_k“ kA	Rated current A	Short-circuit current I_k“ kA
300	5	722	14,4	361	7.2	289	5.8
500	5	1203	24,1	601	12.0	481	9.6
750	5.75	1804	31,4	902	15.7	722	12.6
1000	5.75	2406	41,8	1203	20.9	962	16.7
1500	5.75	3609	62,8	1804	31.4	1444	25.1
2000	5.75	–	–	2406	41.8	1924	33.5
2500	5.75	–	–	3008	52.3	2405	41.8
3000	5.75	–	–	3609	62.8	2886	50.2

Table 4: Rated currents and reference values for short-circuit currents of North American power transformers.

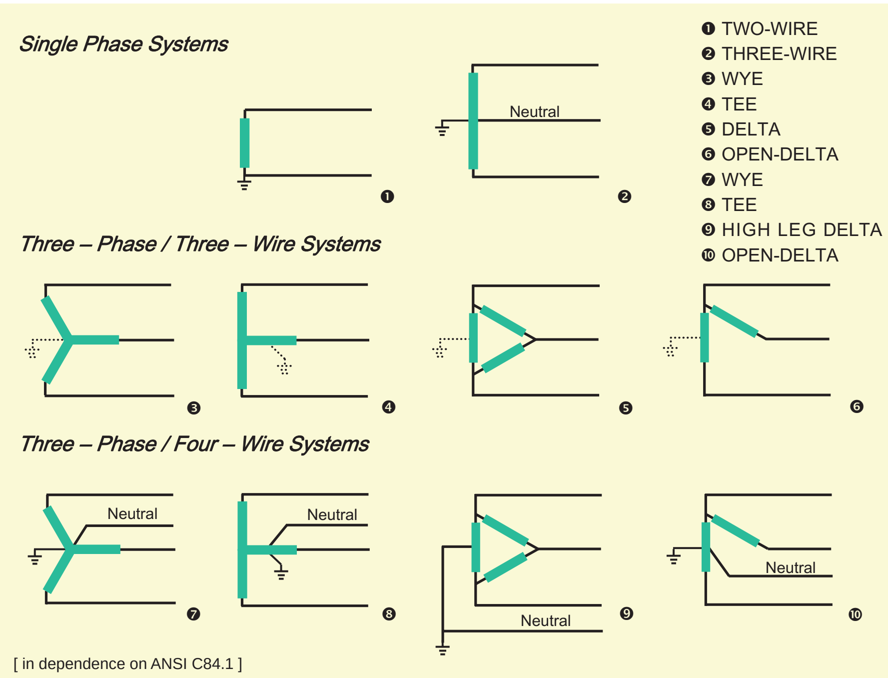
I_k“ = Transformor start-short-circuit current when connected to a network with unlimited short-circuit power.

as the voltage. The type of network has a bearing on the possible use of differing protection measures against electrical shock and if there is at all a neutral conductor present. Therefore the type of mains determines the single phase voltage of the equipment that must, if necessary be connected between two phases. With the export of electrical systems it is always sensible, especially when the available mains configurations cannot be safely clarified (e.g. with serial machines) to install input transformers *(power transformer)* into the system so as not to be dependant upon the availability, or not, of a neutral conductor in the local mains system. Single phase equipment can then be connected in it´s own single phase system with neutral conductor. As described later, it must be considered with the selection of switching and protection devices for AC equipment that devices designed to IEC or EN are approved only for use in an earthed network with neutral conductor due to their clearance and creepage dimensions (e.g. UL 508 Type E motor starter, UL 508 Type F motorstarter). Also with AC networks an adapter transformer can be installed in the incoming conductor of the machine. The transformer allows, for example the construction of a star-delta network for the machine so that devices can be used that require such a network. However due to economic reasons this is only possible up to a certain rating.

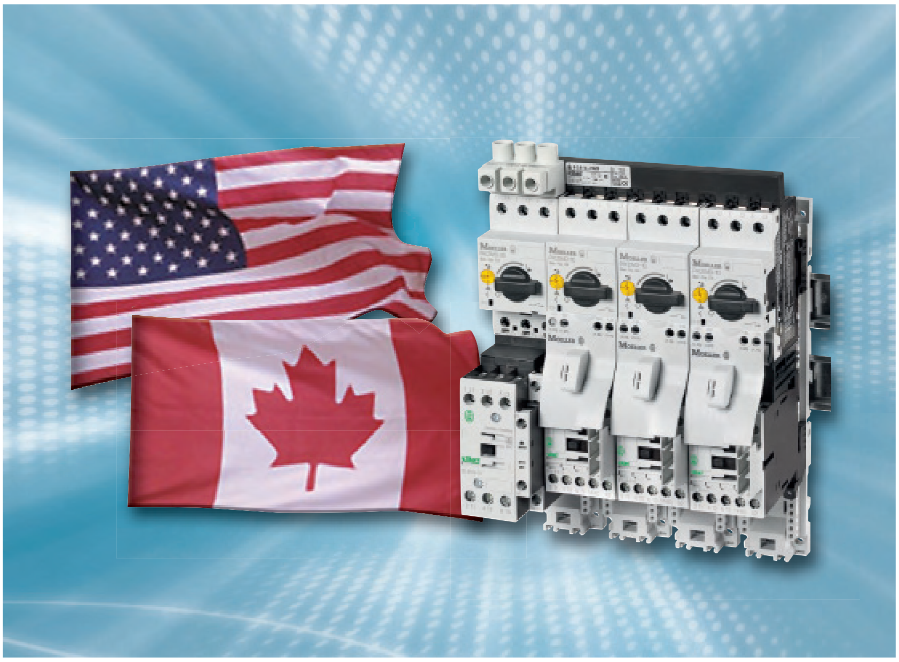
The mains types, in **Picture 2**, are also shown to make clear that in north America it is possible to come across interlinked voltages that are not connected, as is normal in most countries, with the normal factor √ 3, for a 120° phase difference. Some mains types are only found in north America. **Picture 1** doesn´t evaluate the quantitative distribution of the shown mains types, however today mostly earthed networks are found. (It should be considered that the earth potential is not always distributed from a cenral point but from several earthing points. This can lead to differing voltages between the earthing points.)

❶ shows the predomanent form of single phase networks. Occasionlly unearthed single phase networks appear. The nominal mains voltage in single phase networks is mostly 120 V and the connected equipment should have an operating voltage or Nameplate Voltage of 115 V. Network ❷ gives two single phase systems without mutual phase difference, with normally twice 120 V or with 240 V between both phases.

Earthed networks ease generally the use of protection measures that switch off the power (switching off protection measures). In consumer systems e.g. in the automobile industry, also in north America unearthed IT networks are found that ensure that the first isulation fault does not lead to disconnection due to the protection device (higher power availability and system availability in straight forward electrical installations). The first fault in the IT system is signalled by an insulation monitor and can be cleared during a break in operations.



Picture 2: Network types in north America, without evalution of the frequency of use. Only the secondaries of the transformers are shown in this picture. With circuits 5 and 6 the earthing can take place in the middle of a winding (see diagram) or alternatively at a corner. Single phase equipment can be connected to a single phase system or on a three system between two phases or, when present, between phase and neutral conductor.



Picture 3: Many of the switching and protection devices from Moeller have been especially designed for the requirments of the American markets. They can however be used also in countries where IEC standards must be used. Important project engineering information shows the usual voltage and type of network in the field of operation.

A further, second fault causes a normal disconnection of the power supply. A variant of this network is the earthing of the star point with a, sometimes settable, high ohmic impedance that limits the size of the earth-fault current. The presence and the size of the earth-fault current can, for example, be monitored with a current transformer for signalling and protection purposes.

In the USA mostly networks up to 480 V 60 Hz are used and in Canada networks up to 600 V 60 Hz can be found. The machine exporter often has a problem determining the local mains system type. With some types of switchgear shown in the Moeller main catalog and the publication [1] it is important to note that these switching and protection devices are exclusively approved for use with earthed star networks. Therefore some devices must be used exclusively in networks with 600Y / 347 V AC or 480Y / 277 V AC (networks with slash voltages [7]) **(Picture 3).** Information concerning this can also be found on the rating label of the product.

[7] The slash is the slash between the star and delta voltage – it gives the voltage it´s name

When the mains system type is not clear an alternative must be used that can also be a delta network with the full voltage. When this limitation only applies to a few devices the following is possible:

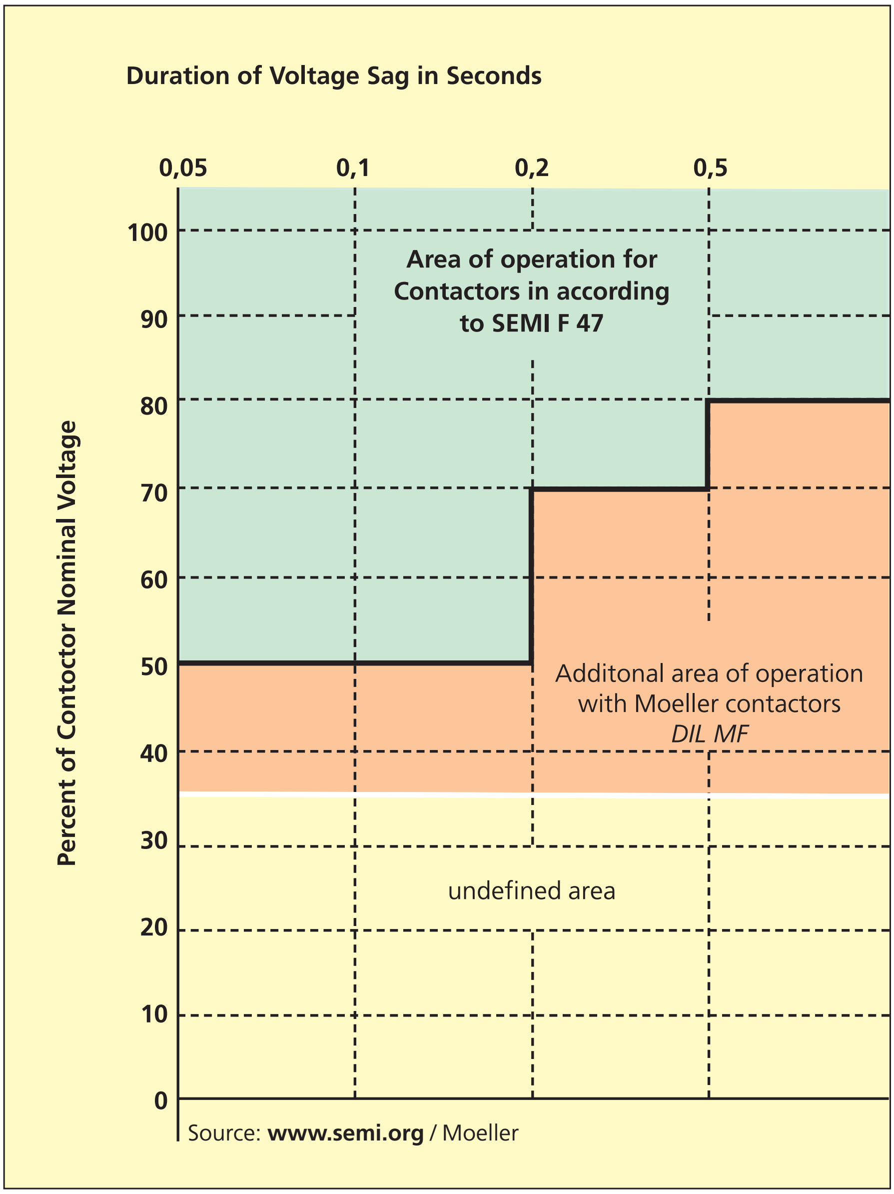
- Use larger **NZM** circuit-breaker instead of smaller **FAZ-NA** circuit-breaker
- Use **motor-protective circuit-breaker** with group protection upstream protective device instead of compacter ***Type E*** or ***Type F motor starters.*** (then for example, with busbar systems the requirements of the assembly in branch are can be fulfilled)
- Use the larger ***NZM2*** circuit-breaker in certain current ranges instead of the more compact ***NZM1***.

Switchgear for export and for retroactive voltage conversion.

Increasingly there is the problem that machines or total production lines are transfered to a location with completely different voltage and/or frequency relationships. Moeller offers contactors with different types of coils to simplify the later conversion to alterations in voltage and frequency or to reduce the stocking levels and variants of the switchgear panel builder. Moeller recommends the solution that with a change of location the control voltage of the total system is supplied from control voltage transformer. At one time double frequency coils were offered that could be used for the same voltage at 50 and 60 Hz. This compromise, due to a small over power in the contactor when used in 50 Hz networks, lead to a life span deduction of approx. 30 %. To be recommended are the double voltage coils that can be used for a 50 Hz standard voltage and are at the same time optimal for a second 60 Hz standard voltage. With a system designed for 230 V, 50 Hz the control transformer would be exchanged and the system would then be supplied with a control voltage of 240 V, 60 Hz (using Moeller contactors with double voltage coils). For use in north America Moeller recommends the use of a centrally produced control voltage of 120 V 60 Hz. For this contactors with the double voltage 110 V 50 Hz / 120 V 60 Hz are offered. Alternatively there are also single voltage coils for 115 V 60 Hz. Normally, approved control voltage transformers have an extra primary tapping so that the control voltage can be matched to the local voltage conditions. Moeller new generation contactors xStart [3] have additionally a minimum safe operating range between 0.8 and 1.1 x U_c. As well as the mentioned adaption of the control voltage the complete machine switchgear must be investigated for necessary modifications (altered motor currents / protection devices, effect of altered motor speed, etc.)

Especially according to the demands of the American semi-conductor manufacturer Moeller offers a range of contactors according to the specification SEMI F47[8] with increased voltage safety for especially breakdown critical switchgear. These contactors drop out firstly at 30 % of the control voltage **(picture 4)** and can be used in other branches with an especially high demand on system availability.

[8] www.semi.org



Picture 4: The American semi-conductor industry demands an increased drop-out safety for contactor coils according to the guidelines SEMI F47. In the green area the contactor contacts must not open. These demands can be exceded with the special contactors DIL MF from the Moeller xStart system.

However the voltage conversion is only a part of the conversion of a switchgear system. It must also be noted that a 50 Hz IEC switchgear system has other differences from a 60 Hz north American system that must be altered [2]. All components must be approved and also, for example, approved wiring material must be used. It must be checked that the equipment currents agree with the appropriate settings of the protection devices. The protection of the control voltage transformer and the control circuit is covered in a seperate essay [4].

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