Voltage Rating information for
USA and Canada

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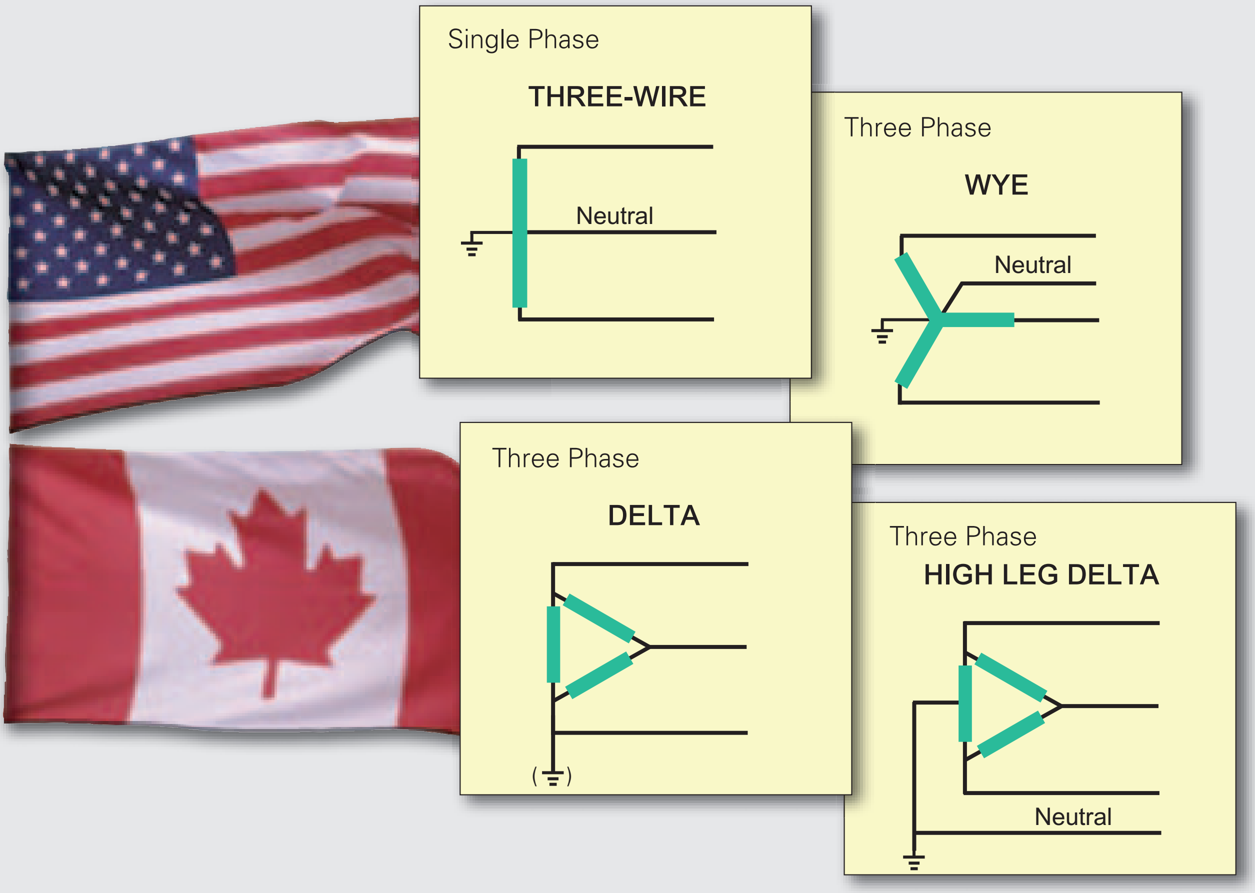
Export relevant information on supply distribution networks in North America



Technical Paper

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EATON
Powering Business Worldwide

An earlier compilation of typical networks and standardized voltages in North America showed a multitude of local variations. This was certainly due in part to the historical aspects, but also could be traced to the huge geographical size of the continent, the relatively large distances between energy supply locations and major electricity consumption centers, the generally high demand for power, and the individual needs of local power utilities. Such variety, combined with lack of uniformity, can ultimately stifle economic, as well as technical, progress. The standard ANSI1 C84.[1] has introduced much needed rationalization in the overall process nationally, and presented a glaring example of the positive impact which well intended standards can bring about in the industry. The standard had the arduous task of combining and coordinating the differing interests of the energy producers and suppliers on the one hand, with the needs and demands, e.g. the establishment of applicable voltage tolerances, of power and electricity consumers on the other. Whereas the energy production, energy trading and distribution were in the past more or less controlled by the same parties, today the industry has been largely deregulated and most activities have fallen under the jurisdiction of private industrial concerns which maintain cross-regional interests and keep a close eye on the bottom line.

Regional differences in the way utilities supply power across America still exist today. Exporting suppliers of machines and/or systems (OEM[2]), together with the end-user, are thus urged to take the matter of local energy supply networks into consideration at the early stages of project planning in order to establish which design parameters will be appropriate locally. A proper determination and understanding of the energy distribution setup on site will be vital to both professionals and lay people alike.

Dealing with local voltages when planning a vacation to North America could perhaps prove to be challenging, but not nearly as varied and uncertain as the task awaiting specialists involved in the export of industrial machinery and systems to the US and Canada. This is due to the fact that various voltage references are often provided (Service Voltage or Utilization Voltage, Nominal System Voltage or Rated Voltage and finally the Motor Nameplate Voltage), which have no equivalent in the IEC world. In the IEC world, from source of supply to end-use, we talk about the Operating Voltage and simply assume proper compliance with tolerances with respect to voltage drops. In Germany, voltage is considered an electrical parameter with relatively few aspects to be concerned about.

This essay deals exclusively with low voltage supply networks in the public and industrial domain along with the loads they service. It provides extracts of important information vital for project engineers of companies exporting to North America. Binding information is detailed in ANSI C84.1-2006 „American National Standard for Electric Power Systems and Equipment – Voltage Ratings (60 Hertz), and „CAN-3-C235-83". the comparative CSA[3] Standard for Canada.

Service Voltage und Utilization Voltage

This paper will only concern itself with the low voltage range. In North America this would essentially include all voltages up to 1000 V (increased to 1200 V by ANSI C84.1-2006). Above 1000 V (1200 V) brings in medium and high voltage considerations. AC voltages will be the main focus, including 3 phase systems. The rated frequency for all voltages is uniformly 60 Hz. All voltages and tolerances discussed are understood to be for continuous operation without taking into account normal short-time anomalies due to transient switching processes or starting of large motors. Loads with demanding or unusually long start-up times can lead in some cases to the necessity for special conductor sizing and starting equipment to insure that voltage tolerances are maintained within acceptable parameters.

Whereas the term operating voltage is applied uniformly in the IEC world (the comparable term in America would be: Nominal System Voltage or Rated Voltage), voltage references in North America are assigned specific terms as a function of their location in the electrical supply system. The Service Voltage is the voltage at the point of connection between the servicing utility and the premises wiring. It's especially important that voltage tolerance levels be maintained at the location where the servicing utility is supplying electrical energy to the end user and wiring premises (point of connection, point of common coupling). The servicing utility is responsible for maintaining the quality levels of this supply voltage. The actual Service Voltage is normally between 95 ... 105 % of the nominal voltage rating. When considering these permissible voltage tolerance levels it's important to take into account that the larger geographical area of the North American landscape requires more frequent use of longer transmission lines rather than an abundance of compact mesh-type networks, which can make supply lines more stable and dependable in maintaining voltage levels constant.

The Utilization Voltage is the voltage that is present at the end-user level or at the equipment that is utilizing the electrical energy. In worst cases the Utilization Voltage can fluctuate between 87 ... 106 % of the rated voltage. The difference between the minimum Service Voltage and the minimum Utilization Voltage is the permissible value of Voltage drop at the utilization site. The end-user is responsible for the quality of this voltage by making sure that electrical conductors are properly sized for the loads and installation guidelines provided by the electrical codes are strictly followed. Conductor sizing per the NEC[4] is designed to prevent a voltage drop exceeding 5% in both feeders and branch circuits, which typically breaks down to a maximum drop of 3% at the farthest outlet where a load is supplied and a remaining 2% at the point of utilization equipment.

With respect to tolerances in both service and utilization voltage levels, a differentiation is made between an ideal (defined as Range A) and a tolerable range (defined as Range B). Voltages in Range B should be limited in extent, frequency and duration of their occurrence. There are, however, no defined limitations on the occurrence of voltages outside Range B. The tolerances can be especially critical whenever large voltage drops or heavy load fluctuations occur due to lightly meshed networks combined with long transmission lines.

In addition to tolerances in voltage amplitude levels, AC polyphase systems can also be subject to a Voltage Unbalance between individual phases, or any phase and a possibly existing neutral conductor. The voltage unbalance under no load conditions is not allowed to exceed 3 % according to ANSI C84.1. Appendix D of ANSI C84.1 also references additional

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

information on voltage unbalance with respect to motor contributions and associated derating factors as a function of voltage unbalance percentages. For example, a derating factor of 0.9 would be applicable to a 3% voltage unbalance condition.

The standard determines voltage unbalance in accordance with the following formula:

Voltage unbalance [%] =

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

Example:
With phase to phase voltages of 230 V, 232 V and 225 V, the average is 229 V and the maximum deviation from the average would be 4 V. The percent voltage unbalance is 1.75 %.

Where motors are concerned, a voltage unbalance also leads to a current unbalance. That would be a typical application where the use of an IEC based motor overload protective device with phase-failure sensitivity would be especially suited. Table 1 shows how a motor can be impacted by deviations between its rated voltage and the actual voltage present at its terminations.

EPRI [5] conducted a survey which showed that the majority of end users typically deal with daily voltage fluctuations in the range of ≤ 3 %. At the same time more than 10 % of end-users encounter voltage fluctuations of ≥ 7 %, which could then lie outside Range B [1]. In 98 % of all supply networks the voltage unbalance is ≤ 3 % and in 66 % of networks ≤ 1 %.

The end-user, other than what can be achieved through his own energy awareness, has virtually no influence over the quality of the electrical supply from the utility. Load fluctuations, long supply lines and power generation stations which are not under the control of the local utility can make voltage regulation, also for the power supply companies, a daily challenge. Frequent and long lasting voltage fluctuations should be reported to the power utility company so that they can have a better overview of the situation and be more responsive to ongoing problems. Utilities must always deal with expansion planning and regulation measures made more difficult by ever changing targets. The provision of supplemental voltage regulation equipment in end-user installations with sensitive equipment in North America is often a necessity. The normal division in America between Service Voltage and Utilization Voltage is very much a determinant factor in assigning responsibility for the quality and maintenance of appropriate voltage levels throughout the electrical system.

	Impact on motor from deviations in the actual operating voltage U_e versus the rated voltage of the motor U_n	
	Operation at 90 % U_n	Operation at 110 % U_n
Starting 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	Differs, depending on motor size and design	Differs, depending on motor size and design
No load current	decreases (~ 10 to 30 %)	increases (~ 10 to 30 %)
Temperature rise in motor	Differs, depending on motor size and design	Differs, depending on motor size and design
Full load efficiency	Differs, depending on motor size and design	Differs, depending on motor size and design
Full load power factor	slight increase	slight decrease
Magnetically induced noise	slight decrease	slight increase

Table 1: General effects on AC motor performance when applied voltage differs from rated voltage. Neither the undervoltage nor overvoltage condition has an especially positive effect, therefore, achieving the smallest possible voltage deviations should be the goal.

Nameplate Voltage Rating

It's also customary in North America for motors, along with the electrical equipment sized to switch and protect them, to be marked with their operating voltage. The operating voltage for a motor is referred to as its Nameplate Voltage. It is perhaps peculiar and puzzling that this voltage does not match the nominal service voltage. A motor, for example, with a nameplate voltage of 460V is connected to a nominal voltage supply which is rated 480V. The Nameplate Voltage corresponds roughly to the minimum level of service voltage, which means in effect that the motor is almost never operated at the nominal supply voltage level. The operating currents allow for more precise setting of protective devices and better utilization of permissible voltage tolerances. Catalogues from various equipment manufacturers, as well as equipment markings on nameplates, are not very consistent when it comes to displaying Nameplate Voltage (simpler for the user) or the nominal system voltage (mains voltage) on the equipment itself. Figure 1 shows a nameplate from an Eaton contactor. Both the nominal supply voltage and the motor nameplate voltage are shown. The ratings are in accordance with typical NEMA rated motors. The electrical testing of the equipment is normally done at the higher nominal supply voltage, plus required tolerances. Equipment selection is made somewhat easier by the availability of standardized North American NEMA sizes for contactors and motor starter combinations. Table 2 shows the applicable tolerances for the network voltages mentioned.

The Utilization Voltage (permissible voltage at the connection point of the equipment), per Table 3, is neither identical with the normal operating voltage of the motor (Nameplate Voltage), nor with NEMA [6] permissible voltage tolerances on the equipment. The use of wide range power supplies is especially useful for small and sensitive AC equipment like electric razors, computers, etc. Uninterruptible power supplies (UPS) are often essential for backing up data on computers and automation systems.

5 EPRI = Electric Power Research Institute

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

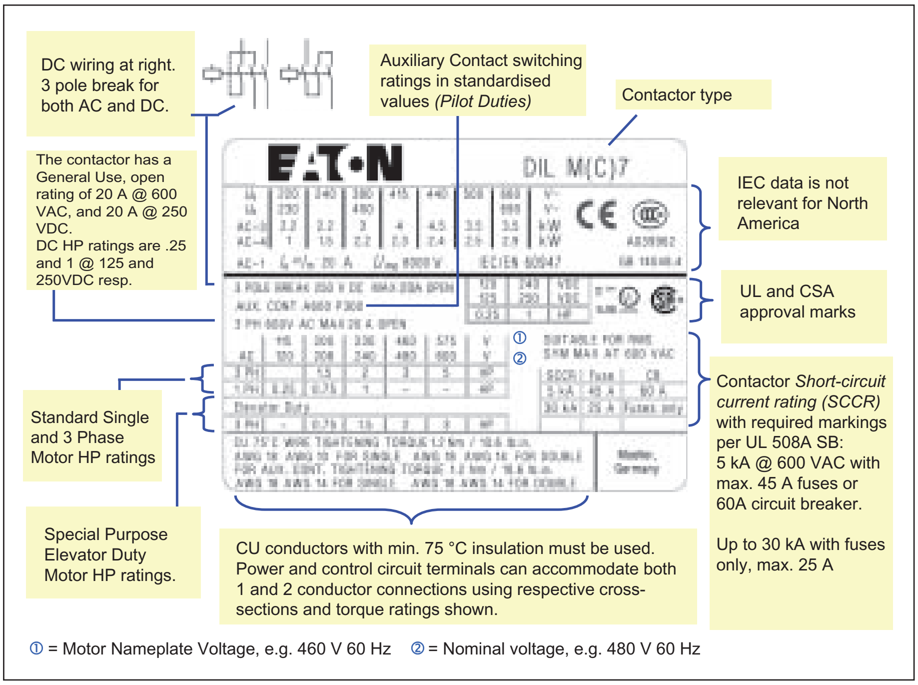

Figure 1: Sample of North American voltage ratings appearing on the nameplate rating label of Eaton contactors. Both the nominal (Systems) and motor nameplate (Utilization) voltage levels appear on the label.

	Range B Minimum	Range A Minimum	Nominal System Voltage	Range A Maximum	Range B Maximum
Utilization Voltage	87 %	90 %		104 %	105,8 %
	418 V	432 V	**480 V**	499 V	508 V
Service Voltage	92 %	95 %		105 %	105,8 %
	442 V	456 V	**480 V**	504 V	508 V

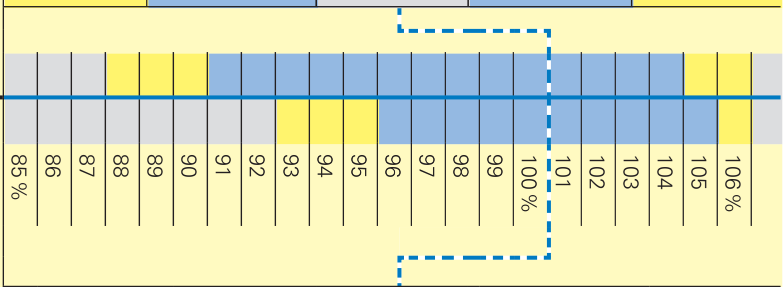

Table 2: *Service Voltage* and *Utilization Voltage* tolerances, using as a reference the most predominant industrial voltage in the USA: 480 V, 60 Hz.

Nominal-mains voltage *Rated voltage* Tolerance →	**Service Voltage** - 5 %, + 5 %	**Utilization Voltage** *Range B* - 13 %, + 6 %	*Range A* - 10 %, + 4 %	**Nameplate Voltage** **Operating voltage of motor**	**NEMA Requirement** - 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 corresponding Nameplate Voltages (operating voltages) for equipment. Permissible tolerance band widths along with absolute voltage values are also shown.

Informational note concerning the acceptance of European equipment when exporting to North America:

Exported motors are often rated in kW. Local inspectors may then opt to convert the kW value into a corresponding HP rating and then base required conductor sizing on the next largest standard HP rated motor. This method can lead to the use of larger cross sections than would otherwise be required for the actual motor current flowing.

Short-circuit capacity and short-circuit currents in North America

North American supply networks are generally not as tight as European networks, since distribution transformers can often have impedance ratings as high as 7 %. It's particularly important in larger installations to take the varying impedance ratings into consideration for short-circuit calculation purposes. A higher impedance rating translates into a smaller maximum short circuit current for the power transformer. IEC transformer short-circuit current tables are based normally on the short-circuit current that the transformer itself can deliver in the secondary. North American tables typically feature higher currents since they also take motor contributions under short circuit conditions into consideration. Details on short-circuit currents that could potentially appear on the transformer primary side are also normally provided. The North American tables are generally more detailed and contain more selection parameters. Table 4 shows, from an IEC standpoint, available short-circuit current values based on North American voltage ratings and unlimited primary side short-circuit capacity.

Supply networks in North America

Normally, the type of supply network is not as important a factor to the electrical end-user as the magnitude of the voltage. However, the type of network does have an impact on the choice of protective devices that are permissible, as well as determining the availability of a neutral conductor, and whether or not this neutral will be grounded or ungrounded. Thus, the supply network ultimately determines the voltage present for connection of single phase loads, which in case of need may require to be connected between two main phases. When exporting electrical equipment and assemblies it is always sensible, especially when the type of supply network configuration available cannot be reliably verified (e.g. with serially produced

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'' = Transformer start-short-circuit current when connected to a network with unlimited short-circuit capacity.

machinery) to have a power transformer on hand so as not to be dependent on the availability of a neutral conductor in the local supply network. Single phase loads can then be connected within their own single phase system with the availability of a neutral conductor. As described later, protective and switching devices designed to IEC or EN standards are often only certified for use in solidly ground supply networks with neutral conductors due to a number of design reasons, including their clearance and creepage clearances (e.g. UL 508 Type E and Type F motor controllers). Polyphase networks also lend themselves well to the use of matching transformers in the incoming supply line to a machine. The transformer allows, for example, the build-up of a solidly grounded wye configuration for the machine supply so that equipment rated accordingly can also be installed. Of course, the commercial viability of this solution is dependent to a large extent on the overall power rating of the machinery assembly.

The supply networks, per **Figure 2**, are also shown to make clear that it is possible in North America to come across interlinked voltages that are not a product of the standard √ 3 vectorial relationship, based on a 120° phase difference, as is the case in most countries. Some network configurations are peculiar only to North America. **Figure 1** doesn't provide any quantitative insight into the distribution of the networks shown. However, it's safe to say that the majority of systems encountered today are of the grounded variety. (It should be taken into consideration that the potential to earth is not always distributed from a centralized connection point but from several earthed locations. This can lead to the presence of differing earth potentials between these various grounded points.) The use of conduits as earth conductors is permitted and still encountered but increasingly a separate grounding conductor is run throughout the installation.

❶ represents the most common configuration for single phase supply. Occasionally, ungrounded single phase networks can be encountered. The nominal single phase voltage rating is predominantly 120V, and connected loads typically feature voltage nameplate ratings of 115V. The supply configuration ❷ features two separate single phase systems, with a grounded neutral conductor tapped from the mid-point, and is typical of residential service. Each leg is rated 120V with a 240V phase to phase potential.

Grounded supply networks generally simplifies the use of protective measures, which operate to switch off the power source. The use of ungrounded IT networks is sometimes encountered in North America, for example in end-user applications such as the automobile industry. These systems ensure that the protective device will not respond to the presence of an initial ground fault (higher level of service continuity in installations that are managed accordingly). The first fault in the IT system is normally detected and annunciated by an insulation monitoring system, and can be attended to during a planned break when it is more convenient to do so from an operational standpoint. A second ground fault arising would cause the protective means to disconnect the power source. A variation of this network involves grounding of the network star point with a high ohmic impedance that can be adjustable and acts to limit the magnitude of the ground-fault current. The presence and size of the ground-fault current can also be monitored with a current transformer for signalling and protection purposes.

The predominent industrial voltages encountered in the USA and Canada are rated up to 480V, 60Hz and 600V, 60 Hz respectively. It's often problematic for a machine exporter to know ahead of time what kind of network configuration will

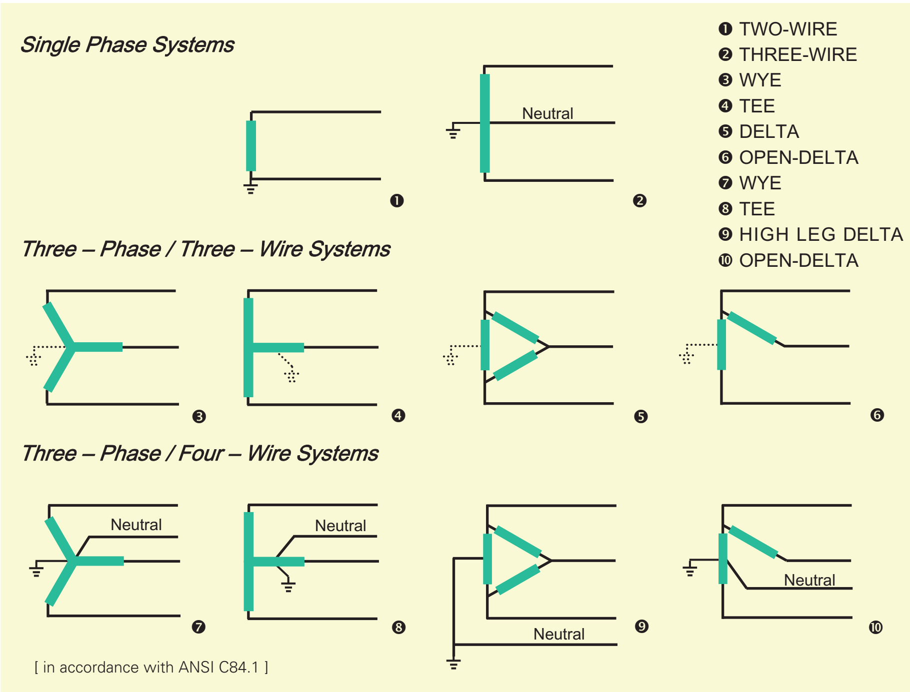

Figure 2: Supply networks encountered in North America, without any quantitative insight into their distribution throughout the electrical grid. Only the transformer supply secondary winding configurations are pictured. Grounding in configurations (5) and (6) can be provided either at the mid-point of a phase or, alternatively, at a corner (refer to figure). Single phase loads can be connected to single phase systems, or phase to phase in polyphase systems or, when available, between phase and neutral.

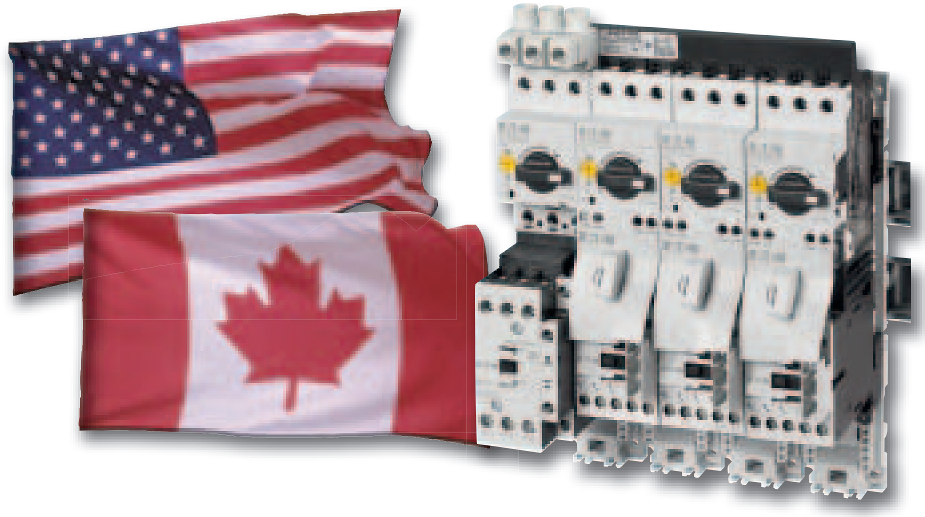

Figure 3: Many switching and protective devices from Eaton were designed especially to meet the requirements of the North American market, but these can also be applied in all countries where IEC standards dominate. An important factor to consider at the engineering and design stages is the determination of the magnitude of the voltage and the power network configuration present at the project installation site.

actually be available locally at the end-user site. Certain power circuit devices found in the Eaton Main Catalogue, and mentioned in various technical publications [2], have been certified for use only in solidly grounded wye networks, so advance knowledge of the particular network configuration available can be critical. Such devices would be suitable for power distribution networks with ratings such as 600Y / 347 V AC or 480Y / 277 V AC (Slash-Voltages[7]) **(Figure 3)**. Further information can be obtained from product literature or equipment nameplate ratings.

It would be advantageous to establish alternative equipment selection schemes, i.e. with full ratings suitable for delta networks, whenever there is any uncertainty regarding the power network configuration available locally. Assuming that restrictions apply only to a few devices, one could, for example:

- Utilize larger *NZM* molded case circuit breakers instead of the miniature *FAZ-NA* version,
- Establish group installation schemes with suitably certified motor controllers and fully rated back-up group protective devices instead of relying on more compact ***Type E-*** or ***Type F-*** **Motor starter assemblies** (which would also permit branch circuit industrial control rules with respect to mounting and wiring equipment such as busbar systems).
- Apply the larger NZM2 series of circuit breakers in particular current ranges instead of the smaller NZM1 variety.

Equipment suitable for export and adaptible to local changes in voltage ratings

There is an increasing trend that machines or even total production lines are being transferred to locations with completely different voltage and/or frequency relationships. Eaton offers contactors with a variety of available coil ratings to simplify potential later conversions to different voltages and frequencies, and also to minimize the stocking needs of local panel and assembly builders. Eaton took the approach that a change in equipment location would necessarily involve the need for a new control circuit transformer to provide control circuit power to the installation. Dual frequency coils were offered at one time, which permitted the application of the same voltage at both 50 and 60Hz frequency levels. However, this compromise leads to a slight increase in energy levels applied to the magnet system of contactors being operated at 50Hz, and a resultant decrease in overall contactor life expectancy of about 30%. The better solution involves the use of dual voltage/ dual frequency coils, which permit the optimal application of the coil at more than one standardized voltage and frequency rating. In the case of an installation designed for 230V, 50Hz, one could simply exchange the control transformer to accommodate a typical 240V, 60Hz rating, and keep the same contactor coil (assuming the use of Eaton contactors with dual voltage/dual frequency coils). For applications in North America, Eaton recommends the use of centralized control circuit power transformer sources which can supply a control voltage rated 120V, 60 Hz. Contactors with 110 V 50 Hz / 120 V 60 Hz dual voltage coils are offered for this purpose. Another alternative would be single voltage coils, such as 115 V 60 Hz. Certified control circuit transformers for use in North America are also typically provided with more than one available voltage tap on the primary side to accommodate various primary rated voltages available locally. Eaton contactors from the xStart series [3] come standard with coils which operate safely in the range between minimum 0,8 and 1,1 x U_c. Besides the changes already mentioned in the control voltage area, the entire machine assembly would also need to be checked for potential modifications as a result of a change in the incoming supply source (new motor currents / protective devices, possible effects from changes in motor speed/ torque characteristics etc.…)

Eaton offers a line of contactors that was specifically developed to accommodate the requirements of the SEMI F47[8] standard and the needs of the North American semi-conductor industry for equipment that can offer more reliable performance in applications where momentary power shortages can be especially critical. These contactors would drop out only when the control voltage would dip down to appr. 30% (Figure 4) and they can be used in any industry where continuity of service and maintenance of operational status are considered essential.

The voltage conversion represents only a portion of the factors to consider when retrofitting electrical assemblies. It must also be noted that 50 Hz based IEC equipment contains many additional elements that are different from a traditional 60 Hz based North American system, and which would need to be modified [2]. All components and wiring materials would need to be certified for the purpose. Co-ordination of load and equipment running currents with conductor sizing and settings of protective devices would have to be re-checked to make sure that they are in compliance with requirements. Protection requirements for control voltage transformers and con-

7 The slash refers to the oblique line between the line-to-line and line-to-ground voltage ratings, and gives the voltage rating its name.

8 www.semi.org

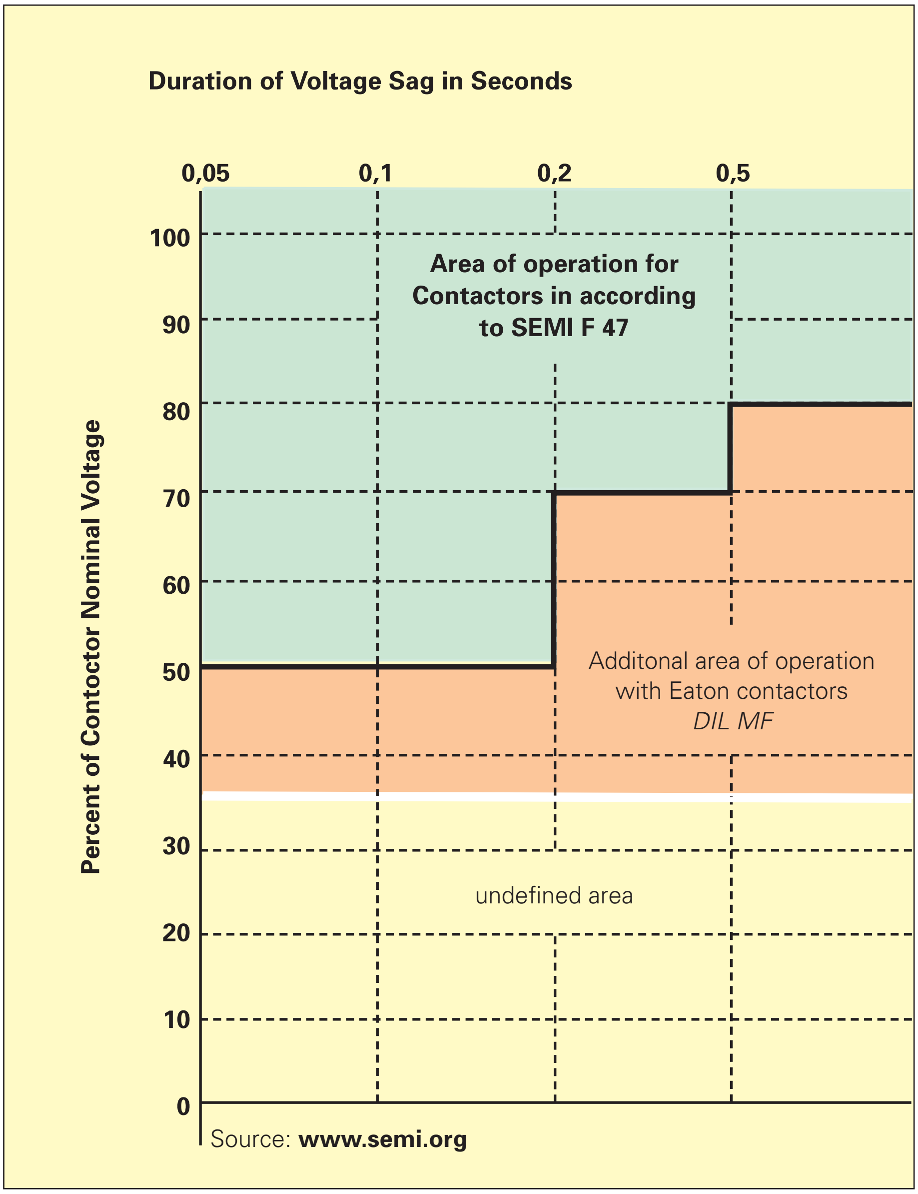

Figure 4: The North American semi-conductor industry, per the SEMI F47 standard, requires a better performance level with respect to contactor coil drop-out ratings. The contactor is not allowed to drop out in the area marked in green. The requirement can be surpassed with the use of specially designed DIL MF contactors from the Eaton System xStart series [4].

trol circuits are covered in a separate paper [5].

Recommendations for Export

In cases where the supply network configuration can't be reliably determined ahead of time, it would be best to indicate that the machine or assembly is being supplied for solidly grounded wye systems, such as 480Y/277VAC.

Matching supply transformers with a grounded secondary voltage rating of 480Y/277V or 400Y/230V are often used for this purpose, since not all protective devices carry a full 600V rating.

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