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Power Around
The World

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Preface

This publication lists, for the information of U.S. manufacturers and exporters and individuals living or traveling abroad, the characteristics of electric power available in principal countries throughout the world.

The information in this publication was taken from a 1998 document entitled "Electric Current Abroad - 1998 Edition" provided by the International Trade Administration, U.S. Department of Commerce and from various other agencies around the world.

Georator Corporation has updated much of the information to agree with today's world map. Since there are many changes occurring within the countries of the world, some of the information may be incorrect. Georator Corporation will welcome any current information that you may be able to provide to help us improve this document but cannot assume responsibility for incorrect data.

If you need assistance with electric power frequency conversion, please call Georator Corporation and ask for Sales Engineering. Our numbers are:

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Introduction

The characteristics of electric power – alternating or direct current, number of phases, frequency and voltage – found in major foreign countries are listed in this report. In addition, the stability of the frequency and the number of wires to a commercial or residential installation are given where available.

The current characteristics and other data furnished relate to domestic and commercial service only. It does not include special commercial installations involving relatively high voltage requirements nor does it refer to any industrial installations.

Persons who are planning to use or export appliances abroad should acquaint themselves with the characteristics of the electric supply available in the area in which the appliance is to be used. It may be less expensive to buy a new appliance than to purchase the auxiliary equipment needed to make presently owned appliances useable. A transformer may be obtained locally to correct the voltage if required. Auxiliary equipment to change frequency is too bulky and expensive for the average residential installation, however, Georator Corporation manufactures equipment for converting the frequency of commercial power to that used in the United States.

Some foreign hotels have a special circuit, providing approximately 120volts, for the convenience of guests using electric shavers and other low-wattage appliances made in the U.S. Such circuits are usually labeled at the convenience outlet indicating the voltage.

Among the nominal voltages indicated in this publication, the lower voltages shown are used primarily for lighting and smaller appliances, while the higher voltages are used primarily for hvac and larger equipment.

Readers are reminded that the list of characteristics presented here was compiled over a period of months from a large number of sources. There is consequently, some possibility of errors and omissions for which the Georator Corporation cannot assume responsibility.

Readers are further reminded that the information presented here should not be taken as final in the case of industrial or highly specialized commercial installations. Georator Corporation regrets that it is impossible for it to maintain complete data on every foreign industrial installation. It is recommended that for special equipment required for commercial use, the characteristics of the electric power in the area of installation be obtained from the end user.

Key to Terms
Used in This Publication

Type of Current – a.c. indicates alternating current and d.c., direct current.

Frequency – Shown in hertz (cycles per second). Even if voltages are similar, a 60-hertz U.S. motor will not function properly on 50-hertz current.

Number of phases – 1 and 3 are the conventional phases, which may be available.

Nominal voltage – In voltages specified for direct current (d.c.) the lower voltage is always ½ of the higher voltage. In a direct current installation, the lower voltage requires two wires while the higher voltage requires three wires.

Alternating current nominal voltage – Alternating current is normally distributed either through 3-phase wye ("star") or delta ("triangle"), 4-wire, secondary distribution systems. In the wye distribution system, the nominal voltage examples are 120/208, 127/220, 220/380, and 230/400. The higher voltage is 1.732 (the square root of 3) times the lower voltage. In a delta system, the 110/220 and 230/460 are examples of nominal voltages. The higher voltage is always double the lower voltage.

The higher voltage may be single or 3-phase while the lower voltage is always single phase and used primarily for lighting and small appliances.

Number of wires – The number of wires, which may be used by the consumer, is shown. Normally, a single phase, 220/380 volt system or 127/220 system will have two wires if only the lower voltage is available (one phase wire and the neutral). It will have three wires if both the higher and lower voltages are available (two-phase wires and the neutral) and, where three phase motors will be used, four wires will be available for the higher voltage (the three phase wires and the neutral wire).

Frequency stability – A "Yes" in the column indicates that the frequency stability is stable and service interruptions are rare.

Power Around The World

Country - Except for Cities as noted below country heading	Type and frequency of current	Number of phases	Nominal voltage	Number of wires	Frequency stability OK for elect. clocks
Afghanistan	a.c. 50	1,3	220/380	2,4	Yes
Albania	a.c. 50	1,3	220/380	2,4	No
Algeria	a.c. 50	1,3	127/220 220/380	2,4	Yes
American Somoa	a.c. 60	1,3	120/240 240/480	2,3,4,	Yes
Andorra	a.c. 50	1,3	127/220 220/380	2,3,4,	Yes
Angola[1,5]	a.c. 50	1,3	220/380	2,4	Yes
Antarctica	see individual nations camps				
Antigua & Barbuda[1]	a.c. 60	1,3	230/400	2,3,4	Yes
Argentina	a.c. 50	1,3	220/380	2,4	Yes
The following cities also have	d.c.		220/440	2,3	
Buenos Aires					
Chivilcoy					
Corrientes					
Jujuy					
Junin					
Mar del Plata					
Mendoza					
Necochea					
Parana					
Posadas					
Resistencia					
Rio Cuarto					
Rosario					
Salta					
San Juan					
Santa Fe					
Tres Arroyos					
Armenia	a.c. 50	1,3	220/380	2,4	No

Aruba	a.c. 60	1,3	127/220	2,3,4	Yes
Lago colony	a.c. 60	1	115/230	2,3	Yes
Ashmore & Cartier Islands	No Indigenous Inhabitants				
Australia[1,7]	a.c. 50	1,3	240/415	2,3,4	Yes
Albany	a.c. 50	1,3	250/440	2,3,4	Yes
Kalgoorlie	a.c. 50	1,3	250/440	2,3,4	Yes
Perth	a.c. 50	1,3	250/440	2,3,4	Yes
Austria[1,7]	a.c. 50	1,3	220/380	3,5	Yes
Azerbaijan	a.c. 50	1,3	220/380	2,4	No
Azores	a.c. 50	1,3	220/380	2,3,4	Yes
Ponta Delgada[23]	a.c. 50	1,3	220/380	2,3,4	Yes
	a.c. 50	1,3	110/190	2,3,4	Yes
Bahamas	a.c. 60	1,3	120/240 120/208	2,3,4	Yes
Bahrain[1,5]	a.c. 50	1,3	230/400	2,3,4	Yes
Awali	a.c. 60	1	110/115	3	Yes
		1,3	220/240		
Baker Island	No Indigenous Inhabitants				
Balearic Islands[1,5]	a.c. 50	1,3	127/220 220/380	2,3,4	Yes
Bangladesh	a.c. 50	1,3	220/440	3,4	No
Barbados[1]	a.c. 50	1,3	115/230 115/200	2,3,4	Yes
Barbuda	see Antiqua				
Bassas de India	a.c. 50	1,3	220/380	2,4	Yes
Belarus	a.c. 50	1,3	220/380	2,4	Yes
Belgium[1,6]	a.c. 50	1,3	220/380	2,3,4	Yes
Charleroi	a.c. 50	1,3	230/400	2,3	Yes
Mons	a.c. 50	1,3	230/400	2,3	Yes
Turnhout	a.c. 50	1,3	220	2,3	Yes
Belize[1]	a.c. 60	1,3	110/220	2,3,4	Yes

			220/440		
Orange Walk	a.c. 60	1	110/220	2,3	No
San Ignacio	a.c. 60	1	110/220	2,3	No
Stann Creek	a.c. 60	1	110/220	2,3	No
San Pedro	a.c. 60	1	110/220	2,3	No
Benin	a.c. 50	1,3	220/380	2,4	Yes
Bermuda[1,5]	a.c. 60	1,3	120/240	2,3,4	Yes
			120/208		
Bhutan	a.c. 50	1,3	220/380	2,4	Yes
Bolivia	a.c. 50	1,3	220/380	2,4	Yes
Cobija	a.c. 50	1,3	230/400	2,4	No
Guayaramerin	a.c. 50	1,3	230/400	2,4	No
La Paz	a.c. 50	1,3	115/230	2,3	Yes
Oruro	a.c. 50	1,3	115/230	2,3	Yes
Riberalta	a.c. 50	1,3	230/400	2,4	No
Trinidad	a.c. 50	1,3	230/400	2,4	No
Viacha	a.c. 50	1,3	115/230	2,3	Yes
Bosnia & Herzegovina	a.c. 50	1,3	220/380	2,4	No
Botswana[13]	a.c. 50	1,3	230/400	2,4	Yes
Bouvet Island	No Indigenous Inhabitants				
Brazil[1]	a.c. 60	1,3	127/220	2,3,4	Yes
Anapolis	a.c. 60	1,3	220/380	2,3,4	Yes
Bage	a.c. 60	1,3	220/380	2,3,4	Yes
Blumenau	a.c. 60	1,3	220/380	2,3,4	Yes
Brazilia, D.F.	a.c. 60	1,3	220/380	2,3,4	Yes
Caruaru	a.c. 60	1,3	220/380	2,3,4	Yes
Caxias do Sul	a.c. 60	1,3	220/380	2,3,4	Yes
Cel Fabriciano	a.c. 60	1,3	110/220	2,3	Yes
Florianopolis	a.c. 60	1,3	220/380	2,3,4	Yes
Fortaleza	a.c. 60	1,3	220/380	2,3,4	Yes
Goiania	a.c. 60	1,3	220/380	2,3,4	Yes
Goias	a.c. 60	1,3	220/380	2,3,4	Yes
Itajai	a.c. 60	1,3	220/380	2,3	Yes
Jequie	a.c. 60	1,3	220/380	2,3,4	Yes
Joao Pessoa	a.c. 60	1,3	220/380	2,3,4	Yes
Joinville	a.c. 60	1,3	220/380	2,3,4	Yes
Juiz de For a	a.c. 60	1,3	120/240	2,3,4	Yes
Jundiai	a.c. 60	1,3	220	2,3	Yes
Livramento	a.c. 60	1,3	220/380	2,3,4	Yes
Maceio	a.c. 60	1,3	220/380	2,3,4	Yes
Manaus	a.c. 60	1,3	110/220	2,3	Yes

Mossoro	a.c. 60	1,3	220/380	2,3,4	Yes
Natal	a.c. 60	1,3	220/380	2,3,4	Yes
Novo Friburgo	a.c. 60	1,3	220/380	2,3	Yes
Olinda	a.c. 60	1,3	220/380	2,3,4	Yes
Parnaiba	a.c. 60	1,3	220/380	2,3	Yes
Pelotas	a.c. 60	1,3	220/380	2,3,4	Yes
Recife	a.c. 60	1,3	220/380	2,3,4	Yes
Santo Andre	a.c. 60	1,3	127/220	2,3	Yes
			220/380		Yes
Sao Bernardo do Campo	a.c. 60	1,3	220/380	2,3	Yes
Sao Caetano do Sul	a.c. 60	1,3	115/230	2,3	Yes
Sao Luiz	a.c. 60	1,3	110/220	2,3	Yes
Sao Paulo	a.c. 60	1,3	115/230	2,3	Yes
Teresina	a.c. 60	1,3	110/220	2,3	Yes
Volta Redonda			125/216	2,3,4	Yes
Brunei[1,5]	a.c. 50	1,3	240/415	2,4	Yes
Bulgaria[17]	a.c. 50	1,3	220/380	2,4	No
Burkino Faso	a.c. 50	1,3	220/380	2,4	No
Burma[1,5]	a.c. 50	1,3	230/400	2,4	No
Burundi	a.c. 50	1,3	220/380	2,4	No
Cambodia	a.c. 50	1,3	120/208	2,4	No
Phnom-Penh	a.c. 50	1,3	220/380	2,3,4	No
Sihanoukville	a.c. 50	1,3	220/380	2,4	Yes
Cameroon	a.c. 50	1,3	127/220	2,4	No
			220/380		
Buea	a.c. 50	1,3	230/400	2,4	N.A.
Douala	a.c. 50	1,3	220/380	2,3,4	Yes
Dschang	a.c. 50	1,3	220/380	2,4	No
Ebolowa	a.c. 50	1,3	220/380	2,4	No
Edea	a.c. 50	1,3	220/380	2,3,4	Yes
Foumban	a.c. 50	1,3	220/380	2,4	No
Garoua	a.c. 50	1,3	220/380	2,3,4	No
Kribi	a.c. 50	1,3	220/380	2,4	No
Limbe	a.c. 50	1,3	230/400	2,4	N.A.
Canada[1,21]	a.c. 60	1,3	120/240	3,4	Yes
Canary Islands[1]	a.c. 50	1,3	127/220	2,3,4	Yes
			220/380		

Cape Verde, Rep. Of[5]	a.c. 50	1,3	220/380	2,3,4	No
Cayman Islands[1]	a.c. 60	1,3	120/240	2,3	Yes
Central African Rep.[5]	a.c. 50	1,3	220/380	2,4	Yes
Chad	a.c. 50	1,3	220/380	2,4	No
Channel Islands	a.c. 50	1,3	240/415	2,4	Yes
Guernsey	a.c. 50	1,3	230/400	2,4	Yes
Chile	a.c. 50	1,3	220/380	2,3,4	Yes
China, People's Rep.	a.c. 50	1,3	220/380	2,3,4	No
Christmas Island	a.c. 50		240		
Clipperton Island	No Indigenous Inhabitants				
Cocos (Keeling) Islands	N.A.	Population 633			
Colombia	a.c. 60	1,3	110/220	2,3,4	No
Bogota[22]	a.c. 60	1,3	110/220 150/260	2,3,4	Yes
Duitama	a.c. 60	1,3	120/208	2,3,4	No
Honda	a.c. 60	1,3	120/208	2,3,4	No
Sogomosa	a.c. 60	1,3	120/240	2,3,4	No
Comoros	a.c. 50	1,3	220/380	2,4	N.A.
Congo, Dem. Rep.[1,5] (formerly Zaire)	a.c. 50	1,3	220/380	2,3,4	Yes
Cook Islands	a.c. 50	1,3	240/415	2,3,4	Yes
Coral Sea Islands	No Indigenous Inhabitants				
Costa Rica	a.c. 60	1,3	120/240	2,3,4	Yes
Cote d'Ivoire (formerly Ivory Coast)	a.c. 50	1,3	220/380	3,4	Yes
Croatia	a.c. 50	1,3	220/380	2,4	No
Cuba	a.c. 60	1,3	110/220	2,3	Yes

Cyprus[1,5]	a.c. 50	1,3	240/415	2,4	Yes
Czech Republic	a.c. 50	1,3	220/380	2,3,4	Yes
Denmark	a.c. 50	1,3	220/380	2,3,4	Yes
Djibouti, Rep. Of	a.c. 50	1,3	220/380	2,4	Yes
Dominica[1,5] (Windward Islands)	a.c. 50	1,3	230/400	2,4	Yes
Dominican Republic	a.c. 60	1,3	110/220	2,3	Yes
Ecuador[1]	a.c. 60	1,3	120/208 127/220	2,3,4	Yes
Cuenca	a.c. 60	1,3	120/208	2,3,4	Yes
Esmeraldas	a.c. 60	1,3	120/208 120/240 127/220	2,3,4	Yes
Guaranda	a.c. 60	1,3	120/208 120/240 127/220	2,3,4	Yes
Guayaquil	a.c. 60	1,3	120/208 120/240 127/220	2,3,4	Yes
Ibarra	a.c. 60	1,3	127/220	2,3,4	Yes
Latacunga	a.c. 60	1,3	120/208	2,3,4	Yes
Loja	a.c. 60	1,3	127/220	2,3,4	Yes
Machala	a.c. 60	1,3	127/220	2,3,4	Yes
Morona	a.c. 60	1,3	127/208	2,3,4	Yes
Portoviejo	a.c. 60	1,3	127/220	2,3,4	Yes
Puyo	a.c. 60	1,3	127/220	2,3,4	Yes
Riobamba	a.c. 60	1,3	110/220 127/220	2,3,4	Yes
Tulcan	a.c. 60	1,3	121/210 127/220	2,3,4	Yes
Zamora	a.c. 60	1,3	121/210 127/220	2,3,4	Yes
Egypt	a.c. 50	1,3	220/380	2,3,4	No
El Salvador[1]	a.c. 60	1,3	115/230	2,3	Yes
England	see United Kingdom				
Equatorial Guinea[14]	a.c. 50	1	220	2	No
Eritrea	a.c. 50	1,3	230/400	2,4	Yes

Estonia	a.c. 50	1,3	230/400	2,4	Yes
Ethiopia	a.c. 50	1,3	220/380	2,4	Yes
Europa Island	No Indigenous Inhabitants				
Falkland Islands	a.c. 50	1,3	240/415	2/4	Yes
Faeroe Islands	a.c. 50	1,3	220/380	2,3,4	Yes
Fiji	a.c. 50	1,3	240/415	2,3,4	Yes
Finland[24]	a.c. 50	1,3	220/380	2,4,5	Yes
France[24]	a.c. 50	1,3	220/380	2,4	Yes
Briancon	a.c. 50	1,3	115/200	2,4	Yes
Caen	a.c. 50	1,3	127/220 220/380	2,4	Yes
Grenoble	a.c. 50	1,3	127/220	2,4	Yes
Lille	a.c. 50	1,3	110/220 220/380	2,4	Yes
Luxeuil-Bains	a.c. 50	1,3	127/220 220/380	2,4	Yes
Lyon	a.c. 50	1,3	110/220 127/220 220/380	2,4	Yes
Mulhouse	a.c. 50	1,3	230 220/380	2,4	Yes
Paris	a.c. 50	1,3	115/230 220/380	2,4	Yes
Royan	a.c. 50	1,3	127/220 220/380	2,4	Yes
Strasbourg	a.c. 50	1,3	125/220 220/380	2,4	Yes
Tourcoing	a.c. 50	1,3	110/220 220/380	2,4	Yes
French Guiana[1,5]	a.c. 50	1,3	220/380	2,3,4	No
French Polynesia	see Tahiti				
Gabon[3,8]	a.c. 50	1,3	220/380	2,4	Yes
Gambia, The[5]	a.c. 50	1,3	220/380	2,4	No
Gaza Strip	a.c. 50	1,3	230/400	2,4	Yes
Georgia	a.c. 50	1,3	220/380	2,4	Yes

Germany,[1,5,24,25] **Fed. Rep. Of**	a.c. 50	1,3	220/380	2,4	Yes
Ghana	a.c. 50	1,3	230/400	2,3,4	No
Gibralter	a.c. 50	1,3	240/415	2,4	Yes
Gloriosa Islands	No Indigenous Inhabitants				
Great Britain	see United Kingdom				
Greece	a.c. 50	1,3	220/380	2,4	Yes
Greenland	a.c. 50	1,3	220/380	2,3,4	Yes
Grenada[1,7] (Windward Islands)	a.c. 50	1,3	230/400	2,4	No
Guadeloupe	a.c. 50	1,3	220/380	2,3,4	Yes
Guam[1]	a.c. 60	1,3	110/220 120/208	3,4	Yes
Guatemala	a.c. 60	1,3	120/240	2,3,4	Yes
Guernsey	see Channel Islands				
Guinea	a.c. 50	1,3	220/380	2,3,4	No
Guinea-Bissau	a.c. 50	1,3	220/380	2,3,4	No
Guyana[1,10,26]	a.c. 60	1,3	110/220	2,3,4	Yes
Georgetown	a.c. 50	1,3	110/220	2,3,4	Yes
Haiti	a.c. 60	1,3	110/220	2,3,4	Yes
Jacmel	a.c. 50	1,3	110/220	2,3,4	No
Heard & McDonald Islands	No Indigenous Inhabitants				
Herzegovina	see Bosnia				
Holy See (Vatican City)	a.c. 50	1,3	220/380 12//220	2,4	Yes
Honduras	a.c. 60	1,3	110/220	2,3	No
Hong Kong	a.c. 50	1,3	220/380	2,3,4	Yes

Howland Island	No Indigenous Inhabitants				
Hungary[4,5]	a.c. 50	1,3	220/380	2,3,4	Yes
Iceland	a.c. 50	1,3	220/380	2,3,4	Yes
India[4,16]	a.c. 50	1,3	230/400	2,4	Yes
Ajmer	d.c.		230/460	2,3	
Ambala	d.c.		220/440	2,3	
Ambala (City)	a.c. 50	1,3	230/400	2,4	Yes
Bombay City	a.c. 50	1,3	230/400	2,4	Yes
			230/460		
	d.c.		300/600	2,3	
Calcutta	a.c. 50	1,3	230/400	2,4	Yes
	d.c.		225/450	2,3	
Cuttack	a.c. 50	1,3	230/400	2,4	Yes
	d.c.		230/460	2,3	
Dehli, including	a.c. 50	1,3	230/400	2,4	Yes
New Dehli			230/415		
	d.c		250/500	2,3	
Gaya	a.c. 50	1,3	230/400	2,4	Yes
	d.c.		220/440	2,3	
Indore	a.c. 50	1,3	230/400	2,4	Yes
	d.c.		230/460	2,3	
Kanpur	a.c. 50	1,3	230/400	2,4	Yes
	d.c.		225/450	2,3	
Lucknow	a.c. 50	1,3	230/400	2,4	Yes
	d.c.		220/440	2,3	
Madras	a.c. 50	1,3	230/400	2,4	Yes
			250/440		
	d.c		225/450	2,3	
Mussoorie	a.c. 50	1,3	220/380	2,4	Yes
Naini Tal	a.c. 50	1,3	220/380	2,4	Yes
New Delhi (see Delhi)					
Patna	a.c. 50	1,3	220/380	2,4	Yes
			230/400		
	d.c.		220/440	2,3	
Rajkot	a.c. 50	1,3	230/400	2,4	Yes
	d.c.		230/460	2,3	
Simla	a.c. 50	1,3	220/380	2,4	Yes
Indonesia[1,27]	a.c. 50	1,3	220/380	2,4	Yes
Bandjarmasin	a.c. 50	1,3	127/220	2,4	No
Medan	a.c. 50	1,3	127/220	2,4	Yes
Padang	a.c. 50	1,3	127/220	2,4	No
Palembang	a.c. 50	1,3	127/220	2,4	Yes
Ujungpandang	a.c. 50	1,3	127/220	2,4	No

Iran	a.c. 50	1,3	220/380	2,3,4	Yes
Iraq[5]	a.c. 50	1,3	220/380	2,4	Yes
Ireland[1,5]	a.c. 50	1,3	220/380	2,4	Yes
Belfast	a.c. 50	1,3	220/380 230/400	2,4	Yes
Londonderry	a.c. 50	1,3	220/380 230/400	2,4	Yes
Isle of Man	a.c. 50	1,3	240/415	2,4	Yes
Israel[1,7]	a.c. 50	1,3	230/400	2,4	Yes
Italy[1,5]	a.c. 50	1,3	220/380	2,4	Yes
The following cities also have			127/220		
Ancona					
Bologna					
Como					
Cremona					
Genoa					
Latina					
Milan					
Perugia					
Pescara & Chieti					
Pisa					
Rome					
Trieste					
Udine					
Venice					
Verona					
Ivory Coast	see Cote d'Ivoire				
Jamaica[1]	a.c. 50	1,3	110/220	2,3,4	Yes
Jan Mayen	No Indigenous Inhabitants				
Japan[1]	a.c. 60	1,3	100/200	2,3	Yes
The following cities have 50Hz frequency					
Chiba	a.c. 50	1,3	100/200	2,3	Yes
Hakodate	a.c. 50	1,3	100/200	2,3	Yes
Kawasaki	a.c. 50	1,3	100/200	2,3	Yes
Muroran	a.c. 50	1,3	100/200	2,3	Yes
Niigata	a.c. 50	1,3	100/200	2,3	Yes
Otaru	a.c. 50	1,3	100/200	2,3	Yes
Sapporo	a.c. 50	1,3	100/200	2,3	Yes
Sendai	a.c. 50	1,3	100/200	2,3	Yes

Tokyo	a.c. 50	1,3	100/200	2,3	Yes
Yokohama	a.c. 50	1,3	100/200	2,3	Yes
Yokosuka	a.c. 50	1,3	100/200	2,3	Yes
Jarvis Island	Usually Uninhabited				
Jersey	a.c. 50	1,3	240/415	2,4	Yes
Jerusalem[1,5]	a.c. 50	1,3	220/380	2,3,4	Yes
Johnston Atoll	U.S. Military Personnel Only				
Jordan[1,5]	a.c. 50	1,3	220/380	2,3,4	Yes
Kazakstan	a.c. 50	1,3	220/380	2,3,4	Yes
Kenya[5]	a.c. 50	1,3	240/415	2,4	Yes
Kingman Reef	No Indigenous Inhabitants				
Kiribati	a.c. 50		240		
Korea[1,9,28]	a.c. 60	1	110	2	Yes
		1	110/220	3	Yes
		3	220/380	4	Yes
Kuwait	a.c. 50	1,3	240/415	2,4	Yes
Kyrgyzstan	a.c. 50	1,3	220/380	2,3,4	Yes
Laos	a.c. 50	1,3	220/380	2,4	No
Lebanon[1]	a.c. 50	1,3	220/380	2,4	No
The following cities also have			110/190		
Aley					
Beirut					
Bhamdoun					
Brummana					
Tripoli					
Tyre					
Lesotho[1,5,18]	a.c. 50	1,3	220/380	2,4	Yes
Liberia[1]	a.c. 60	1,3	120/240	2,3,4	No
			120/208		
Libya[2]	a.c. 50	1,3	127/220	2,4	No
Barce	a.c. 50	1,3	230/400	2,4	No

Benghazi	a.c. 50	1,3	230/400	2,4	No
Derna	a.c. 50	1,3	230/400	2,4	No
El Baida	a.c. 50	1,3	230	2,4	No
Sebha	a.c. 50	1,3	230	2,4	No
Tobruk	a.c. 50	1,3	230/400	2,4	No
Liechtenstein	a.c. 50	1,3	230/400	2,4	Yes
Lithuania	a.c. 50	1,3	230/400	2,4	Yes
Luxembourg[1,5]	a.c. 50	1,3	230/400	2,4	Yes
Macau	a.c. 50	1,3	200/346	2,3	Yes
Macedonia	a.c. 50	1,3	220/380	2,4	Yes
Madagascar[1,23]	a.c. 50	1,3	127/220 220/380	2,3,4	Yes
Ambatolampy	a.c. 50	1,3	220/380	2,4	Yes
Ambatondrazaka	a.c. 50	1,3	220/380	2,4	Yes
Tulear	a.c. 50	1,3	220/380	2,4	Yes
Madeira[1,23]	a.c. 50	1,3	220/380	2,3,4	Yes
	d.c.		220/440	2,3	
Malawi	a.c. 50	1,3	230/400	3,4	No
Malaysia[1,5]	a.c. 50	1,3	240/415	2,4	Yes
Penang	a.c. 50	1,3	230/400	2,4	Yes
Maldives	a.c. 50	1,3	230/400	2,4	Yes
Mali, Rep. Of[1,5]	a.c. 50	1,3	220/380	3,4	No
Malta[1,5]	a.c. 50	1,3	240/415	2,4	Yes
Marshall Islands	N.A.				
Bikini					
Kwajalein					
Enewatak					
Martinique[1,5]	a.c. 50	1,3	220/380	2,3,4	Yes
Mauritania[1,5,12]	a.c. 50	1,3	220	2,3	No
Mauritius Island[5]	a.c. 50	1,3	230/400	2,4	Yes
Mayotte	N.A.				

Mexico	a.c. 60	1,3	127/220	2,3,4	No
Micronesia, Federated States of	See Individual Islands				
Midway Islands	No Indigenous Inhabitants				
Moldava	a.c. 50	1,3	220/380	2,4	Yes
Monaco	a.c. 50	1,3	127/220 220/380	2,4	Yes
Mongolia	a.c. 50	1,3	230/400	2,4	No
Montserrat (Leeward Islands)	a.c. 60	1,3	230/400	2,4	N.A.
Morocco[1,5]	a.c. 50	1,3	127/220	2,4	Yes
Agadir	a.c. 50	1,3	127/220 220/380	2,4	Yes
Beni-Mellal	a.c. 50	1,3	127/220 220/380	2,4	Yes
El-Hoceima	a.c. 50	1,3	220/380	2,4	Yes
Khemisset	a.c. 50	1,3	220/380	2,4	Yes
Khenifra	a.c. 50	1,3	220/380	2,4	Yes
Oud-Zem	a.c. 50	1,3	127/220 220/380	2,4	Yes
Sidi Kacem	a.c. 50	1,3	127/220 220/380	2,4	Yes
Sidi Slimane	a.c. 50	1,3	127/220 220/380	2,4	Yes
Souk-El-Arba Gharb	a.c. 50	1,3	127/220 220/380	2,4	Yes
Mozambique[5]	a.c. 50	1,3	220/380	2,4	Yes
Namibia[1,5]	a.c. 50	1,3	220/380	2,4	Yes
Keetmanshoop	a.c. 50	1,3	230/400	2,4	Yes
Nauru	a.c. 50	1,3	240/415	2,4	Yes
Navassa Island	No Indigenous Inhabitants				
Nepal[1]	a.c. 50	1,3	220/440	2,4	No
Netherlands[1]	a.c. 50	1,3	220/380	2,3	Yes
Netherlands Antilles[1,5]	a.c. 50	1,3	127/220	2,3,4	Yes

Curacao					
Emmastad	a.c. 50	1,3	220/380	2,3,4	Yes
St. Martin					
Philipsburg	a.c. 60	1,3	120/220	2,3,4	Yes
New Caledonia	a.c. 50	1,3	220/380	2,3,4	Yes
New Zealand[1,5]	a.c. 50	1,3	230/400	2,3,4	Yes
Newly Independent[19] **States of the former Soviet Union**	a.c. 50	1,3	220/380	N.A.	No
Nicaragua	a.c. 60	1,3	120/240	2,3,4	Yes
Bonanza	a.c. 60	1,3	120	2,3	Yes
Jalapa	a.c. 60	1,3	120	2,3	No
Matiguas	a.c. 60	1,3	120	2,3	No
Quilali	a.c. 60	1,3	120	2,3	No
Siuna	a.c. 60	1,3	120	2,3	Yes
Telpaneca	a.c. 60	1,3	120	2,3	No
Niger[15]	a.c. 50	1,3	220/380	2,4	No
Nigeria[1]	a.c. 50	1,3	220/380	2,4	Yes
Niue	a.c. 50		240		
Norfolk Island	N.A.				
Northern Mariana Isles	N.A.				
Norway	a.c. 50	1,3	220/380	2,4	Yes
Okinawa Island[1]					
Military Facilities	a.c. 60	1	120/240	2,3	Yes
Non-Military Areas	a.c. 60	1	100/200	2,3	Yes
Oman[5,19]	a.c. 50	1,3	240/415	2,4	No
Pakistan[1,19]	a.c. 50	1,3	230/400	3	No
Palau	a.c. 60	1,3	115/230	2,3	Yes
Palestine	a.c. 50	1,3	230/400	2,4	Yes
Palmyra Atoll	No Indigenous Inhabitants				
Panama	a.c. 60	1,3	110/220	2,3	Yes

Colon	a.c. 60	1,3	115/230	2,3,4	Yes
Panama	a.c. 60	1,3	120/240	2,3,4	Yes
Puerto Armuelles	a.c. 60	1,3	120/240	2,3,4	Yes
Papua New Guinea	a.c. 50	1,3	240/415	2,4	Yes
Paracel Islands	No Indigenous Inhabitants				
Paraguay	a.c. 50	1,3	220/380	2,4	Yes
Peru	a.c. 60	1,3	220	2,3	Yes
Arequipa	a.c. 50	1,3	110/220	2,3	Yes
Talara	a.c. 60	1,3	220	2,3	Yes
Philippines[1,11,29]	a.c. 60	1,3	110/220	2,3	Yes
Manila	a.c. 60	1,3	115/230 110/220	2,3,4	Yes
Pitcairn Islands	N.A.	Population 50			
Poland	a.c. 50	1,3	220/380	2,4	No
Katawice	a.c. 50	1,3	220/380	2,3,4	No
Portugal[1]	a.c. 50	1,3	220/380	2,3,4	Yes
Puerto Rico	a.c. 60	1,3	120/240	2,3,4	Yes
Qatar	a.c. 50	1,3	240/415	2,3,4	Yes
Reunion	a.c. 50	1,3	220/380	2,4	Yes
Romania	a.c. 50	1,3	220/380	2,4	No
Russia	see Newly Independent States				
Rwanda	a.c. 50	1,3	220/380	2,4	Yes
St. Helena	a.c. 50		240		
St. Kitts and Nevis (Leeward Islands)	a.c. 60	1,3	230/400	2,4	Yes
St. Pierre & Miquelon	N.A				
St. Lucia[1,5] (Windward Islands)	a.c. 50	1,3	240/416	2,4	Yes
St. Vincent and the Grenadines[1,5]	a.c. 50	1,3	230/400	2,4	Yes

(Windward Islands)					
Samoa	a.c. 50	1,3	230/400	2,3,4	Yes
San Marino	a.c. 50	1,3	220/380	2,4	Yes
Sao Tome & Principe	a.c. 50	1,3	220/380	2,3,4	
Saudi Arabia[30]	a.c. 60	1,3	127/220	2,4	Yes
Scotland	see United Kingdom				
Senegal[1,30]	a.c. 50	1,3	127/220	2,3,4	No
Serbia - Montenegro (was Yugoslavia)	a.c. 50	1,3	220/380	3,4,5	Yes
Seychelles	a.c. 50	1,3	240	2,3	Yes
Sierra Leone	a.c. 50	1,3	230/400	2,4	No
Singapore[5]	a.c. 50	1,3	230/400	2,4	Yes
Slovak Republic	a.c. 50	1,3	220/380	2,4	Yes
Slovenia	a.c. 50	1,3	220/380	2,3,4	Yes
Soloman Islands					
Honiara	a.c. 50		230		
Somalia	a.c. 50	1,3	220	2,3	No
Berbera	a.c. 50	1,3	230	2,3	Yes
Brava	a.c. 50	1,3	220/440	2,4	Yes
Merca	a.c. 50	1,3	110/220	2,4	No
Mogadishu	a.c. 50	1,3	220/380	2,4	No
South Africa[1,5]	a.c. 50	1,3	220/380	2,3,4	Yes
Beaufort West	a.c. 50	1,3	230/400	2,4	Yes
Benoni	a.c. 50	1,3	230/400	2,4	Yes
Boksburg	a.c. 50	1,3	230/400	2,4	Yes
Cradock	a.c. 50	1,3	230/400	2,4	N.A.
Germiston	a.c. 50	1,3	230/400	2,3,4	Yes
Grahamstad	a.c. 50	1,3	250/430	2,4	Yes
Johannesburg	a.c. 50	1,3	220/380	2,3,4	Yes
	d.c.		230/460	2,3	
King Williams	a.c. 50	1,3	220/380 250/433	2,3,4	Yes
Klerksdorp	a.c. 50	1,3	230/400	2,3,4	Yes
Kroonstad	a.c. 50	1,3	230/400	2,3,4	Yes

Paarl	a.c. 50	1,3	230/400	2,4	Yes
Port Elizabeth	a.c. 50	1,3	250/433	2,4	Yes
Pretoria	a.c. 50	1,3	240/415	2,3,4	Yes
Roodeport	a.c. 50	1,3	230/400	2,4	Yes
Somerset West	a.c. 50	1,3	230/400	2,4	Yes
Springs	a.c. 50	1,3	220/380 230/400	2,3,4	Yes
Umtata	a.c. 50	1,3	230/400	2,3,4	Yes
Upington	a.c. 50	1,3	230/400	2,4	Yes
Virginia	a.c. 50	1,3	230/400	2,4	Yes
Vryheid	a.c. 50	1,3	230/400	2,3,4	Yes
Walvis Bay	a.c. 50	1,3	230/400	2,3,4	Yes
Wellington	a.c. 50	1,3	230/400	2,4	Yes
Worcester	a.c. 50	1,3	230/400	2,4	Yes
South Georgia and South Sandwich Isles	Small Military Installation at Grytviken No Indigenous Inhabitants				
Spain[10,31]	a.c. 50	1,3	127/220 220/380	2,3,4	Yes
Spratly Islands	No Indigenous Inhabitants				
Sri Lanka[1,5]	a.c. 50	1,3	230/400	2,4	Yes
Sudan[1]	a.c. 50	1,3	240/415	2,4	Yes
Wau	a.c. 50	1	240	2	Yes
Suriname	a.c. 60	1,3	127/220	2,3,4	Yes
Swaziland	a.c. 50	1,3	230/400	2,4	Yes
Sweden[1,5]	a.c. 50	1,3	220/380	2,3,4,5	Yes
Switzerland[1,5]	a.c. 50	1,3	220/380	2,3,4	Yes
Syria	a.c. 50	1,3	220/380	2,3	No
Tahiti	a.c. 60	1,3	127/220	2,3,4	No
Taiwan[1]	a.c. 60	1,3	110/220	2,3,4	Yes
Tajikistan	a.c. 50	1,3	220/380	2,3	No
Tanzania[1,5]	a.c. 50	1,3	230/400	2,3,4	Yes
Thailand	a.c. 50	1,3	220/380	2,3,4	Yes

Togo	a.c. 50	1,3	220/380	2,4	Yes
Lome	a.c. 50	1,3	220/380 127/220	2,4	Yes
Tokelau	N.A.	Population 1,400			
Tonga	a.c. 50	1,3	240/415	2,3,4	N.A.
Trinidad and Tobago	a.c. 60	1,3	115/230 230/400	2,3,4	Yes
Tromelin Island	No Indigenous Inhabitants				
Tunisia[1,31]	a.c. 50	1,3	127/220 220/380	2,4	Yes
Bardo	a.c. 50	1,3	220/380	2,4	Yes
Beja	a.c. 50	1,3	220/380	2,4	Yes
Carthage	a.c. 50	1,3	220/380	2,4	Yes
Djemmal	a.c. 50	1,3	220/380	2,4	Yes
Gabes	a.c. 50	1,3	220/380	2,4	Yes
Gafsa	a.c. 50	1,3	220/380	2,4	Yes
Hammam-Lif	a.c. 50	1,3	127/220	2,4	Yes
Kalaa-Kebira	a.c. 50	1,3	220/380	2,4	Yes
Ksar Hellal	a.c. 50	1,3	220/380	2,4	Yes
Ksour Essaf	a.c. 50	1,3	220/380	2,4	Yes
La Goulette	a.c. 50	1,3	127/220	2,4	Yes
La Manouba	a.c. 50	1,3	127/220	2,4	Yes
Le Kef	a.c. 50	1,3	220/380	2,4	Yes
Mahdia	a.c. 50	1,3	220/380	2,4	Yes
Maxula-Rades	a.c. 50	1,3	220/380	2,4	Yes
Menzel Temime	a.c. 50	1,3	220/380	2,4	Yes
Moknine	a.c. 50	1,3	220/380	2,4	Yes
Monastir	a.c. 50	1,3	220/380	2,4	Yes
M'saken	a.c. 50	1,3	220/380	2,4	Yes
Nabeul	a.c. 50	1,3	220/380	2,4	Yes
Nefta	a.c. 50	1,3	220/380	2,4	Yes
Ras Djebel	a.c. 50	1,3	220/380	2,4	Yes
Tozeur	a.c. 50	1,3	220/380	2,4	Yes
Zarsis	a.c. 50	1,3	220/380	2,4	Yes
Turkey[1]	a.c. 50	1,3	220/380	2,3,4	Yes
Turkmenistan	a.c. 50	1,3	220/380	2,3	Yes
Turks & Caicos Isles					
Grand Turk, Cockburn	a.c. 60	1,3	120/240	3,4	Yes
Tuvalu					

Funafuti	a.c. 50	1,3	240/415	2,3,4	Yes
Uganda[1,19,23]	a.c. 50	1,3	240/415	2,4	Yes
Ukraine	a.c. 50	1,3	220/380	2,4	Yes
United Arab Emirates	a.c. 50	1,3	220/380	2,3,4	Yes
Abu Dhabi	a.c. 50	1,3	220/415	2,3,4	Yes
Ajman	a.c. 50	1,3	230/400	2,3,4	Yes
Sharjah	a.c. 50	1,3	230/415	2,3,4	Yes
United Kingdom:[1,7]					
England	a.c. 50	1,3	240/480	2,3	Yes
		3	240/415	4	Yes
Scotland	a.c. 50	1,3	240/415	2,4	Yes
Wales	a.c. 50	1,3	240/415	2,4	Yes
Northern Ireland	a.c. 50	1,3	220/380 230/400	2,4	Yes
Uruguay[5]	a.c. 50	1,3	220	2,3	Yes
Uzbekistan	a.c. 50	1,3	220/380	2,4	Yes
Vanuatu - Port-vila (formerly New Hebrides)	a.c. 50	1,3	240/415	2,3,4	-
Vatican City	see Holy See				
Venezuela	a.c. 60	1,3	120/240	2,3,4	Yes
Viet Nam[1,32]	a.c. 50	1,3	220/380	2,4	No
Can Tho	a.c. 50	1,3	127/220 220/380	2,4	No
Dalat	a.c. 50	1,3	120/208 220/380	2,4	No
Da Nang	a.c. 50	1,3	127/220	2,4	No
Hanoi	a.c. 50	1,3	127/220 220/380	2,4	No
Hue	a.c. 50	1,3	127/220	2,4	No
Nha Trang	a.c. 50	1,3	127/220	2,4	No
Saigon-Cholon	a.c. 50	1,3	120/208 220/380	2,4	No
Virgin Islands (British and American)	a.c. 60	1,3	120/240	2,3,4	Yes
Wake Island	No Indigenous Inhabitants				
Wales	see United Kingdom				

Wallis and Futuna	N.A.	Population 15,000			
West Bank	see Gaza				
Western Sahara	a.c. 50	1,3	220	2,3	No
Western Samoa	a.c. 50	1,3	230/400	2,3,4	Yes
Yemen, Rep. Of	a.c. 50	1,3	220/380	2,4	Yes
Hodeida	a.c. 50	1,3	220/400	2,4	No
Sanaa	a.c. 50	1,3	220/400	2,4	No
Taiz	a.c. 50	1,3	220/400	2,4	No
Yugoslavia	see Serbia - Montenegro				
Zaire, Republic Of	see Congo, The Democratic Republic of				
Zambia[1,5]	a.c. 50	1,3	220/380	2,4	Yes
Zimbabwe	a.c. 50	1,3	220/380	2,3,4	Yes

Country Specific Notes:

1. The neutral wire of the secondary distribution system is grounded.
2. The neutral wire of the secondary distribution system is grounded except in the case of Sebha.
3. The neutral wire of the secondary distribution system is grounded at the generator.
4. Separate ground and neutral wires.
5. A grounding conductor is required in the electrical cord attached to appliances.
6. A grounding conductor is required in the electrical cord attached to appliances except for class 2 appliances.
7. A grounding conductor is required in the electrical cord attached to appliances that are not double insulated.
8. A grounding conductor is required in the electrical cord attached to appliances using 10 amps and above. It is suggested but not required for appliances using less than 10 amps.
9. A grounding conductor is required in the electrical cord attached to appliances designed for 150 volts or more.
10. A grounding conductor is required for any 220/380 volt appliance.
11. A grounding conductor is required in the electrical cord attached to air conditioning appliances and electrical ranges above 8kw rating.
12. Voltage tolerance +/- 20 to 30%.
13. Voltage tolerance +/- 100%.
14. Voltage generally varies between 150 and 175. Frequent power outages.
15. Frequency and voltage tolerances +/-15%.
16. Frequency and voltage tolerances +/-25%.
17. Electric clocks lose about 6 minutes during 24 hours.
18. Voltage fluctuations are common.
19. Voltage variations sufficient to damage electrical appliances are common.
20. Voltage is being systematically changed from 127/220 to 220/380.
21. Three phase, 4-wire systems such as 120/208 are available. Also, 347/600 is available for commercial establishments.
22. Seventy-five percent of the city uses 110/220. Mostly older sector uses 150/260.
23. The nominal voltage is being standardized and converted to 220/380.
24. Nominal voltage being changed to 230/400.
25. Most residences are served by 4 wires (the 3-phase wires and neutral).
26. Guyana plans to standardize domestic power at 115/230, 60Hz, 2 & 3 wire single phase and its industrial power at 480 volts, 3-phase, 3-wire.
27. Conversion to 220/380 completed in Jakarta and other principal cities in Java. Other parts of the country are in process.
28. All household appliances must be designed to operate at 220 volts without addition of transformers or any other modification.
29. Commercial establishments use 230/460 volts.
30. 380 volts is available in industrial areas.
31. Nominal voltage of 220 is used in commercial establishments and is becoming common in private residences.
32. The electric utility system of Vietnam is to be standardized at 220/380, 3-phase, 4-wire wye. It may be several years before all of the system will be changed.

Addendum #1

A Guide to
Power Frequency Converters
GEORATOR CORPORATION

By Daniel L. Heflin

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Introduction

This is intended as a basic guide for an end user who needs to specify an appropriate power frequency converter for an application. Georator Corporation is in a unique position to provide an unbiased guide to Power Frequency Converters because we provide both solid state and rotary converters. In most situations either type may provide the desired power but there are usually clear reasons why one type is superior to the other for a given application.

A Power Frequency Converter is a machine that takes electrical input power at one frequency and voltage and provides electrical output power at a different frequency and usually at a different voltage. An example of this is to take United States 120/208 VAC 3 Phase 60 Hertz power as an input and provide 220/380 VAC 3 Phase 50 Hertz as an output, which is nominal power in many European countries.

As a refresher to those who are unfamiliar with terms such as frequency and voltage, AC[1] (Alternating Current) power is provided as a voltage sine wave of a specified frequency. Frequency is the number of cycles (called Hertz or Hz) of the voltage sine wave that occur each second. AC Voltage is defined as the RMS[2] electrical potential between a point and some given reference. For example, a L-N (Line to Neutral) voltage uses Neutral as the reference whereas a L-L (line to Line) voltage references one line against another.

Although some devices can be and are designed to operate on both 60 and 50 Hertz input power, many are not. A synchronous motor, for example, will run at a different speed, which can cause problems in many systems. Other systems may overheat, provide reduced capability, and/or have increased failure rate if operated with a power frequency different than that for which they were designed. Additionally, many regulatory agencies require testing of products at the power frequency of the country where the products will be used.

[1] AC or Alternating Current is used to describe power that has a continuously changing, usually symmetric voltage, such that each half cycle the current reverses direction.

[2] In sinusoidal systems, the RMS (mathematical Root Mean Square) voltage is 0.707 times the value of the sine wave peak.

Types of Power Frequency Converters

A common misconception is that a power frequency converter is similar to and therefore should cost about the same as a transformer used to change line voltage. This misconception about cost is further fed by the abundance of low cost DC[3] to AC inverters[4] used in automotive and RV applications.

A transformer changes the amplitude of the voltage waveform but has no effect on the frequency. It is, by closest comparison, only a single-stage “converter” of voltage but not frequency. An inverter is also a single stage converter, converting DC into a rough equivalent of AC. All true power frequency converters provide *two* stages of conversion. The incoming AC electrical power is first converted to a steady, non-alternating form of energy, and then in the second stage, the non-alternating energy is re-converted into output AC power of the new frequency. Some amount of storage capability is usually provided for the non-alternating intermediate energy stage. Implementations of this conversion scheme can be categorized into two general groups:

- Rotary (motor-generators)
- Solid State (electronic)

The major technical difference between the two is the method used to convert input power at one frequency into outgoing power at a different frequency. Rotary units use input power to run a motor, which produces mechanical energy to spin a generator, which in turn produces the required output power. Solid state units convert incoming AC power into DC, and then convert the DC into the required output power. Either method of conversion supplies an output that is acceptable for most applications but there are differences in the capabilities and features that make one type of converter more suitable for a particular application.

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[3] DC or Direct Current is used to describe power that has a fixed, non-varying voltage such that the current flow does not reverse direction.

[4] Inverters, in this context, refers to devices commonly used to change DC power to AC power by switching the DC’s polarity each half cycle to reverse the current flow. Such devices generally have poor output waveform quality that may even damage some types of equipment.

Comparative Study

The table below outlines the strengths and weaknesses of each approach. By analyzing the specific needs relative to the application, the user can make an educated choice regarding the converter type that is best for their specific application.

Comparative Features

Rotary	Solid State
Less costly per kW (or KVA)	More costly per kW (or KVA)
Costs do not increase linearly with power; e.g., 3x power costs 1.5x dollars	Costs are more linear, e.g., 3x power costs 3x dollars (because hardware expansion is linear).
More attuned to larger applications 10 KVA plus	More attuned to smaller applications 1-5 KVA
Rugged floor mount construction	Generally in equipment racks or rack mountable
Generally fixed output frequency	Highly variable output frequency, typically 45-500 Hertz
MTBF[5]: 20,000 to 32,000 Hrs. (belted) 30,000 to 60,000 Hrs. (single shaft)	MTBF: 10,000 to 20,000 Hrs.
Preventive maintenance is required, e.g., bearing maintenance, belt replacement (except single shaft units), cleaning air intakes and exhausts	Little or no preventive maintenance other than cleaning fans, exhausts
Some installation and setup is required, e.g., concrete pad, power circuits	Some installation and setup may be required, but usually less than rotary alternative
Some environmental objections, e.g., audible noise, unit weight, space factor, etc.	Fewer environmental objections, e.g., generally quieter, lighter weight, etc.

[5] MTBF Mean Time Between Failure is the mathematical mean (average) of the individual operating times before the first failure for each unit of a population

Input to the converter's motor has lagging power factor that increases with load.	Input current has high crest factor that also causes leading power factor that increases with load.
Harmonic distortion and noise on the input power is not passed to the output	Harmonic distortion and noise on the input power is not normally passed to the output, some high frequency noise may be passed to output.
Output harmonic distortion is moderately low, typically <4 to 5%	Output harmonic distortion is lower, <0.05%,
Low output source impedance	Very low output source impedance
Can source heavy overload currents 2-4 X for short periods of time, depends upon generator windings and momentum of rotating components. Overloads generally cause voltage reduction but not large waveform distortion	Can source overloads for generally shorter periods of time, depends upon capacitive storage in unit. Overloads may cause a sharp rise in distortion.
Full load efficiency 60 to 65% on smallest units (<6.25 KVA) up to 85 to 92% on large units	Full load efficiency 60 to 92 % all sizes
Efficiency varies with load, better with heavy loads	Efficiency varies with load, better with heavy resistive loads and lower output frequencies

Rotary Power Frequency Converters

Rotary power frequency converters can be further categorized as Belted, Coupled Inline and Single Shaft, each of which have features and characteristics that make them suited well to specific applications. The next few sections describe each of the types and the characteristics of them.

Belt Drive Rotary Power Frequency Converters

Belt drive units consist of a motor, generator, base, belts, pulleys and controls. The motor power is transferred to the generator via the belts and pulleys. The ratio of the sizes of the pulleys determines the speed ratio between the motor and the generator. The use of high-efficiency induction motors[6] and precision manufacturing can yield a low-cost, highly accurate (+-1%) output frequency. This high degree of accuracy is provided by properly sizing the motor such that the slip stays within tolerable limits, and by the use of precision turned V-belt pulleys to accurately set the pulley ratio. Synchronous motors[7] combined with timing belts and pulleys provide even higher frequency accuracy but are much more costly.

A variation on the induction motor frequency converter uses variable pitch pulleys to allow a variable output frequency. Although this method does allow frequency variation, the range of variation cannot approach that of solid state converters. Another method of providing a variable frequency output is using a V-S Drive[8] to control the motor speed. This method is much more costly but does allow wider variability and is more precise.

Control systems for belt drive converters vary widely depending upon type and application. The minimum is usually just a motor starter and an output voltage regulator. More complex systems may include metering for input and output current and output voltage and frequency; output overload protection; output control; thermal protection; over and under voltage protection, and many other forms of protection designed to prevent damage to the converter and or the user's load.

[6] Induction Motors inherently have slip that causes reduction in rotational speed as load increases. Typical 1800 RPM induction motors run at 1750 to 1785 RPM at full load.

[7] Synchronous motors operate at fixed rotational speeds therefore can provide very accurate converter output frequency but require more complex control system for starting, protection and converter output control than the lower cost induction motor.

[8] V-S Drive or Variable Speed Drive is an electronic system used to change the speed of a motor.

Coupled Inline Rotary Power Frequency Converters

Coupled inline rotary power frequency converters are much like the belted units described above except that power is transferred from motor to generator via an inline coupling attached to the motor and generator shafts. This coupling generally requires less maintenance than belts. The inherent difficulty with this type of unit is that no pulley ratio exists and therefore the motor and generator will rotate at the same speed. This limits the ability to convert frequency[9] because motors and generators are only available with practical numbers of poles[10]. There is however, a common application of this type of machine for line isolation instead of frequency conversion.

Coupled inline units used as line isolators prevent noise or other disturbances on the input from reaching the output. Similarly, noise or disturbances on the output will not reach the input. Many times units such as these are used to separate delicate electronics or precise test systems from motor drives or other devices that may cause significant power disturbances.

Single Shaft Rotary Power Frequency Converters

Single shaft rotary power frequency converters have both the motor and generator rotors[11] on the same shaft. These units are manufactured as a single assembly for the sole purpose of power frequency conversion as compared to the generic motors and generators employed for belted units. Instead of a pulley ratio being used to achieve a speed differential, the single shaft unit applies a ratio to the number of poles in the motor and generator halves of the unit.

Single shaft units are generally more efficient and smaller than other rotary converters. The increased efficiency is achieved since there are fewer moving parts and no losses associated with belts. These units are also generally more reliable for the same reasons. As may be expected these units are more costly than similarly rated belted units.

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[9] In rotating machines, the rotation speed is inherently related to the electrical frequency. Motor-generators that convert frequency with a single, common shaft speed must therefore have magnetic pole count ratios according to the frequency shift required. For instance, a motor of 12 poles must be matched to a generator of 10 poles to achieve 60 to 50 Hz conversion.

[10] Poles of a motor or generator are magnetic poles similar to the north and south poles of a bar magnet. There can only be an even, whole number of magnetic poles in a conventional rotary machine.

[11] A rotor is the rotating electromagnetic portion of a motor or generator, and is mounted on the rotating shaft running through the center of the unit.

Solid State Power Frequency Converters

Solid State Power Frequency Converters have very few moving parts (usually only cooling fans) therefore they have lower requirements for preventive maintenance. The increased complexity of these units does reduce MTBF. Solid state units have an input stage that converts the input AC power to DC, then stores that DC power in large capacitors. The amount of capacitor storage is one factor that determines the ability of the unit to provide large current surges that may be required by the load.

The output stages of the units generally use high power transistors such as MOSFET[12] or IGBT[13] modules. Although there are a few systems that use linear output stages[14] most use PWM[15] methods to produce the output power. In either case the output power usually has very low distortion although linear output stages may be slightly better in this respect. PWM output stages are much more efficient and therefore are almost always used for higher output solid-state units.

The Final Analysis

Solid State units are available in sizes from 1KVA or less to over 200 KVA. That range provides a large overlap between the solid state and rotary units that are also built from 1KVA to well above 200 KVA. This means that for most applications, there are sizes in both categories that will work. The user must then decide based upon the requirements of the specific application which type of system is more appropriate.

Georator Corporation has over 45 years experience in engineering electric power frequency converters for specific customer requirements. Call Georator for assistance with your application.

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[12] MOSFET or Metal Oxide Semiconductor Field Effect Transistor is a common electronic device used primarily for its ability to control large currents with very low control currents. This device can be used in linear or switching modes.

[13] IGBT or Insulated Gate Bipolar Transistor is special power device with a gate similar to an FET (described above) but with an output stage that is similar to a conventional Bipolar Junction Transistor or BJT. The BJT is the original type of transistor and has a relatively linear gain.

[14] Linear output stages are electronic amplifiers similar to those used in audio amplifiers.

[15] PWM or Pulse Width Modulation is a technique used to create an output by varying the width of fixed amplitude pulses then filtering to achieve the final output signal.

Addendum #2

U.K. Electrical Equipment Safety Regulations 1994
CE Marking Requirements

The CE Mark may be placed on electrical products by the manufacturer if it can be shown that the product complies with the safety requirements of the Low-Voltage Directive.

The requirements of the Low-Voltage Directive and applicable CE marking amendments have been placed into U.K. legislation by the Electrical Equipment (Safety) regulations of 1994 that replace the 1989 regulations. The U.K. Department of Trade and Industry has published a guidance document on the U.K. regulations. The following information summarizes items from that document.

The amended Low-Voltage Directive defines that:

1. Only electrical equipment that does not jeopardize the safety of people, domestic animals or property shall be placed on the market.
2. Only electrical equipment that satisfies the CE marking requirements will be taken as complying with the requirements of the modified Low-Voltage Directive and thereby be entitled to free circulation throughout the EEA, unless there are reasonable grounds for suspecting that the product does not in fact meet the requirements.
3. Electrical equipment is not required to be tested, or marked for approval by an independent third party.
4. Enforcement is the responsibility of each member state within its national jurisdiction.
5. Electrical equipment that complies with the 1994 regulations will be taken to comply with the modified directive and will be entitled to free circulation throughout the EEA.

An EEA-based manufacturer constitutes the first link in the supply chain permitted to affix the CE mark, originate and hold an EC Declaration of Conformity or compile and maintain the technical documentation.

Manufacturers not established within the EEA may still affix the CE mark, draw up the EC Declaration of Conformity and compile the technical documentation. If such a manufacturer has appointed an authorized representative within the EEA, that representative should retain copies of the EC Declaration of Conformity and the technical documentation. If no such representative has been appointed, the first supplier of the electrical equipment within the EEA should retain this information.

Because the 1994 regulations permit an authorized representative to undertake more tasks than may be undertaken by an importer, the manufacturer and his representative should make sure that the appointment is clearly documented and can be substantiated if required.

Subject to the conditions of appointment, the authorized representative may:

- affix the CE mark
- originate and retain the EC Declaration of Conformity
- retain the technical documentation within the EEA territory if the manufacturer is not located within the European Union.

The importer is any person who first places electrical equipment from a third country on the EEA market. Unless he or she is also the manufacturer's authorized representative, the importer cannot:

- affix the CE mark
- originate and retain the EC Declaration of Conformity
- compile the technical documentation.

The importer is, however, required to retain copies of the EC Declaration of Conformity and the technical documentation. All other suppliers – wholesalers, retailers, etc. – have a statutory duty to ensure that the equipment that they supply satisfies the safety requirements and bears a CE mark.

Electrical equipment that has been constructed in such a way as to meet the safety provisions of one or another level in an accepted hierarchy of standards and requirements will be taken to satisfy the 1994 regulations unless there are reasonable grounds for suspecting that it does not so comply. In descending order of authority, the hierarchy is as follows:

1. harmonized standards as published in the "Official Journal of the European Communities",
2. international standards as published in the "Official Journal of the European Communities" and
3. national standards where no harmonized or international standards exist, provided that such national standards do in fact satisfy the safety requirements of the regulations.

Electrical equipment that has not been manufactured to comply with one of the above categories of standards must nevertheless comply with the essential safety requirements. In such cases, it may be prudent for the supplier to have the equipment assessed for safety by an independent third party, optimally a Notified Body.

The manufacturer is responsible for ensuring that its manufacturing process conforms to that described in the technical documentation relating to the electrical equipment being produced.

Technical documentation must be such as to enable enforcement authorities to assess the conformity of the electrical equipment with the requirements of the 1994 regulations. It must, as far as is relevant for such assessment, cover the design, manufacture and operation of electrical equipment and must include the following:

1. A general description of the equipment. This requirement may normally be met by the description provided in the user's manual.
2. Design and manufacturing drawings and schemes of components, subassemblies, etc. This provision may be met by a general assembly drawing, photographs, and circuit diagrams of required elements, provided that all of these relate to a particular model and year of manufacture.
3. Any descriptions or explanations necessary to understand the drawings supplied. The user's manual may include information to fulfill this requirement.
4. A list of standards applied in full, or in part, along with descriptions of any solutions adopted to satisfy the safety requirements where specific standards have not been applied.
5. Results of all design calculations made, examinations carried out, etc. Test reports may meet this requirement if it can be demonstrated that the design calculations have been made correctly.
6. Test reports. This item could include reports originated by the manufacturer, by a Notified Body, or by any other entity that the manufacturer considers competent.
7. A copy of the EC Declaration of Conformity.

It should be noted that the CE mark is essentially a statement representing that the product meets the requirements of all applicable directives. Where exceptions exist, the technical documentation must call out those directives and regulations with which compliance is being claimed.

The information in this addendum summarizes the main points of the Low-Voltage Directive and is for your guidance only. When implementing this process – especially for the first time – a copy of the Low-Voltage Directive must be studied and advice of independent consultants should be obtained.