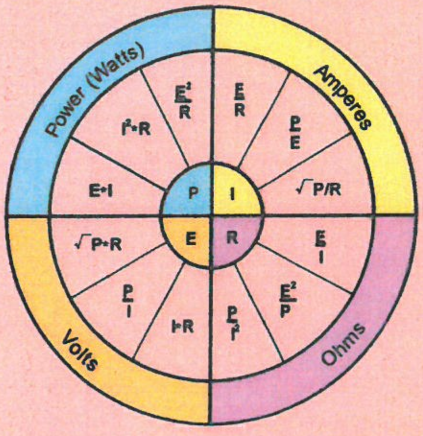
Rules of Electricity

Ohm's Law
One volt of electromotive force will force one amp of current flow through one ohm of resistance.

E = Voltage
I = Current
R = Resistance
P = Power (watts)
There are 3 formulas for each value

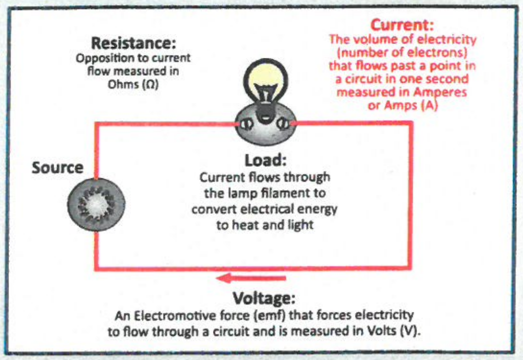


Example:
1. What is the current in a 120 volt circuit with a load of 1800 watts?
   I = P/E = 1800/120 = 15 amps

2. What is the Voltage of a circuit with a resistance of 12 Ω and a current draw of 10 amps?
   E = IR = 10 x 12 = 120 volts

Kirchhoff's Laws
Current: the sum of current in a junction equals the sum of current out of the junction. (what goes in must come out)
Voltage: The algebraic sum of the voltage (potential) differences in any loop must equal zero. **(voltage applied equals voltage drops)**

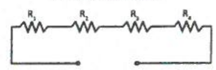
Basic Electrical Circuit



Voltage forces current flow through a resistance. The current returns to the source. There must be a complete path for electrical current to flow.

Series & Parallel Circuits

Series Circuits



A series circuit is a circuit that has only one path through which electrons may flow.

Rules for a Series Circuit
The total current in a series circuit is equal to the current in any other part of the circuit.

Total Current $I_T = I_1 = I_2 = I_3 = I_4$

The total voltage in a series circuit is equal to the sum of the voltages across all parts of the circuit.

Total Voltage $E_T = E_1 + E_2 + E_3 + E_4$, etc.

The total resistance of a series circuit is equal to the sum of the resistances of all the parts of the circuit.

Total Resistance $R_T = R_1 + R_2 + R_3$, etc.

Rules for a Parallel Circuit

The total current in a parallel circuit is equal to the sum of the currents in all the branches of the circuit.

Total Current $I_T = I_1 + I_2 + I_3$

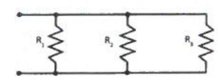
The total voltage across any branch in parallel is equal to the voltage across any other branch and the total voltage.

Total Voltage $E_T = E_1 = E_2 = E_3 = E_4$, etc.

The total resistance of a parallel circuit is found by applying Ohm's Law to the total value of the circuit.

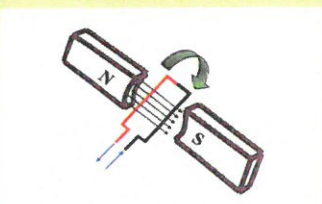
Total Resistance $(R_T) = \frac{\text{Total Voltage } (E_T)}{\text{Total Amperes } (I_T)}$

Parallel Circuits



A parallel circuit is a circuit that has more than one path through which the electrons may flow.

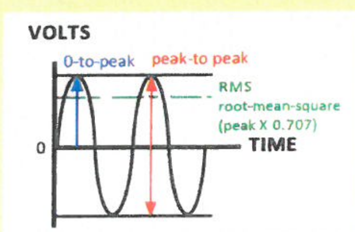
Electrical Generation

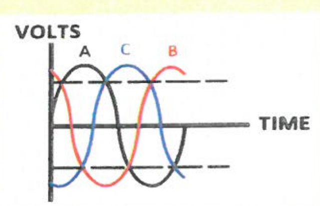


Electrical Generators: Devices that convert mechanical energy into electrical energy. Operation of power generators is based on the phenomenon of electromagnetic induction: whenever a conductor moves relative to a magnetic field, voltage is induced in the conductor.

Single-Phase Power

Single-Phase (1Ø) Power: One complete cycle of a sine wave. North America operates at a frequency of 60 Hz (cycles per second).



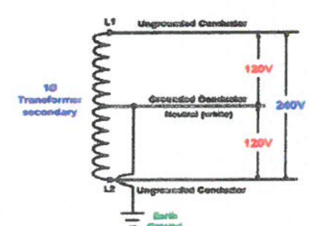


Three-Phase Power

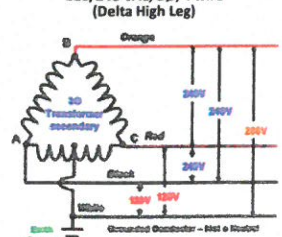
Three-Phase (3Ø) Power: Consist of three separate sine waves equally spaced 120° apart. The advantage of 3Ø power is more energy can be delivered to a load per unit of time. Most commercial and industrial facilities are supplied with 3Ø power.

Common Distribution Systems

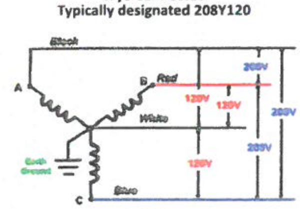
120/240 VAC, 1Ø, 3 wire



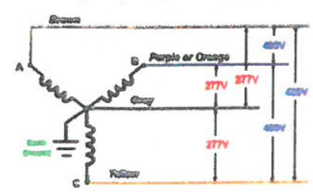
120/240 VAC, 3Ø, 4 wire
(Delta High Leg)



120/208 VAC, 3Ø, 4 wire
Wye Connected
Typically designated 208Y120



277/480VAC, 3Ø, 4 wire
Wye Connected
Typically designated 480Y277



Electrical Formulas

Variable	Word Formula w/Units	Simplified Formula
Resistance - R	Ohms = Volts/Amperes	$R = \frac{E}{I}$
Amperes- I	Amperes = Volts/Ohms	$I = \frac{E}{R}$
Volts - E	Volts = Amperes x Ohms	E= I x R
% Efficiency - %Eff	$\%Eff = \frac{746 \times \text{Output Horsepower}}{\text{Input Watts}}$	$\%Eff = \frac{746 \times HP_{Out}}{W_{In}}$
Single Phase		
Kilowatts - KW	$KW = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor}}{1000}$	$KW = \frac{E \times I \times PF}{1000}$
Amperes - I	$I = \frac{746 \times \text{Horsepower}}{\text{Volts} \times \text{Efficiency} \times \text{Power Factor}}$	$I = \frac{746 \times HP}{E \times \%Eff \times PF}$
% Efficiency - %Eff	$\%Eff = \frac{746 \times \text{Horsepower}}{\text{Volts} \times \text{Amperes} \times \text{Power Factor}}$	$\%Eff = \frac{746 \times HP}{E \times I \times PF}$
Power Factor - PF	$PF = \frac{\text{Input Watts}}{\text{Volts} \times \text{Amperes}}$	$PF = \frac{W}{E \times I}$
Three Phase		
Kilowatts - Kw	$KW = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor} \times 1.732}{1000}$	$KW = \frac{E \times I \times PF \times 1.732}{1000}$
Volt-Amperes - VA	VA = Volts x Amperes x 1.732	VA = E x I x 1.732
Amperes - I	$I = \frac{746 \times \text{Horsepower}}{\text{Volts} \times \text{Efficiency} \times \text{Power Factor} \times 1.732}$	$I = \frac{746 \times HP}{E \times \%Eff \times PF \times 1.732}$
% Efficiency	$\%Eff = \frac{746 \times \text{Horsepower}}{\text{Volts} \times \text{Amperes} \times \text{Power Factor} \times 1.732}$	$\%Eff = \frac{746 \times HP}{E \times I \times PF \times 1.732}$
Power Factor - PF	$PF = \frac{\text{Input Watts}}{\text{Volts} \times \text{Amperes} \times 1.732}$	$PF = \frac{W}{E \times I \times 1.732}$
Horsepower		
Horsepower (1 Ph)	$HP = \frac{\text{Volts} \times \text{Amperes} \times \text{Efficiency} \times \text{Power Factor}}{746}$	$HP = \frac{E \times I \times \%Eff \times PF}{746}$
Horsepower (3 Ph)	$HP = \frac{\text{Volts} \times \text{Amperes} \times 1.732 \times \text{Efficiency} \times \text{Power Factor}}{746}$	$HP = \frac{E \times I \times 1.732 \times \%Eff \times PF}{746}$
Power DC Circuits		
Watts (W)	Watts = Volts x Amperes	W = EI
Amperes - I	Amperes = Watts / Volts	I = W/E
Horsepower - HP	$HP = \frac{\text{Volts} \times \text{Amperes} \times \text{Efficiency}}{746}$	$HP = \frac{E \times I \times \%Eff}{746}$

Minimum Working Clearances

Nominal Voltage to Ground	Condition		
	1	2	3
	Minimum Clear Distance (ft.)		
0 150 V	3	3	3
151 - 600 V	3	3.5	4
601 - 2500 V	3	4	5
2501 - 9000 V	4	5	6
9001 - 25000 V	5	6	9
25001 V - 75 kV	6	8	10
Above 75 kV	8	10	12

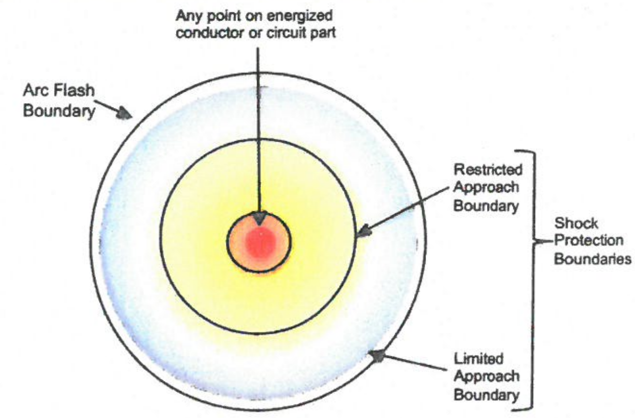
Condition 1 - Exposed live parts on one side of the working space and no live or grounded parts on the other. Exposed live parts on both sides that effectively guarded by insulating materials.

Condition 2 - Exposed live parts on one side of the work space and grounded parts on the other. Concrete, brick, and tiles walls are considered grounded.

Condition 3 - Exposed live parts on both sides of the work space.

Refer to NEC® Table 110.34 (A) for additional information.

Flash/Shock Boundaries & PPE



Note: Per NFPA 70E® Article 130.5(A) Arc Flash Boundary for systems ≥ 50 volts shall be the distance at which the incident energy equals 1.2 cal/cm².

Current vs. Sensation Results

Current	Sensation
0.3 to 3 milliamps	Tingling
3 to 10 milliamps	Muscle contraction and pain
10 to 40 milliamps	"Let-go" threshold
30 to 75 milliamps	Respiratory paralysis
100 to 200 milliamps	Ventricular fibrillation
200 to 500 milliamps	Heart clamps tight
1.5 amps	Tissue and organs start to burn

The length of time a body is exposed to electrical current, as well as the path of the current through the body, will determine the severity of electrical shock. When a person becomes electrocuted, care must be exercised to keep the rescue personnel from becoming part of the electrical circuit; otherwise, a rescuer may also become injured.

Energized Electrical Work Permit

When energized work is permitted in accordance with 130.2(A), an energized electrical work permit shall be required under the following conditions:
1. When work is performed within the restricted approach boundary
2. When the employee interacts with the equipment when conductors or circuit parts are not exposed but an increased likelihood of injury from an exposure to an arc flash hazard exists
Required by OSHA / 70E®
• If the voltage is greater than 50 volts
• If equipment can not be placed in an electrically safe work condition
• Work is considered energized electrical work and can be performed by written permit only
• Can only be filled out by qualified persons
• Example of Work Permit in Annex J of the NFPA 70E®
Exceptions
• Testing, troubleshooting, and voltage measuring
• Thermography and visual inspections if the restricted approach boundary is not crossed
• Access to and egress from an area with energized electrical equipment if no electrical work is performed and the restricted approach boundary is not crossed
• General housekeeping and miscellaneous non-electrical tasks if the restricted approach boundary is not crossed

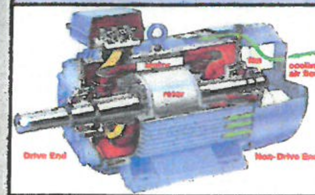
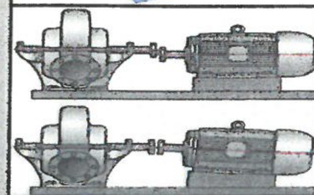
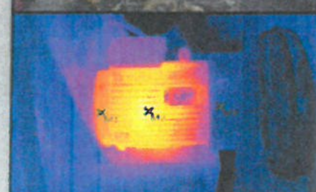
OSHA 29 CFR 1910.333(c)(2)

Work on energized equipment. Only qualified persons may work on electric circuit parts or equipment that have not been de-energized under the procedures of paragraph (b) of this section. Such persons shall be capable of working safely on energized circuits and shall be familiar with the proper use of special precautionary techniques, personal protective equipment, insulating and shielding materials, and insulated tools.

Motor Troubleshooting Chart

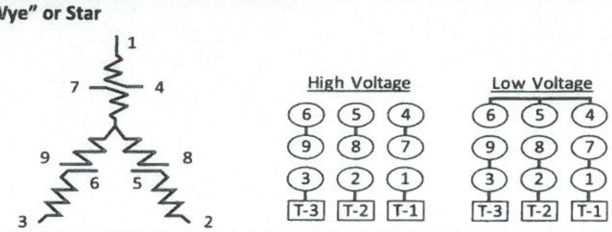
General Problem	Probable Cause	Corrective Action
Motor fails to start after initial installation	-Motor is wired wrong	-Verify motor is wired correctly
	-Motor damaged or rotor is striking stator	-Replace motor or disassemble and repair
	-Rear fan stuck on guard	-Remove cover and repair
		Always ensure that the motor (rotor) turns freely before it is installed
Motor used to run but now fails to start	-Fuse or circuit breaker tripped	-Replace fuse or reset the circuit breaker
	-Stator is shorted or grounded (Motor makes a humming noise and the circuit breaker or fuse will trip.)	-Disassemble the motor and inspect the windings and internal connections. A shorted stator will show burn signs. Motor must be replaced or the stator rewound.
	-Motor overloaded	-Verify that the load is not bound.
		-Verify current draw (amps) of motor versus nameplate data
Motor takes too long to accelerate	-Bad bearings	-Noisy or rough feeling bearings should be replaced
	-Voltage too low	-Make sure that the voltage is within 10% of the motor's nameplate rating.
Motor runs wrong way	-Incorrect wiring	-Rewire motor according to wiring schematic. For three phase motors, simply switch any two power leads.
Motor overload protection continually trips.	-Load too high	-Verify that the load is not jammed. If motor is a replacement, verify that the rating is the same as the old motor. If previous motor was a special design, a stock motor may not be able to duplicate the performance. Remove the load from the motor and inspect the amp draw of the motor unloaded. It should be less than the full load rating stamped on the nameplate.
	-Ambient temperature too high.	-Verify that the motor is getting enough air for proper cooling. Most motors are designed to run in an ambient temperature of less than 40°C. (Note: A properly operating motor may be hot to the touch.)
	-Winding shorted or grounded	-Inspect stator for defects, or loose or cut wires that may cause it to go to ground.
No power at the motor	-Fuses are blown or the circuit breakers have tripped	-Turn off the power and remove the fuses. Check for continuity with an ohmmeter. Replace the blown fuses or reset the circuit breaker. If the new fuses blow or the circuit breaker trips,the electrical installation, motor, and wires must be checked for defects.
Starter does not energize	-Starter coil not functioning	-If there is no voltage, check the control circuit fuses. If there is voltage, check the holding coil for faulty connections. Ensure that the holding coil is designed to operate with the available control voltage. Replace the coil if defects are found.
Motor vibrates.	-Motor misaligned to load	-Realign load.
	-Motor bearings defective	-Test motor by itself. If bearings are bad, you will hear noise or feel roughness. Replace bearings. Add oil if a sleeve of bearing. Add grease if bearings have grease fittings.
	-Motor may have too much endplay	-With the motor disconnected from power turned shaft. It should move but with some resistance. If the shaft moves in and out too freely, this may indicate a preload problem and the bearings may need additional shimming.
Bearings continuously fail.	-Load to motor may be excessive or unbalanced.	-Besides checking load, also inspect drive belt tension to ensure it's not too tight may be too high. An unbalanced load will also cause the bearings to fail.
	-High ambient temperature	-If the motor is used in a high ambient, a different type of bearing grease may be required. You may need to consult the factory or a bearing distributor.

Common Motor Failure

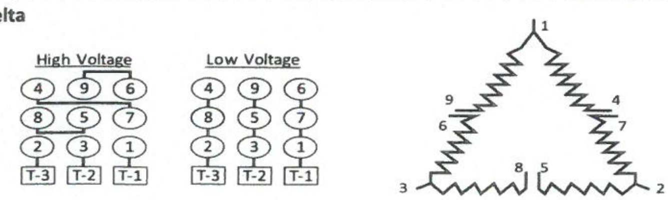
General Problem	Type of Failure	Percentage of Failure
	Rotor Failure	5%
	Misalignment	9%
	Old Age	10%
	Bearing Failure	13%
	Single Phasing	14%
	Contaminants	19%
	Overloading	30%

Three Phase AC Motor Wiring

"Wye" or Star



Delta



Branch Circuit Protective Devices

PERCENT OF FULL-LOAD CURRENT				
Type of Motor	Non-time Delay Fuse	Duel Element (time-delay fuse)	Inverse Time (circuit breaker)	Instantaneous trip (circuit breaker)
Single Phase	300%	175%	250%	800%
AC Polyphase (other than wound-rotor)	300%	175%	250%	800%
Squirrel Cage (other than Design B)	300%	175%	250%	800%
Squirrel Cage (Design B energy eff.)	300%	175%	250%	1100%
Synchronous	300%	175%	250%	800%
Wound Rotor	150%	150%	150%	800%
Direct Current (DC)	150%	150%	150%	250%

Refer to NEC® Article 430.52 for additional information.

AC Motor Data

Horsepower	Voltage	Full-Load Current	Maximum Allowable Overcurrent Protection Device (Amps)			Wire Size *	Conduit Size (EMT) Max 3 Current Carrying Conductors	Motor Starter Size
			Nontime Delay Fuse	Duel Element (time-delay fuse)	Inverse Time (circuit breaker)			
1/2	230V	2.2	6	6	15	14	1/2	0
	460V	1.1	3	3	15	14	1/2	0
3/4	230V	3.2	10	6	15	14	1/2	0
	460V	1.6	6	3	15	14	1/2	0
1	230V	4.2	15	10	15	14	1/2	0
	460V	2.1	6	6	15	14	1/2	0
1 1/2	230V	6	20	10	15	14	1/2	0
	460V	3	10	6	15	14	1/2	0
2	230V	6.8	20	15	20	14	1/2	0
	460V	3.4	10	6	10	14	1/2	0
3	230V	9.6	30	20	25	14	1/2	0
	460V	4.8	15	10	15	14	1/2	0
5	230V	15.2	50	30	40	12	1/2	1
	460V	7.6	25	15	20	14	1/2	0
7 1/2	230V	22	70	40	60	10	1/2	1
	460V	11	35	20	30	14	1/2	1
10	230V	28	90	50	70	8	3/4	2
	460V	14	45	25	35	12	1/2	1
15	230V	42	125	75	110	6	1	2
	460V	21	70	40	60	10	1/2	2
20	230V	54	175	100	150	4	1	3
	460V	27	90	50	70	10	1/2	2
25	230V	68	200	125	175	3	1 1/4	3
	460V	34	100	60	90	8	3/4	2

*THHN, THWN, or MTW with all terminations rated at 75° C or above.

For additional information refer to the NEC®.

General Motor Rules

When an AC motor is energized, a high inrush current occurs that can reach 4 to 8 times the normal current. Due to this high starting current, the motor and motor circuit conductors are allowed to be protected by fuses and circuit breakers at values that are higher than the actual motor and conductor ampere ratings. These larger valued overcurrent devices do not provide overload protection. Motor overload protection is calculated from the motor nameplate data.

Motor Rules

- Use FLC (Full-Load Current) from NEC® Tables instead of motor nameplate data.
- Branch Circuit Conductors - Use 125% of FLC (Full-Load Current) to find proper conductor size.
- Branch Circuit OCP (Over Current Protection) Size - Use percentages given in NEC® Table 430.52.
- Feeder Conductor Size - 125% of largest motor and the sum of the rest.
- Feeder OCP (Over Current Protection) - Use the largest OCP plus the rest of the full-load currents.

Branch Circuit Example

25 HP (Squirrel Cage), 460 VAC, 60 Hz., 3 PH., 30 FLA (Full-Load Amps), Design B, S.F. 1.15, FLC (Full-Load Current) = 34A. *From NEC® Tables.*

Branch Circuit Conductor Sizing
125% of FLC
34 X 125% = 42.5
#8 AWG (Minimum)

Branch Circuit OCP Sizing
175% of FLC (Dual Element Fuse)
34 X 175% = 59.5
60 Amps (Maximum)

Motor Overload Protection

Motors with a Service Factor (SF) of 1.15 or higher, use 125% of nameplate FLA (Full-Load Amps). For all others, use 115% of motor nameplate FLA (Full-Load Amps).

Sizing Motor Overload Example

30 Amps (FLA) X 125% = 37.5A (Full-Load Current is from the motor nameplate)
For proper motor protection, select the overload protection for 37.5 Amperes. If this is not available, select the next size larger.

Refer to NEC® Article 430 for additional information.

Motor Nameplate Information

AC MOTOR				MADE IN USA	
1 FRAME	2 TYPE (ENCL.)	3 INSUL. CLASS	IDENTIFICATION NO.		
324T	TEFC	F	8779787246		
4 HP	5 RPM	6 VOLTS	7 FLA	8 HZ.	9 SF
25	1760	230 / 460	60 / 30	60	1.15
10 CODE LTR	11 PHASE	12 DUTY	13 AMB.	14 BEARINGS	
				DE	ODE
H	3	CONT.	40°C	6312	6311

1. Frame

Motor frame size have been standardized with a uniform frame size numbering system. This system was developed by NEMA and specific frame sizes have been assigned to standard motor ratings based on enclosure, horsepower and speed.

2. Type/Enclosure

This designation, often shown as "ENCL." on the nameplate, classifies the motor as its degree of protection from its environment, and its method of cooling.

3. INSUL. Class/Insulation Class

An industry standard classification of the thermal tolerance of the motor winding. Insulation is crucial in a motor. This determined by the ambient temperature, the heat generated at fully loaded conditions (temperature rise), and the thermal capacity of the motor insulation. These materials are classified as A, B, F, and H.

4. Horsepower

Shaft horsepower is a measure of the motors mechanical output rating, its ability to deliver the torque required for the load at rated speed. It is usually give in "HP" on the name plate. The standardized NEMA table of motor horsepower ratings run from 1 to 450 hp. When application horsepower requirements fall between two standardized values, the larger size is usually chosen. In some instances motors may be rated in KW. (746 watts per motor horsepower)

5. RPM - Revolutions per Minute

Full load RPM (Revolutions per Minute) of the motor is the approximate speed under full-load conditions, when the voltage and frequency are at the rated values. An induction motor's speed is always less than synchronous speed and drops of as load increases.

6. Voltage

The rated voltage is the voltage at which the motor is designed to operate and yield optimal performance. Nameplate defined parameters for the motor such as power factor, efficiency, torque, and current are at rated voltage and frequency.

7. FLA - Full Load Amperage

When the full-load torque and horsepower is reach, the corresponding amperage is know as the full load amperage (FLA). The name plate FLA is used to select the correct wire size, motor starter, and overload protection devices necessary to serve and protect the motor.

8. HZ - Hertz

Rated frequency is the frequency the motor is designed to operate and is represented in Hertz (Hz, cycles per second). In North America and Canada, this frequency is 60 Hz (cycles). In other parts of the world, the frequency may be 50 or 60 HZ.

9. SF - Service Factor

Motor Service Factor (SF) is the percentage of overloading the motor can handle for short periods when normally within the correct voltage tolerances.

10. Code Letter - Locked Rotor

When AC motors are started with full voltage applied, they create an inrush current that is usually many times greater than the value of the Full-Load Current. The value of this high current can be important on some installations because it can cause a voltage dip that might affect other equipment. The start inrush current has been standardized and defined by a series of code letters which group motors based on the amount of inrush in terms of kilovolt amperes.

11. Phase

This represents the number of AC power lines supplying the motor. Typically either single-phase or three-phase.

12. Duty

NEMA motors refer to duty cycle as continuous, intermittent, or special duty (typically expressed in minutes). Continuous Duty motors work at a constant load for enough time to reach temperature equilibrium. Intermittent duty motors work at a constant load, but not long enough to reach temperature equilibrium and the off period is long enough for the motor to return to ambient temperature.

13. AMB. - Ambient Temperature

The maximum ambient temperature at which the motor can operate and still be within the tolerance of the insulation class at the maximum temperature rise.

14. Bearings

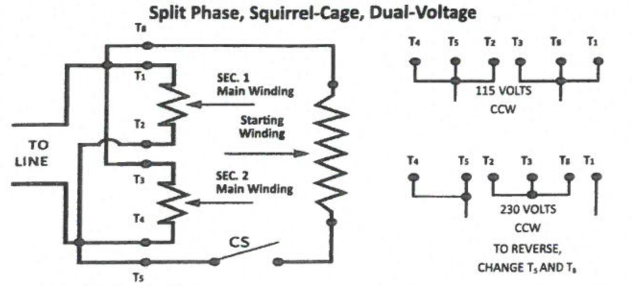
Though NEMA does not require it, many manufacturers supply nameplate data on bearings. Many special bearings are applied in motors for reasons such as high speed, high temperature, high thrust, or low noise. The types of bearings used are Sleeve, Ball, Ball and Sleeve, and Roller.

Formulas - Electrical

Variable	Word Formula w/Units	Simplified Formula
Resistance - R	Ohms = Volts/Amperes	$R = \frac{E}{I}$
Amperes- I	Amperes = Volts/Ohms	$I = \frac{E}{R}$
Volts - E	Volts = Amperes x Ohms	E= I x R
% Efficiency - %Eff	$\%Eff = \frac{746 \times \text{Output Horsepower}}{\text{Input Watts}}$	$\%Eff = \frac{746 \times HP_{Out}}{W_{In}}$
Single Phase		
Kilowatts - KW	$KW = \frac{\text{Volts x Amperes x Power Factor}}{1000}$	$KW = \frac{E \times I \times PF}{1000}$
Amperes - I	$I = \frac{746 \times \text{Horsepower}}{\text{Volts x Efficiency x Power Factor}}$	$I = \frac{746 \times HP}{E \times \%Eff \times PF}$
% Efficiency - %Eff	$\%Eff = \frac{746 \times \text{Horsepower}}{\text{Volts x Amperes x Power Factor}}$	$\%Eff = \frac{746 \times HP}{E \times I \times PF}$
Power Factor - PF	$PF = \frac{\text{Input Watts}}{\text{Volts x Amperes}}$	$PF = \frac{W}{E \times I}$
Three Phase		
Kilowatts - Kw	$KW = \frac{\text{Volts x Amperes x Power Factor x } 1.732}{1000}$	$KW = \frac{E \times I \times PF \times 1.732}{1000}$
Volt-Amperes - VA	VA = Volts x Amperes x 1.732	VA = E x I x 1.732
Amperes - I	$I = \frac{746 \times \text{Horsepower}}{\text{Volts x Efficiency x Power Factor x } 1.732}$	$I = \frac{746 \times HP}{E \times \%Eff \times PF \times 1.732}$
% Efficiency	$\%Eff = \frac{746 \times \text{Horsepower}}{\text{Volts x Amperes x Power Factor x } 1.732}$	$\%Eff = \frac{746 \times HP}{E \times I \times PF \times 1.732}$
Power Factor - PF	$PF = \frac{\text{Input Watts}}{\text{Volts x Amperes x } 1.732}$	$PF = \frac{W}{E \times I \times 1.732}$
Horsepower		
Horsepower (1 Ph)	$HP = \frac{\text{Volts x Amperes x Efficiency x Power Factor}}{746}$	$HP = \frac{E \times I \times \%Eff \times PF}{746}$
Horsepower (3 Ph)	$HP = \frac{\text{Volts x Amperes x } 1.732 \text{ x Efficiency x Power Factor}}{746}$	$HP = \frac{E \times I \times 1.732 \times \%Eff \times PF}{746}$
Power DC Circuits		
Watts (W)	Watts = Volts x Amperes	W = EI
Amperes - I	Amperes = Watts / Volts	I = W/E
Horsepower - HP	$HP = \frac{\text{Volts x Amperes x Efficiency}}{746}$	$HP = \frac{E \times I \times \%Eff}{746}$

Single Phase AC Motor Wiring

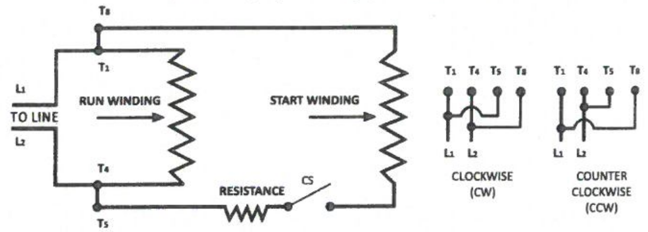
Split Phase, Squirrel-Cage, Dual-Voltage



Terminal Color Marking
T_1 - Blue, T_2 - White
T_3 - Orange, T_4 - Yellow
T_5 - Black, T_8 - Red

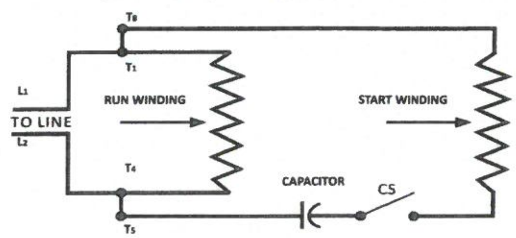
Split-phase motors are usually fractional horsepower. The number of poles must be changes to change speeds

Split Phase, Squirrel-Cage, Resistance Start



Note: A resistance start motor has a resistance connected in series with the start windings. The centrifugal switch (CS) opens after reaching 75% of normal speed

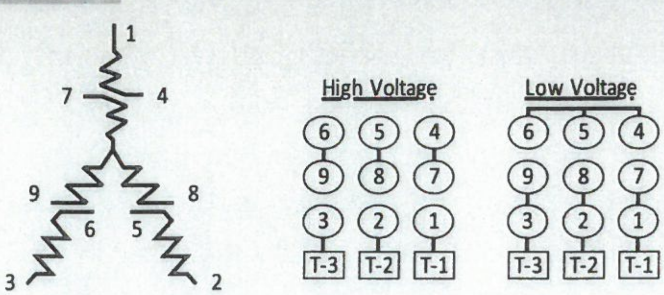
Split Phase, Squirrel-Cage, Capacitor Start



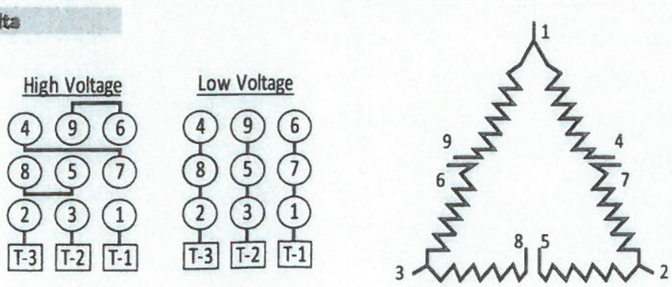
Note: The capacitor start motor is employed where a high starting torque is required. The centrifugal switch (CS) opens after reaching 75% of normal speed.

Three Phase AC Motor Wiring

"Y" or Star



Delta



Always refer to manufacturer's recommendations for proper motor wiring

Motor Full-Load Current

Motor (HP)	Full-Load Current (Amps): Single Phase 115 V	Single Phase 230 V	Three Phase (AC) 208 V	Three Phase (AC) 230 V	Three Phase (AC) 460 V	Three Phase (AC) 575 V	DC 120 V	DC 240 V
1/4	5.8	2.9	1.1	0.9	0.5	0.4	3.1	1.6
1/3	7.2	3.6	1.3	1.1	0.6	0.5	4.1	2
1/2	9.8	4.9	2.4	2.2	1.1	0.9	5.4	2.7
3/4	13.8	6.9	3.5	3.2	1.6	1.3	7.6	3.8
1	16	8	4.6	4.2	2.1	1.7	9.5	4.7
1 1/2	20	10	6.6	6	3	2.4	13.2	6.6
2	24	12	7.5	6.8	3.4	2.7	17	8.5
3	34	17	10.6	9.6	4.8	3.9	25	12.2
5	56	28	16.7	15.2	7.6	6.1	40	20
7 1/2	80	40	24	22	11	9	58	29
10	100	50	31	28	14	11	76	38
15			46	42	21	17		55
20			59	54	27	22		72
25			75	68	34	27		89
30			88	80	40	32		106
40			114	104	52	41		140
50			143	130	65	52		173
60			169	154	77	62		206
75			211	192	96	77		255
100			273	248	124	99		341

For additional information refer to NEC® Tables 430.247, 430.248, and 430.250

Industrial Lighting

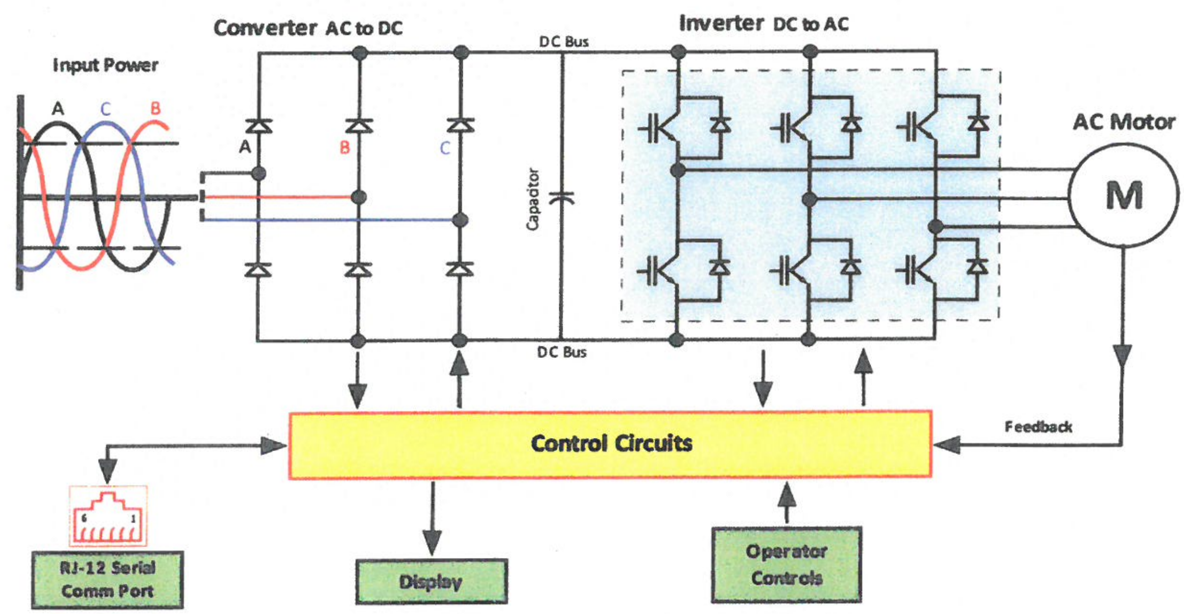
Lamp Types and Characteristics			
Lamp	**Lamp Life**	**Advantages**	**Disadvantages**
Induction	100,000 hours	Instant illumination upon start-up or warm restart. Crisp, white light > 80 color rending index. Low operation cost.	Initial cost is higher than HID type luminaires.
High Pressure Sodium	24,000 hours	Good beam control. Highest light output (lumens per watt). Low operating cost. Shortest restart time of HID lamps (instant with optional restrike).	High initial cost. Requires warm-up period.
Metal Halide Pulse Start	15,000 - 30,000 hours	Increased lumen output over standard metal halide by 25 to 50%. Better lumen maintenance (80%). Superior cold starting (-40°C). Improved color stability. Improved lamp-to-lamp color consistency. Warm up time 2 minutes. Restrike time 3 - 4 minutes.	High initial cost. Requires warm-up period. Does not restart immediately after power outage.
Metal Halide	7500 (+) hours	Moderately long lamp life. High light output (lumens per watt). Makes colors look close to natural. Low operating cost.	High initial cost. Requires warm-up period. Does not restart immediately after power outage.
Mercury	24,000 hours	Long lamp life. High light output per watt. Low operating cost.	High initial cost. Requires warm-up period. Does not restart immediately after power outage.
Fluorescent	7500 - 24,000 hours	Long lamp life. High light output per watt. Low operating cost. Low brightness. Cool operation.	High initial cost. Poor light control. Output may vary with ambient temperature.
Incandescent	500 - 2000 hours	Low initial cost. Good color rendition. Good light control. Instant start.	Low light output (lumens per watt). Short lamp life. High operating cost.

Meter Categories

Category Rating	Use
CAT I	Protected electronic equipment; high-voltage, low-energy sources derived from a high-winding resistance transformer.
CAT II	1-phase receptacle connected loads; appliances, portable tools, outlets at more than 30 feet from CAT III source or more than 60 feet from CAT IV source.
CAT III	3-phase distribution, including single-phase commercial lighting; switchgear, polyphase motors, bus and feeders, lighting systems in larger buildings.
CAT IV	3-phase at utility connection, any outdoor conductors; "Origin of installation", electricity meters, service drop from pole to building, overhead lines etc.

A greater voltage rating within a category indicates the multimeter can withstand a more powerful transient (for example, a CAT III – 1000V meter offers greater protection than a CAT III – 600V meter). However, confusion occurs when people think a higher voltage rating on a lower category meter will give better protection. A CAT II – 1000V meter will NOT protect the operator better than a CAT III – 600V meter, because the source impedance increases with the category. Even though the voltage rating could appear lower, the higher category multimeter offers transient protection several or many times higher than the lower one because of the source impedance.

Variable Frequency Drive (VFD)



Troubleshooting VFDs

Key Points

- You are troubleshooting an application, not just a VFD.
- Most people tend to over troubleshoot the problem, in turn causing new problems for themselves.
- Use all your senses in troubleshooting. (sight, sound, smell, hearing, and feel)
- Always use the manufacturer's manual during troubleshooting.
- Most accidents, on the job, occur while troubleshooting and repairing equipment.

Conditions Required for Proper Operation of VFDs

1. **Power**
2. **DC Buss Voltage**
3. **Motor**
4. **Enable or Permissive Signal**
5. **A Run or Start Command**
6. **Reference Speed Signal**

The steps needed to verify each of the four items varies from different manufacturers. The manual must be consulted for these steps.

Tips

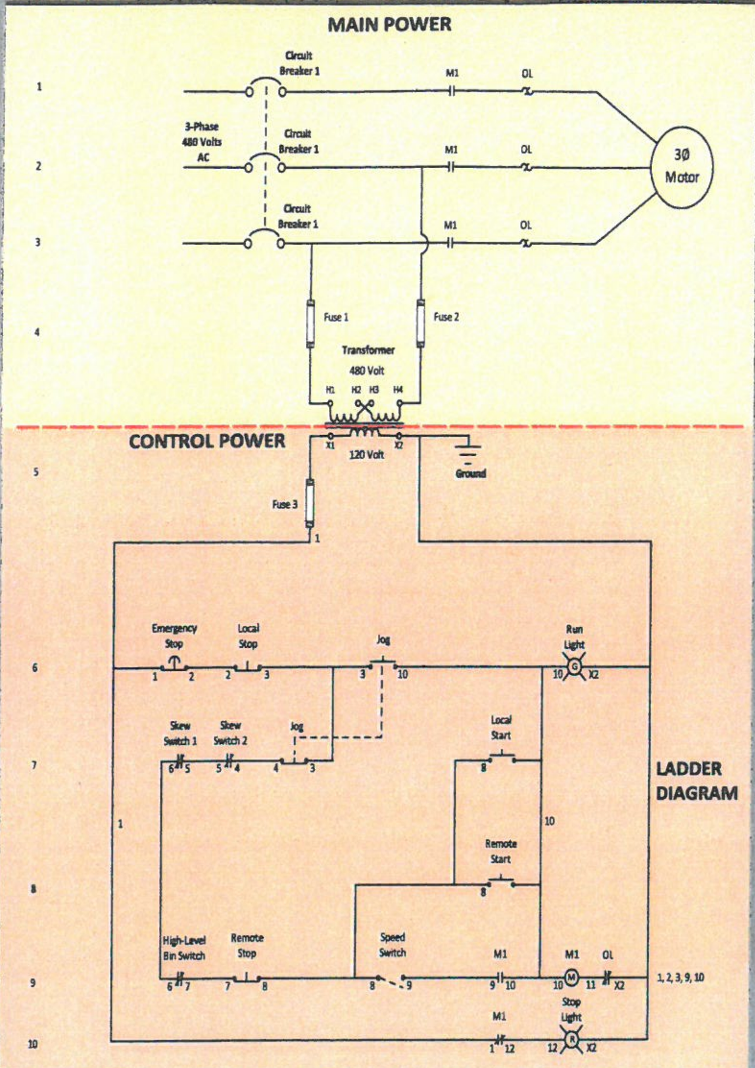
- Never change two at the same time. Change one item at a time and see what effect it has. If none is noticed, put it back the way it was.
- If you remove more than one of anything (wire, card screw, etc.), label it or make a drawing of where it came from. A lot of time can be wasted trying to remember where it came from.

Troubleshooting VFDs

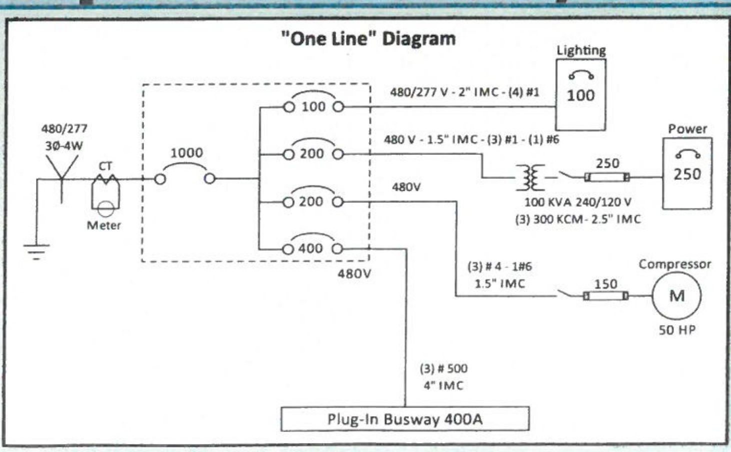
Tips (Continued)

- If you make a measurement or take a reading, write the information down. This will prevent having to take the same readings again.
- Do not connect or install anything (fuses, circuit boards, wires, etc.) while the equipment is energized.
- Do not disconnect or remove anything (fuses, circuit boards, wires, etc.) while the equipment is energized.
- Do not jump out, disconnect, bypass, remove, or disable any safety device, fuse, breaker, or over current relay. During troubleshooting, you could make a mistake and short something out. Without the safety's or overcurrent protection devices, you have no protection.
- Never put more than one of anything in the equipment. If you replace a fuse and it blows a second time, locate what is causing the fuse to blow. Do not continue to replace circuit boards either.
- Just because a problem goes away, it doesn't mean that you fixed the problem.
- Never troubleshoot to destruction. If you think putting a piece of copper pipe or tubing, in place of a fuse, will help. You will be making a big mistake.
- When the little voice in your head says, "you have got nothing else to try", stop all troubleshooting actions. When there is no plan of action in troubleshooting, you place yourself in a position in which you can get hurt or potentially destroy the equipment.

Industrial Control Ladder Diagram

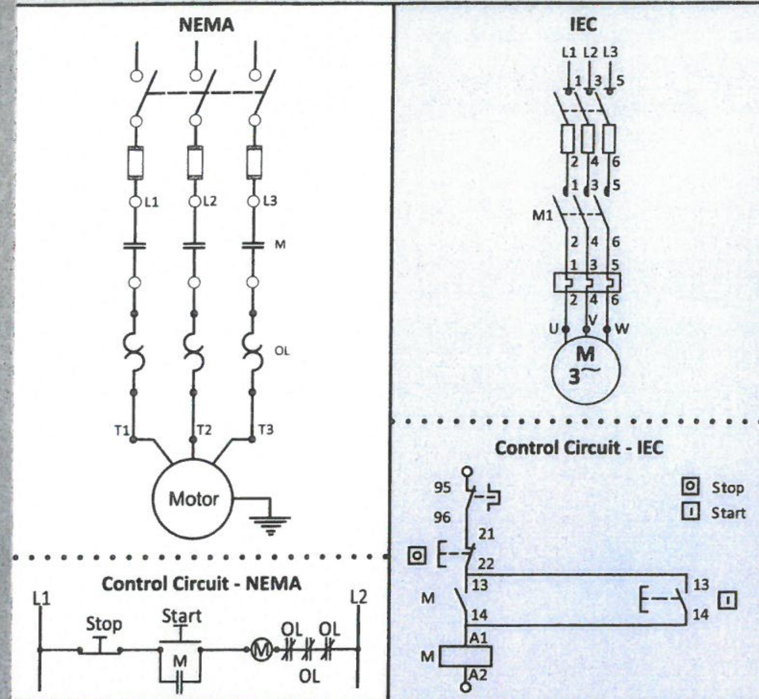


Simplified 3-Phase Power System



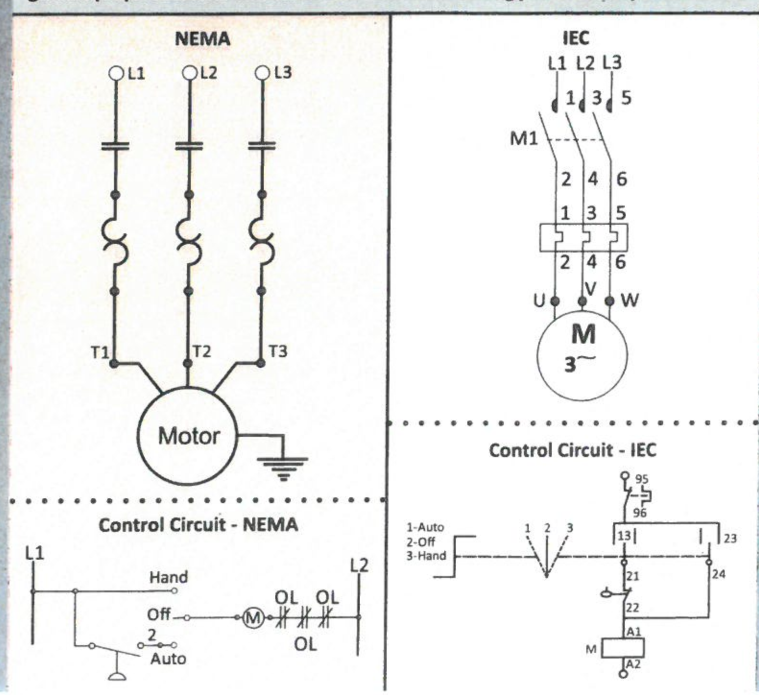
Combination Starter w/ Fused Disconnect

A combination starter with fused or breaker disconnection protects personnel from live parts and provides a means for short-circuit motor protection of line voltage.



Full Voltage, Non-Reversing Starter

Across-the-line, or full voltage non-reversing (FVNR), is the most commonly used general purpose starter. This starter connects the incoming power directly to the motor.



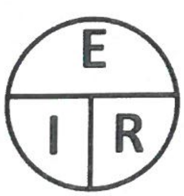
Electrical Troubleshooting

⚠ DANGER Before using a voltmeter on electrical components, do the following:

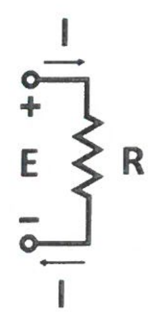
- Conduct a hazard assessment and follow approved safe work practices.
- Wear appropriate protective clothing and equipment.
- Use insulated gloves, tools, blankets, and barriers if required.

For more information, refer to the HOLT CAT Electrical Safety Policy and Procedures or your Company's Safety Policy.

Ohm's Law Fundamentals



E, **I**, and **R**, the parameters of Ohm's law.



E (Volts) = Electromotive Force. The potential difference measured across the conductor in units of volts.

I (Amperage) = Intensity. The current through the conductor in units of amperes.

R (Ohm) = Resistance. The resistance of the load in units of ohms.

Electrical Troubleshooting

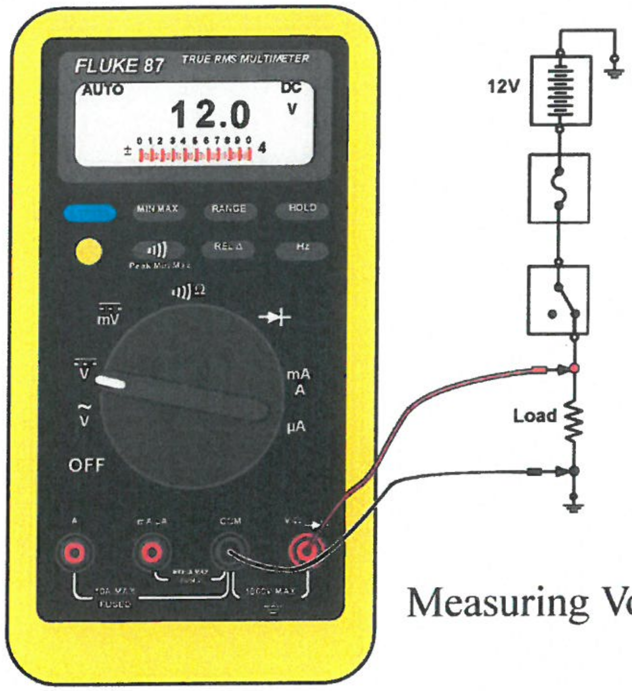
When using the multimeter to make voltage measurements it is important to remember that the voltmeter must always be connected in parallel with the load or circuit under test. The accuracy of the multimeter is approximately ± 0.01% in the five ac/dc voltage ranges with an input impedance of approximately 10 M∧ when connected in parallel.

To measure voltage perform the following tasks:

- Make sure the circuit is turned ON.
- Place the black meter lead in the COM input port on the meter and the red lead in the VOLT/OHM input port.
- Place the rotary switch in the desired position AC or DC.
- Place the black meter lead in the on the low side or the ground side of the component or circuit being measured.
- Place the red meter lead in the on the high side or the positive side of the component or circuit being measured.

NOTE: The **Fluke 87** illustrated in these pages is used with permission from the Fluke Corporation.

Electrical Troubleshooting



Measuring Voltage Drop

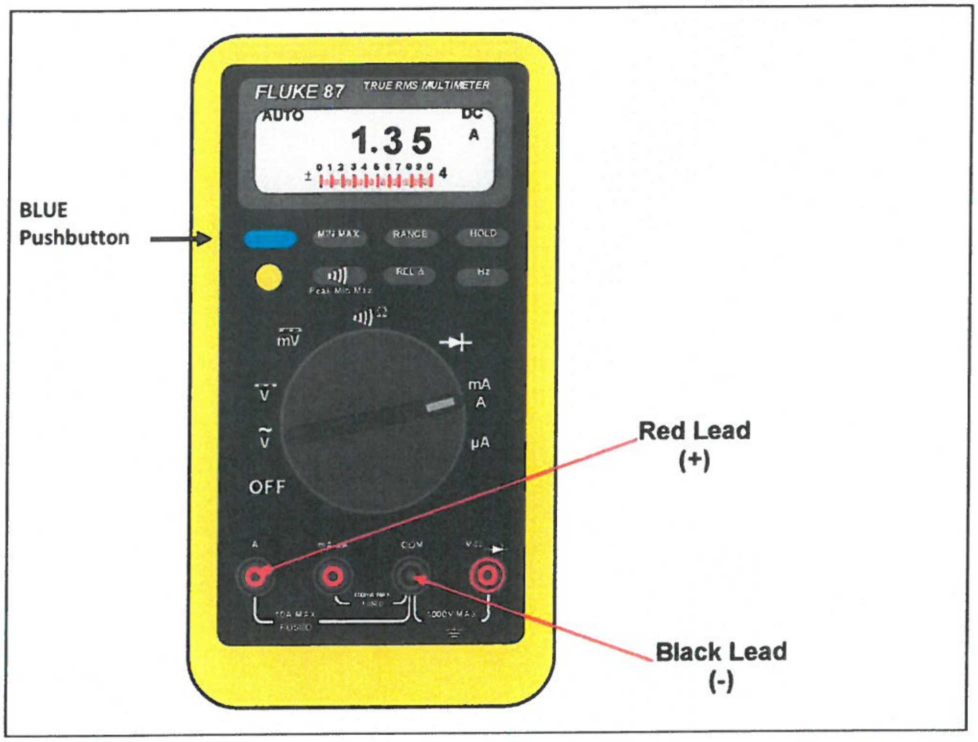
Measuring Voltage Drop

Observe the circuit above. The test leads are connected in parallel across the circuit load. With a 12 volt power source connected to the load, the meter should read a voltage drop equal to the source voltage or 12 volts.

If the meter reads a voltage drop less than 12 volts, it would indicate that an unwanted resistance was present in the circuit. A logical process would be to measure the voltage drop across the closed switch contacts. If a voltage reading was present it would indicate that the switch contacts were corroded, requiring the switch to be replaced.

The digital multimeter is a high impedance meter. This means the meter will not significantly increase the current flow in the circuit being measured. Voltage measurements should always be made with the circuit under power. The digital multimeter is ideal for use in circuits controlled by solid state devices such as, electronic components and computers.

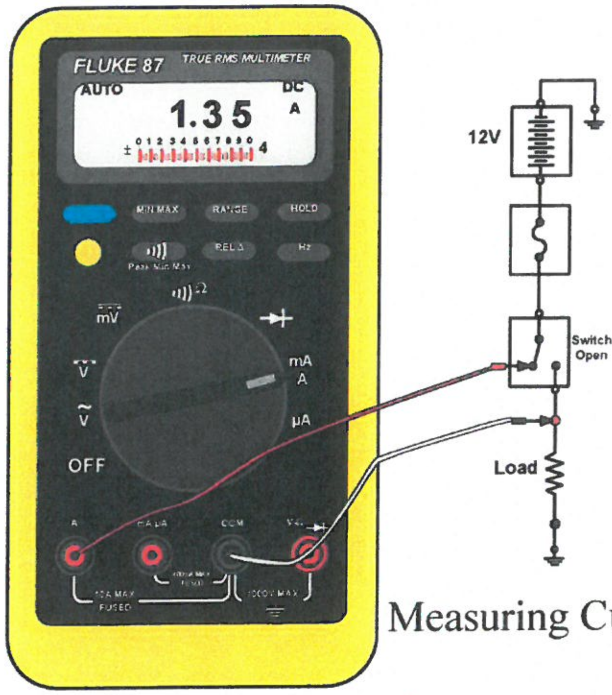
Electrical Troubleshooting



When using the multimeter to make current measurements it is necessary that the meter probes must be connected in SERIES with the load or circuit under test. To toggle between alternating and direct current measurements, use the BLUE pushbutton.

When measuring current, the meter's internal shunt resistors develop a voltage across the meter's terminals called "burden voltage." The burden voltage is very low, but could possibly affect precision measurements. When measuring current flow, the Fluke 87 multimeter is designed with low resistance to not affect the current flow in the circuit. When measuring current in a circuit, always start with the red lead of the multimeter in the Amp input (10 A fused) of the meter. Only move the red lead into the mA/μA input after you have determined the current is below the mA/μA input maximum current rating (400 mA).

The meter has a "buffer" which allows it to momentarily measure current flows higher than 10A. This buffer is designed to handle the "surge" current when a circuit is first turned on. As stated earlier, the meter is capable of reading 20 amps for a period not to exceed 30 seconds.



Measuring Current Flow

Measuring Current Flow

To measure current, perform the following tasks:

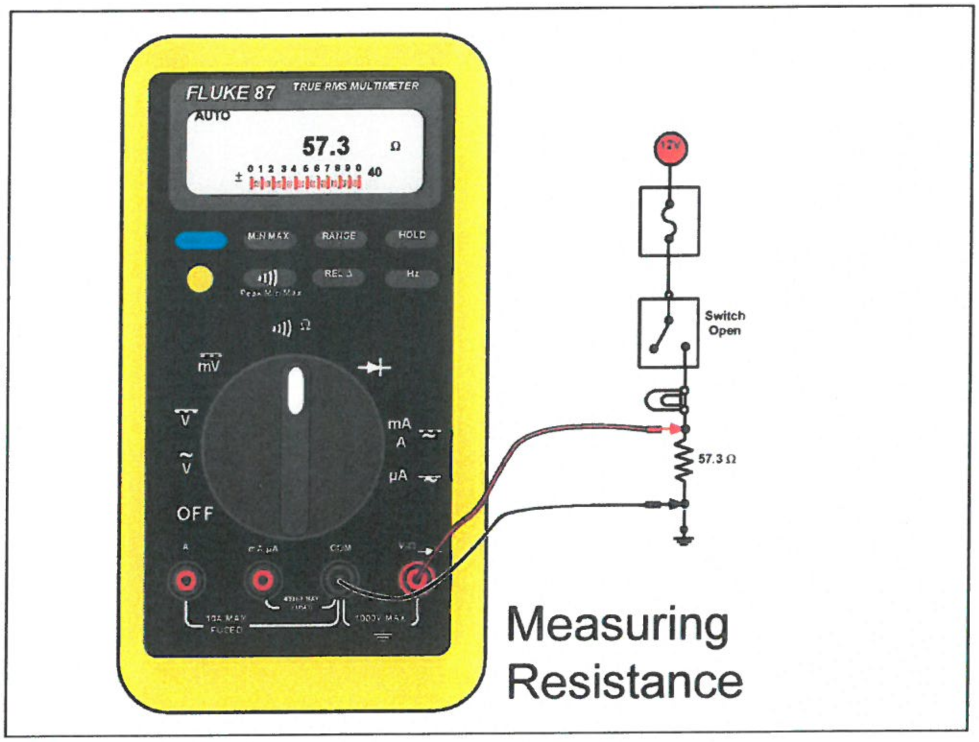
- Place the black multimeter input lead in the COM port and the red input lead in the A (amp) port.
- Create an open in the circuit, preferably by “pulling” the fuse, or by "opening" the switch.
- Place the leads in SERIES with the circuit, so that the circuit amperage is flowing through the meter.
- Apply power to the circuit.

Caution: If the current flow exceeds the rating of the fuse in the meter, the fuse will "open."

Measuring Resistance

When using the multimeter to make resistance measurements it is necessary to turn off the circuit power and discharge all capacitors before attempting in-circuit measurements. If an external voltage is present across the component being tested, it will be impossible to record an accurate measurement. The digital multimeter measures resistance by passing a known current through the external circuit or component and measures the respective voltage drop. The meter then internally calculates the resistance using the Ohm's Law equation $R = E/I$. It is important to remember, the resistance displayed by the meter is the total resistance through all possible paths between the two meter probes.

To accurately measure most circuits or components it is therefore necessary to isolate the circuit or component from other paths. Additionally, the resistance of the test leads can affect the accuracy when the meter is in its lowest (400 ohm) range. The expected error is approximately 0.1 to 0.2 ohms for a standard pair of test leads. To determine the actual error, short the test leads together and read the value displayed on the meter. Use the (REL) mode on the digital multimeter to automatically subtract the lead resistance from the actual measurements.



Measuring Resistance

To accurately measure resistance, perform the following tasks:

- Make sure the circuit or component power is turned OFF.
- Place the red lead in the jack marked Volt/Ohms and the black lead in the jack marked COM.
- Place the rotary selector in the Ω position.
- Place the meter leads ACROSS the component or circuit being measured.

IMPORTANT: It is important that your fingers are not touching the tips of the meter leads when performing resistance measurements. Internal body resistance can affect the measurement

NOTE: In the circuit shown, the power source is isolated from the circuit by "opening" the switch. It also, isolates the resistor from any other path that may affect the accuracy of the measurement.