Electrical Basics
&
Classic Control

COURSE CONTENTS

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Electrical Basics
&
Control Circuits

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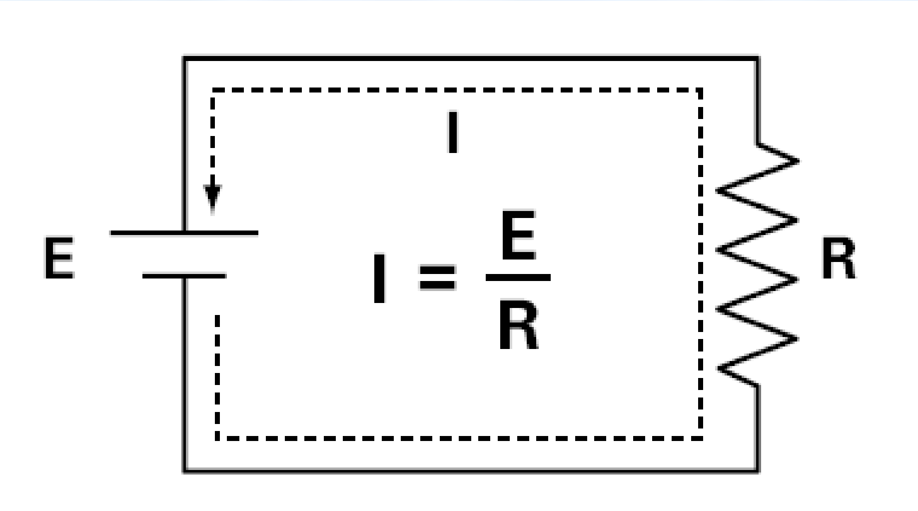
CHAPTER 1

Electrical Basics

Electric Circuit

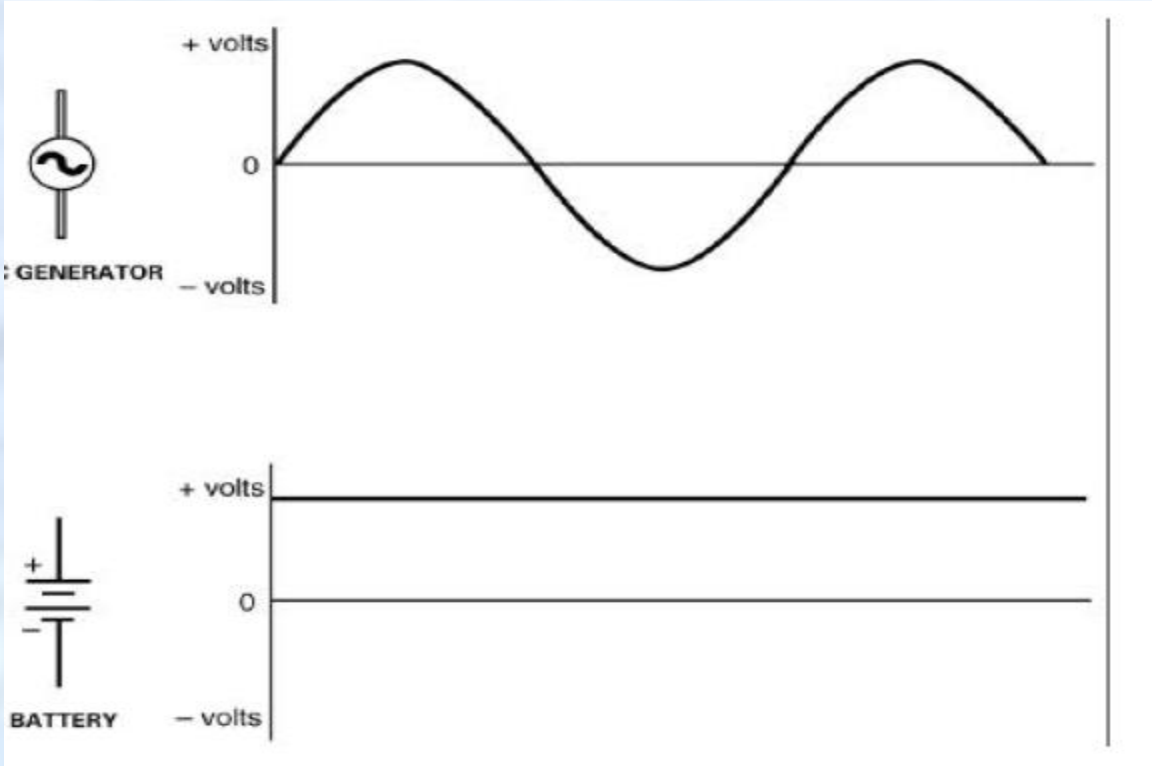
A simple electric circuit consists of a voltage source, some type of loads, and conductors to allow electrons to flow between the voltage source and the load.



Direct & Alternating current

There are two methods that voltage forces current to flow:

- Direct Current
- Alternating Current



peak = RMS x 1.414

Direct & Alternating current

DC (Thomas Edison)

Unidirectional (one way street)

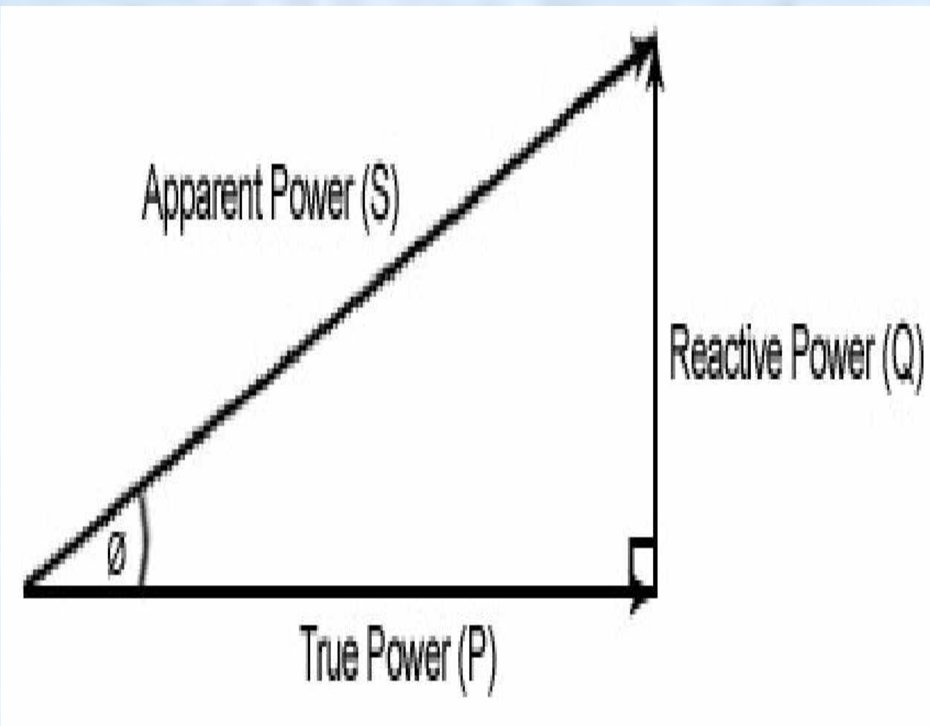
AC (Nicolas Tesla)

Bidirectional (HZ) (number of alternating in a second

50 HZ === It is alternated 50 times in a second.

Electric Power

The apparent power is a combination of both reactive power and true power. True power is a result of resistive components and reactive power is a result of capacitive and inductive components.



P = true power $P = I^2R$ $P = \frac{E^2}{R}$

Measured in units of ***Watts***

Q = reactive power $Q = I^2X$ $Q = \frac{E^2}{X}$

Measured in units of ***Volt-Amps-Reactive (VAR)***

S = apparent power $S = I^2Z$ $S = \frac{E^2}{Z}$ $S = IE$

Measured in units of ***Volt-Amps (VA)***

Formula Cheatsheet

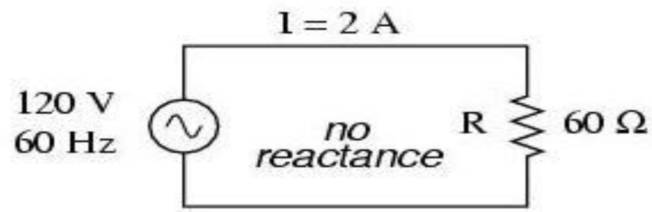
1. Impedance $Z = R$ *or* X_L *or* X_C *(if only one is present)*
2. Impedance **in series only** $Z = \sqrt{(R^2 + X^2)}$ *(if both R and one type of X are present)*
3. Impedance **in series only** $Z = \sqrt{(R^2 + (|X_L - X_C|)^2)}$ *(if R, X_L, and X_C are all present)*
4. Impedance **in any circuit** $= R + jX$ *(j is the imaginary number $\sqrt{(-1)}$)*
5. Resistance $R = I / \Delta V$
6. Inductive reactance $X_L = 2\pi f L = \omega L$
7. Capacative reactance $X_C = {}^{1}/_{2\pi f C} = {}^{1}/_{\omega C}$

Resistive load only:

P = true power $= I^2R = 240$ W

Q = reactive power $= I^2X = 0$ VAR

S = apparent power $= I^2Z = 240$ VA

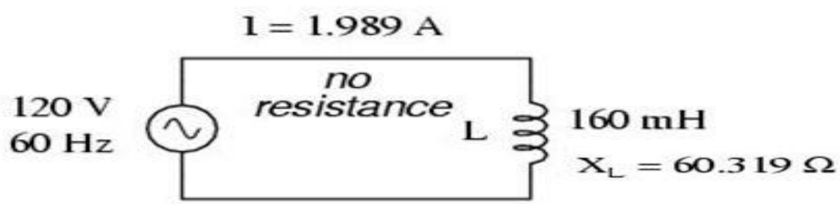


Reactive load only:

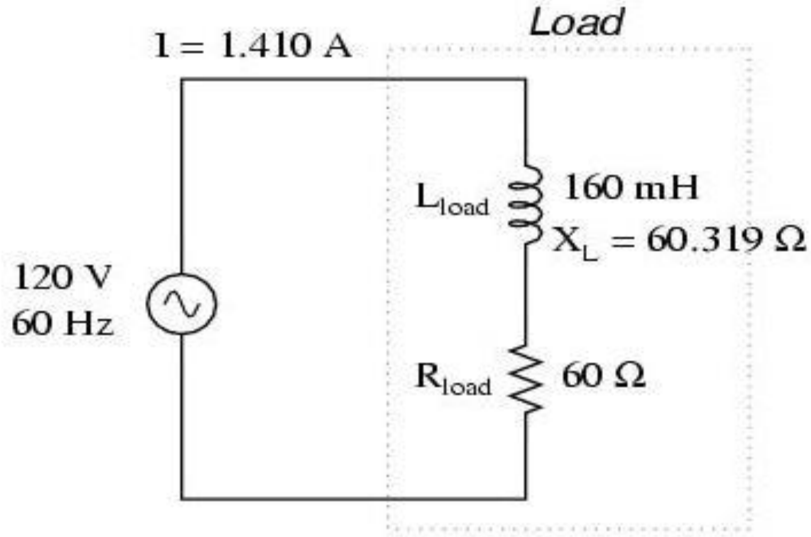
P = true power $= I^2R = 0$ W

Q = reactive power $= I^2X = 238.73$ VAR

S = apparent power $= I^2Z = 238.73$ VA



Resistive/reactive load:



P = true power = I^2R = 119.365 W

Q = reactive power = I^2X = 119.998 VAR

S = apparent power = I^2Z = 169.256 VA

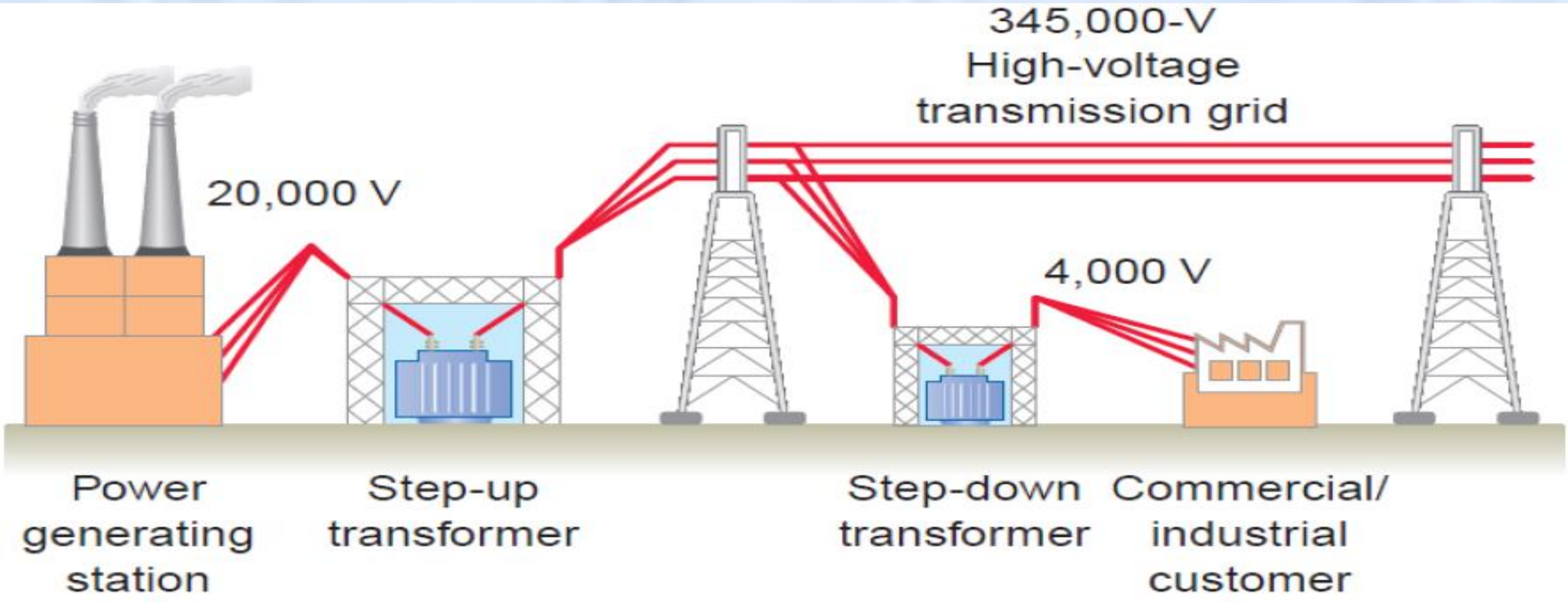
Magnetic field VS Electric field

Magnetic fields are created whenever there is a flow of electric current. This can also be thought of as the flow of water in a garden hose. As the amount of current flowing increases, the level of magnetic field increases. Magnetic fields are measured in milliGauss (mG).

An electric field occurs wherever a voltage is present. Electric fields are created around appliances and wires wherever a voltage exists. You can think of electric voltage as the pressure of water in a garden hose – the higher the voltage, the stronger the electric field strength. Electric field strength is measured in volts per meter (V/m). The strength of an electric field decreases rapidly as you move away from the source. Electric fields can also be shielded by many objects, such as trees or the walls of a building.

	Electric Field	Magnetic Field
Nature	Created around electric charge	Created around moving electric charge and magnets
Units	Newton per coulomb, volts per meter	Gauss or Tesla
Force	Proportional to the electric charge	Proportional to charge and speed of electric charge
Movement In Electromagnetic field	Perpendicular to the magnetic field	Perpendicular to the electric field
Electromagnetic Field	Generates VARS (Capacitive)	Absorbs VARS (Inductive)

Power Flow



Generation → Transmission → Distribution

Generation Plant:
Named by the name of the mechanical unit that move the turbine
- **Gas Station**
- **Steam Station**
- **Hydraulic Station**

- Transmission is done from the **Generation** Plants to **Distribution** Plants
- Transmission is done by
  - **Underground Cables**
  - **Over Head Transmission Line (OHTL)**

- Distribution is done by the Distribution Plants
- Distribution means Distribute the **Electric Source** on the **Electric Loads**
  - **Domestic Loads**
  - **Industrial Loads**
  - **Commercial Loads**

Energy Price

تعريفة عام ٢٠١٥ / ٢٠١٦ للاستخدامات المختلفة

	مقابل القدرة (٢) (جنيه/ك.و.شهر)	متوسط سعر الطاقة (٤) (قرش/ك.و.س)	خارج الذروة (٣) (قرش/ك.و.س)	داخل الذروة (٣) (قرش/ك.و.س)
استخدامات الطاقة على الجهد الفائق (٢٢٠ – ١٣٢ ك . ف)				
كيما	-		٤,٧	
مترو الأنفاق	-		١٨,٠	
الصناعات الكثيفة (١)	١٥,٠	٣٩,٦	٣٦,٦	٥٤,٨
باقي المشتركين	١٥,٠	٢٦,٩	٢٤,٨	٣٧,٢
استخدامات الطاقة على الجهد العالي (٦٦ – ٢٢ ك . ف)				
مترو الأنفاق	-		٢٠,٥٠	
الصناعات الكثيفة (١)	٢٦,٠	٤١,١	٣٧,٩	٥٦,٩
باقي المشتركين	٢٦,٠	٢٩,١	٢٦,٩	٤٠,٣
استخدامات الطاقة على الجهد المتوسط (٢٢ – ١١ ك . ف)				
جميع المشتركين	٣٠,٠	٤٣,٥	٤٠,٢	٦٠,٢
استخدامات الطاقة على الجهد المنخفض (٣٨٠ فولت)				
الري			٢٢,٠	
باقي المشتركين			٤٦,٠	
إنارة عامة			٥٨,٠	
الاستخدامات المنزلية				
شرائح الاستهلاك (ك.و.س / شهر)	قرش / ك.و.س			
من ٠ — ٥٠	٧,٥			
من ٥١ إلى ١٠٠	١٤,٥			
٠ إلى ٢٠٠	١٦,٠			
٢٠١ إلى ٣٥٠	٣٠,٥			
٣٥١ إلى ٦٥٠	٤٠,٥			
٦٥١ إلى ١٠٠٠	٧١,٠			
أكثر من ١٠٠٠	٨٤,٠			
الاستخدامات التجارية				
شرائح الاستهلاك (ك.و.س / شهر)	قرش / ك.و.س			
من ٠ — ١٠٠	٣٢,٠			
من ٠ ـ ٢٥٠	٥٠,٠			
من ٢٥١ إلى ٦٠٠	٦١,٠			
٦٠١ إلى ١٠٠٠	٨١,٠			
أكثر من ١٠٠٠	٨٦,٠			

Energy Price

تعريفة الكهرباء لعام ٢٠١٦/٢٠١٧
للاستخدامات المختلفة

الاستخدام	مقابل القدرة(٢) (جنيه / ك.و.شهر)	متوسط سعر الطاقة (٤) (قرش/ك.و.س)	خارج الذروة(٣) (قرش/ك.و.س)	داخل الذروة(٣) (قرش/ك.و.س)
استخدامات الطاقة على الجهد الفائق(٢٢٠-١٣٢ ك.ف)				
كيما	—		٩,٤	
مترو الأنفاق	—		٣٠,٠	
الصناعات الكثيفة(١)	٢٥,٠	٤٦,٥	٤٢,٩	٦٤,٤
باقى المشتركين	٢٥,٠	٤١,٩	٣٨,٧	٥٨,١
استخدامات الطاقة على الجهد العالى (٦٦ ك.ف)				
مترو الانفاق	—		٣٢,٠٠	
الصناعات الكثيفة(١)	٣٥,٠	٤٩,٠	٤٥,٢	٦٧,٨
باقى المشتركين	٣٥,٠	٤٤,٦	٤١,١	٦١,٧
استخدامات الطاقة على الجهد المتوسط (٢٢-١١ ك.ف)				
جميع المشتركين	٤٥,٠	٥٢,٠	٤٨,٠	٧٢,٠
استخدامات الطاقة على الجهد المنخفض (٣٨٠ فولت)				
الري			٢٧,١	
باقى المشتركين			٦٤,٤	
انارة عامة			٧٥,٠	

الاستخدامات المنزلية

شرائح الاستهلاك (ك.و.س / شهر)	قرش/ك.و.س
من ٠ - ٥٠	١١,٠
من ٥١ الى ١٠٠	١٩,٠
من ٠ الى ٢٠٠	٢١,٥
من ٢٠١ الى ٣٥٠	٤٢,٠
من ٣٥١ الى ٦٥٠	٥٥,٠
من ٦٥١ الى ١٠٠٠	٩٥,٠
من صفر لأكثر من ١٠٠٠	٩٥,٠

Energy Price

رقم العداد	النوع	القراءة السابقة ٢٠١٤-٠٧-٠١	القراءة الحالية ٢٠١٤-٠٨-٠١	الفرق	الثابت	يوليو"٢٠١٤ الاستهلاك
٦٦٥٤٤٩٧	فعال ١صفحة ٢٦	٣٩٢٩١.٠٠	٤١٢١٧.٠٠	١٩٢٦.٠٠	١٠٠٠	١٩٢٦٠٠٠
٥٧١٢٦٤٢	فعال ٢صفحة ٢٦	٥١٦٣٥.٠٠	٥٢١٠٤.٠٠	٤٦٩.٠٠	١٠٠٠	٤٦٩٠٠٠

	اجمالى الاستهلاك ك.و.س	٢٣٩٥٠٠٠
	يخصم الانارة ٠.٥ %	١١٩٧٥
	استهلاك القوى المحركة	٢٣٨٣٠٢٥
اولا	اجمالى قيمة القوى المحركة	٦٥٥٣٣١.٨٨
	دمغة نوعية للقوى المحركة	١٤٢٩.٨٢
	فرق دمغة نوعية للقوى المحركة	٠.٠٣
	مقابل القدره خلال العام السابق +مقابل خدمة العملاء ٢٠جنيه شهريا	٧٥٠٢٠.٠٠
	دمغا ت ورسوم	٠.٤١
	اجمالى مطالبة القوى المحركة	٧٣١٧٨٢.١٤
ثانيا	اجمالى قيمة الانارة ١١٩٧٥ ك.و.س	٣٢٩٣.١٣
	اذاعه ٢ مليم	٢٣.٩٥
	دمغه نوعية ٣٠مليم	٣٥٩.٢٥
	دمغات ورسوم	٠.٤١
	اجمالى مطالبة الانارة	٣٦٧٦.٧٤
	اجمالى المطالبة (فقط وقدره سبعمائة خمسة و ثلاثون ألفا و أربعمائة ثمانية وخمسون جنيها و ٨٨ قرشا لاغير) ٧٣٥٤٥٨.٨٨	٧٣٥٤٥٨.٨٨

ملحوظة١: يراعي عدم اجراء اي تعديل في هذه المطالبة قبل الرجوع الينا.

ملحوظة٢: لأتعتبر هذه المطالبة مخالصة عن مبالغ سابقة مستحقة للشركة المصرية لنقل الكهرباء.

Energy Price

رقم العداد	نوع العداد	رقم المحاولة	القراءة الحالية	الثابت	الاجمالى
	قياس اقصى حمل اثناء الذروة	٦٨	٤	١٠٠٠	٤٠٠٠

متوسط الحمل الشهرى $= \dfrac{\text{الطاقة المستهلكة خلال الشهر}}{\text{عدد ساعات الشهر}} = \dfrac{٢٣٥٤٥٨٠}{٧٤٤}$ ٣١٦٥ ٨٣٥

٣٣٢٣.٢٥

متوسط الحمل الشهرى $= \dfrac{١٠٥}{١٠٠}$

بناء على الفقرة (ج) من البند الرابع من عقد توريد التيار الكهربى :

فى حالة زيادةالحمل الأقصى خلال فترة الذروة عن ١٠٥% من متوسط الحمل الشهرى

يلتزم المنتفع بأداء مايقابل كامل الزيادة عن متوسط الحمل الشهرى

بسعر قدره ٢جنيه / كيلو وات	٨٣٥.٠٠
فروق الاحمال	١٦٧٠.٠٠
قيمة فروق الاحمال	٠.٤١٠
دمغات ورسوم	١٦٧٠.٤١
احمالى المطالبة (فقط وقدرة ألف وستمائة و سبعون جنيها و ٤١ قرش لاغير.)	

Energy Price

مقابل القدرة

اقصى حمل x 35 ج

نحيط سيادتكم علما أن مقابل القدره الذى تم المحاسبة عليه خلال الفترة من أكتوبر٢٠١٦/ ديسمبر٢٠١٦ أعلى أقصى حمل هو ١٣٥٠ ك٠و (أسترشادى من الفترة السابقة) وحيث أنه تم تسجيل أقصى حمل وصلت إليه شركتكم فعلى خلال الفترة من أكتوبر٢٠١٦ حتى ديسمبر ٢٠١٦هو ٨٣٠ ك٠و(فعلى) ٠

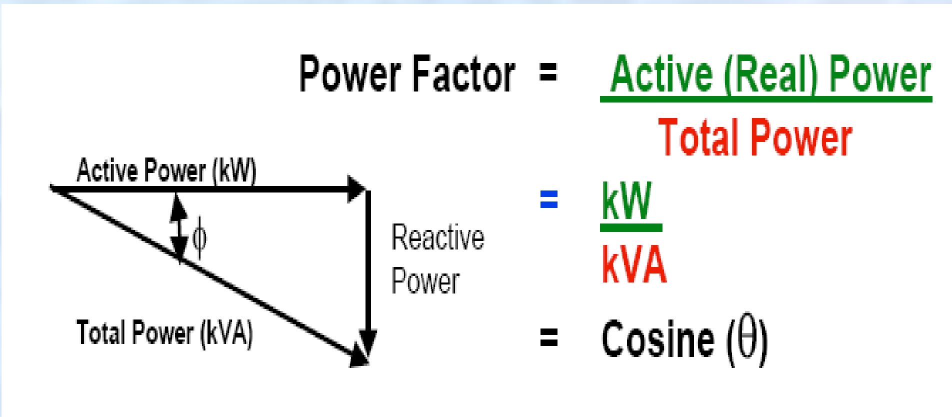
نتشرف بأن نرفق لسيادتكم التسوية الخاصة بفرق حساب مقابل القدره عن الفترة من ٢٠١٦/١٠/١ حتى ٢٠١٦/١٢/٣١ كالأتى:

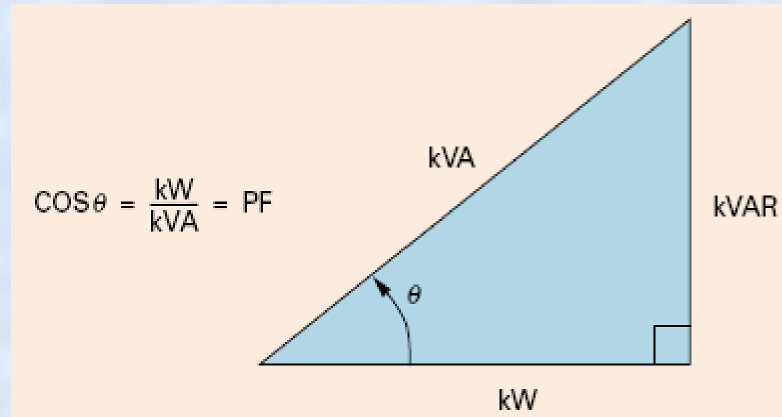
ماتم المحاسبة عليه	أقصى حمل	السعر	القيمة شهريا	القيمة ٣شهور
	١٣٥٠	٣٥.٠٠	٤٧٢٥٠.٠٠	١٤١٧٥٠.٠٠
مايجب المحاسبة عليه	أقصى حمل	السعر	القيمة شهريا	القيمة ٣شهور
	٨٣٠	٣٥.٠٠	٢٩٠٥٠.٠٠	٨٧١٥٠.٠٠

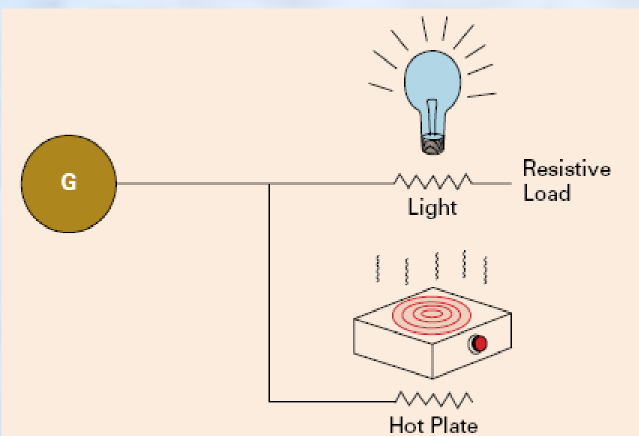
- الفرق المستحق لشركتكم من فرق مقابل القدره الذى تم المحاسبة عليه ٥٤٦٠٠.٠٠

Power factor

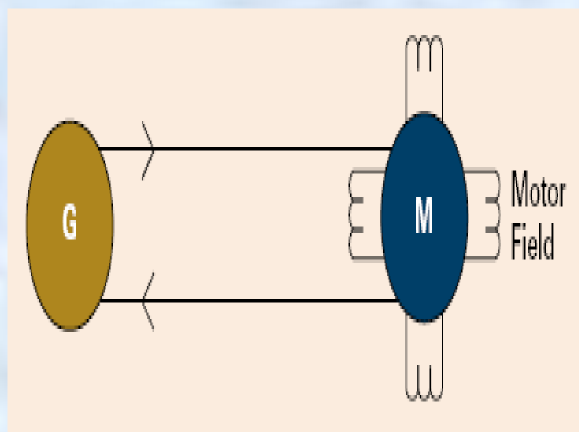
Power Factor is the ratio of Active Power to Total Power



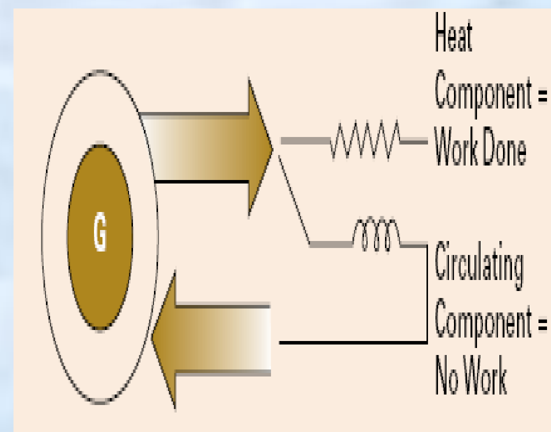




P

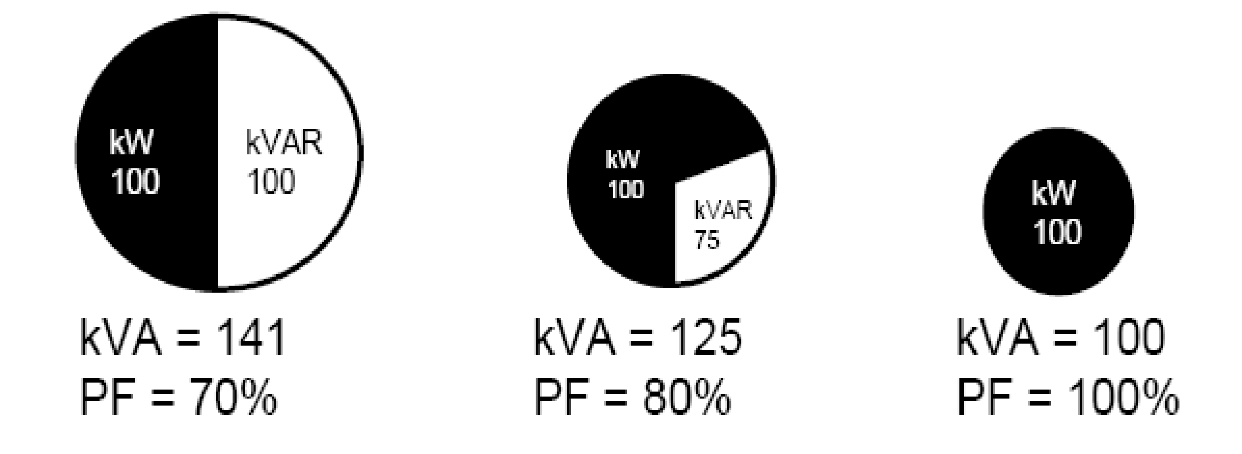


Q



S

The effect of PF on current drawn is shown below:



Decreasing size of conductors required to carry the same 100kW load at P.F. ranging from 70% to 100%

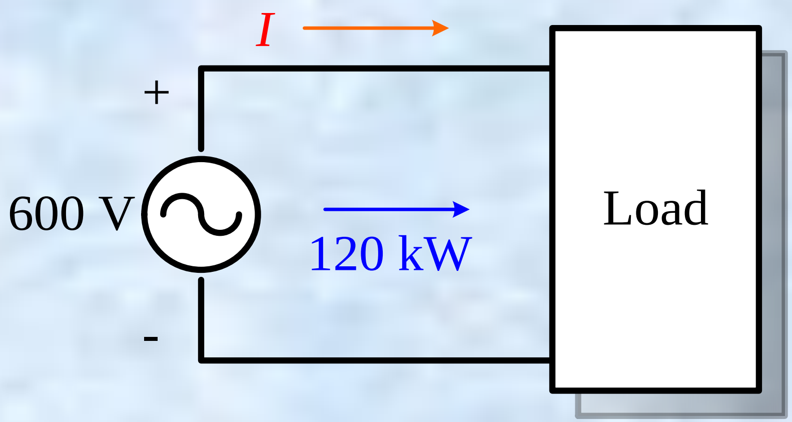
Why is Power Factor Important?

Consider the following example: A generator is rated at 600 V and supplies one of two possible loads.

Load 1: $P = 120$ kW, $PF = 1$

Load 2: $P = 120$ kW, $PF = 0.6$

How much current (I) is the generator required to supply in each case?

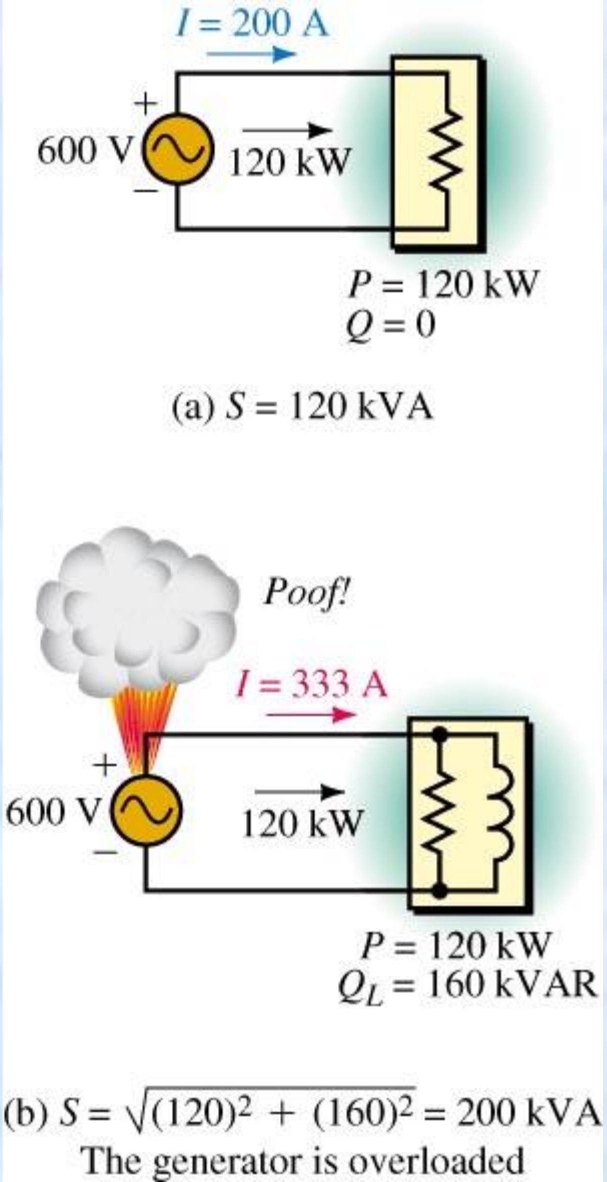


Why is Power Factor Important?

For the load with $PF = 0.6$, the generator had to supply 133 more amperes in order to do the same work (P)!

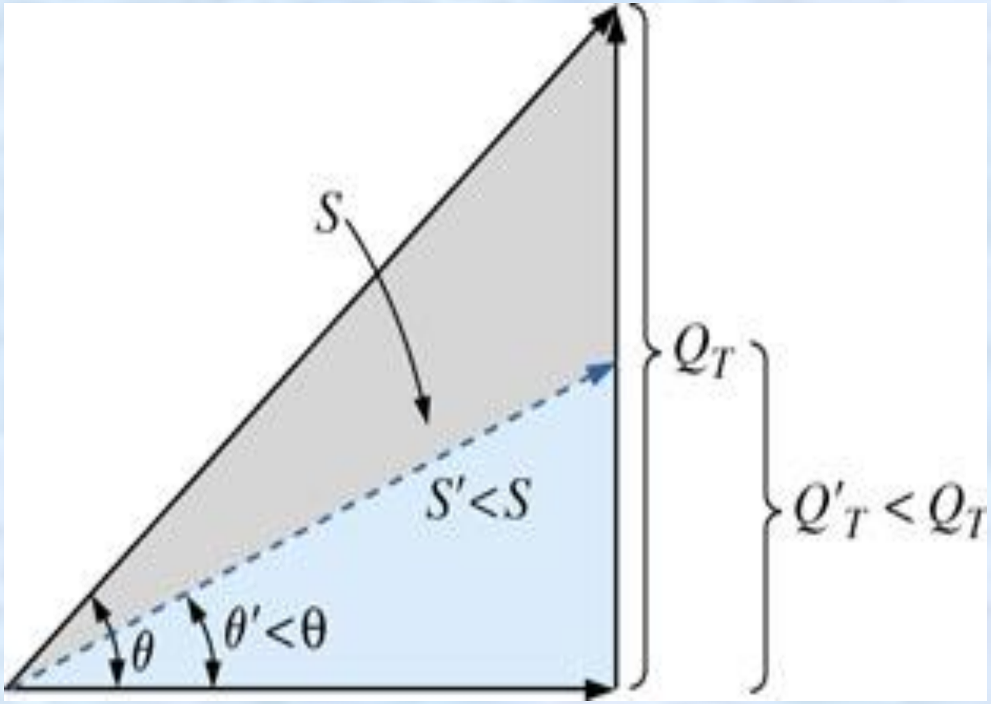
Larger current means larger equipment (wires, transformers, generators) which cost more.

Larger current also means larger transmission losses (think I^2R).



Is it possible to change the power factor of the load?

Power Factor Correction



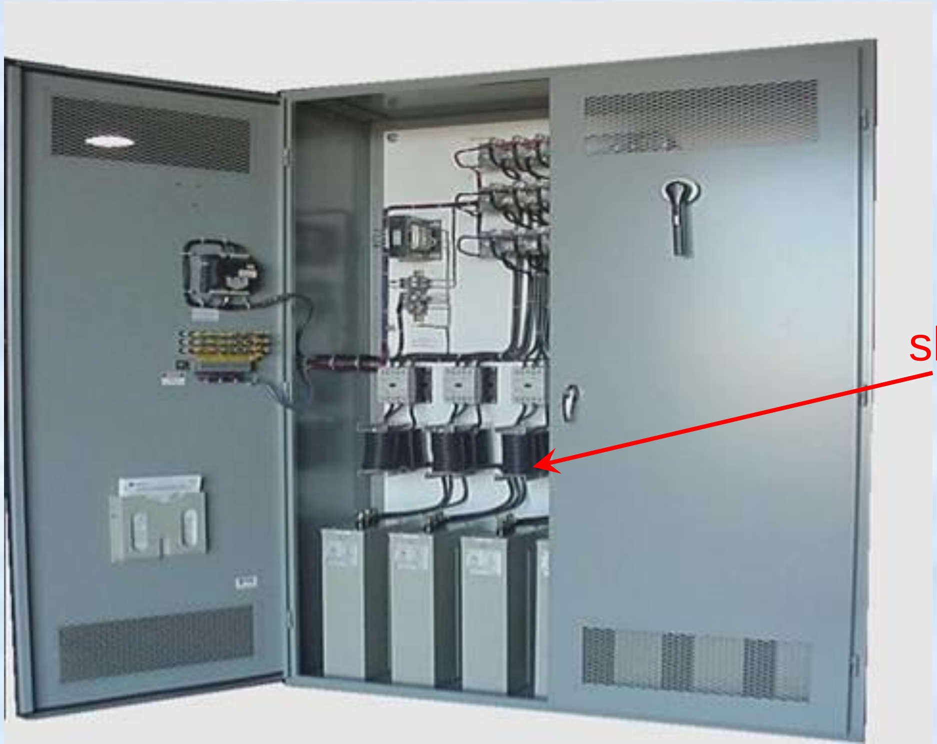
Demonstrating the impact of power-factor correction on the power triangle of a network.

Power Factor Correction

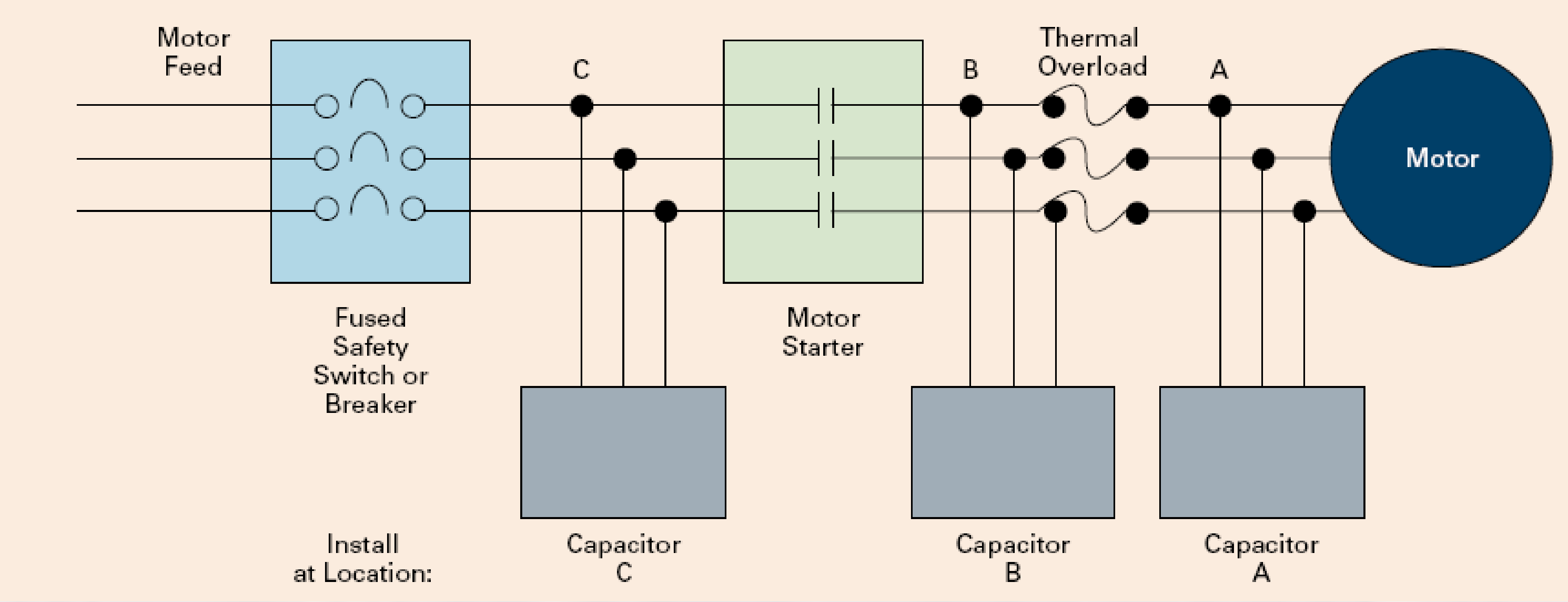
Almost all loads are inductive.

In order to cancel the reactive component of power, we must add reactance of the opposite type . This is called **power factor correction**.

P.F Regulator


Capacitor bank in shipboard power panel for PF correction

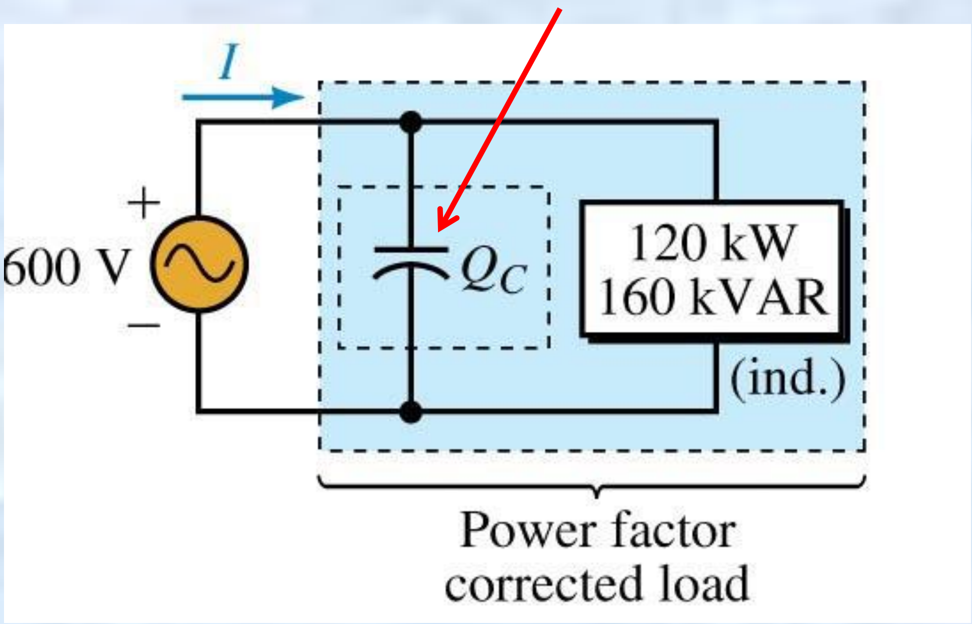
Power Factor Correction



Power Factor Correction

In practice, almost all loads (commercial, industrial and residential) look ***inductive*** (due to motors, fluorescent lamp ballasts, etc.).

Hence, almost all power factor correction consists of adding ***capacitance***.



Power Factor Correction Solution Steps

- Calculate the reactive power (Q) of the load
- Insert a component in parallel of the load that will cancel out that reactive power

e.g. If the load has Q_{LD}=512 VAR, insert a capacitor with Q_C=-512 VAR.

- Calculate the reactance (X) that will give this value of Q Normally the $Q=V^2/X$ formula will work
- Calculate the component value (F or H) required to provide that reactance.

Power Factor Correction

$Q_c = P\ (\tan(\cos^{-1} \theta_1) - \tan(\cos^{-1} \theta_2))$

Desired Power Factor [Proposed / Target P.F ($\cos\theta_2$)]

Existing Power Factor $\cos\theta_1$	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
0.50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.442	1.481	1.529	1.590	1.732
0.51	.937	.962	.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1.544	1.687
0.52	.893	.919	.945	.971	.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	.850	.876	.902	.928	.954	.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.457	1.600
0.54	.809	.835	.861	.887	.913	.939	.966	.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1.416	1.559
0.55	.769	.795	.821	.847	.873	.899	.926	.952	.979	1.007	1.035	1.063	1.090	1.124	1.156	1.190	1.228	1.268	1.316	1.377	1.519
0.56	.730	.756	.782	.808	.834	.860	.887	.913	.940	.968	.996	1.024	1.051	1.085	1.117	1.151	1.189	1.229	1.277	1.338	1.480
0.57	.692	.718	.744	.770	.796	.822	.849	.875	.902	.930	.958	.986	1.013	1.047	1.079	1.113	1.151	1.191	1.239	1.300	1.442
0.58	.655	.681	.707	.733	.759	.785	.812	.838	.865	.893	.921	.949	.976	1.010	1.042	1.076	1.114	1.154	1.202	1.263	1.405
0.59	.618	.644	.670	.696	.722	.748	.775	.801	.828	.856	.884	.912	.939	.973	1.005	1.039	1.077	1.117	1.165	1.226	1.368
0.60	.584	.610	.636	.662	.688	.714	.741	.767	.794	.822	.850	.878	.905	.939	.971	1.005	1.043	1.083	1.131	1.192	1.334
0.61	.549	.575	.601	.627	.653	.679	.706	.732	.759	.787	.815	.843	.870	.904	.936	.970	1.008	1.048	1.096	1.157	1.299
0.62	.515	.541	.567	.593	.619	.645	.672	.698	.725	.753	.781	.809	.836	.870	.902	.936	.974	1.014	1.062	1.123	1.265
0.63	.483	.509	.535	.561	.587	.613	.640	.666	.693	.721	.749	.777	.804	.838	.870	.904	.942	.982	1.030	1.091	1.233
0.64	.450	.476	.502	.528	.554	.580	.607	.633	.660	.688	.716	.744	.771	.805	.837	.871	.909	.949	.997	1.058	1.200
0.65	.419	.445	.471	.497	.523	.549	.576	.602	.629	.657	.685	.713	.740	.774	.806	.840	.878	.918	.966	1.027	1.169
0.66	.388	.414	.440	.466	.492	.518	.545	.571	.598	.626	.554	.682	.709	.743	.775	.809	.847	.887	.935	.996	1.138
0.67	.358	.384	.410	.436	.462	.488	.515	.541	.568	.596	.624	.652	.679	.713	.745	.779	.817	.857	.905	.966	1.108
0.68	.329	.355	.381	.407	.433	.459	.486	.512	.539	.567	.595	.623	.650	.684	.716	.750	.788	.828	.876	.937	1.079
0.69	.299	.325	.351	.377	.403	.429	.456	.482	.509	.537	.565	.593	.620	.654	.866	.720	.758	.798	.840	.907	1.049
0.70	.270	.296	.322	.348	.374	.400	.427	.453	.480	.508	.536	.564	.591	.625	.657	.691	.729	.769	.811	.878	1.020
0.71	.242	.268	.294	.320	.346	.372	.399	.425	.452	.480	.508	.536	.563	.597	.629	.663	.701	.741	.783	.850	.992
0.72	.213	.239	.265	.291	.317	.343	.370	.396	.423	.451	.479	.507	.534	.568	.600	.634	.672	.712	.754	.821	.963
0.73	.186	.212	.238	.264	.290	.316	.343	.369	.396	.424	.452	.480	.507	.541	.573	.607	.645	.685	.727	.794	.936
0.74	.159	.185	.211	.237	.263	.289	.316	.342	.369	.397	.425	.453	.480	.514	.546	.580	.618	.658	.700	.767	.909

Q_c = P * Multiplier (get from table 0.536 if 0.7 to be 0.9)

Formula

Power Factor penalty

If PF desire is 0,9
Actual PF = 0,87
D(PF) =0,03

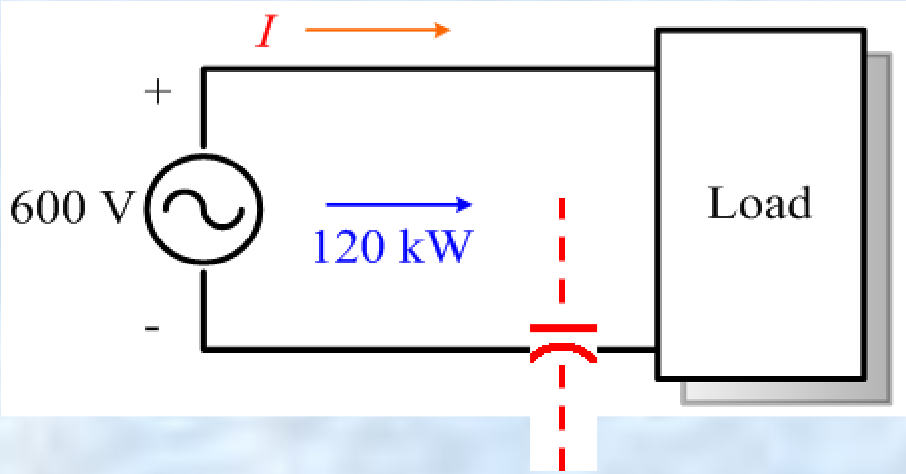
Penalty (LE) = D(PF) x LE/KWH x (KWH)

Example

The 600 V (60 Hz) generator is connected to a load with P_{LD} = 120 kW and Q_{LD} = 160 kVAR.

a. Determine the power factor of the load.

b. Determine the Capacitance (in Farads) required to correct the power factor to unity.

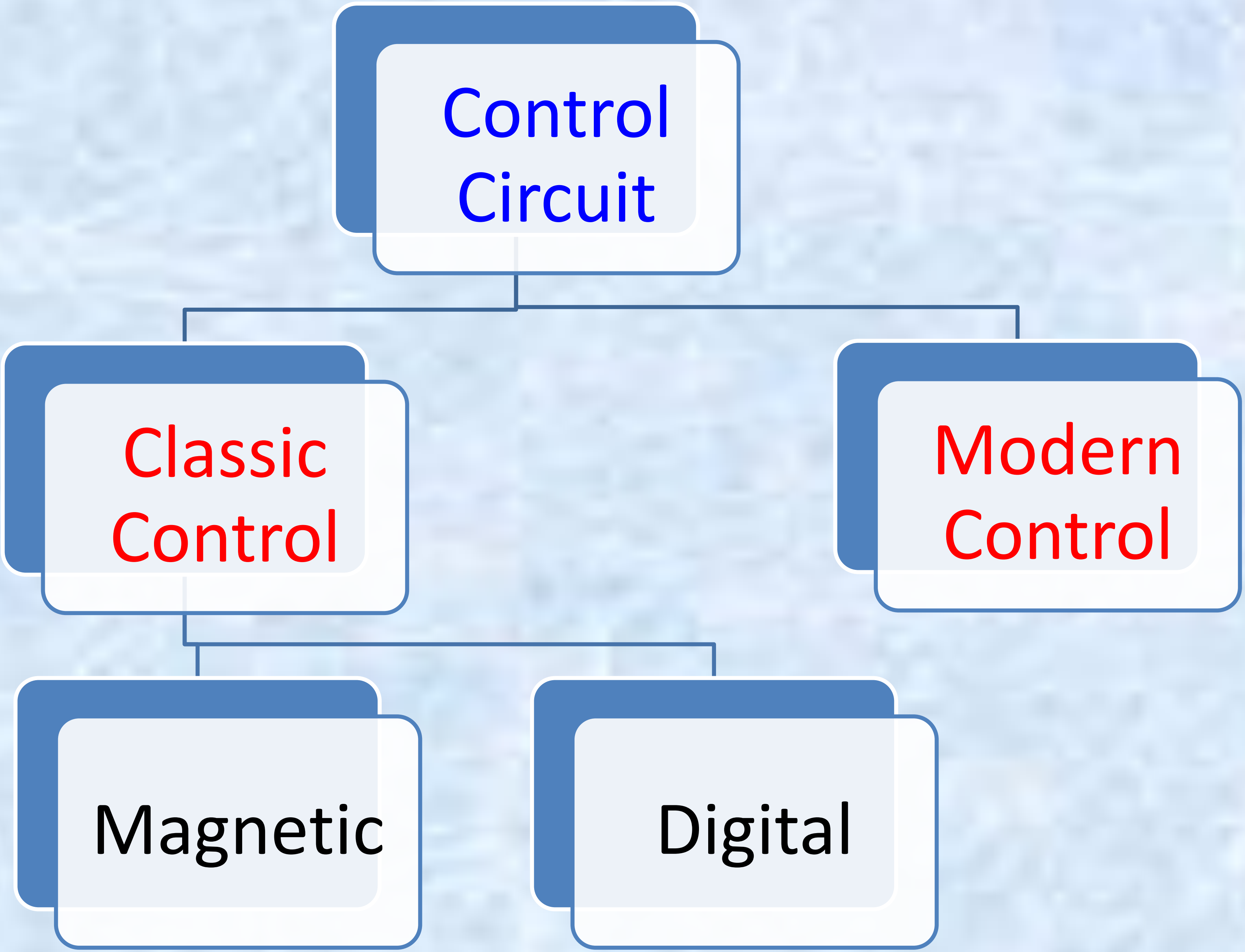


Other Examples

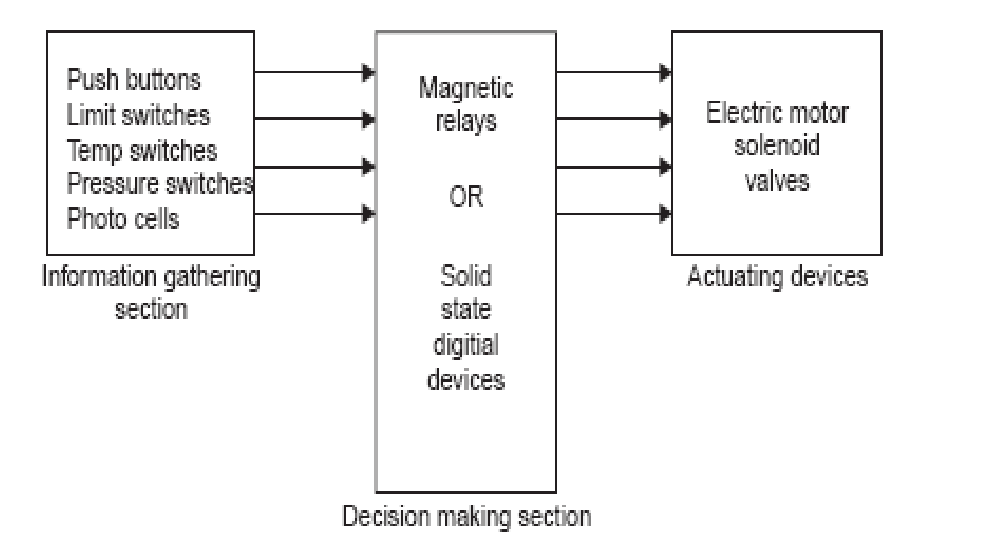
http://www.electricaltechnology.org/2013/11/How-to-Calculate-Suitable-Capacitor-Size-for-Power-factor-Improvement.html

CHAPTER 2

Types of Control System


Control Circuit
Classic Control
Modern Control
Magnetic
Digital

1- Classic control

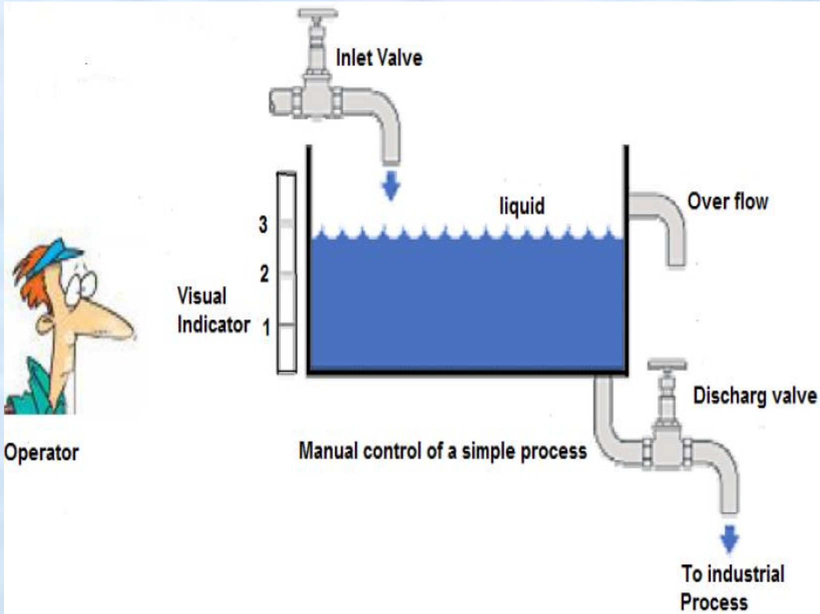


An industrial control system, whether it is magnetic control or static control can be divided into three

(*i*) *input section*

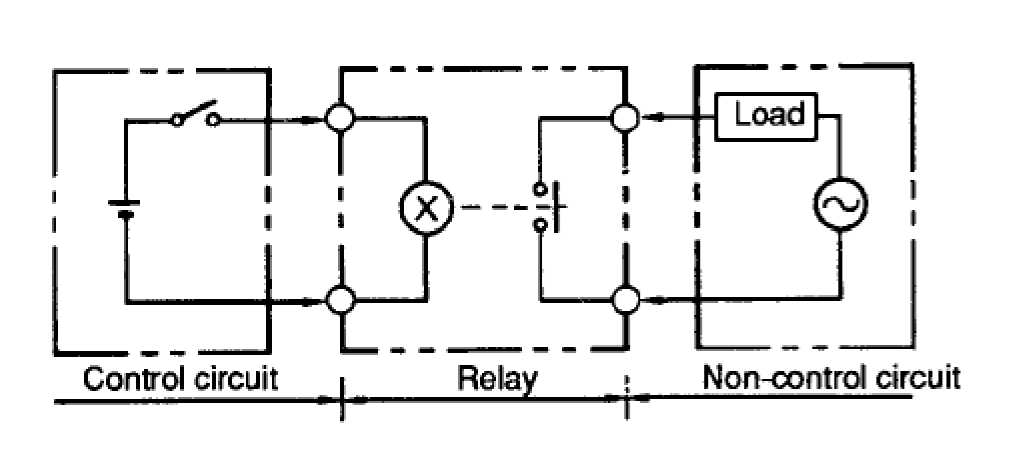
(*ii*) *logic section*

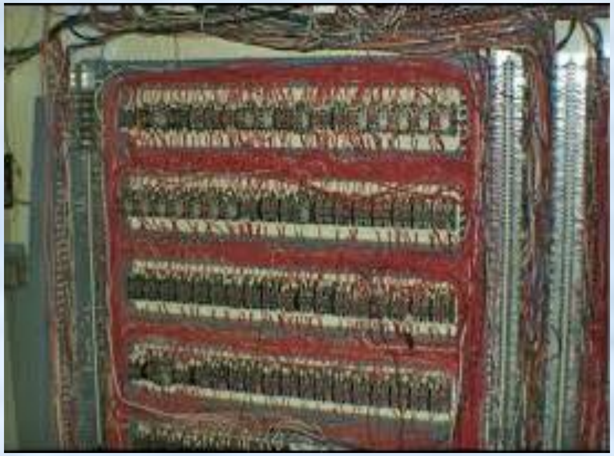
(*iii*) *output section*

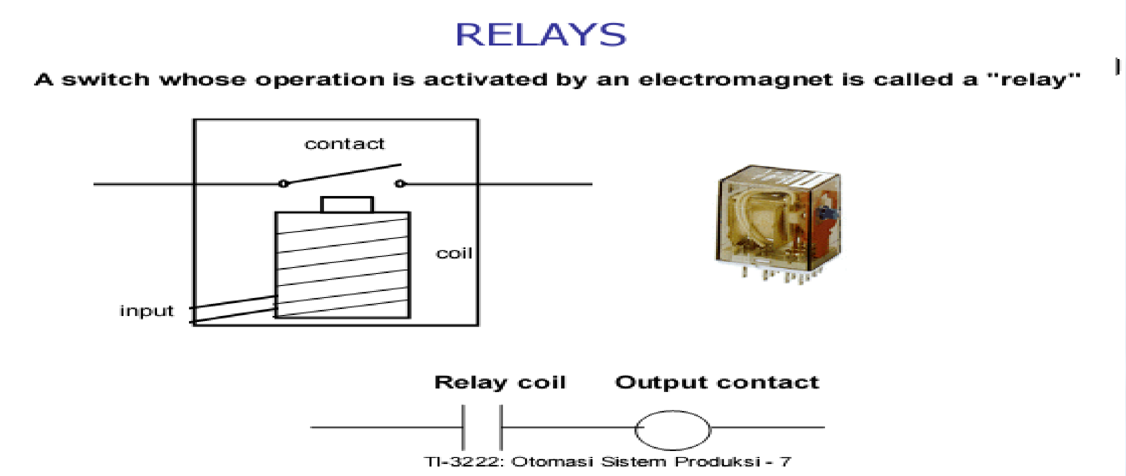


A- Relay control System

A relay is defined as a device in which predefined changes occur rapidly in single or multiple electrical output circuits, when the control electrical input circuit fulfills a certain condition



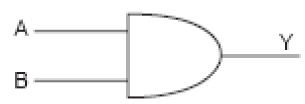




B- Digital control System

- Digital ICs processing information through various logic gates
- Operate at much higher speeds & less power than relay circuit
- Advantage of small size but it cannot switch higher power signal

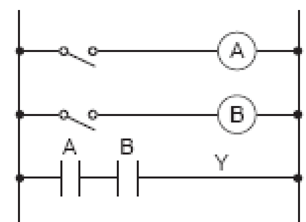
AND Gate



(a)

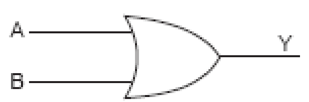
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

(b)



(c)

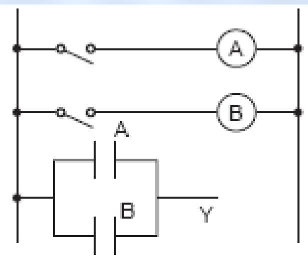
OR Gate



(a)

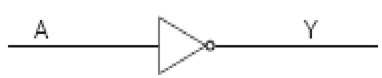
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

(b)



(c)

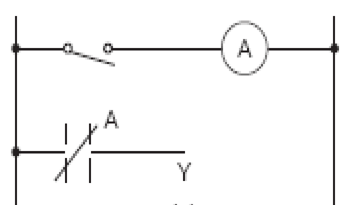
NOT Gate



(a)

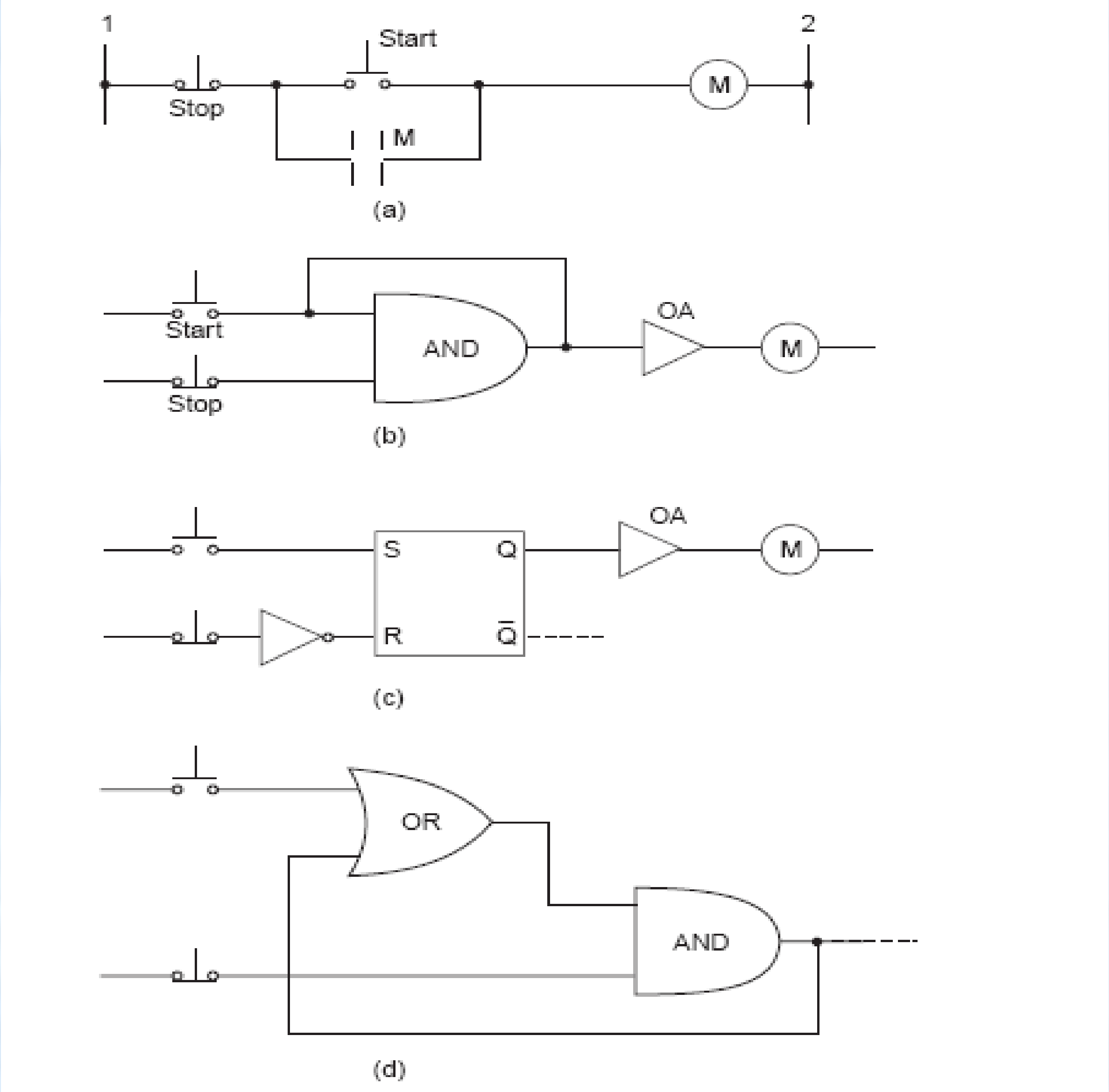
A	Y
0	1
1	0

(b)



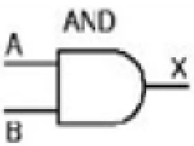
(c)

Example of both system

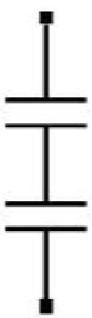


Other logic gates

AND

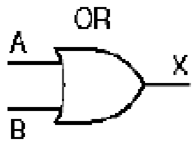


A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

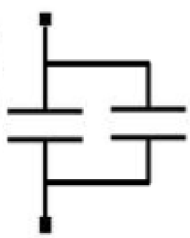


Serial

OR

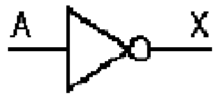


A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

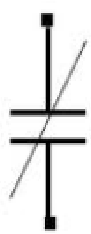


Parallel

NOT

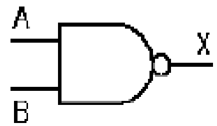


A	X
0	1
1	0

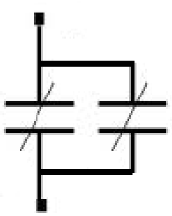


NOT

NAND

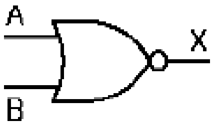


A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

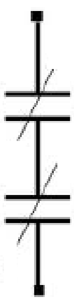


NAND

NOR

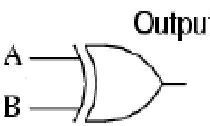


A	B	X
0	0	1
0	1	0
1	0	0
1	1	0

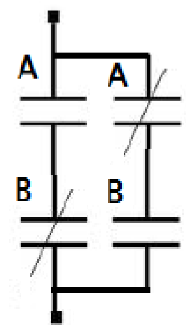


NOR

EOR(XOR)

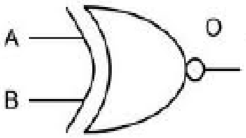


A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0

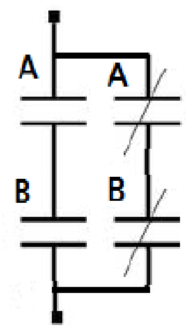


XOR

ENOR



A B	O
0 0	1
0 1	0
1 0	0
1 1	1



XNOR

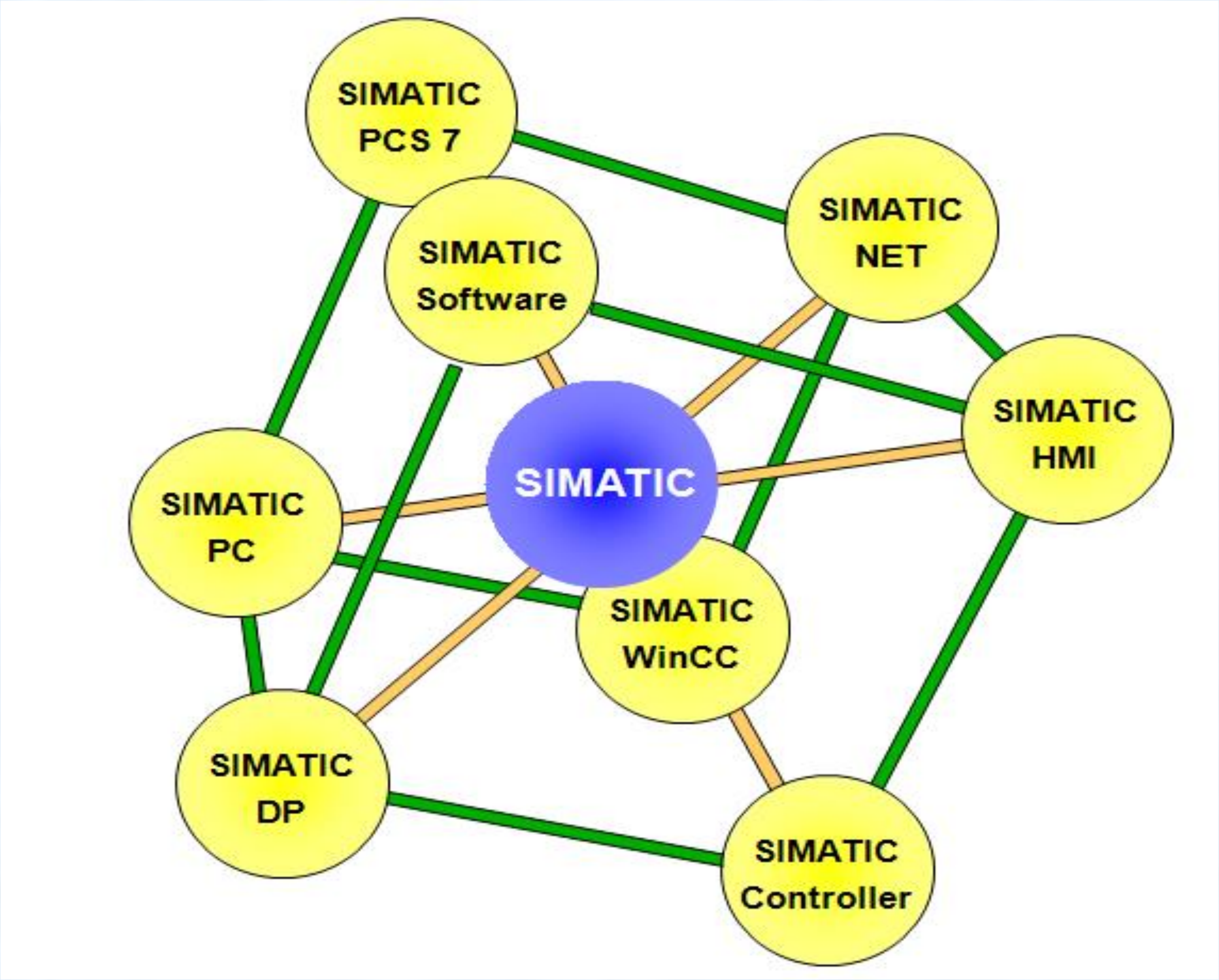
2- Modern control

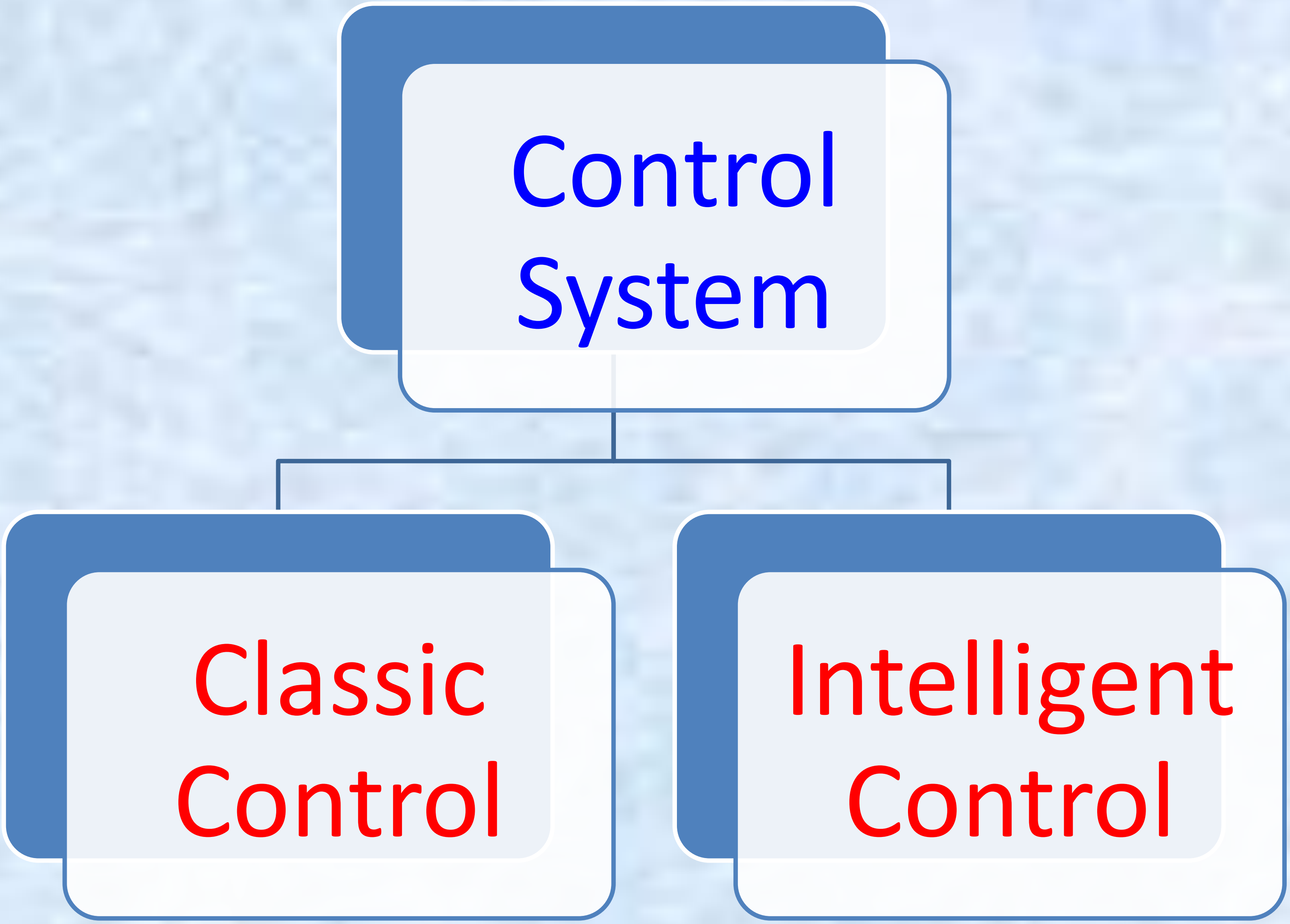
The early history of the PLC & DCS goes back to the 1960's when control systems were still handled using relay control. During this time the control rooms consisted of several walls containing many relays, terminal blocks and mass of wires. The problems related to such kind of systems were many, among those one could mention:

- The lack of flexibility
- Troubleshooting.

"necessity is the mother of invention"

The SIMATIC S7 System Family



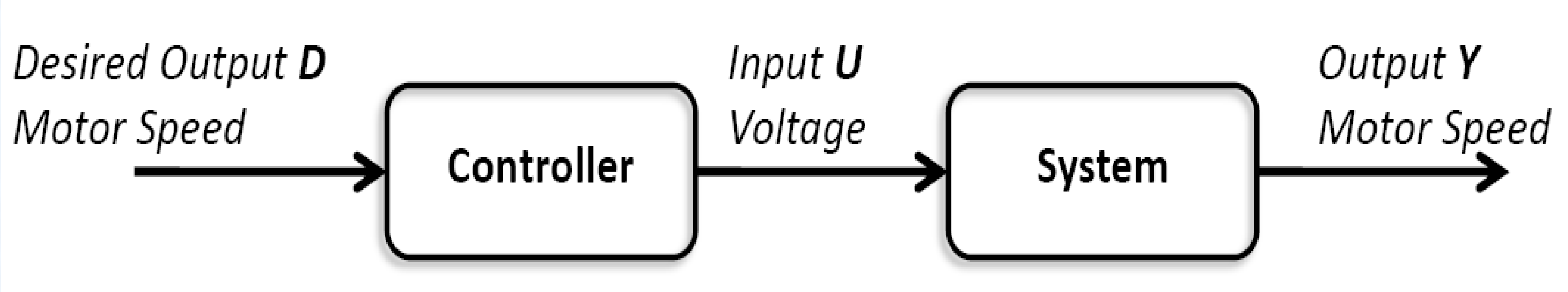

Control System
Classic Control
Intelligent Control

1- Classic control

the designer constructs a mathematical model of the system. This model contains all the dynamics of the plant that affects controlling it.

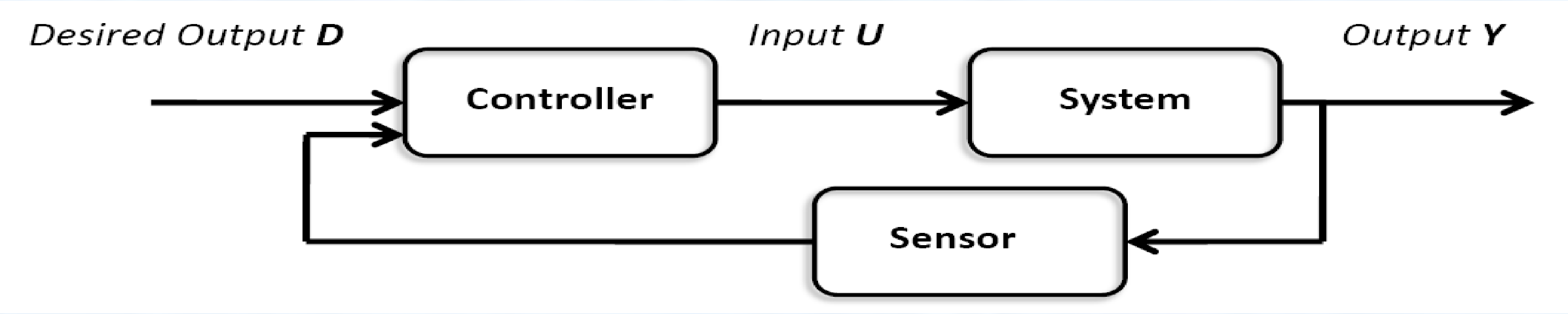
A- Open loop

U = K . D

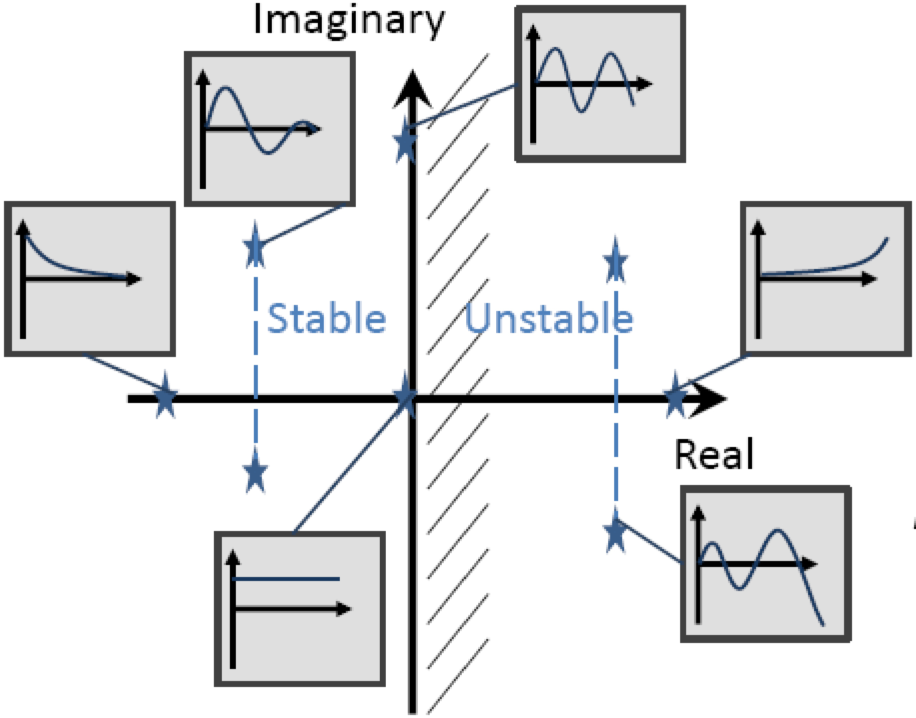


B- Closed loop

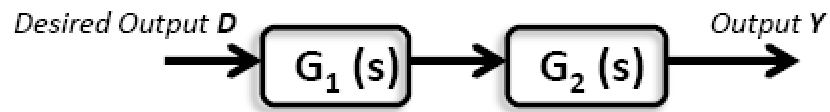
U = K . (D – Y)



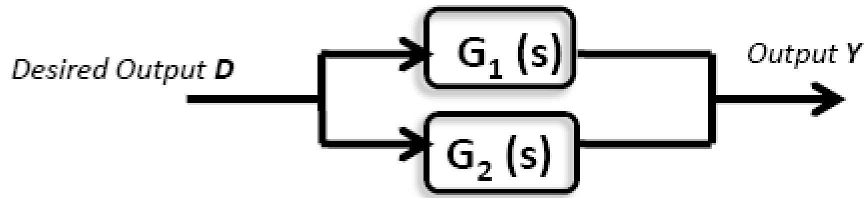
System modeling & Stability



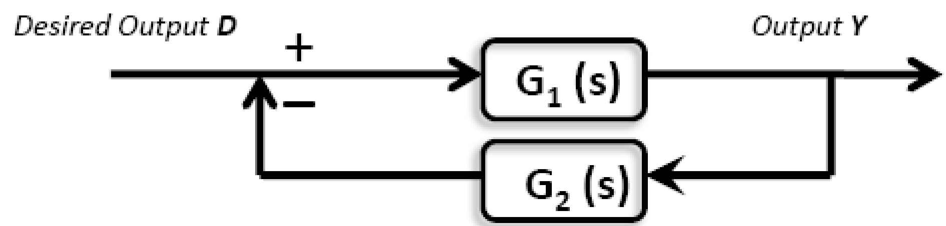
Roots of Characteristic equation determine stability



$$Y = G_1(s)\, G_1(s)\, D$$

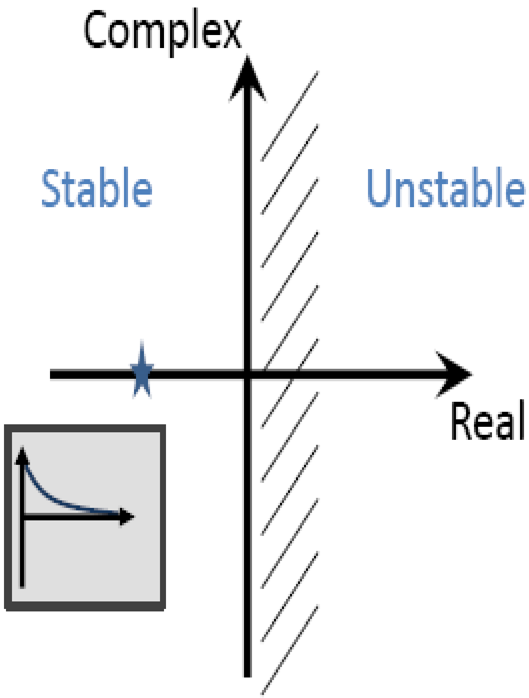


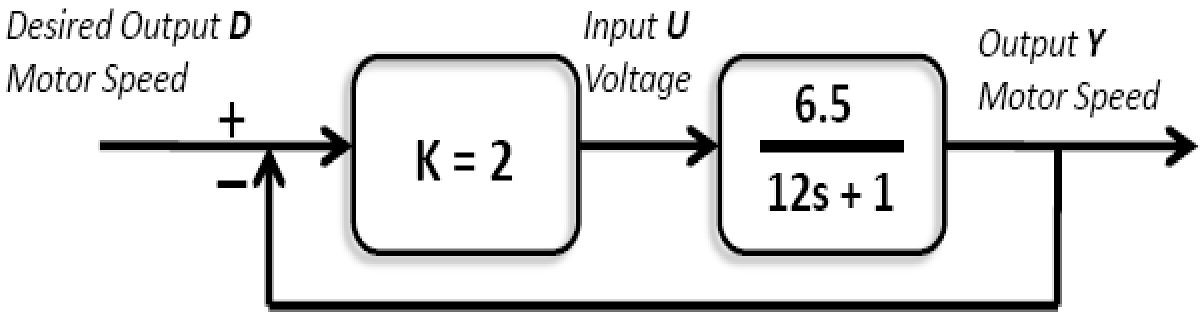
$$Y = G_1(s) + G_1(s)\, D$$



$$Y = \frac{G_1(s)}{1 + G_1(s)G_2(s)} \times D$$

Closed Loop Stability





$$Y = \frac{\dfrac{K\,6.5}{12s+1}}{1 + \dfrac{K\,6.5}{12s+1}} \times D = \frac{K\,6.5}{12s + K\,6.5 + 1} \times D$$

$$= \frac{13}{12s+14} \times D$$

Roots of Characteristic equation determine stability

Root = -1.167 <u>STABLE</u>

Control Requirement PID

Proportional Gain

Applicable to Error between setpoint & output

Larger values → faster response

Very large values → process instability and oscillation.

Results in Steady State Error

Integral Gain

Proportional to integral of Error between setpoint & output

Larger values → steady state errors rapidly eliminated.

Overshoot may lead to instability

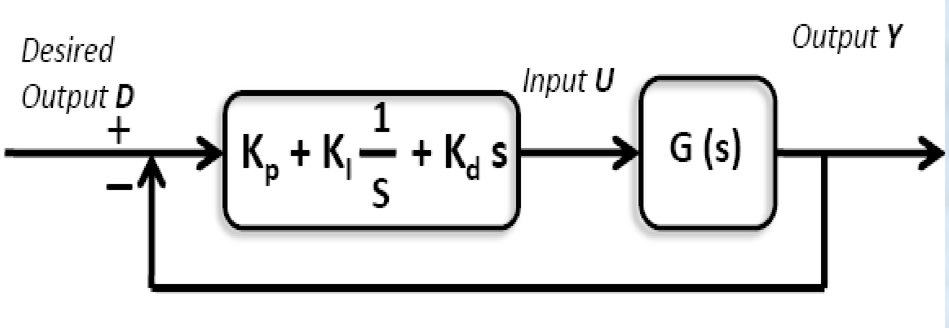
Zero Steady State Error

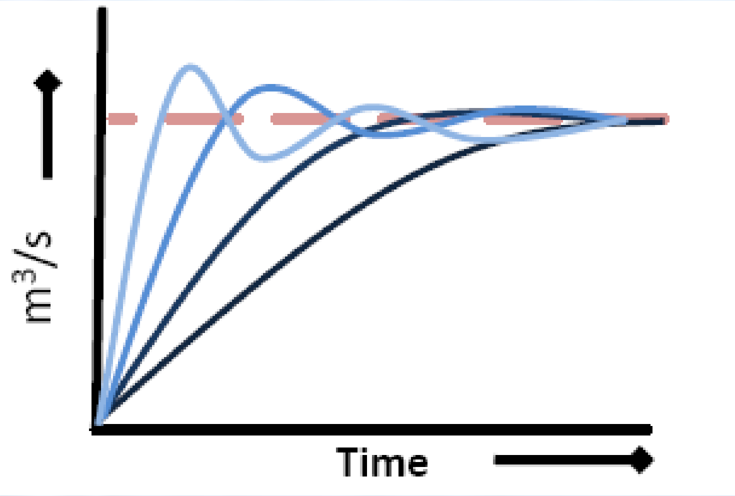
Derivative Gain

Proportional to derivative of Error between setpoint & output

Larger values → decreased overshoot, but slower transient response

May lead to instability due to signal noise amplification in the differentiation of the error





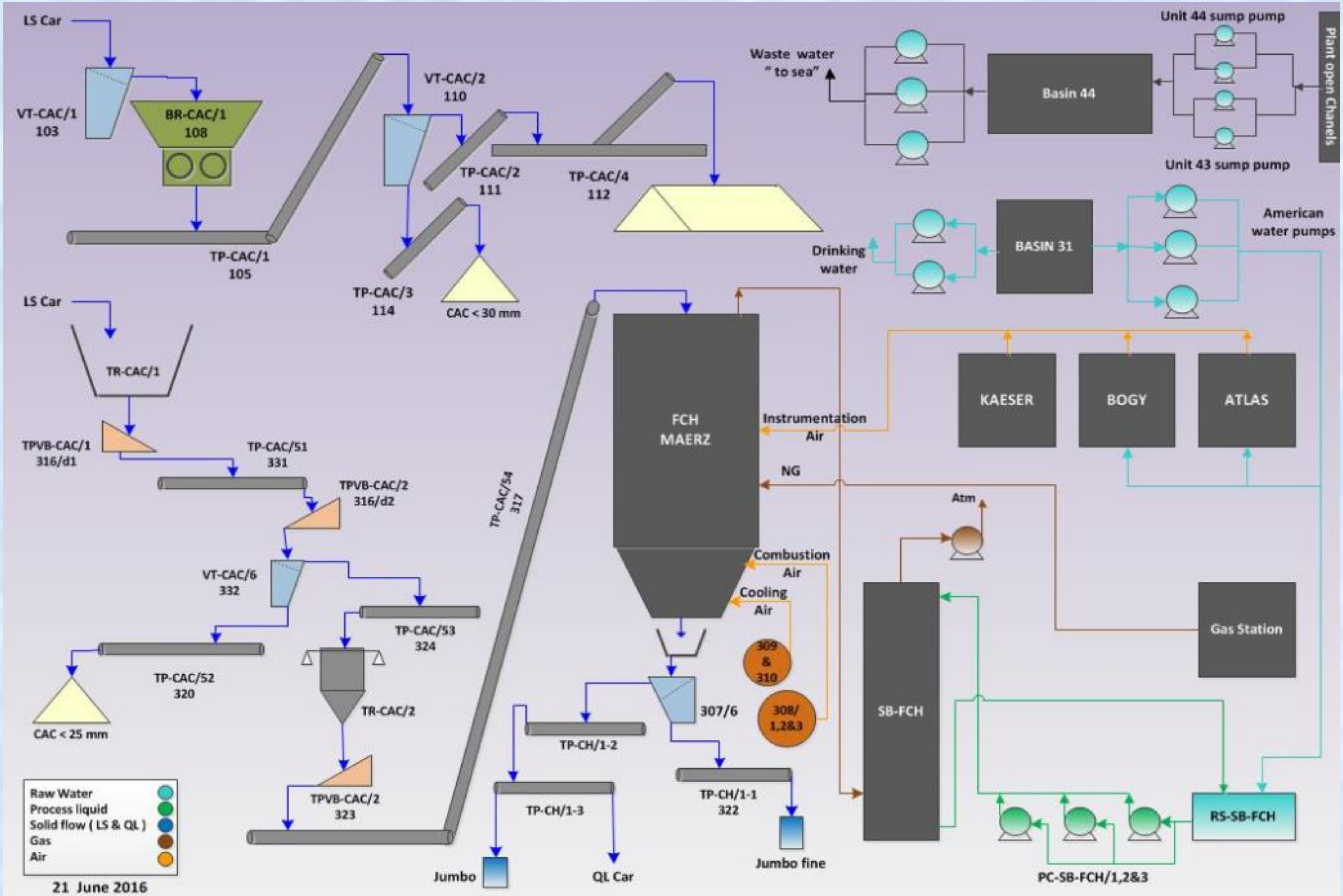
Explain this video

Video

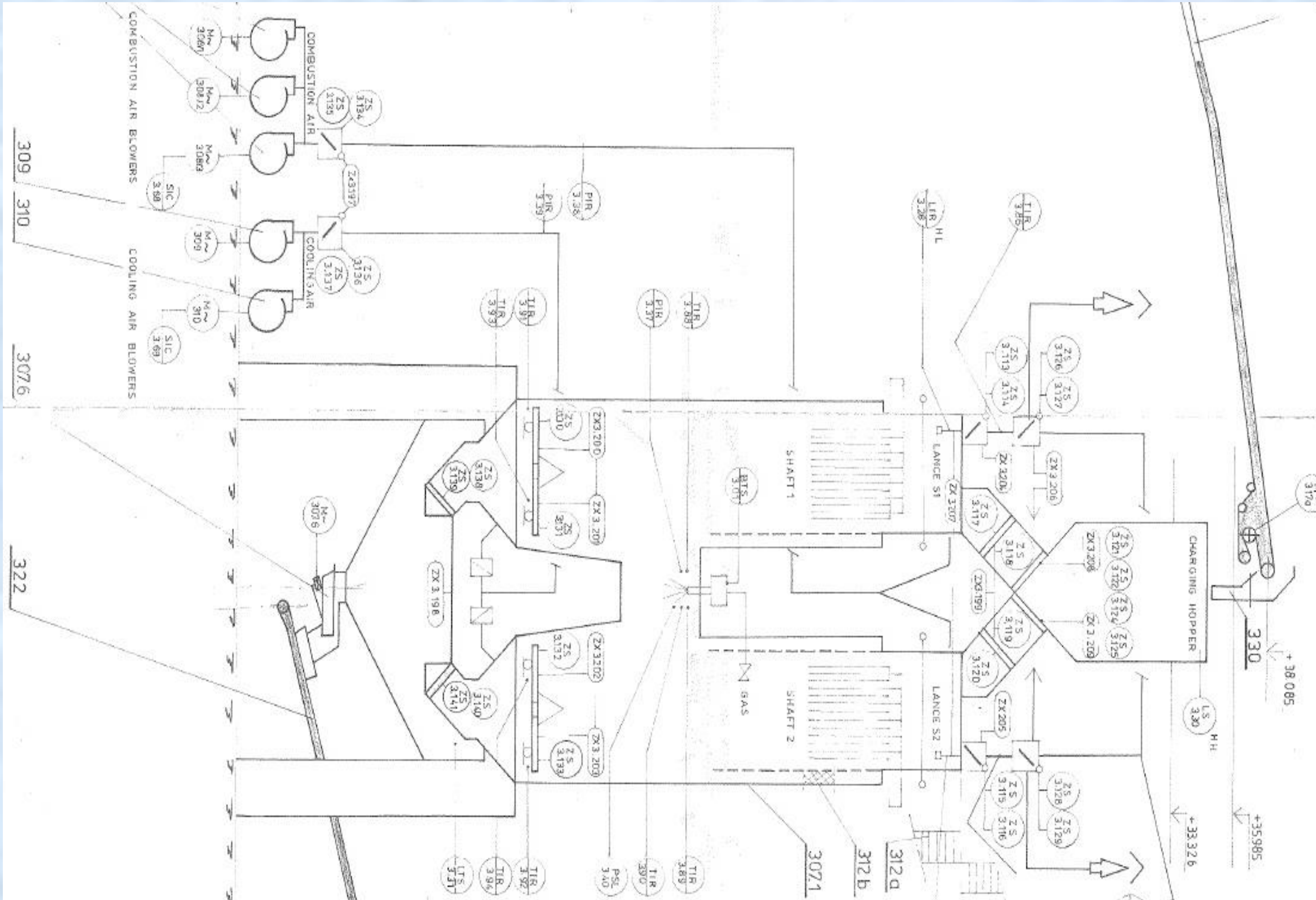
CHAPTER 3

Classic Control Components

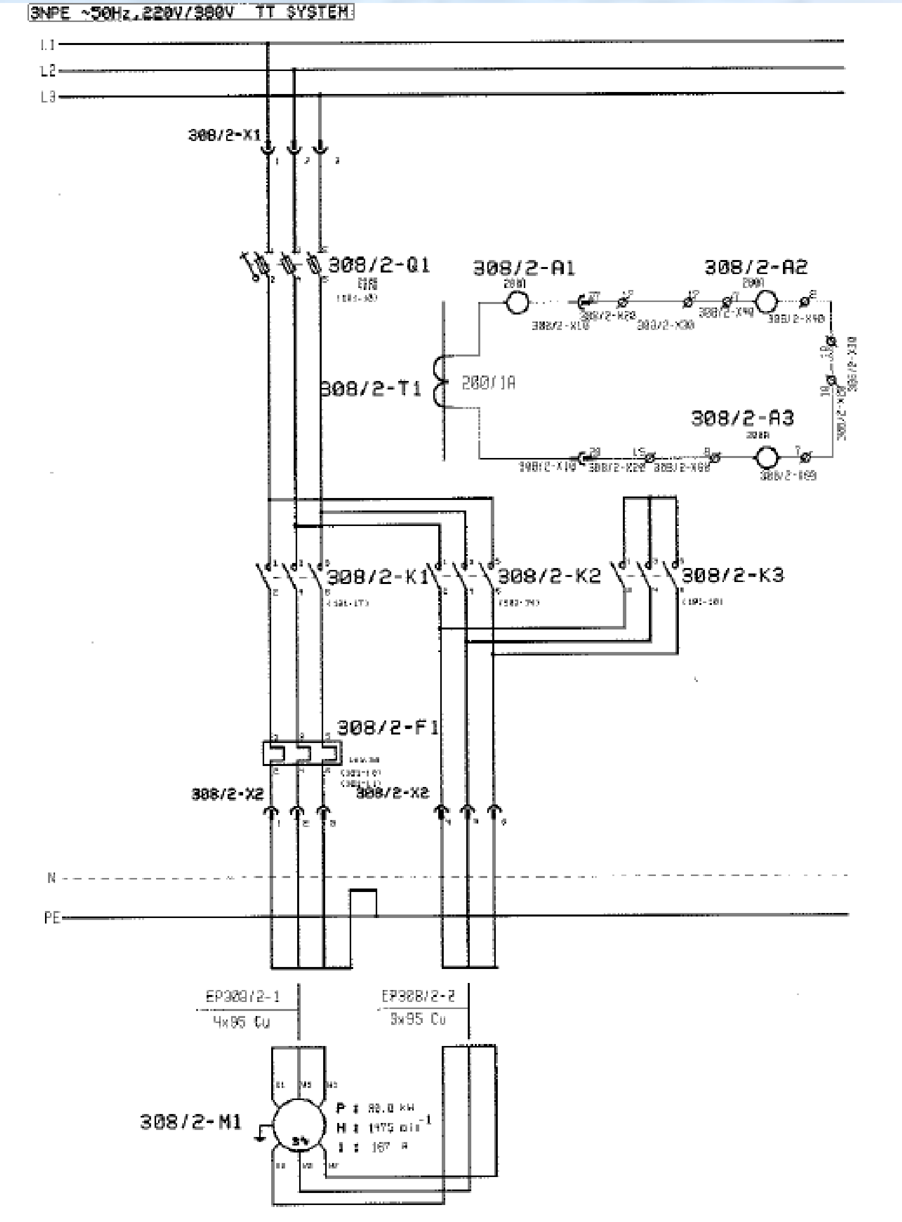
Process flow sheet

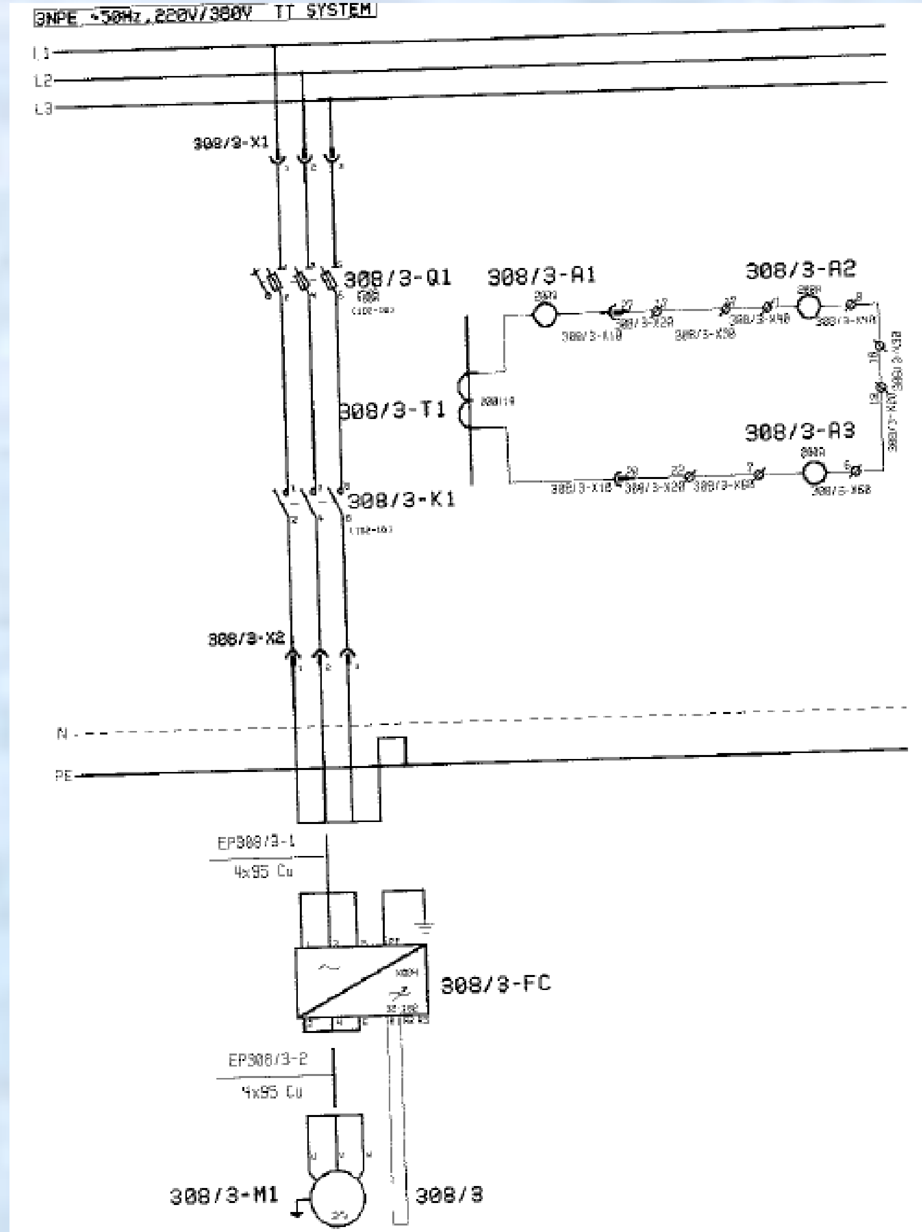


Process P&ID

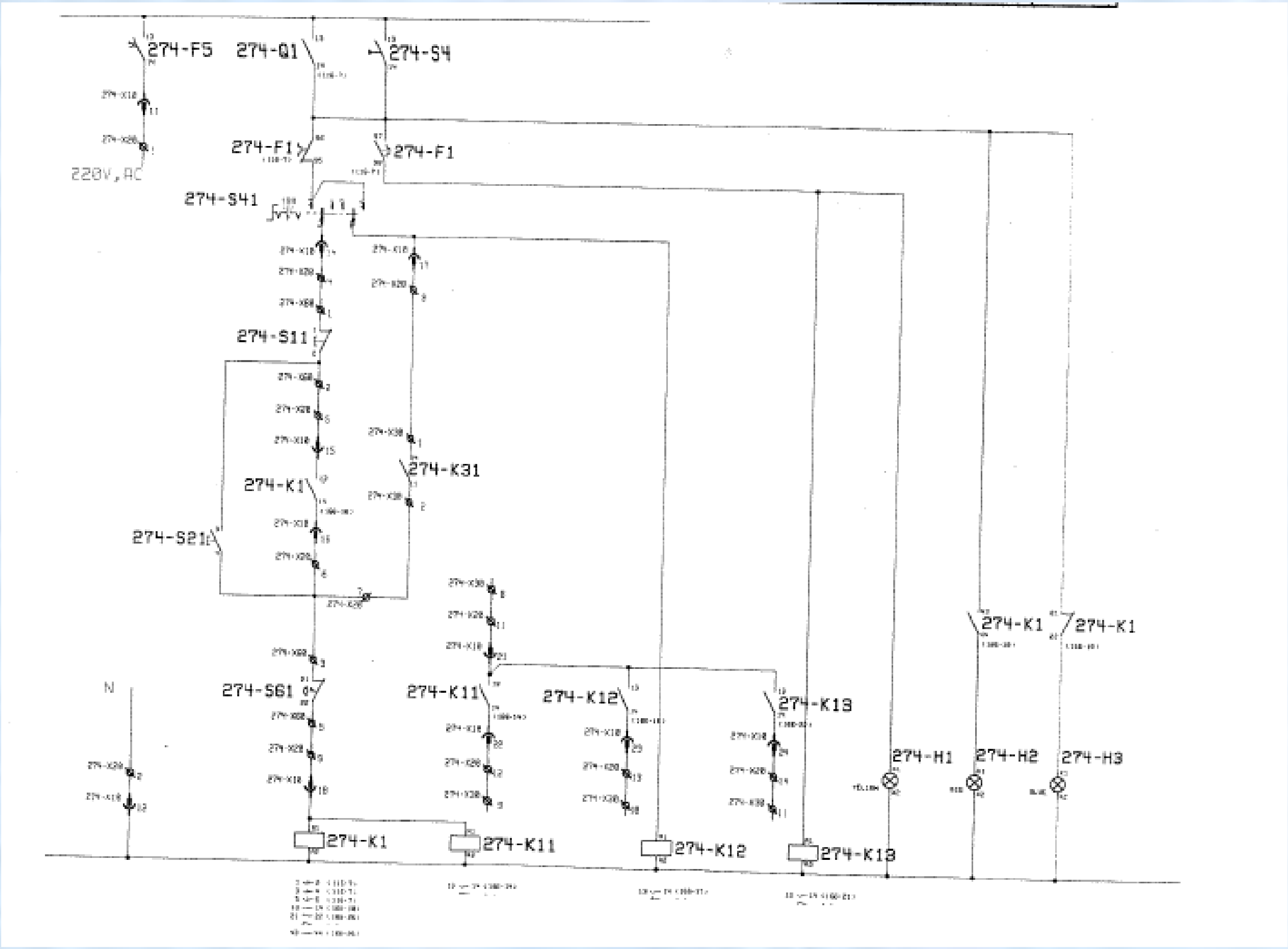

COMBUSTION AIR BLOWERS
COMBUSTION AIR
COOLING AIR BLOWERS
COOLING AIR
SHAFT 1
SHAFT 2
LANCE S1
LANCE S2
CHARGING HOPPER
GAS

Power circuit

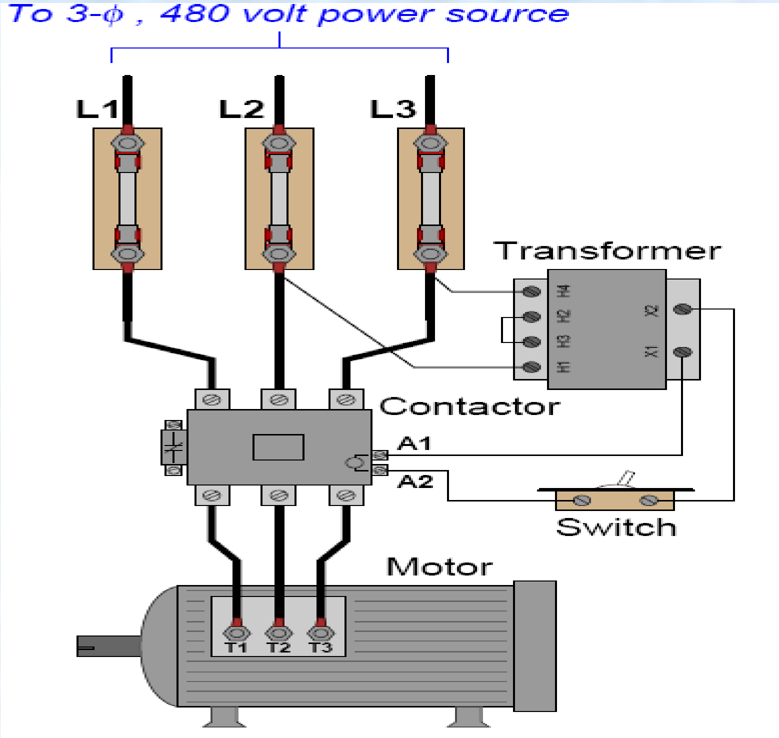


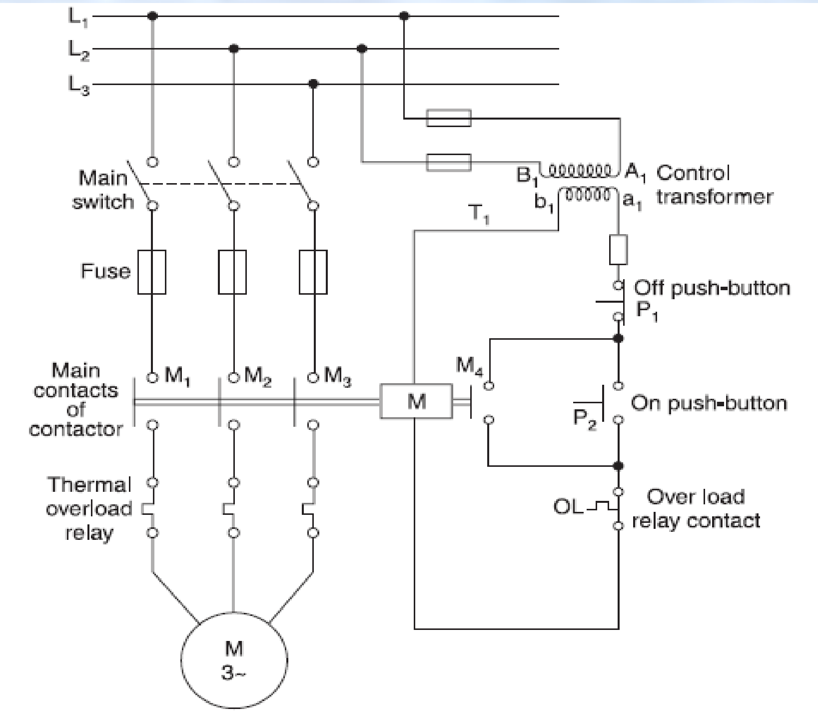


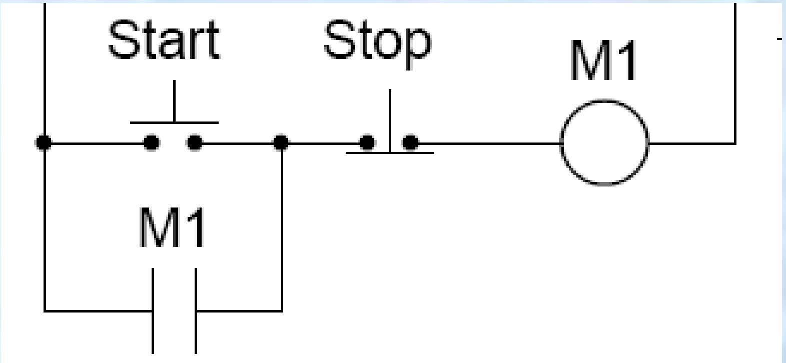
Control circuit

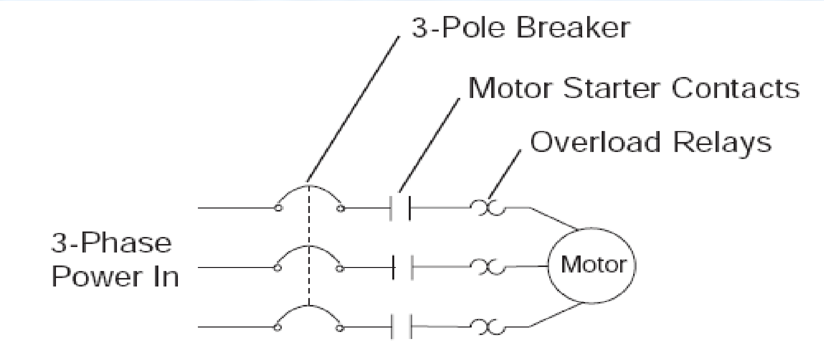


Power & control circuit







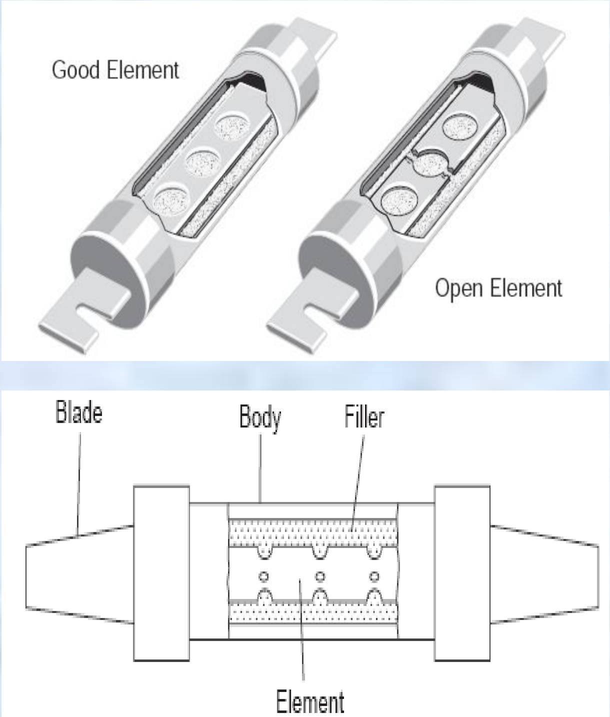


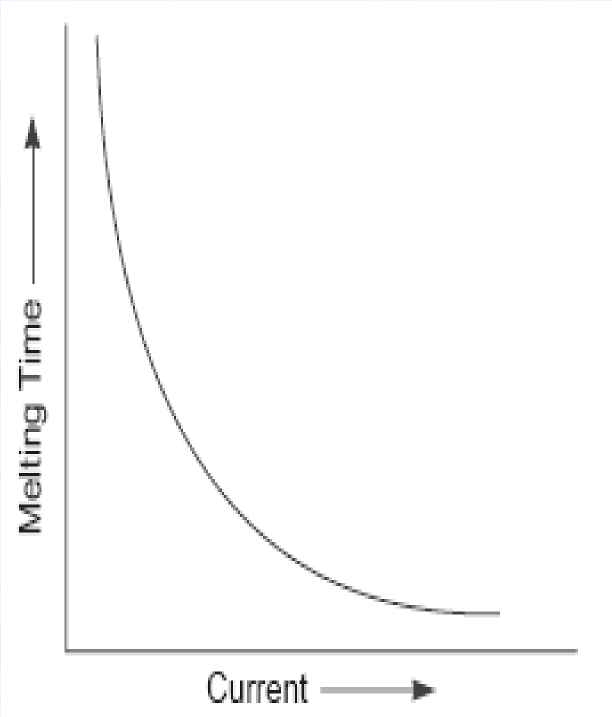
Control circuit

Power circuit

Power circuit components

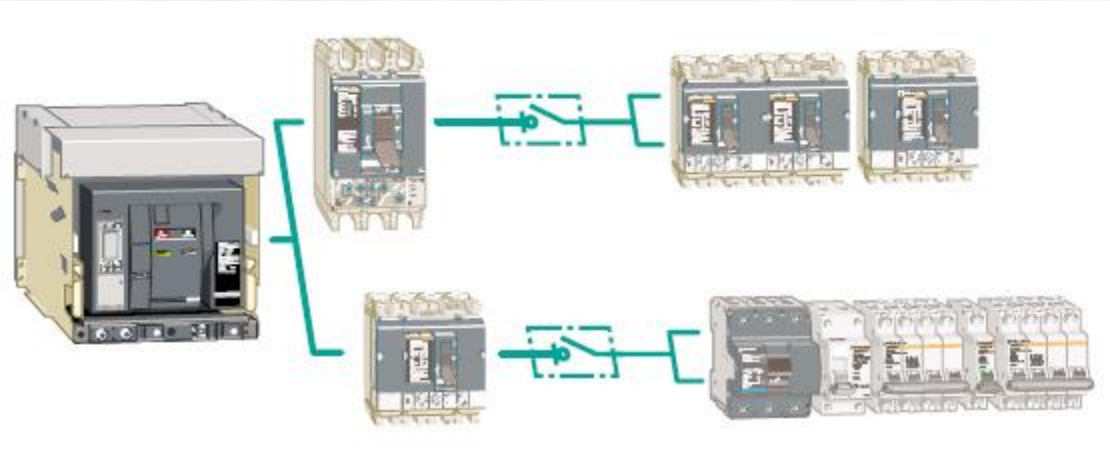
Fuses

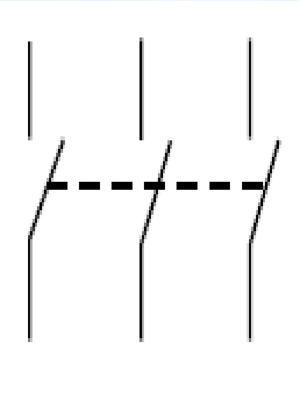




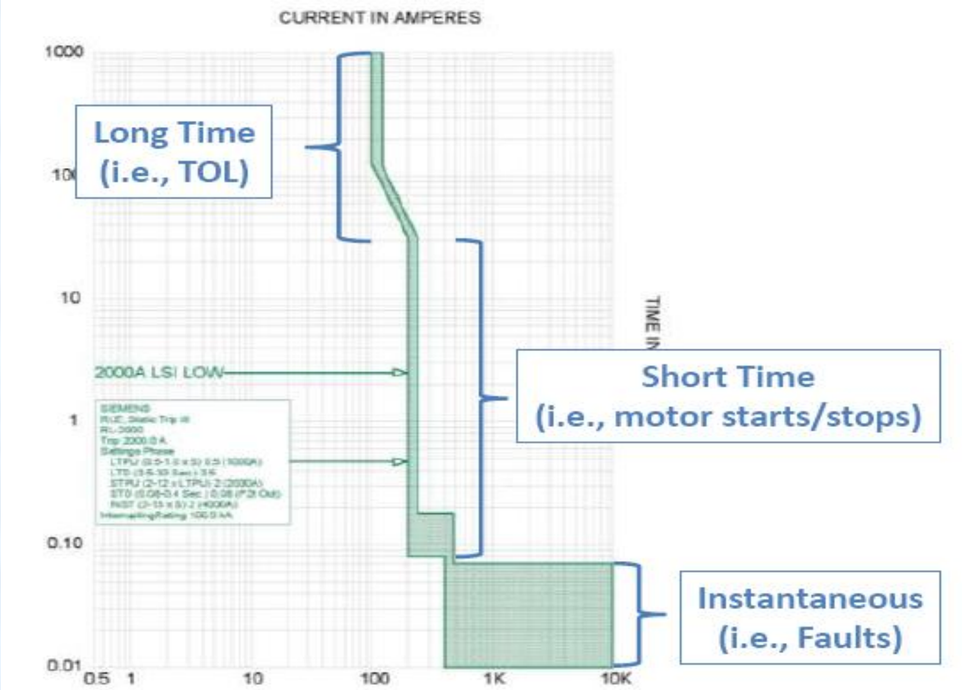
The fuse element can sustain small overloads for longer duration but in case of large overloads and short circuits the small cross-section of the fuse element melts quickly and opens the circuit.

Circuit Breaker



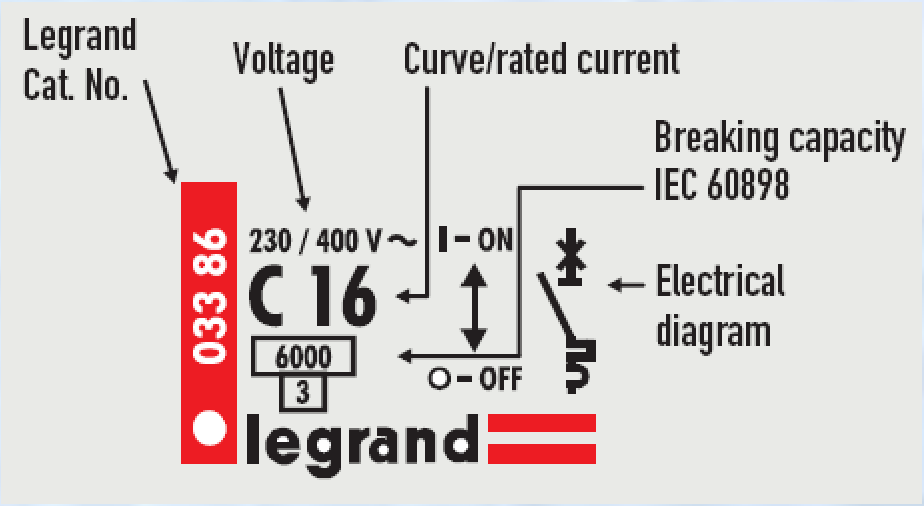


An MCCB automatically isolates an electrical circuit under sustained overloads or short circuits.

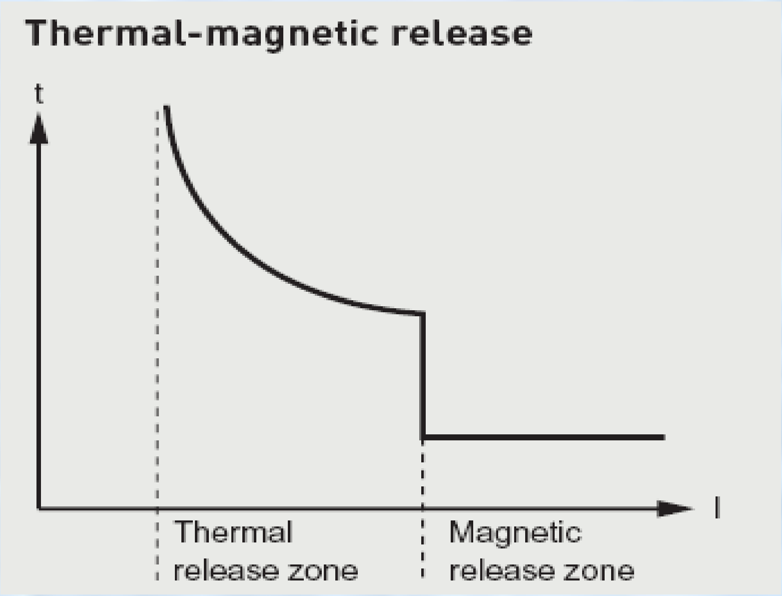


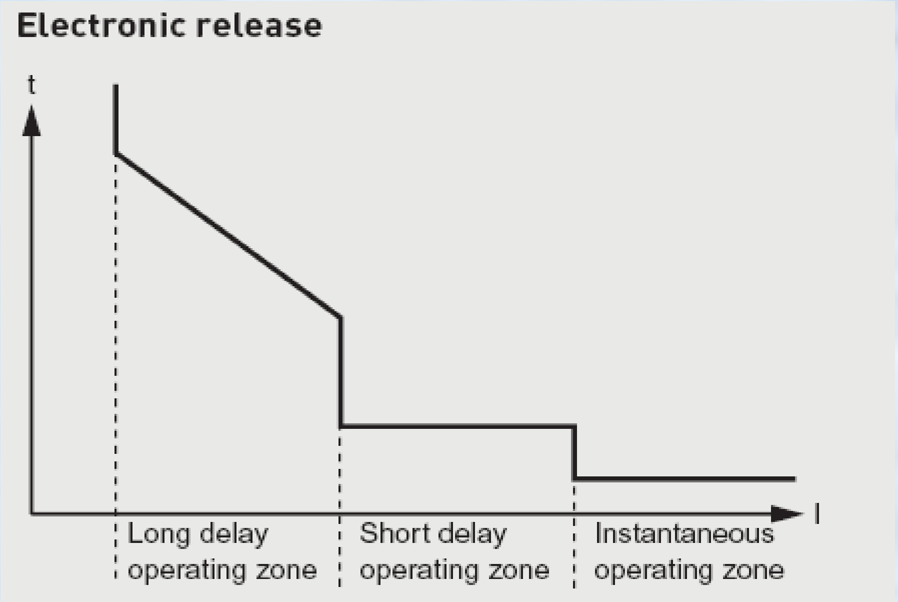
Video

Name plate



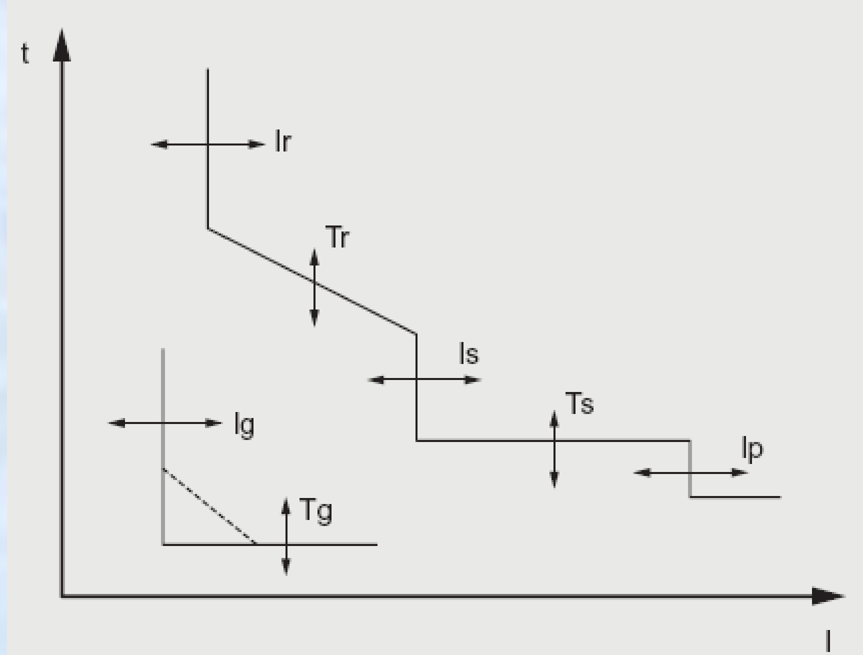
Tripping curve

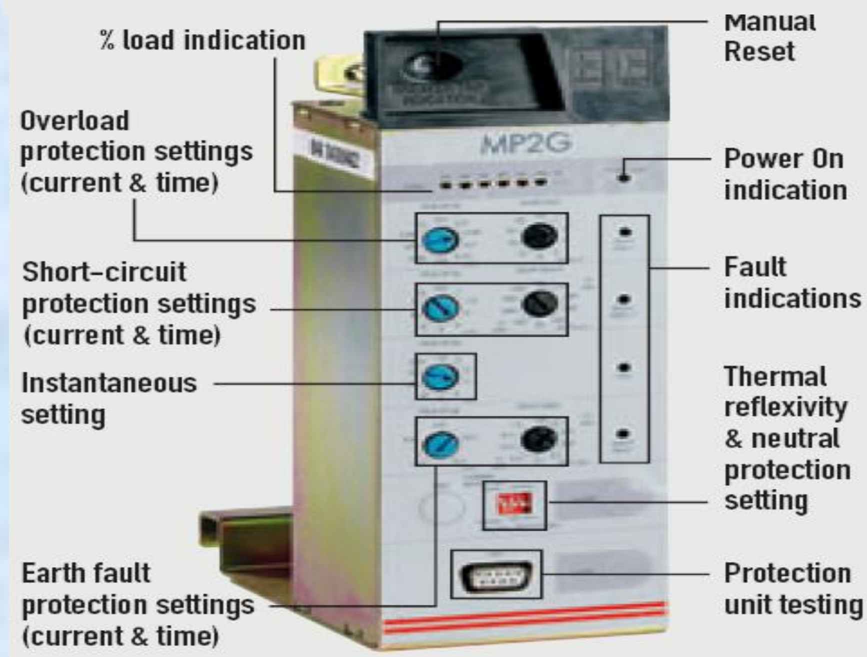




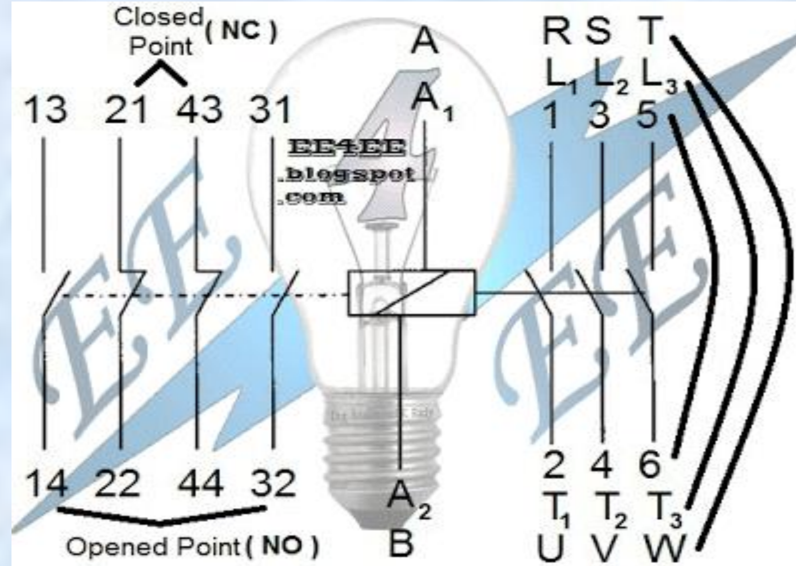
Adjustment

Parameters			Settings
Overload	Ir	Ir = In × ...	0.4 - 0.5 - 0.6 0.7 - 0.75 - 0.8 0.85 - 0.9 0.95 - 1
	Tr	Time delay in s at 6 x Ir	0.5 - 1 - 2 - 4 6 - 8 - 12 - 18 24 - 30
	Neutral protection	I_N = Ir × ...	0 % - 50 % - 100 %
Short-circuit	Is	Is = In × ...	0.6 - 1 - 1.5 2 - 3 - 4 - 6 8 - 9 - 10
	Ts	Time delay in ms at 10 × In - I^2t Off	20 - 100 - 200 300 - 400
		Time delay in ms at 10 × In - I^2t On	20 - 100 - 200 - 300 - 400
Instantaneous	Ip	Ip = Ir × ...	1.5 - 2 - 3 - 4 5 - 6 - 8 - 10 12 - Max.
Earth fault	Ig	Ig = Ir × ...	0.2 - 0.3 - 0.4 0.5 - 0.6
	Tg	Time delay in s I^2t Off	0.1 - 0.2 - 0.3 0.4 - 1 - Off
		Time delay in s - I^2t On	0.1 - 0.2 - 0.3 0.4

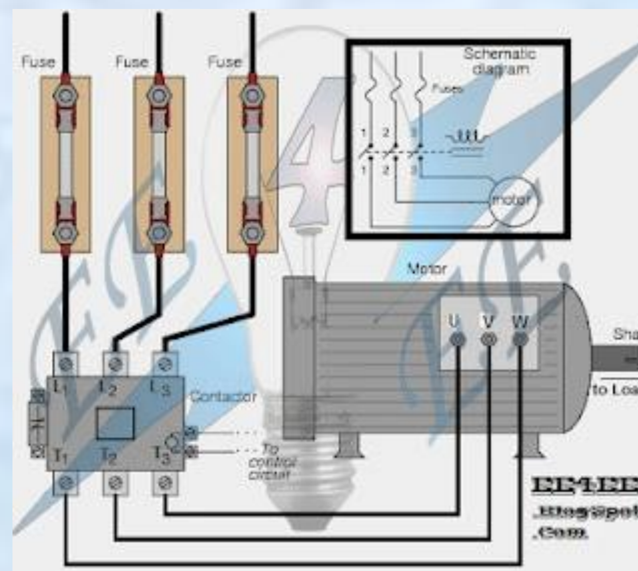


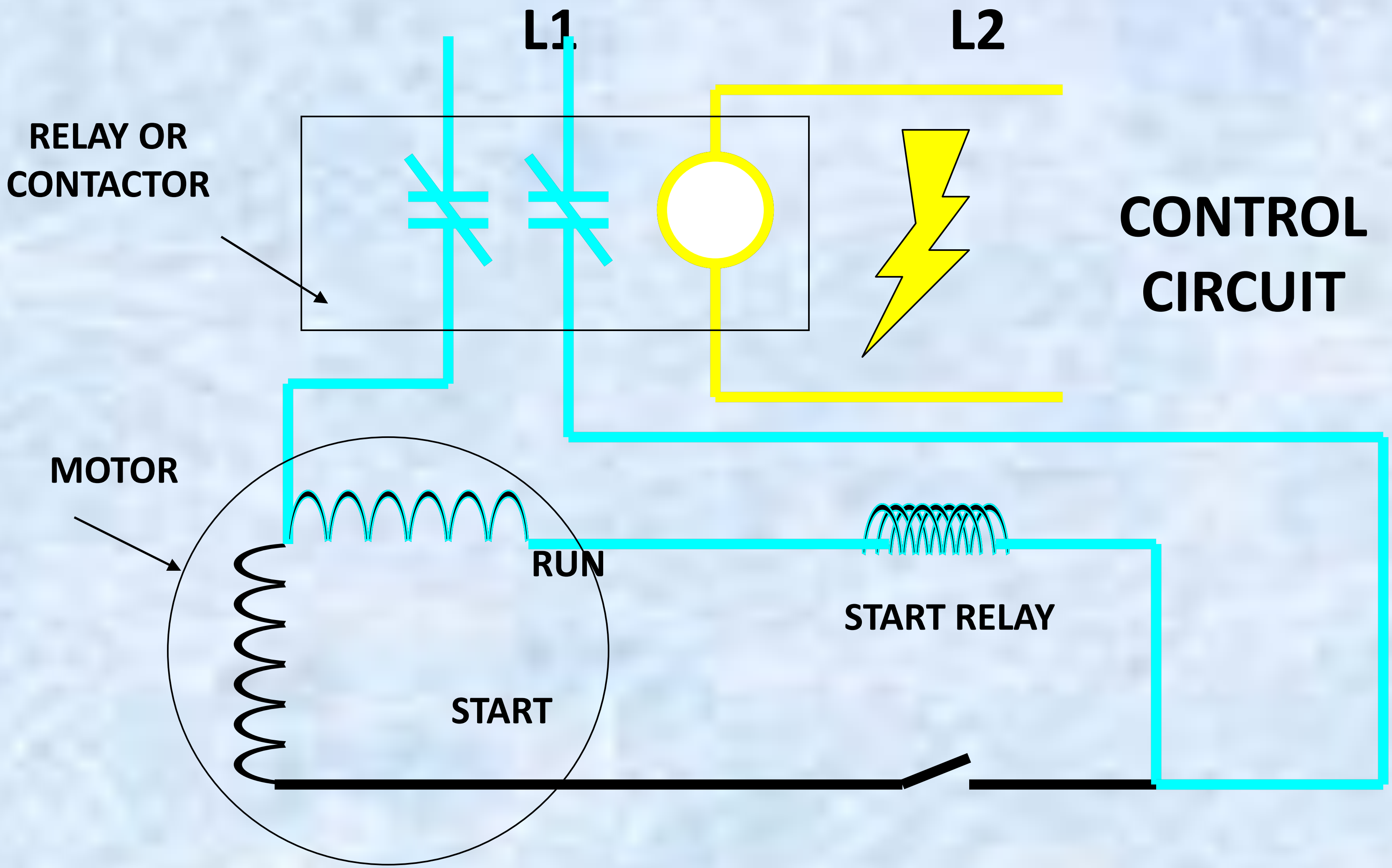


Contactor

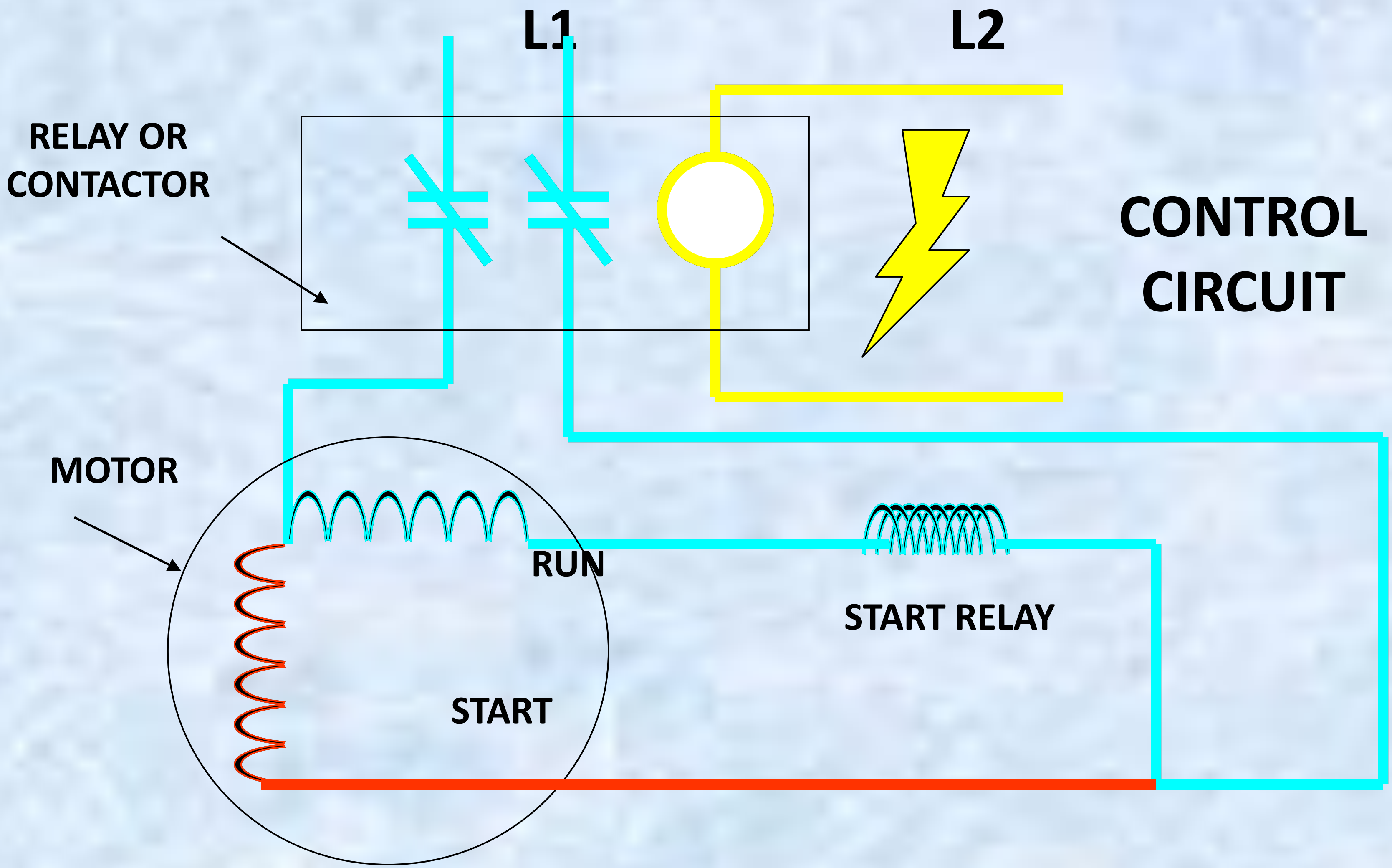


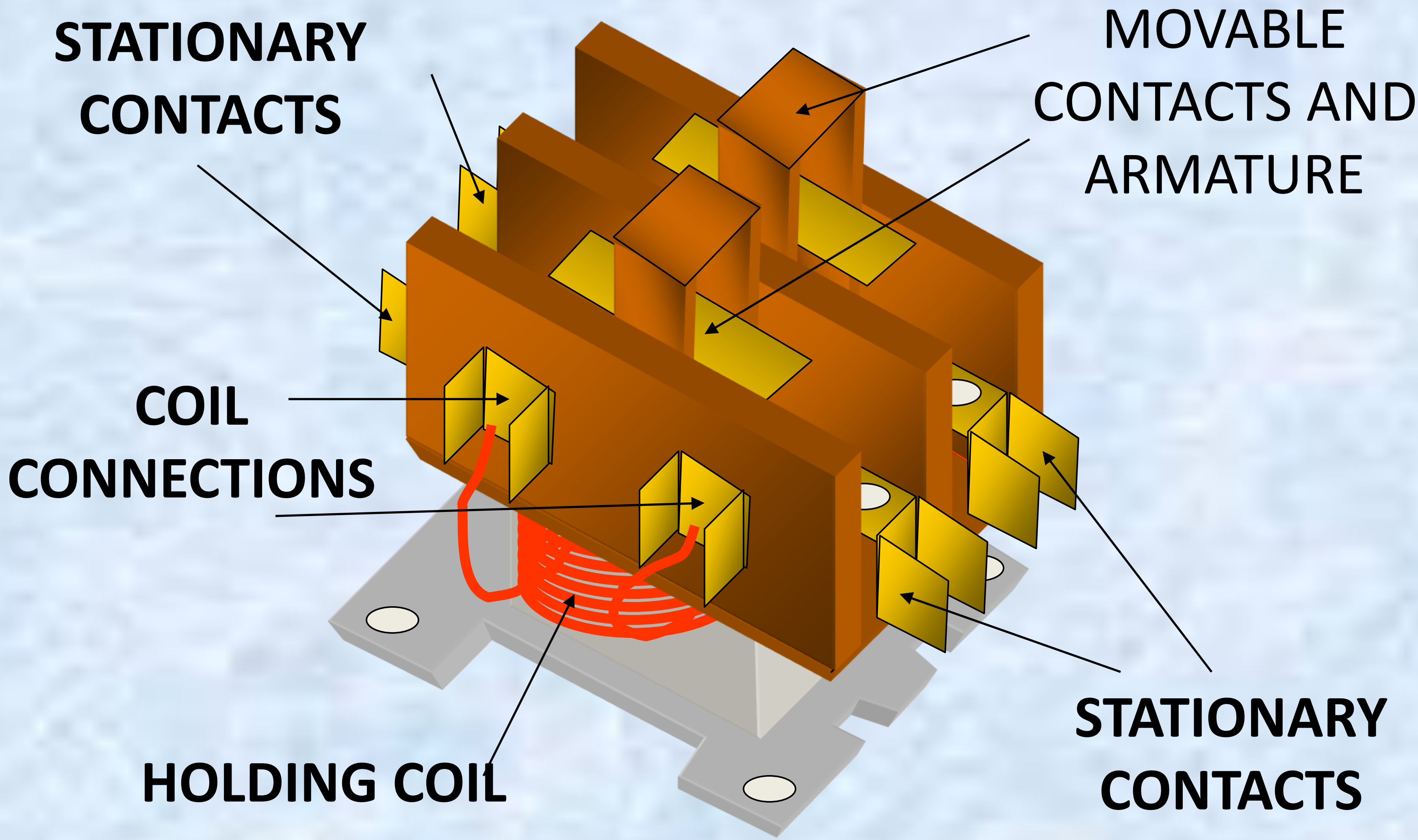
Category		Type of Duty
AC	AC_1	Non Inductive or slightly inductive loads, resistance furnaces.
	AC_2	Starting of slip ring motors, Reverse current breaking
	AC_3	Starting of squirrel cage motors, switching off motors during running.
	AC_4	Starting of squirrel cage motors, plugging, inching.
DC	DC_1	Non inductive and slightly inductive loads, resistance furnaces.
	DC_2	Starting shunt motors, switching off shunt motors during running.
	DC_3	Starting shunt motors, plugging, inching
	DC_4	Starting series motors, switching of series motors during running.
	DC_5	Starting series motors, plugging, inching

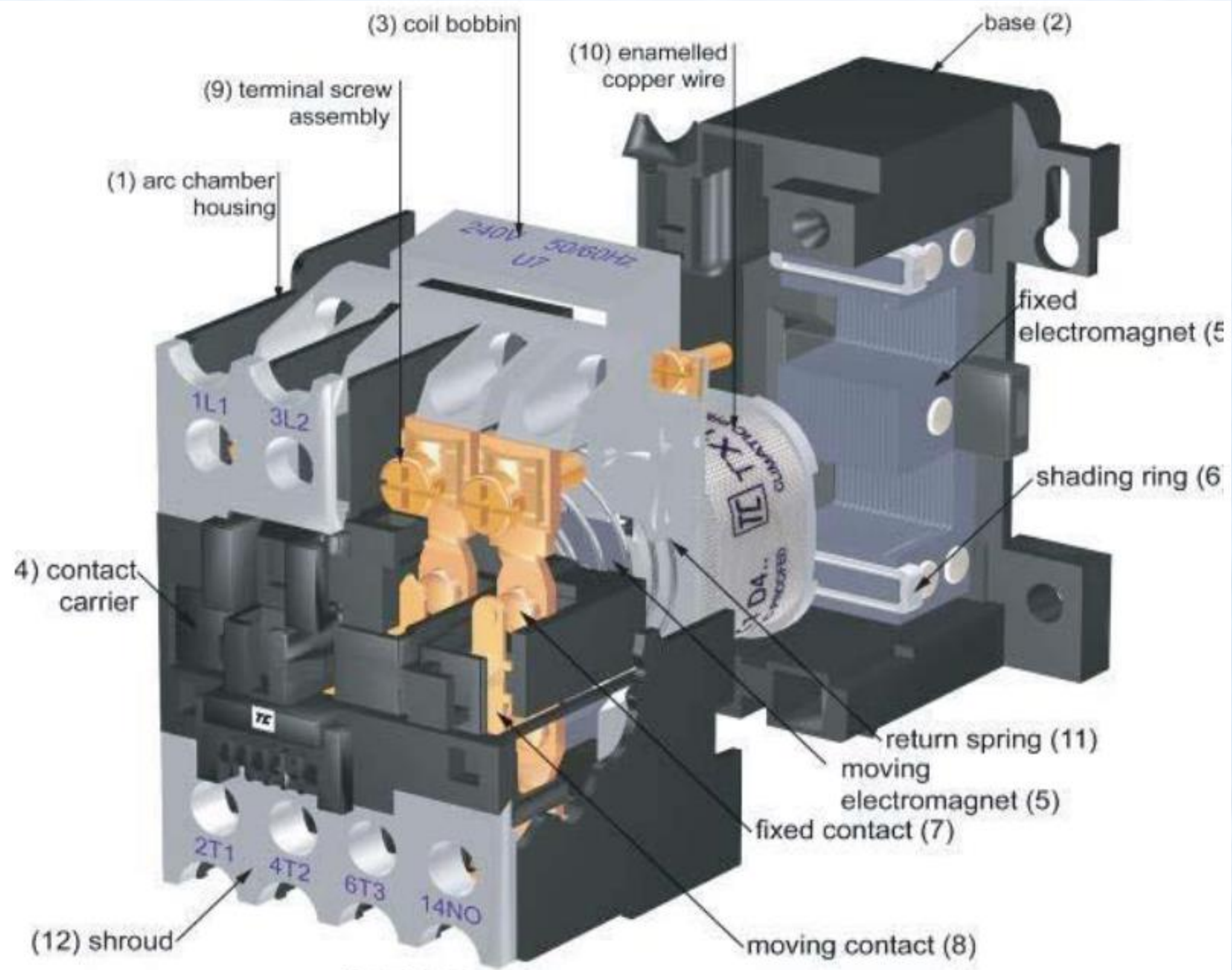




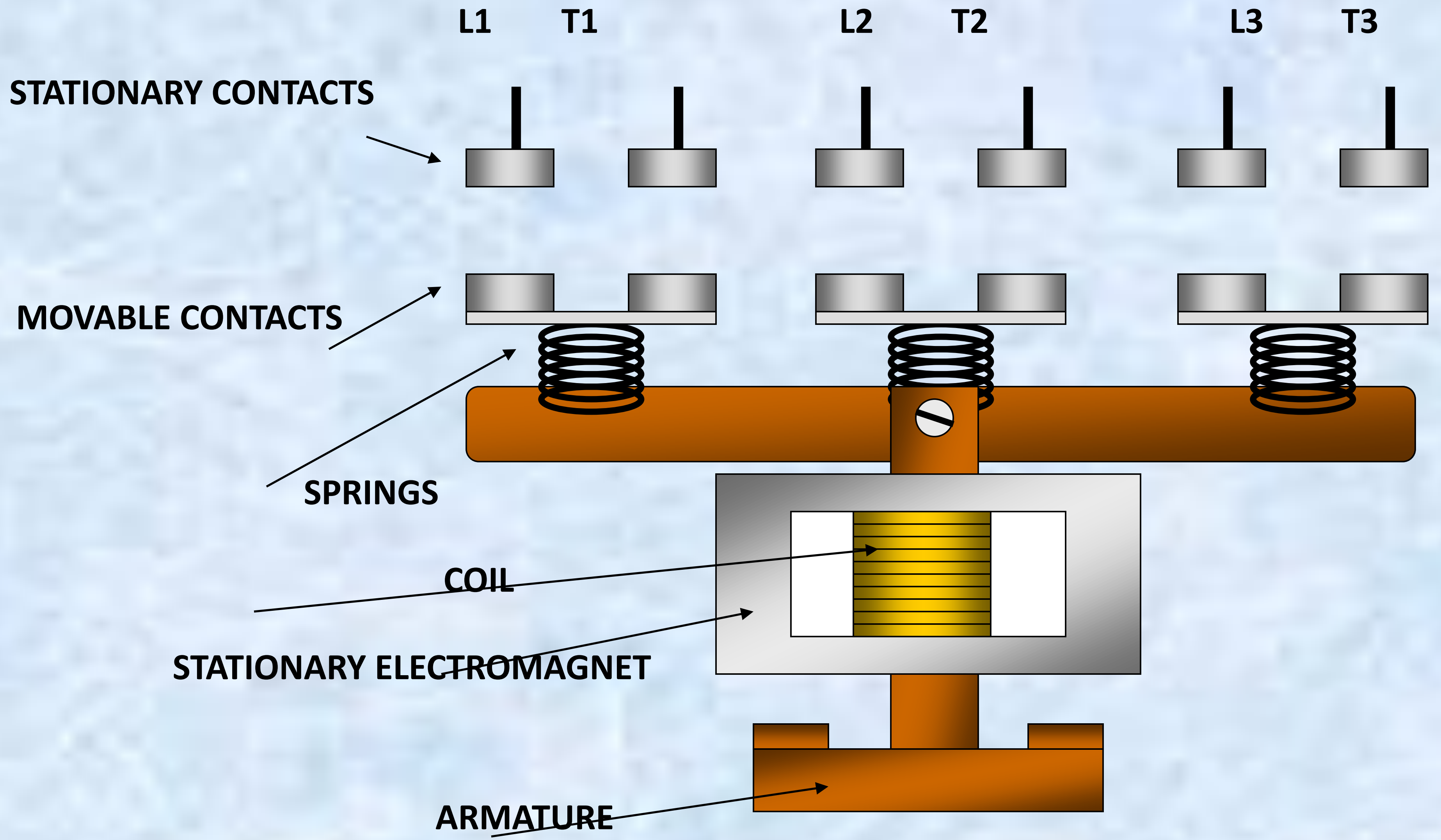
L1
L2
RELAY OR
CONTACTOR
CONTROL
CIRCUIT
MOTOR
RUN
START RELAY
START

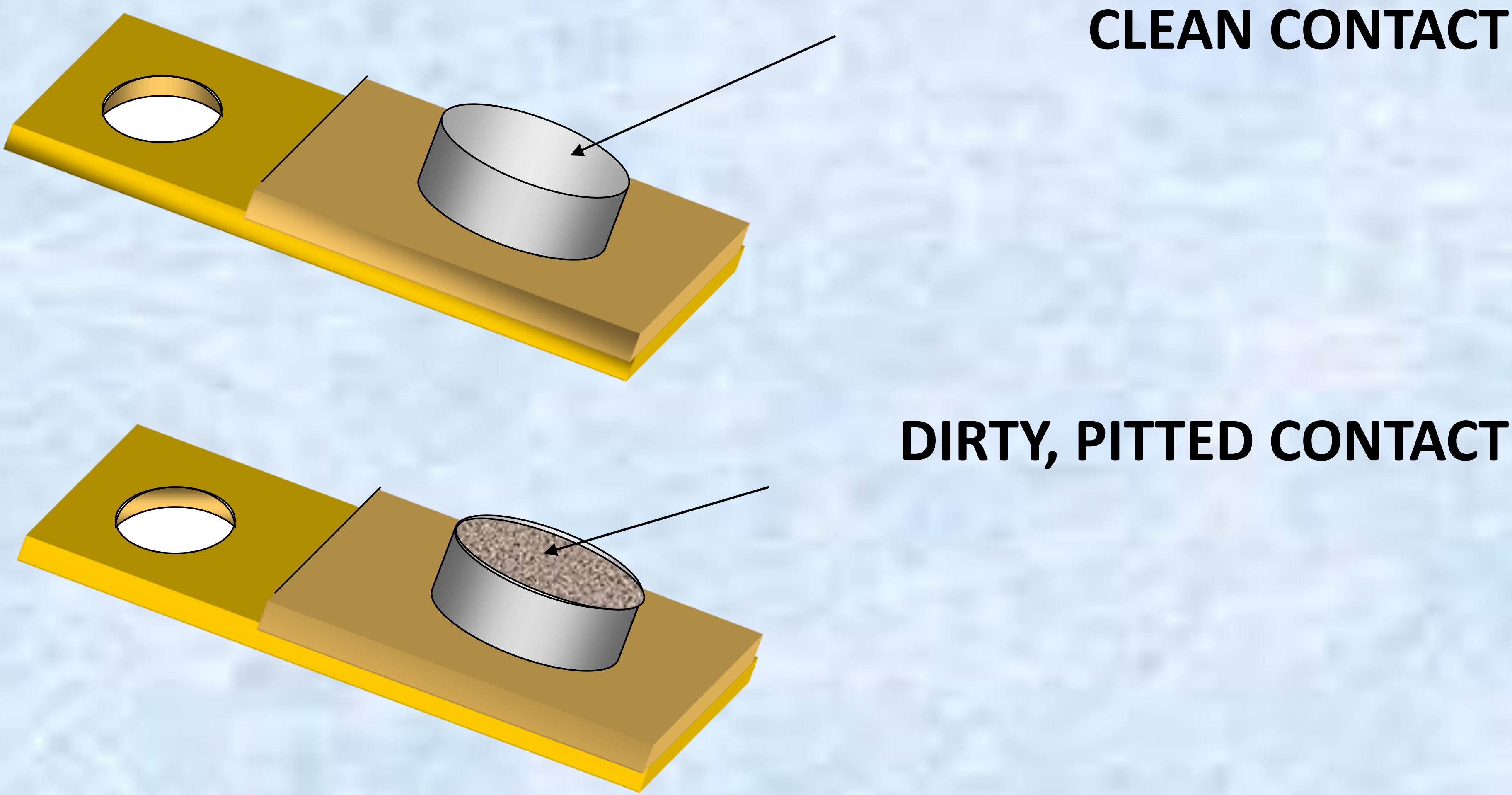

L1
L2
RELAY OR
CONTACTOR
CONTROL
CIRCUIT
MOTOR
RUN
START RELAY
START


STATIONARY CONTACTS
MOVABLE CONTACTS AND ARMATURE
COIL CONNECTIONS
HOLDING COIL
STATIONARY CONTACTS



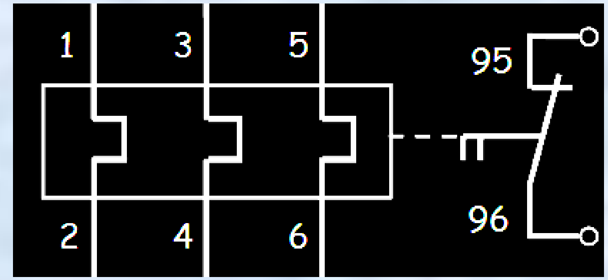
(3) coil bobbin
base (2)
(10) enamelled copper wire
(9) terminal screw assembly
(1) arc chamber housing
240V 50/60Hz
U7
1L1
3L2
fixed electromagnet (5
shading ring (6
4) contact carrier
return spring (11)
moving electromagnet (5)
fixed contact (7)
2T1
4T2
6T3
14NO
(12) shroud
moving contact (8)


L1
T1
L2
T2
L3
T3
STATIONARY CONTACTS
MOVABLE CONTACTS
SPRINGS
COIL
STATIONARY ELECTROMAGNET
ARMATURE

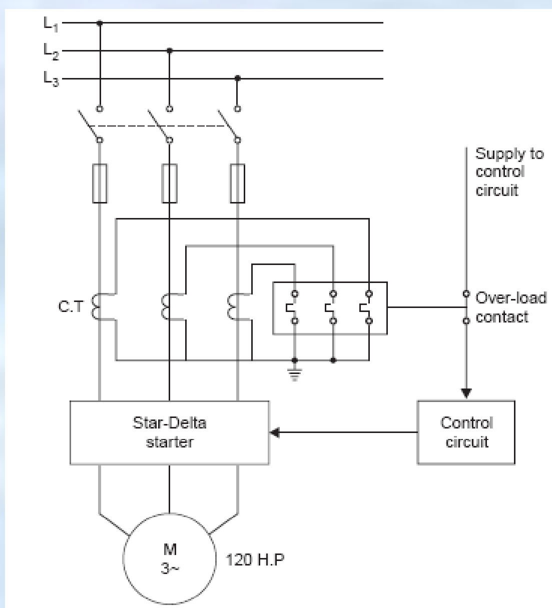

CLEAN CONTACT
DIRTY, PITTED CONTACT

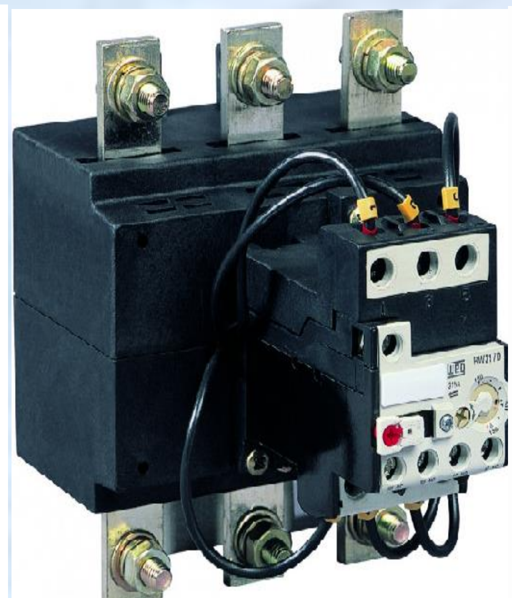
Overload

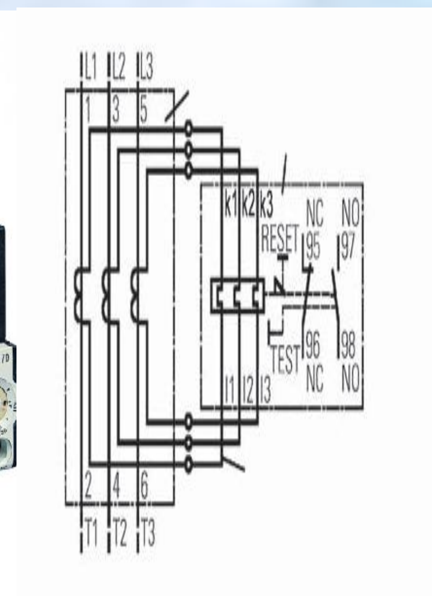
For low rating



For high rating

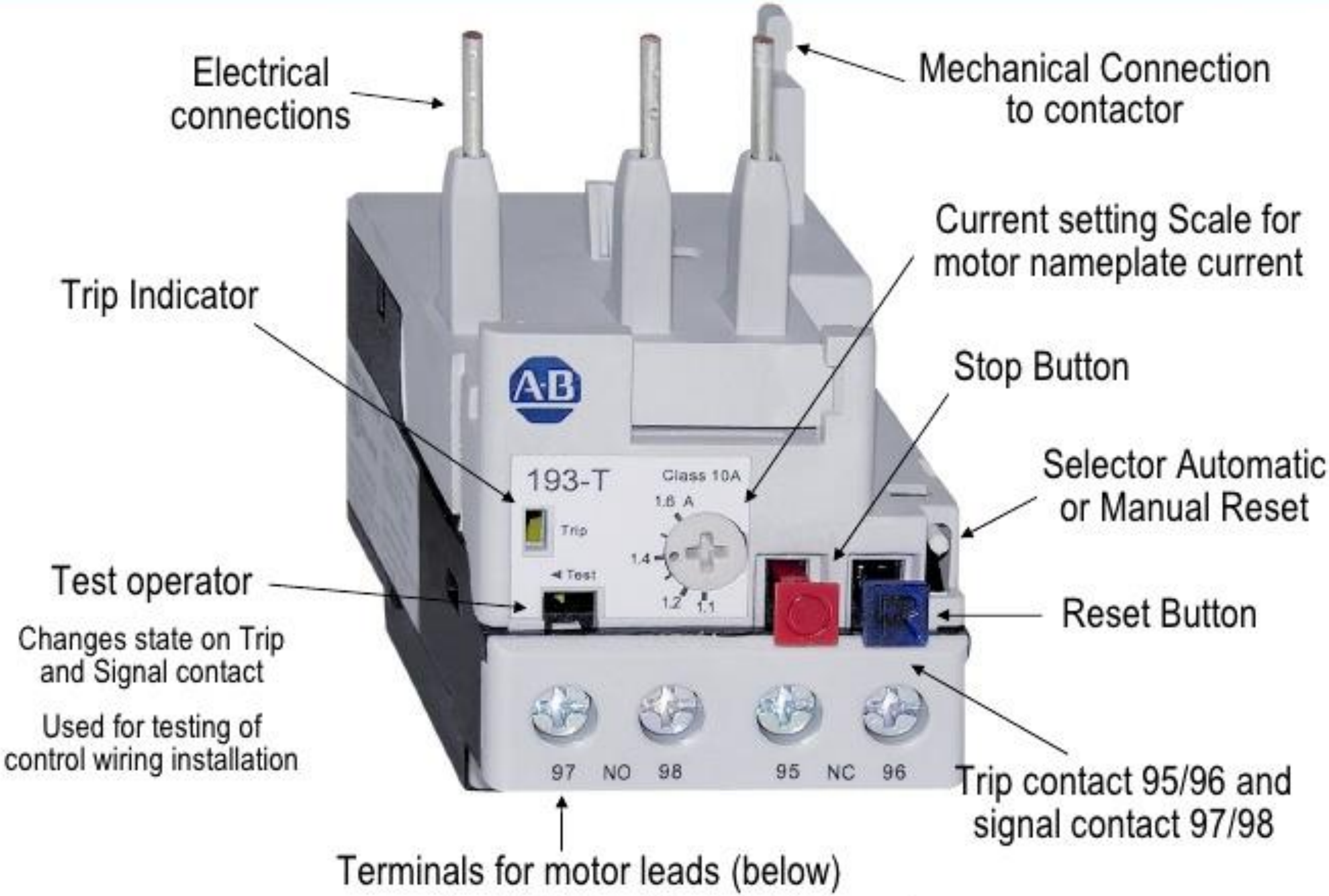






IEC Bimetallic Overload Relay

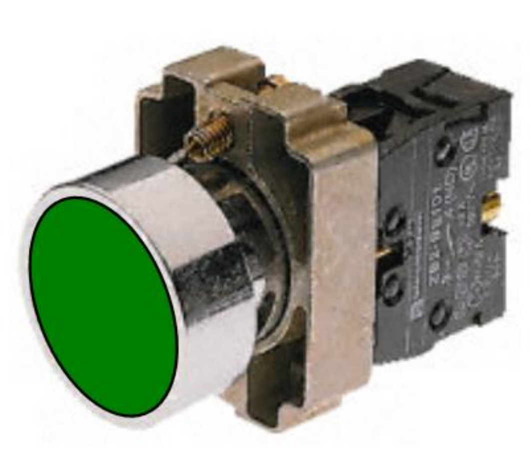
Rockwell Automation *on the move*

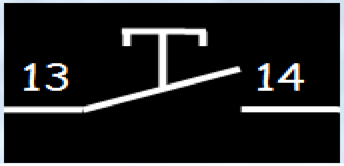


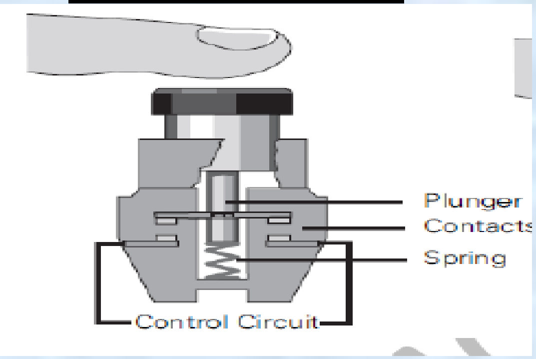
Control circuit components

Start and Stop pushbuttons

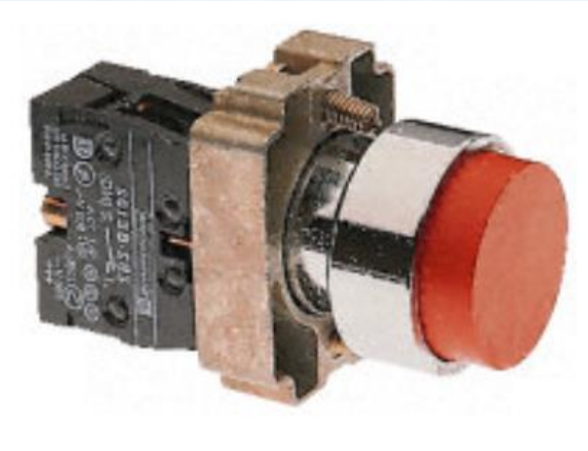
Start button is green

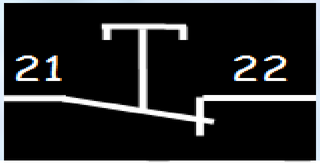


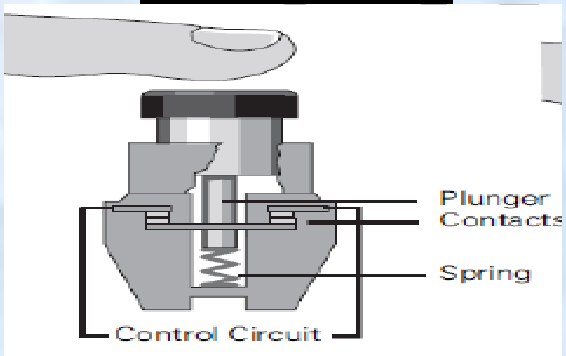




Stop button is red





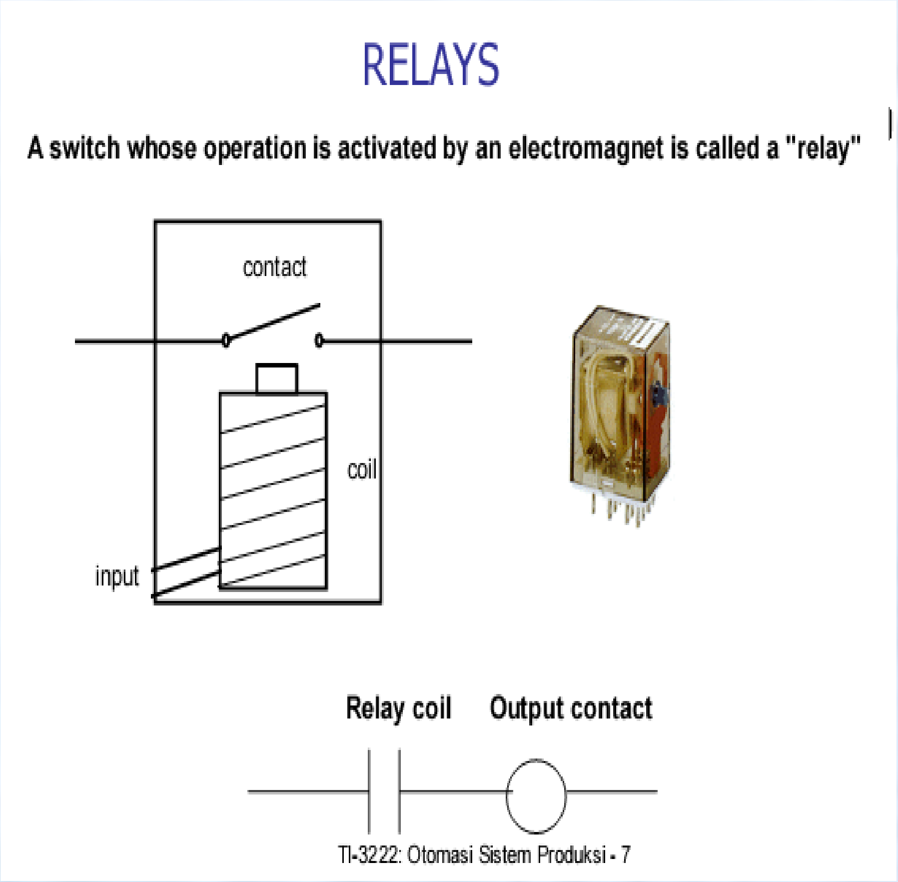


Emergency Stop button has a red mushroom head which latches in and must be turned to release

Selector 2 position

Relays

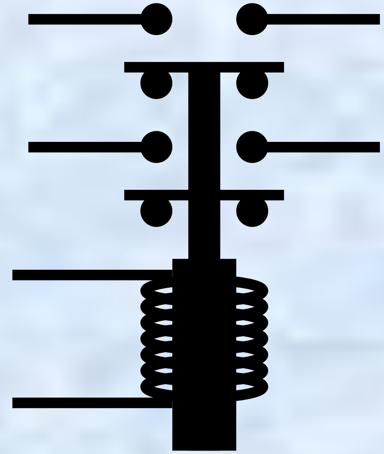
- Input & Output contacts in series and/or parallel
- Combinations of logic elements create complex control plans



Control Relay

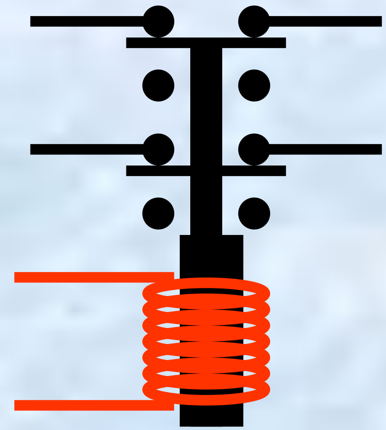
relay
not
activated

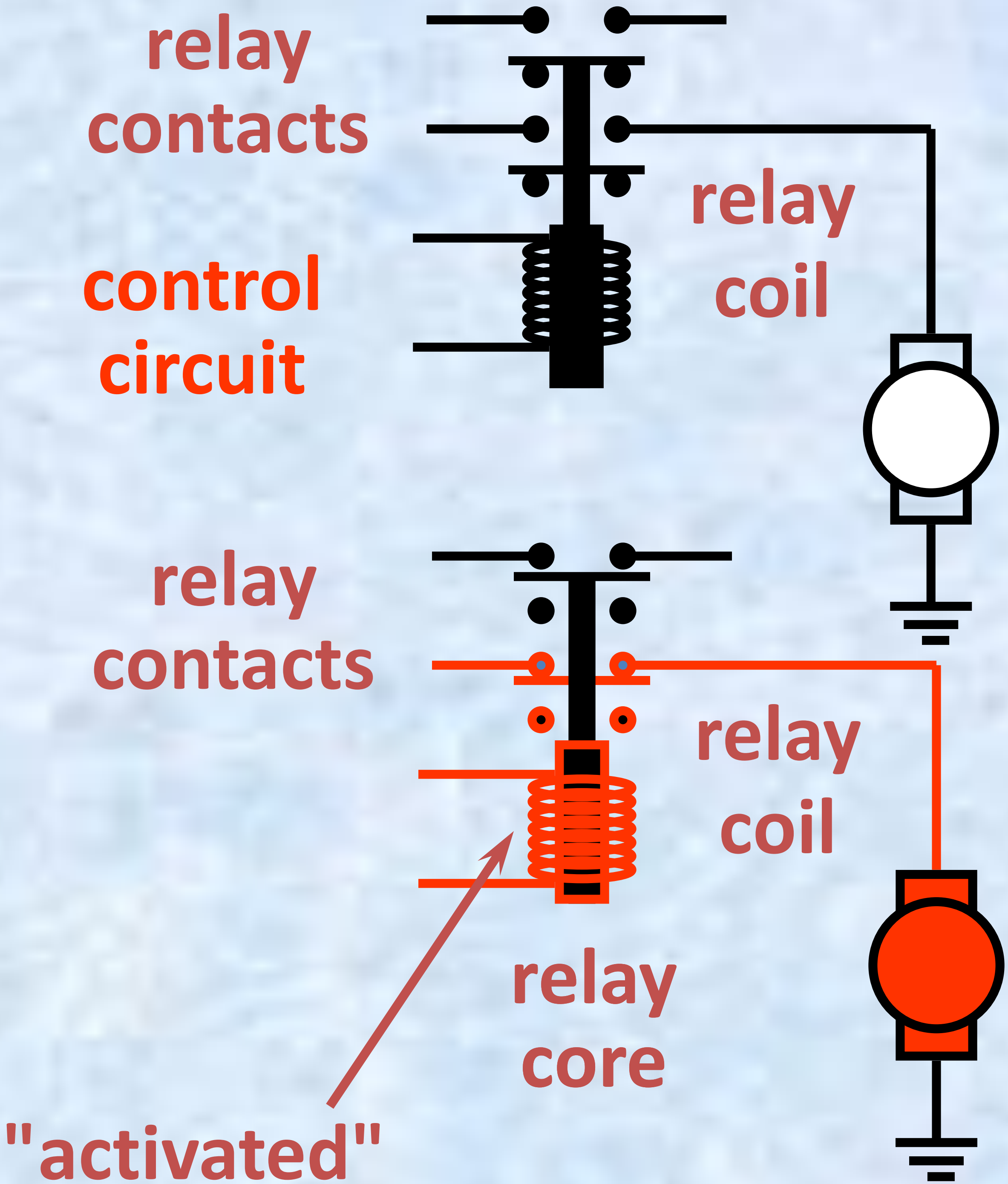
relay
contacts



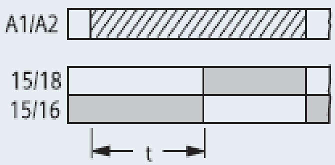
relay
activated

relay
contacts

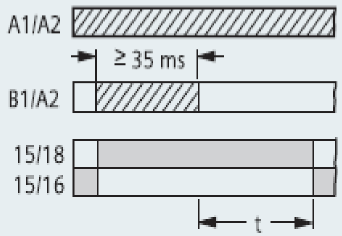



relay contacts
control circuit
relay coil
relay contacts
relay coil
relay core
"activated"

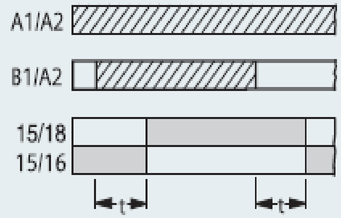
Electronic Timer



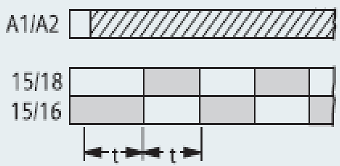
ON-delay



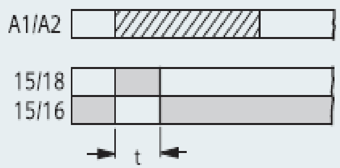
OFF-delay
With auxiliary voltage



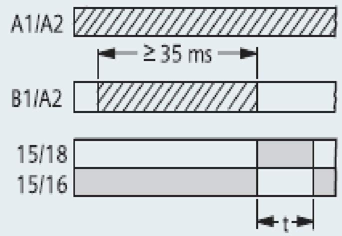
ON + OFF delay
($t = t_{ON} = t_{OFF}$)



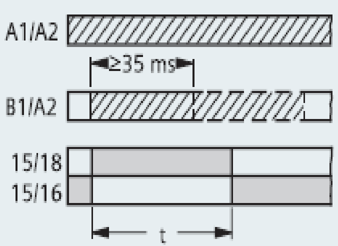
Flashing (Cyclic)
(Pulse interval 1:1)



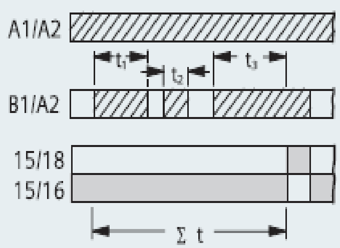
Make Contact



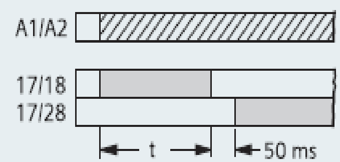
Break contact



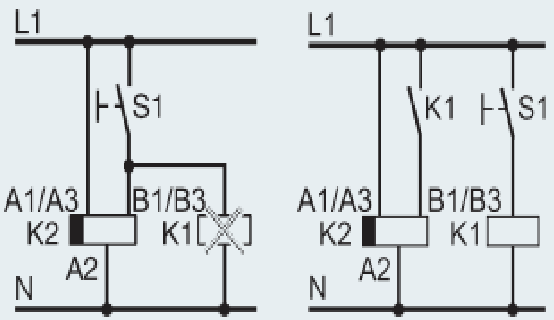
Pulse shaping



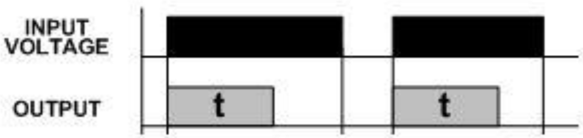
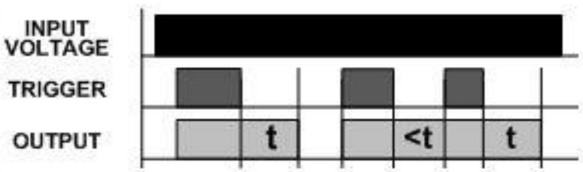
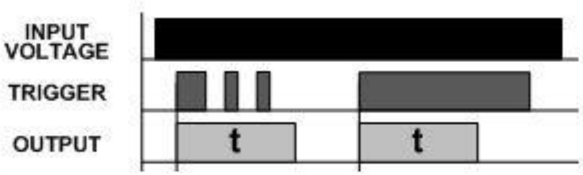
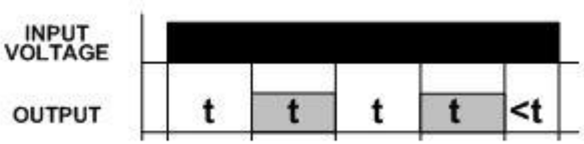
Additive ON-delay



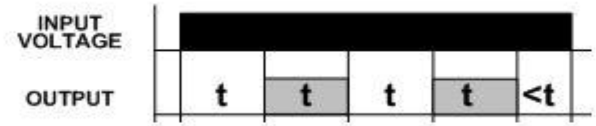
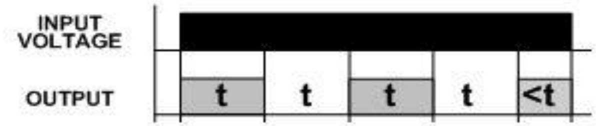
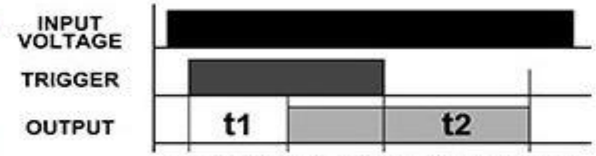
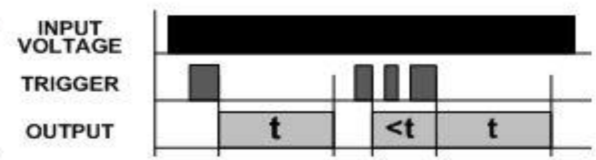
Star delta



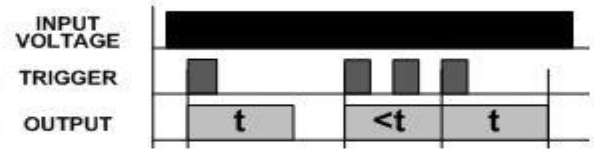
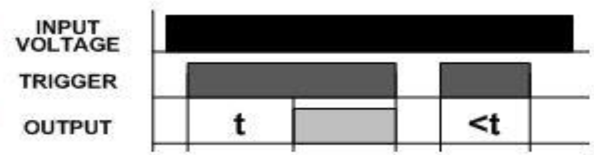
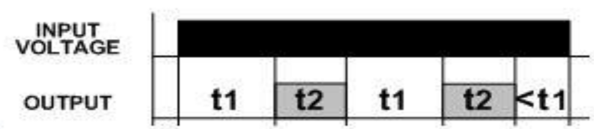
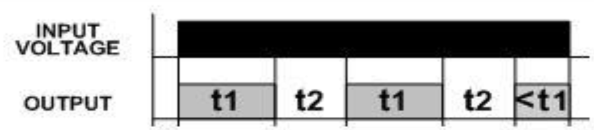
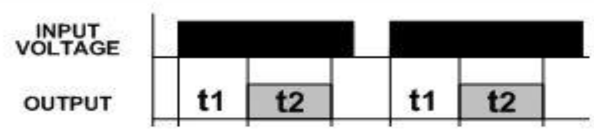
Electronic Timer

Function	Operation	Timing Chart
ON DELAY Delay on Make Delay on Operate	Upon application of input voltage, the time delay (t) begins. At the end of the time delay (t), the output is energized. Input voltage must be removed to reset the time delay relay & de-energize the output.	
INTERVAL ON Interval	Upon application of input voltage, the output is energized and the time delay (t) begins. At the end of the time delay (t), the output is de-energized. Input voltage must be removed to reset the time delay relay.	
OFF DELAY Delay on Release Delay on Break Delay on De-Energization	Upon application of input voltage, the time delay relay is ready to accept a trigger. When the trigger is applied, the output is energized. Upon removal of the trigger, the time delay (t) begins. At the end of the time delay (t), the output is de-energized. Any application of the trigger during the time delay will reset the time delay (t) and the output remains energized.	
SINGLE SHOT One Shot Momentary Interval	Upon application of input voltage, the time delay relay is ready to accept a trigger. When the trigger is applied, the output is energized and the time delay (t) begins. During the time delay (t), the trigger is ignored. At the end of the time delay (t), the output is de-energized and the time delay relay is ready to accept another trigger.	
FLASHER (Off First)	Upon application of input voltage, the time delay (t) begins. At the end of the time delay (t), the output is energized and remains in that condition for the time delay (t). At the end of the time delay (t), the output is de-energized and the sequence repeats until input voltage is removed.	

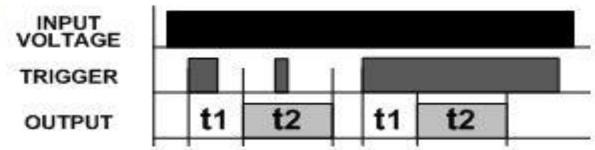
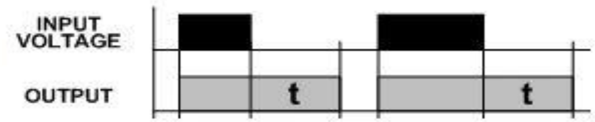
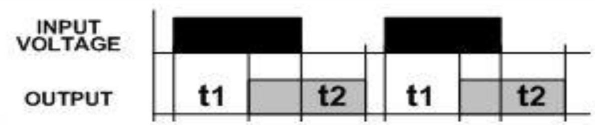
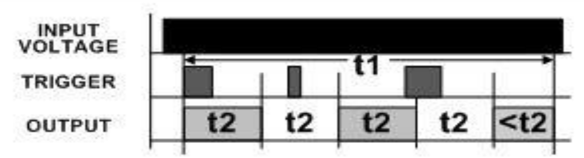
Electronic Timer

Function	Operation	Timing Chart
FLASHER (Off First)	Upon application of input voltage, the time delay (t) begins. At the end of the time delay (t), the output is energized and remains in that condition for the time delay (t). At the end of the time delay (t), the output is de-energized and the sequence repeats until input voltage is removed.	
FLASHER (On First)	Upon application of input voltage, the output is energized and the time delay (t) begins. At the end of the time delay (t), the output is de-energized and remains in that condition for the time delay (t). At the end of the time delay (t), the output is energized and the sequence repeats until input voltage is removed.	
ON/OFF DELAY	Upon application of input voltage, the time delay relay is ready to accept a trigger. When the trigger is applied, the time delay (t1) begins. At the end of the time delay (t1), the output is energized. When the trigger is removed, the output contacts remain energized for the time delay (t2). At the end of the time delay (t2), the output is de-energized & the time delay relay is ready to accept another trigger. If the trigger is removed during time delay period (t1), the output will remain de-energized and time delay (t1) will reset. If the trigger is re-applied during time delay period (t2), the output will remain energized and the time delay (t2) will reset.	 * For TD-7 catalog numbers, t1 & t2 are the same length of time.
SINGLE SHOT FALLING EDGE	Upon application of input voltage, the time delay relay is ready to accept a trigger. When the trigger is applied, the output remains de-energized. Upon removal of the trigger, the output is energized and the time delay (t) begins. At the end of the time delay (t), the output is de-energized unless the trigger is removed and re-applied prior to time out (before time delay (t) elapses). Continuous cycling of the trigger at a rate faster than the time delay (t) will cause the output to remain energized indefinitely.	

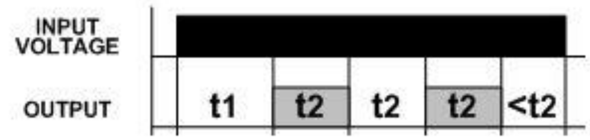
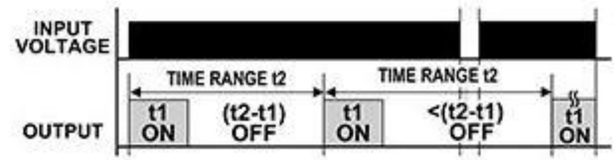
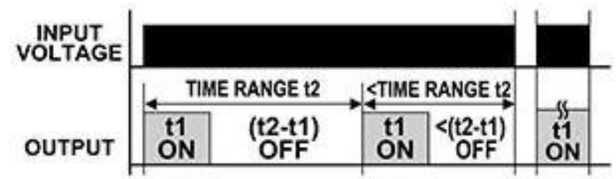
Electronic Timer

Function	Operation	Timing Chart
WATCHDOG Retriggerable Single Shot	Upon application of input voltage, the time delay relay is ready to accept a trigger. When the trigger is applied, the output is energized and the time delay (t) begins. At the end of the time delay (t), the output is de-energized unless the trigger is removed and re-applied prior to time out (before time delay (t) elapses). Continuous cycling of the trigger at a rate faster than the time delay (t) will cause the output to remain energized indefinitely.	
TRIGGERED ON DELAY	Upon application of input voltage, the time delay relay is ready to accept a trigger. When the trigger is applied, the time delay (t) begins. At the end of the time delay (t), the output is energized and remains in that condition as long as either the trigger is applied or the input voltage remains. If the trigger is removed during the time delay (t), the output remains de-energized & the time delay (t) is reset.	
REPEAT CYCLE (OFF 1st)	Upon application of input voltage, the time delay (t1) begins. At the end of the time delay (t1), the output is energized and remains in that condition for the time delay (t2). At the end of this time delay, the output is de-energized and the sequence repeats until input voltage is removed.	
REPEAT CYCLE (ON 1st)	Upon application of input voltage, the output is energized and the time delay (t1) begins. At the end of the time delay (t1), the output is de-energized and remains in that condition for the time delay (t2). At the end of this time delay, the output is energized and the sequence repeats until input voltage is removed.	
DELAYED INTERVAL Single Cycle	Upon application of input voltage, the time delay (t1) begins. At the end of the time delay (t1), the output is energized and remains in that condition for the time delay (t2). At the end of this time delay (t2), the output is de-energized. Input voltage must be removed to reset the time delay relay.	

Electronic Timer

<table>
<tr><th>Function</th><th>Operation</th><th>Timing Chart</th></tr>
<tr><td>TRIGGERED DELAYED INTERVAL Single Cycle</td><td>Upon application of input voltage, the time delay relay is ready to accept a trigger. When the trigger is applied, the time delay (t1) begins. At the end of the time delay (t1), the output is energized and remains in that condition for the time delay (t2). At the end of the time delay (t2), the output is de-energized & the relay is ready to accept another trigger. During both time delay (t1) & time delay (t2), the trigger is ignored.</td><td>
</td></tr>
<tr><td>TRUE OFF DELAY</td><td>Upon application of input voltage, the output is energized. When the input voltage is removed, the time delay (t) begins. At the end of the time delay (t), the output is de-energized. Input voltage must be applied for a minimum of 0.5 seconds to assure proper operation. Any application of the input voltage during the time delay (t) will reset the time delay. No external trigger is required.</td><td>
</td></tr>
<tr><td>ON DELAY/ TRUE OFF DELAY</td><td>Upon application of input voltage, the time delay (t1) begins. At the end of the time delay (t1), the output is energized. When the input voltage is removed, the output remains energized for the time delay (t2). At the end of the time delay (t2), the output is de-energized. Input voltage must be applied for a minimum of 0.5 seconds to assure proper operation. Any application of the input voltage during the time delay (t2) will keep the output energized & reset the time delay (t2). No external trigger is required.</td><td>
</td></tr>
<tr><td>SINGLE SHOT-FLASHER</td><td>Upon application of input voltage, the time delay relay is ready to accept a trigger. When the trigger is applied, the time delay (t1) begins and the output is energized for the time delay (t2). At the end of this time delay (t2), the output is de-energized and remains in that condition for the time delay (t2). At the end of the time delay (t2), the output is energized and the sequence repeats until time delay (t1) is completed. During the time delay (t1), the trigger is ignored.</td><td>
</td></tr>
</table>

Electronic Timer

Function	Operation	Timing Chart
ON DELAY-FLASHER	Upon application of input voltage, the time delay begins (t1). At the end of the time delay (t1), the output is energized and remains in that condition for the time delay (t2). At the end of this time delay (t2), the output is de-energized and remains in that condition for the time delay (t2). At the end of the time delay (t2), the output is energized and the sequence repeats until input voltage is removed.	
PERCENTAGE	Upon initial application of input voltage, the output is energized and time delay (t1) begins. Time Delay (t1) is adjustable as a percentage of the overall cycle time (t2). At the end of time delay (t1), the output is de-energized for the remainder of overall cycle (t2-t1). The sequence then repeats until input voltage is removed. If input voltage is removed and reapplied, the timing cycle will continue from where it left off when the input voltage was removed. A setting of 100% energizes the output continuously while a setting of 0% de-energizes the output continuously.	
PERCENTAGE (NO MEMORY)	Upon initial application of input voltage, the output is energized and time delay (t1) begins. Time Delay (t1) is adjustable as a percentage if the overall cycle time (t2). At the end of time delay (t1), the output is de-energized for the remainder of overall cycle (t2-t1). The sequence then repeats until input voltage is removed. If input voltage is removed and reapplied, the timing cycle will be reset. A setting of 100% energizes the output continuously while a setting of 0% de-energizes the output continuously.	

Transducers

- A device which converts 1 form of energy into another.

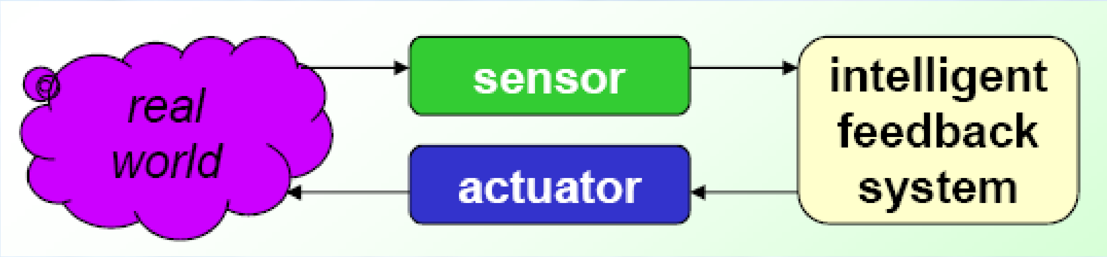
- In a process industry 4 basic and very important parameters to be measured and controlled are:

1) Flow

2) Temperature

3) Pressure

4) Level



Sensor (e.g., thermometer)

- Device that detects/measures a signal
- Acquires information from the "real world"

Actuator (e.g., heater)

- Device that generates a signal or stimulus

CHAPTER 4

Motor Name Plate

ABB IE2 CE

3~Motor M3BP 90SLB 4 IMB3/IM1001 734278-2

3GBP092322-ASB441 No.3GF12141567 Cl. F IP 55

V		Hz	r/min	kW	A	cosφ	Duty
400	Y	50	1435	1.1	2.3	0.80	S1
230	D	50	1435	1.1	3.9	0.80	S1
460	Y	60	1740	1.1	2.0	0.77	S1

IE2-50Hz-83.6%(100%)-84.5%(75%) / IE2-60Hz-85.4%(100%)

6205-2Z/C3 6204-2Z/C3 2013 25 kg

IEC 60034-1

Motor sizes 71 to 90

ABB IE2

3~Motor M3BP 112MB 2 IMB3/IM1001 2013 Cl. F IP 55

3GBP111322-ADB

738524-1 No. 3GF12143206

V		Hz	r/min	kW	A	cosφ	Duty
690	Y	50	2895	4	4.4	0.86	S1
400	D	50	2895	4	7.7	0.86	S1
460	D	60	2900	4	7.6	0.85	S1

IE2-86.1%(100%)-87.0%(75%)-86.6%(50%)

6206-2Z/C3 6205-2Z/C3 37 kg

IEC60034-1

Motor sizes 100 to 132

ABB CE

3~ Motor M3BP 180 MLB4 Cl.F IP 55 IEC 60034-1

V		Hz	kW	r/min	A	cos φ	duty
400	Δ	50	22	1475	40,9	0,84	S1
690	Y	50	22	1475	23,7	0.84	S1
415	Δ	50	22	1477	39,8	0,83	S1
460	Y	60	22	1780	35.7	0,83	S1

3GBP 182 032-ADG No.

50 Hz: IE2-92,4(100%)-93,3(75%)-93,0(50%)
60 Hz: IE2-93,1(100%)-93,4(75%)-92,6(50%)

2013

6310/C3 6209/C3 222 kg

spare-parts: www.abb.com/partsonline

Motor sizes 160 to 180

M3BP 160MLC 3GBP 161 033 - ADG 003, etc.

1 2 3 4 5 6 7 8 9 10 11 12 13 14

Positions 1 to 4

3GBP: Totally enclosed fan cooled squirrel cage motor with cast iron frame

Positions 5 and 6

IEC size

71:	71
80:	80
90:	90
10:	100
12:	112
13:	132
16:	160
18:	180
20:	200
22:	225
25:	250
28:	280
31:	315
35:	355
40:	400
45:	450

Position 7

Speed (Pole pairs)

1:	2 poles
2:	4 poles
3:	6 poles
4:	8 poles
5:	10 poles
6:	12 poles
7:	> 12 poles
8:	Two-speed motors for fan drive motors for constant torque
9:	Multi-speed motors, two-speed

Positions 8 to 10

Serial number

Position 11

- (dash)

Position 12

Mounting arrangement

A:	Foot-mounted, top-mounted terminal box
R:	Foot-mounted, terminal box RHS seen from D-end
L:	Foot-mounted, terminal box LHS seen from D-end
B:	Flange-mounted, large flange
C:	Flange-mounted, small flange (sizes 71 to 112)
H:	Foot- and flange-mounted, terminal box top-mounted
J:	Foot- and flange-mounted, small flange with tapped holes
S:	Foot- and flange-mounted, terminal box RHS seen from D-end
T:	Foot- and flange-mounted, terminal box LHS seen from D-end
V:	Flange-mounted, special flange
F:	Foot- and flange-mounted. Special flange

Position 13

Voltage and frequency

Single-speed motors

B:	380 VΔ 50 Hz
D:	400 VΔ, 415 VΔ, 690 VY 50 Hz
E:	500 VΔ 50 Hz
F:	500 VY 50 Hz
S:	230 VΔ, 400 VY, 415 VY 50 Hz
T:	660 VΔ 50 Hz
U:	690 VΔ 50 Hz
X:	Other rated voltage, connection or frequency, 690 V maximum

Two-speed motors

A:	220 V 50 Hz
B:	380 V 50 Hz
D:	400 V 50 Hz
E:	500 V 50 Hz
S:	230 V 50 Hz
X:	Other rated voltage, connection or frequency, 690 V maximum

Remark: For voltage code X the variant code "209 Non-standard voltage or frequency (special winding)" must be ordered.

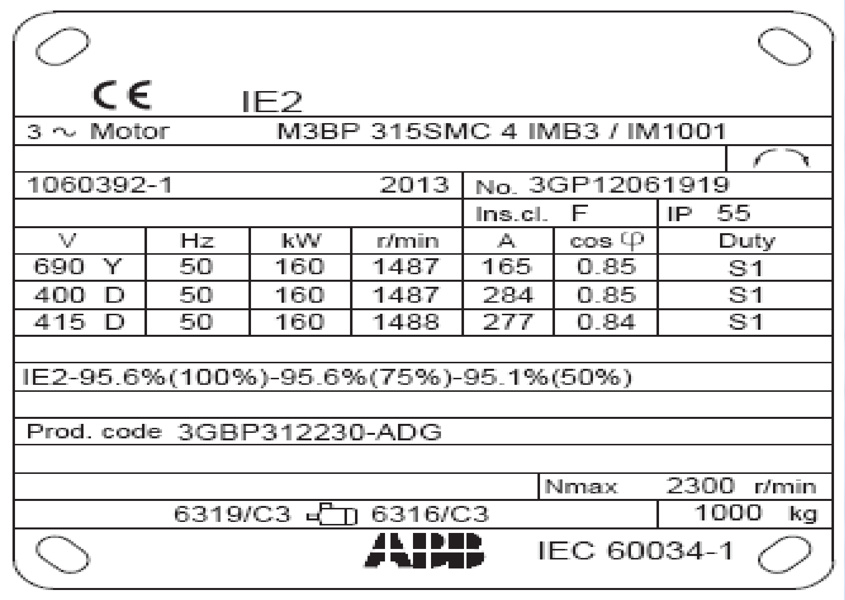
Position 14

Generation code

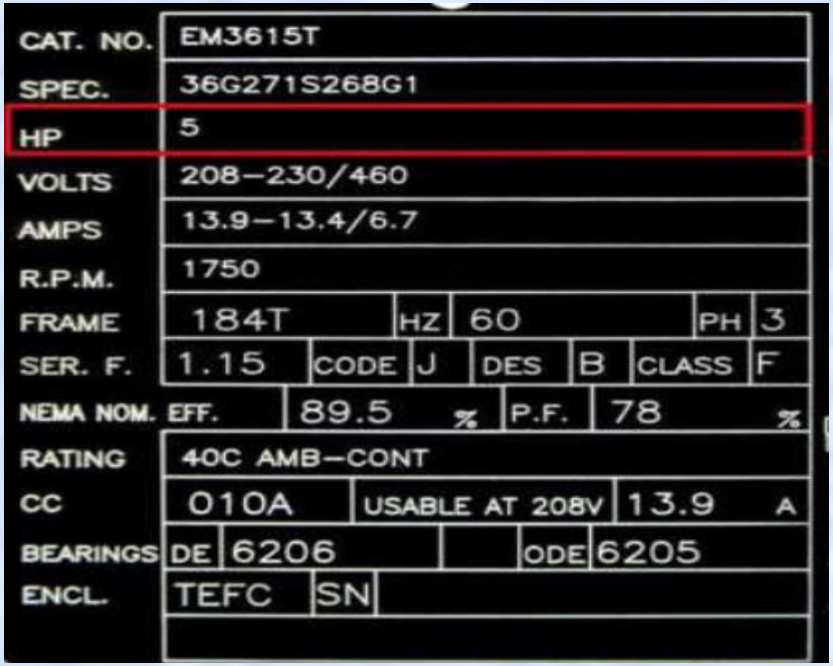
A, B, C...G...K: The product code must be, if needed, followed by variant codes.

- Manufacturer type
- Rated horsepower
- Rated voltage and amps
- Rated full-load amps
- Rated full-load speed
- Frequency
- Service Factor
- Frame Size
- Insulation class
- Efficiency

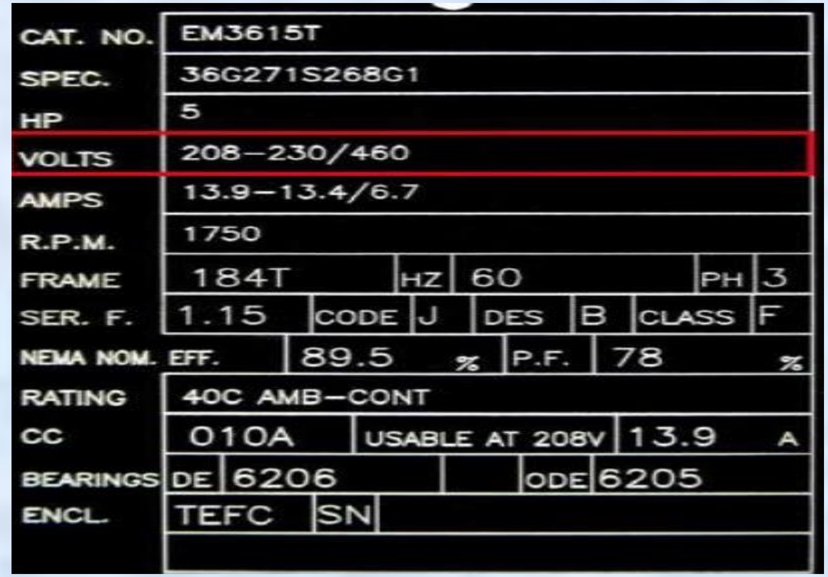
- **Manufacturer type**



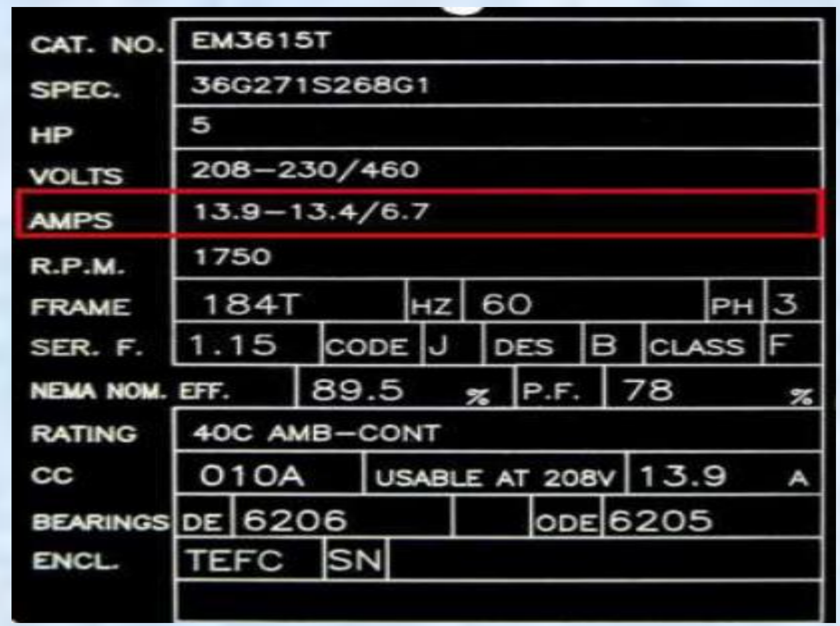
- **Rated horsepower**



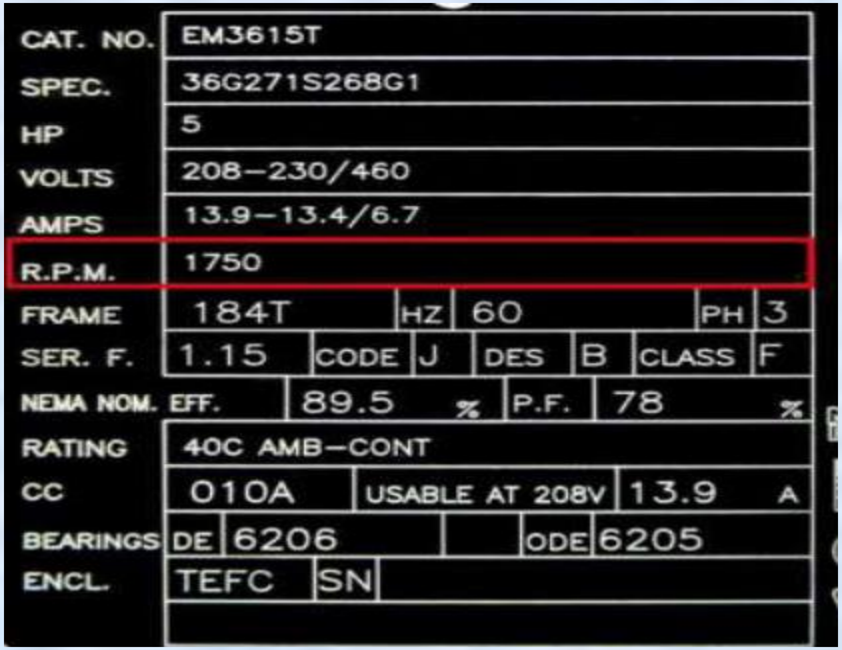
➢**Rated voltage**



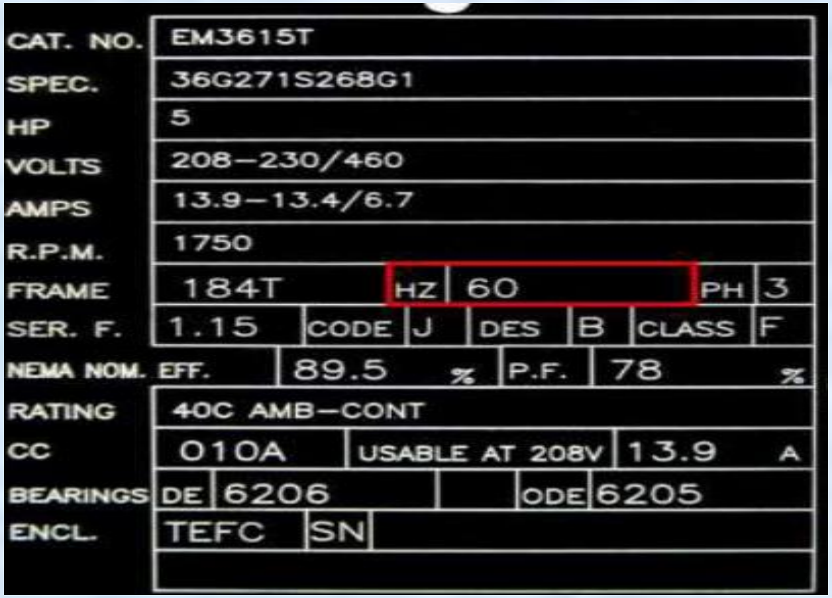
➢**Rated full load current**



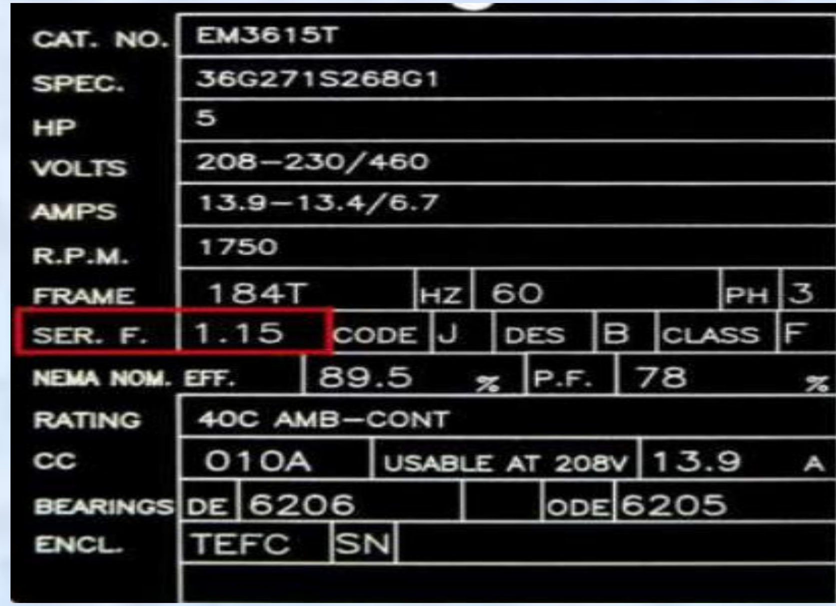
➢Rated speed



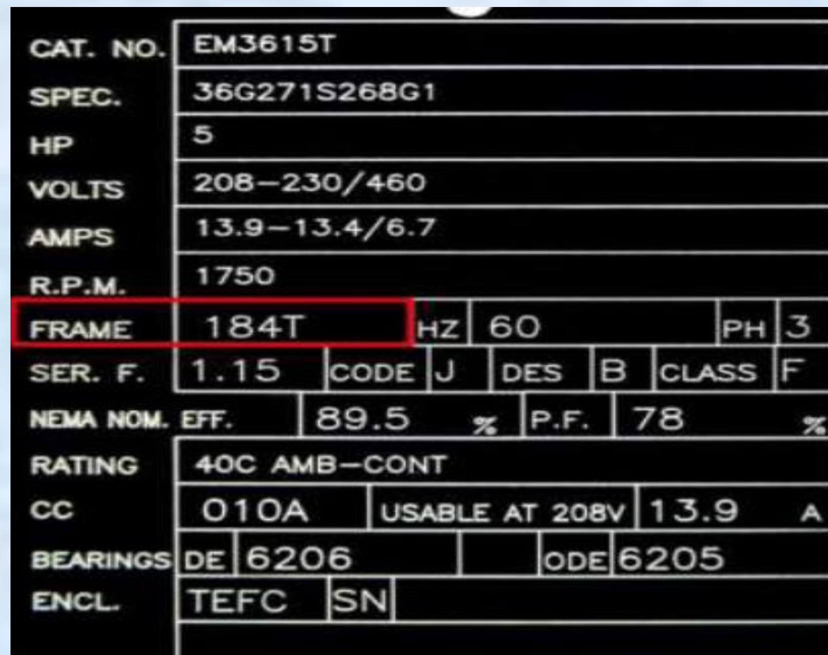
➢Frequency



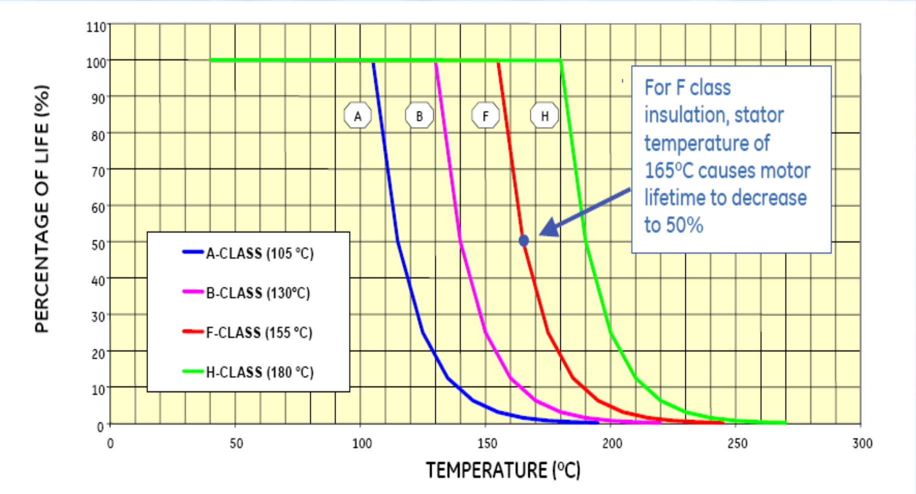
➢Service factor

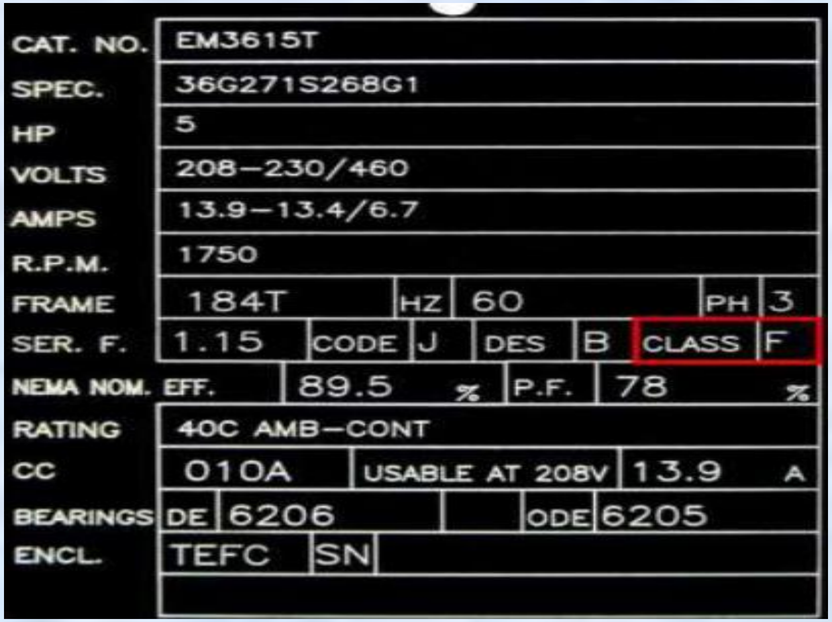


➢Frame size

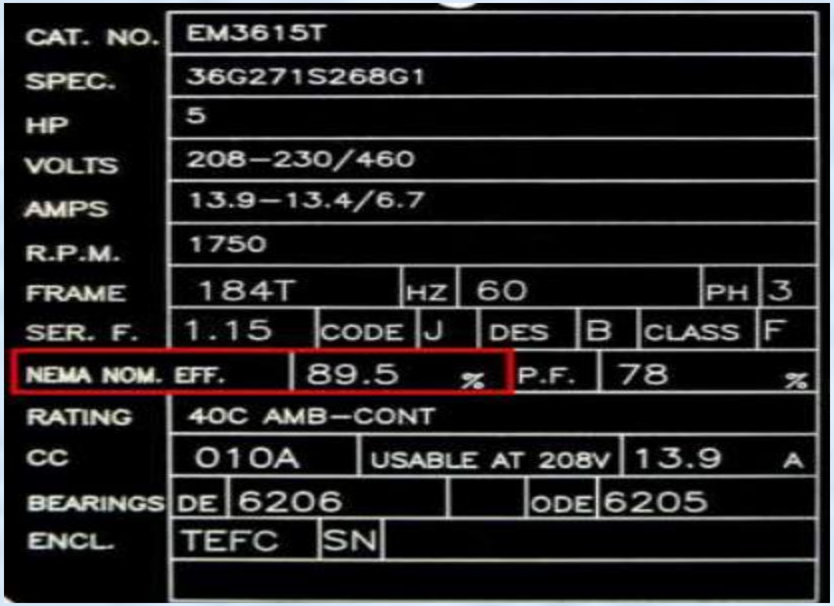


➢Insulation class

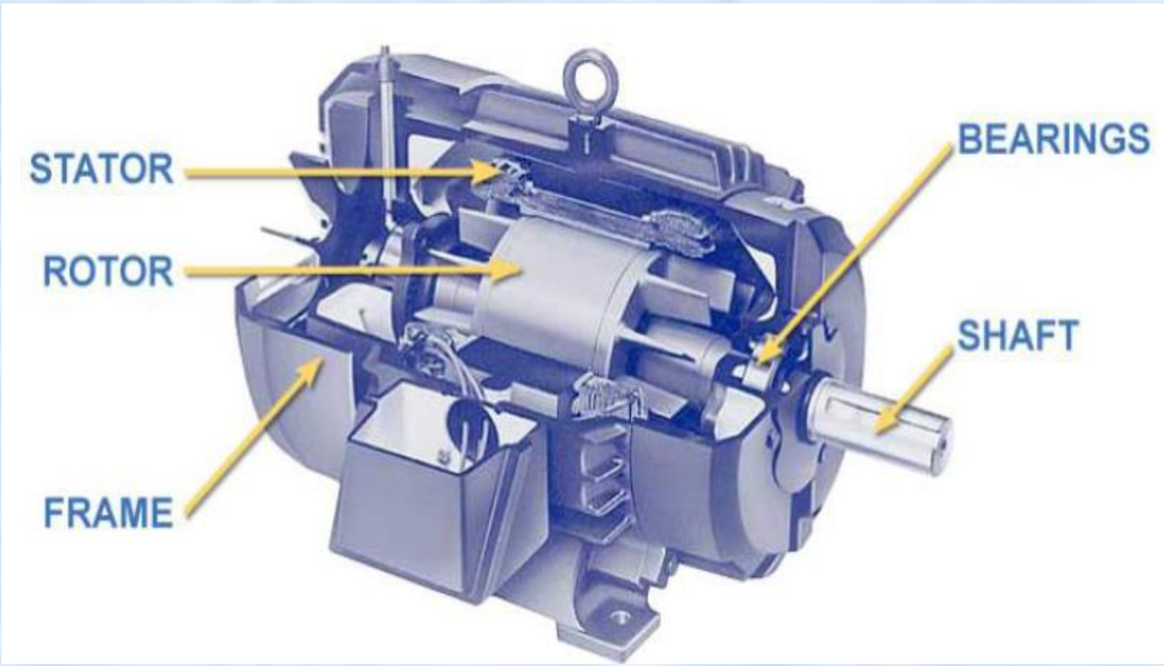


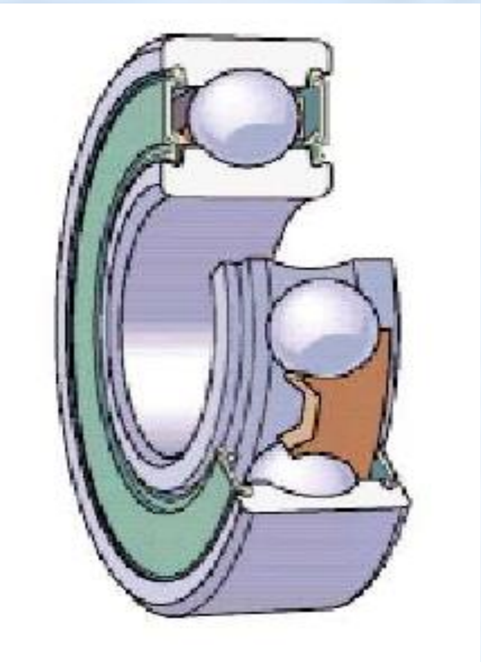


➢Efficiency



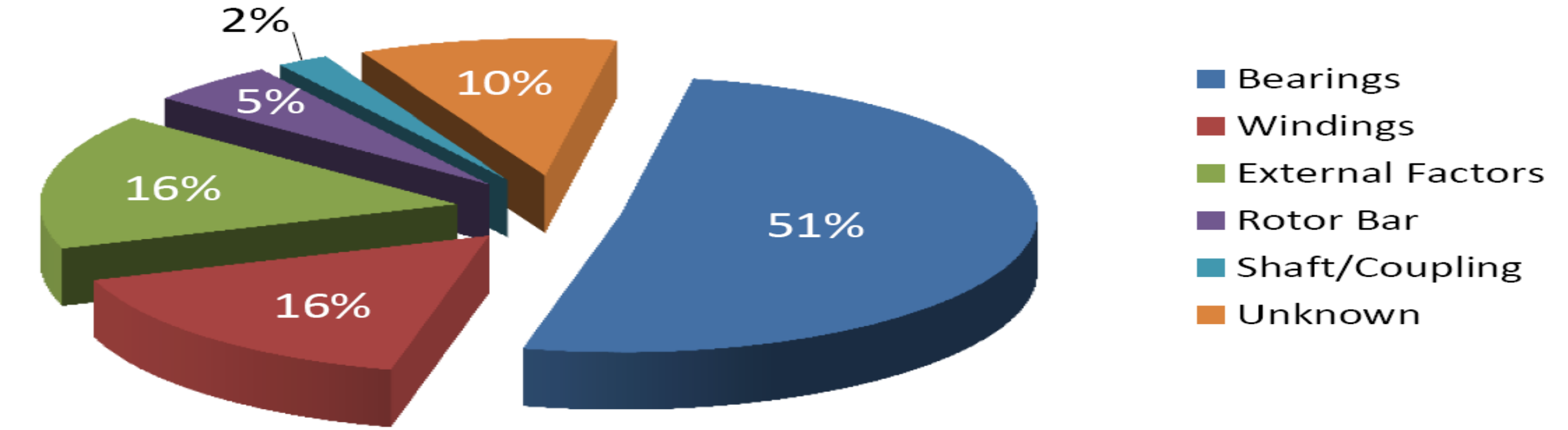
➢Roll Bearing





Note : Last 2 number * 5 except 00,01,02,03 (6205 inner diameter 25 mm)

Typical motor failure

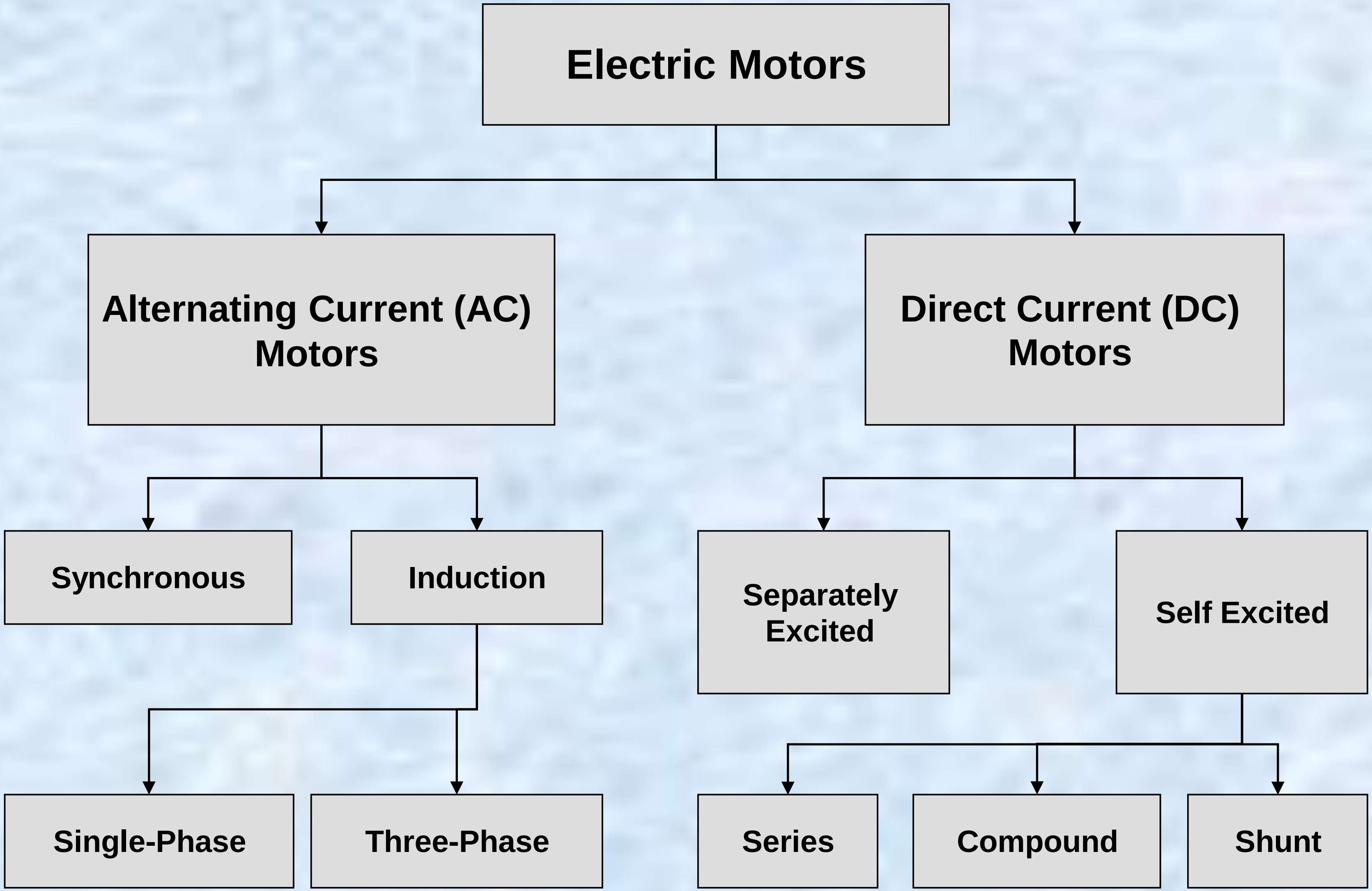


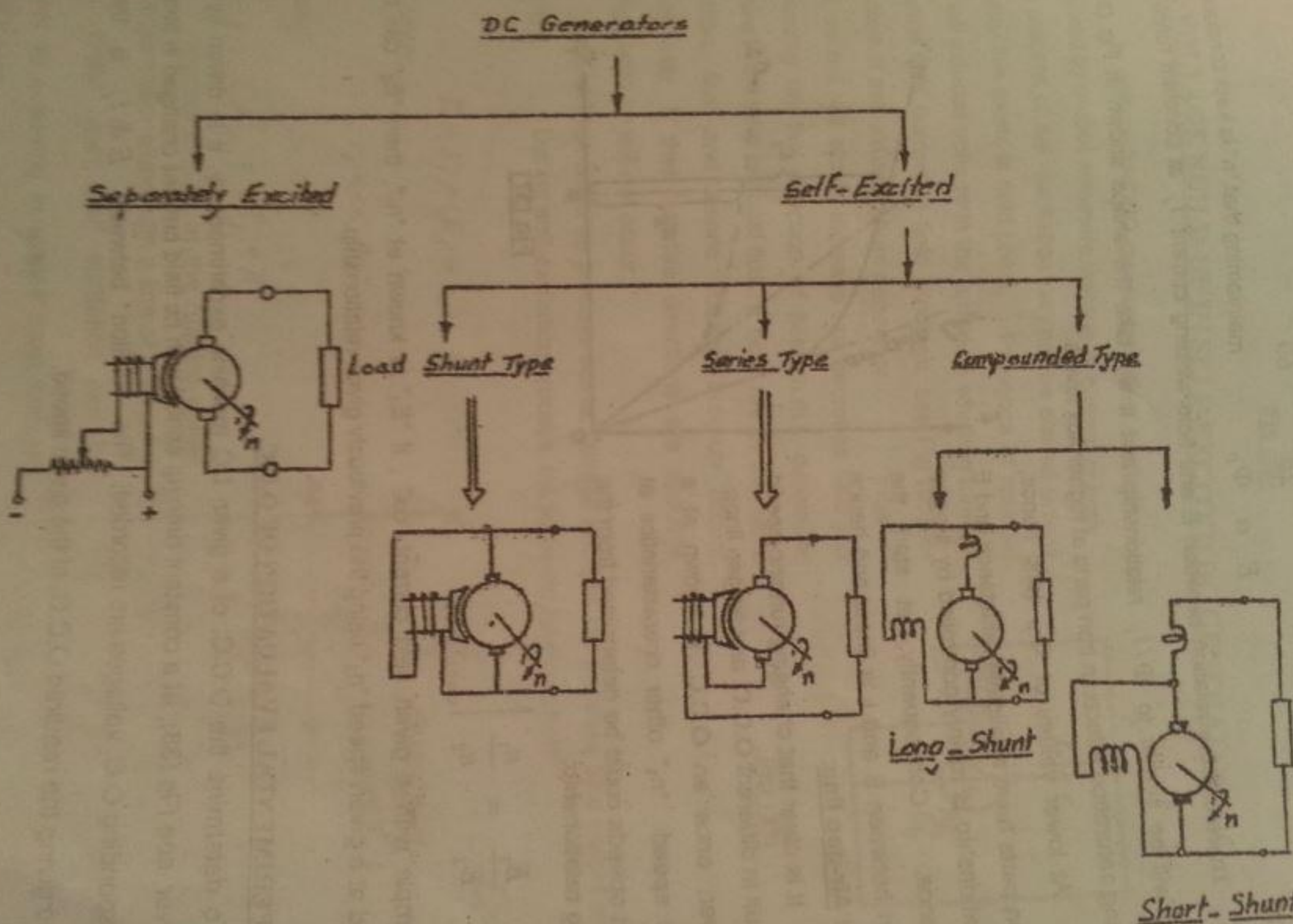
Component	% Failures	Potential Cause
Bearings	51%	Lubrication, mechanical, shaft currents, contamination
Windings	16%	Overvoltage, water, overload, undervoltage, environment
External Factors	16%	Environmental or load related
Rotor Bar	5%	Overload, locked rotor, vibration
Shaft/Coupling	2%	Mechanical, overload
Unknown	10%	No root cause determined

CHAPTER 5

Types of AC Motors

Classification of Motors




DC Generators
Separately Excited
Self-Excited
Load
Shunt Type
Series Type
Compounded Type
Long-Shunt
Short-Shunt

What is the difference between an AC motor and a DC motor ?

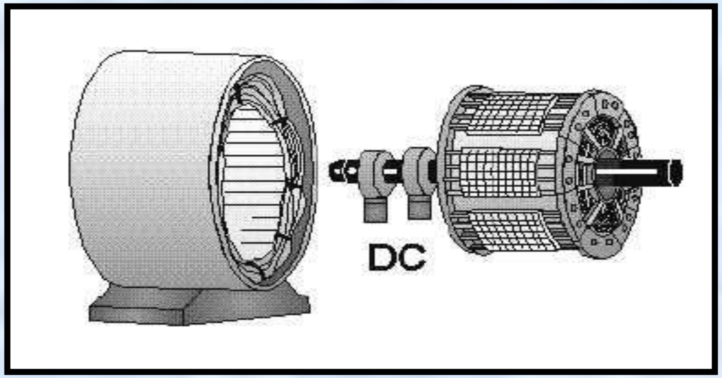
While both A.C. and D.C. motors serve the same function of converting electrical energy into mechanical energy, they are powered, constructed and controlled differently. The most basic difference is the power source. A.C. motors are powered from alternating current (A.C.) while D.C. motors are powered from direct current (D.C.), such as batteries, D.C. power supplies or an AC-to-DC power converter. D.C wound field motors are constructed with brushes and a commutator, which add to the maintenance, limit the speed and usually reduce the life expectancy of brushed D.C. motors.

A.C. induction motors do not use brushes; they are very rugged and have long life expectancies. The final basic difference is speed control.

The speed of a D.C. motor is controlled by varying the armature winding’s current while the speed of an A.C. motor is controlled by varying the frequency, which is commonly done with an adjustable frequency drive control.

AC Motors

- Two parts: stator and rotor
  - Stator: stationary electrical component
  - Rotor: rotates the motor shaft
- Speed difficult to control
- Two types
  - Synchronous motor
  - Induction motor



Synchronous motor

- **Constant speed fixed by system frequency**
- **DC for excitation and low starting torque: suited for low load applications**
- **Can improve power factor: suited for high electricity use systems**
- **Synchronous speed (Ns):**

$$Ns = 120\ f / P$$

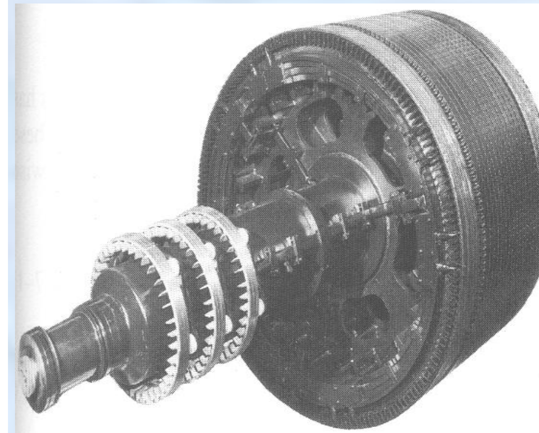
F = supply frequency
P = number of poles

Induction motor

Components

➢**Rotor**

➢**Squirrel cage:** conducting bars in parallel slots

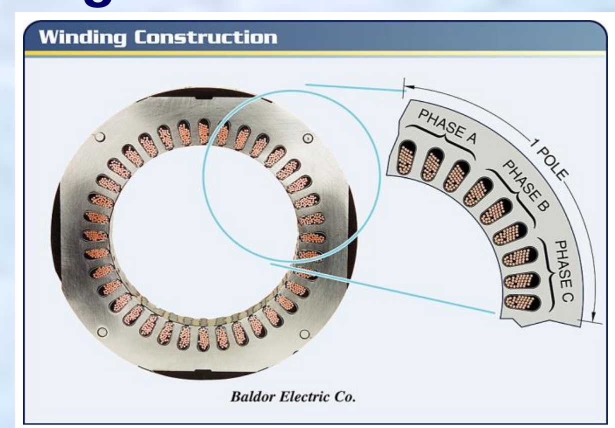


➢**Wound rotor:** 3-phase, distributed winding

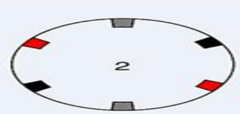
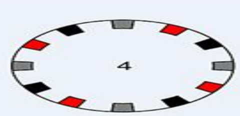
➢**Stator**

➢Stampings with slots to carry 3-phase

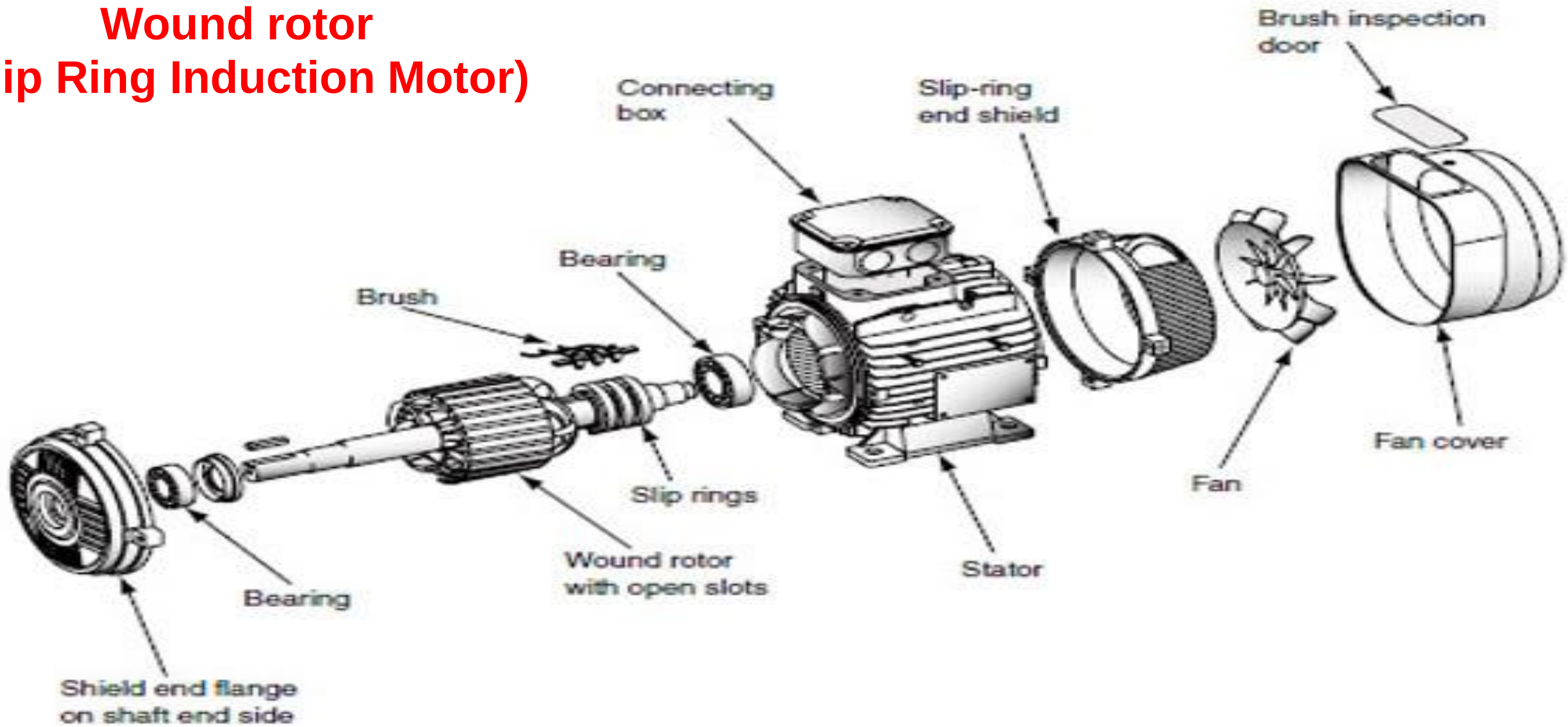
➢Wound for definite number of poles

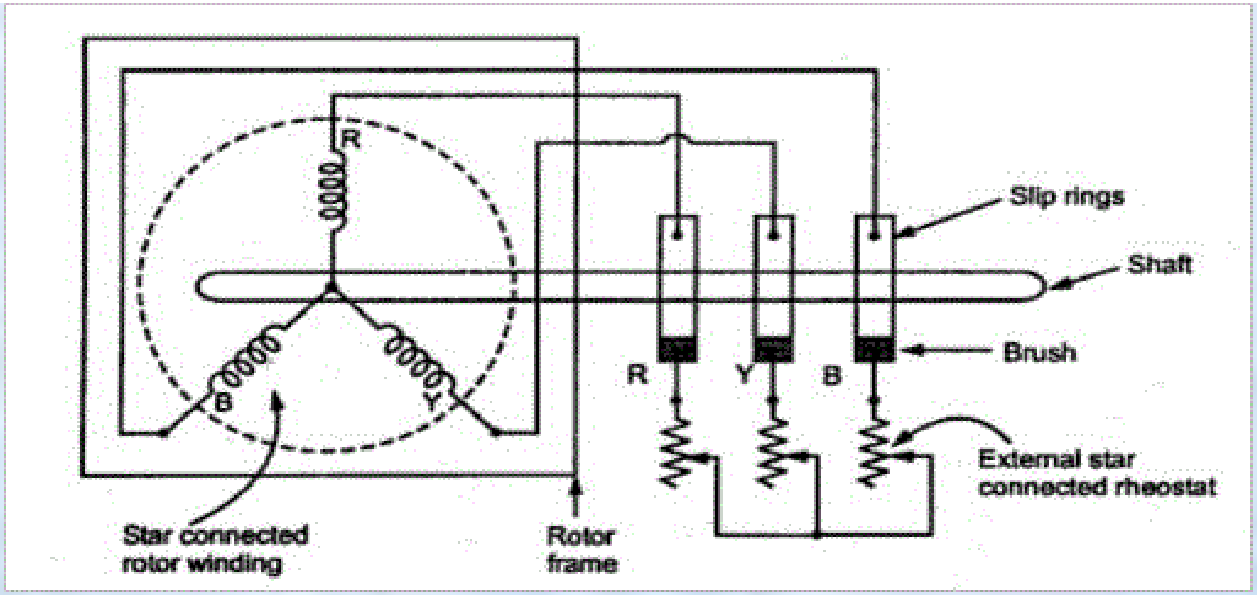


Electrical Degrees

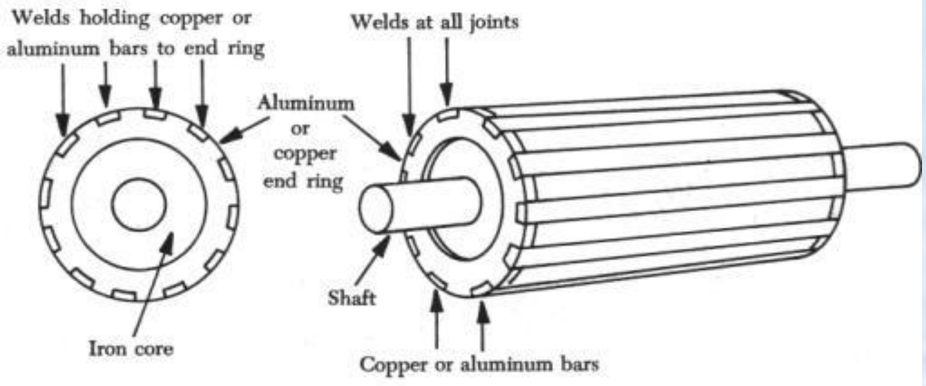
Poles per Phase	Electrical Degrees per Revolution
 2	2 × 180 = 360
 4	4 × 180 = 720

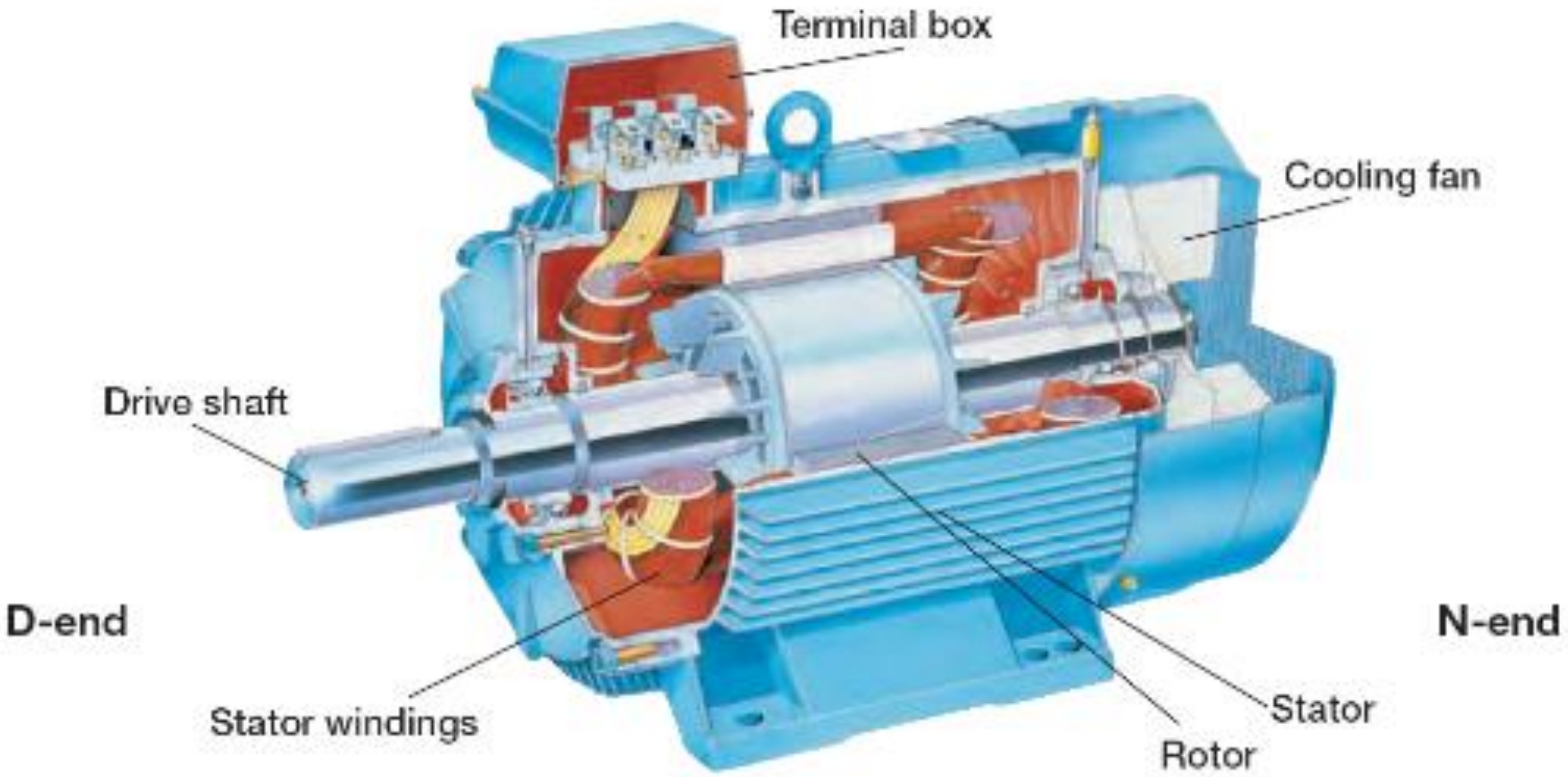
Wound rotor
(Slip Ring Induction Motor)





Squirrel cage Induction Motor





What is the difference between a slip ring and a squirrel cage?

Both are the types of Asynchronous machines(Induction Machines), difference is that in Slip ring we can change the starting torque by simply varying the external resistance connected to rotor, this is not possible in case of squirrel cage induction motor.

Although Squirrel cage is easy to maintain and cost effective as compared to slip ring as it has slip rings, brushes.

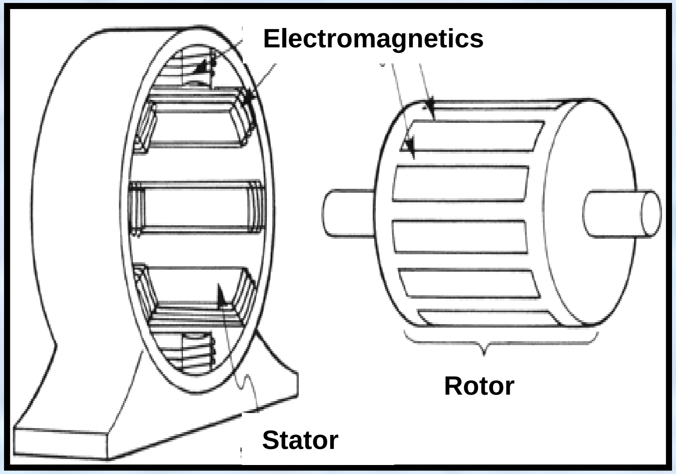
Application of slip ring: Hoist, Elevators, pumps where high starting torque is required.

Application of Squirrel cage: motor used in industries because there is need of high torque production by motor.

How induction motors work

- Electricity supplied to stator
- Magnetic field generated that moves around rotor
- Current induced in rotor

- Rotor produces second magnetic field that opposes stator magnetic field
- Rotor begins to rotate



Types of Induction motor

- **Single-phase induction motor**
  - **Single-phase power supply**
  - **Squirrel cage rotor**
  - **Require device to start motor**
  - **3 to 4 HP applications**

- **Three-phase induction motor**
  - **Three-phase supply produces magnetic field**
  - **Squirrel cage or wound rotor**
  - **Self-starting**
  - **1/3 to hundreds HP applications: pumps, compressors, conveyor belts, grinders**

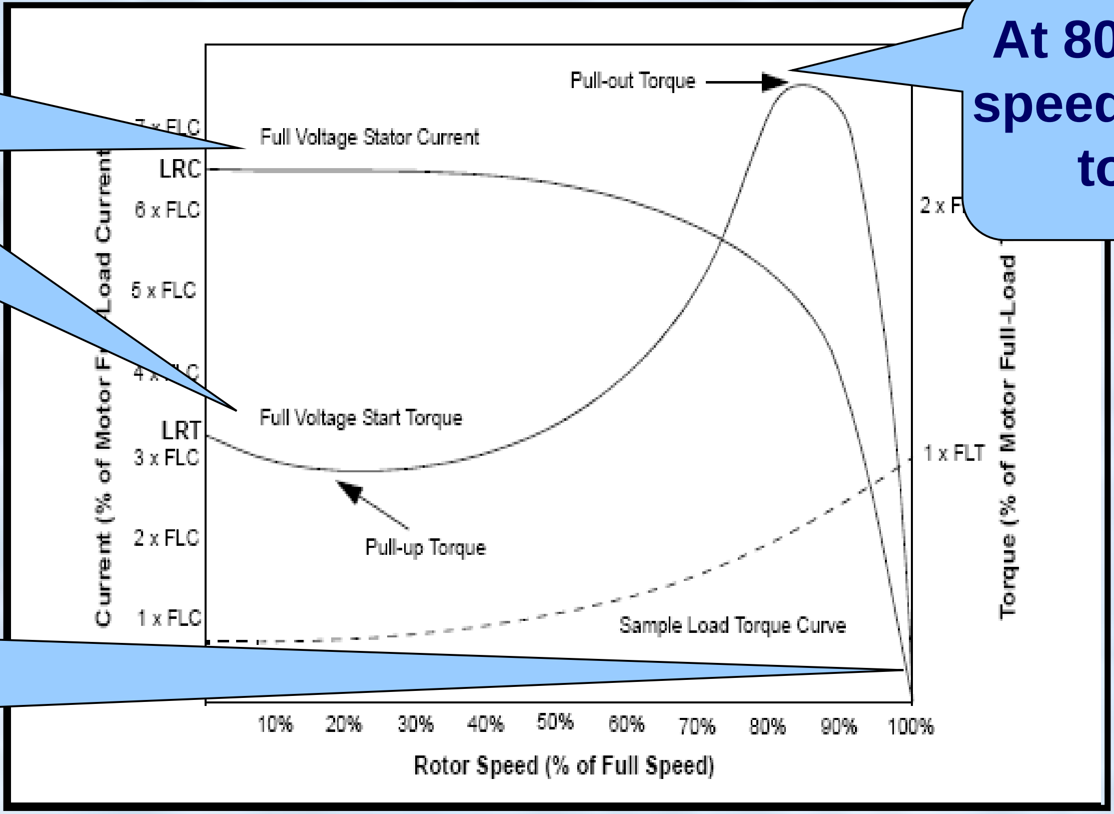
Speed and slip

- **Motor never runs at synchronous speed but lower "base speed"**
- **Difference is "slip"**
- **Calculate % slip:**

$$\% \text{ Slip} = \frac{Ns - Nr}{Ns} \times 100$$

Ns = synchronous speed in RPM
Nr = rotor speed in RPM

Relationship load, speed and torque



At start: high current and low "pull-up" torque

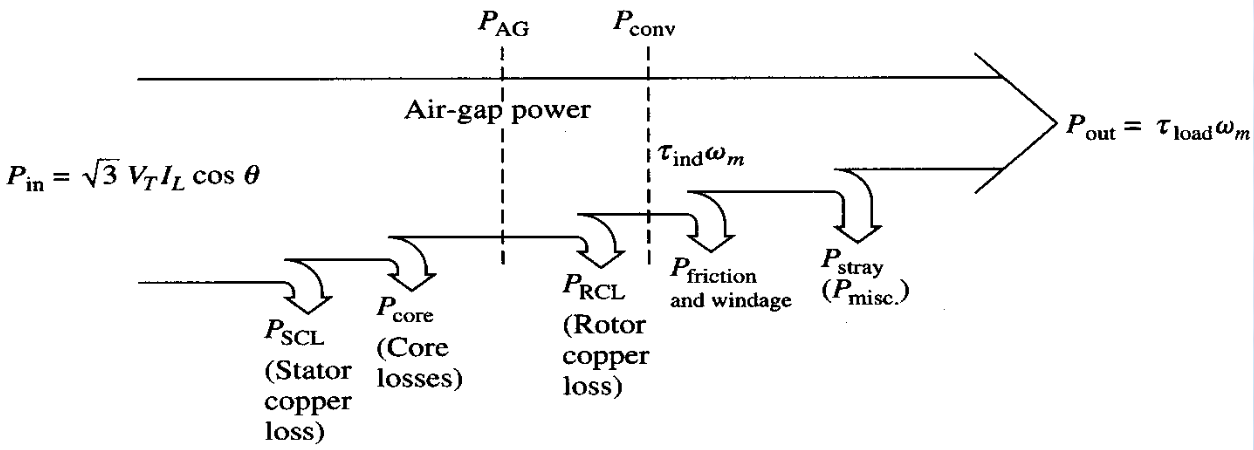
At 80% of full speed: highest torque

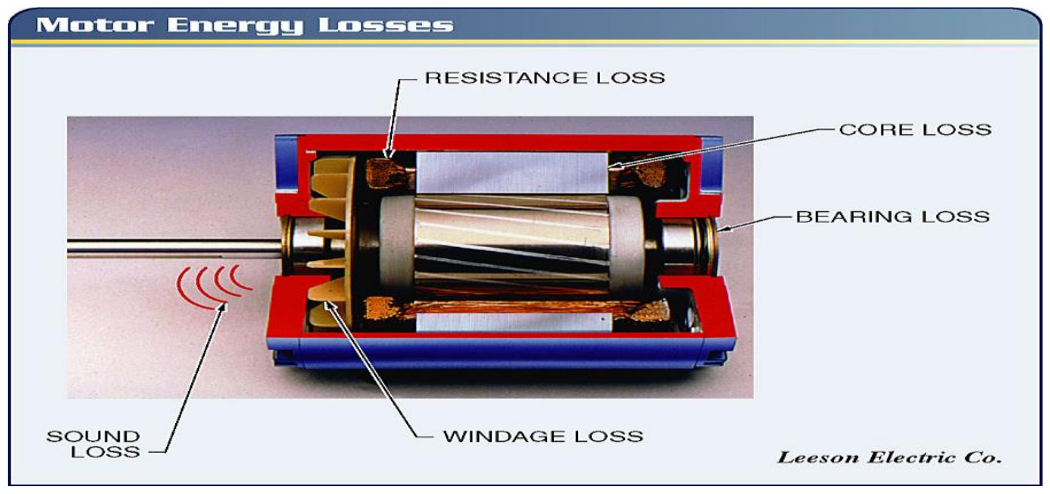
At full speed: torque and stator current are zero

Efficiency of Electric Motors

Motors loose energy when serving a load

- Fixed loss
- Rotor loss
- Stator loss
- Friction and rewinding
- Stray load loss





Maintenance

Checklist to maintain motor efficiency

- Inspect motors regularly for wear, dirt/dust
- Checking motor loads for over loading
- Lubricate appropriately
- Check alignment of motor and equipment
- Ensure supply wiring and terminal box and properly sized and installed
- Provide adequate ventilation

Speed & Torque control of Induction Motor

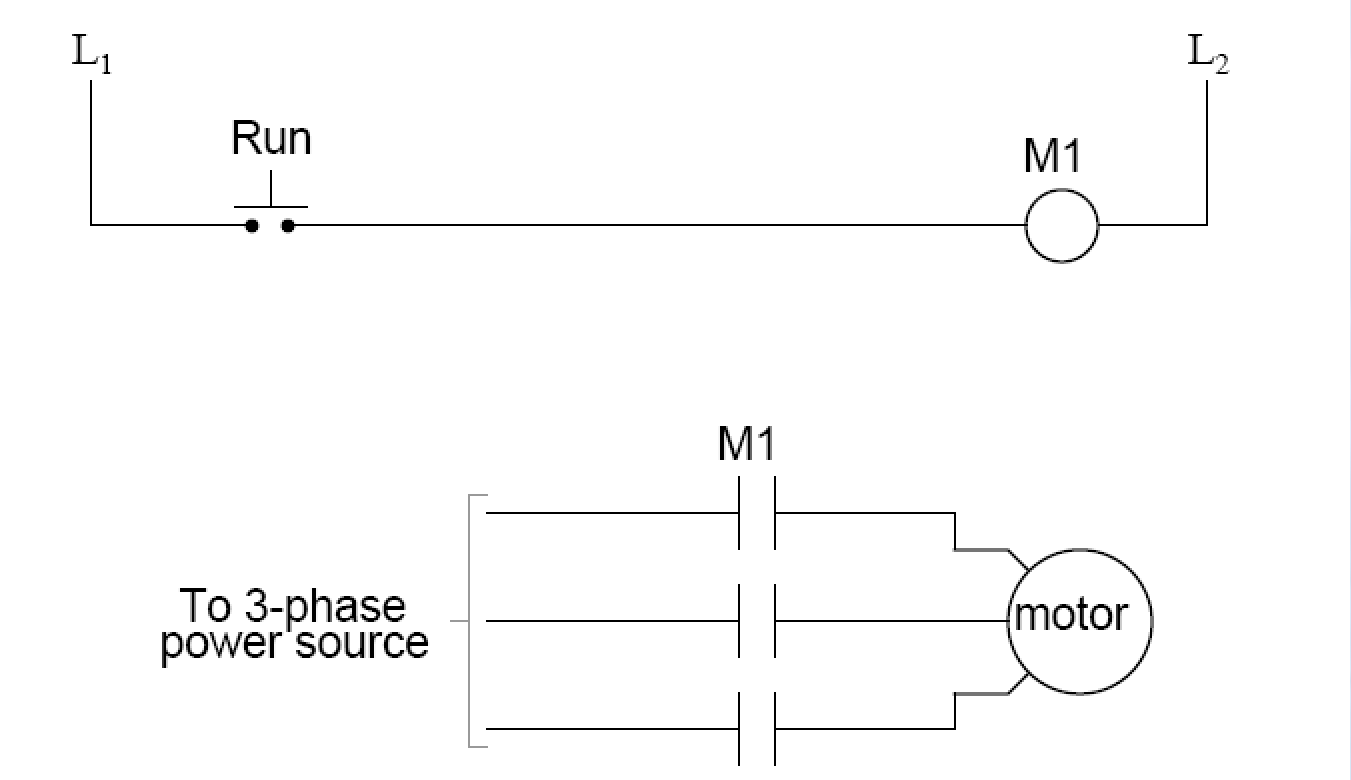
- **Multi-speed motors**
  - **Limited speed control: 2 – 4 fixed speeds**
- **Wound rotor motor drives**
  - **Variable resistors to control torque performance**
- **Variable speed drives (VSDs)**
  - **Reduce electricity by >50% in fans and pumps**
  - **Convert 50Hz incoming power to variable frequency and voltage: change speed**

CHAPTER 6

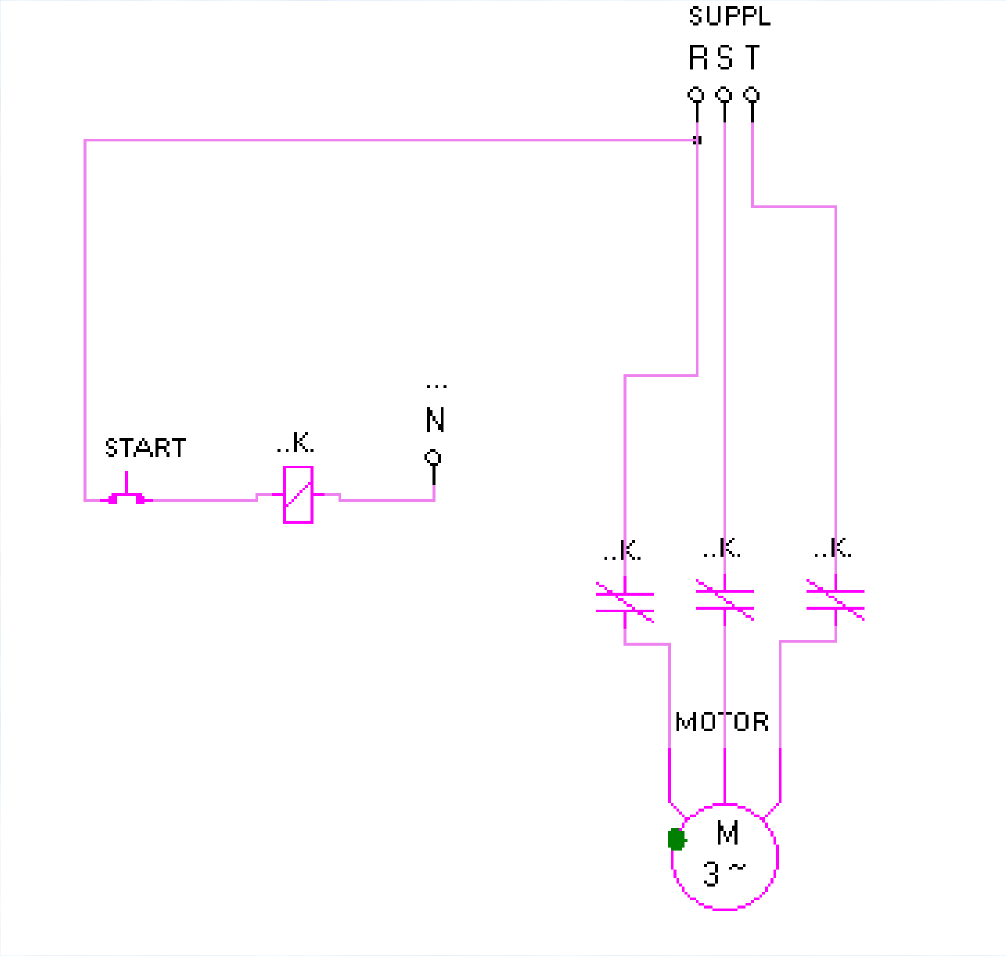
Different types of Motor Control Circuit

1- Motor control circuit

1-Wire control

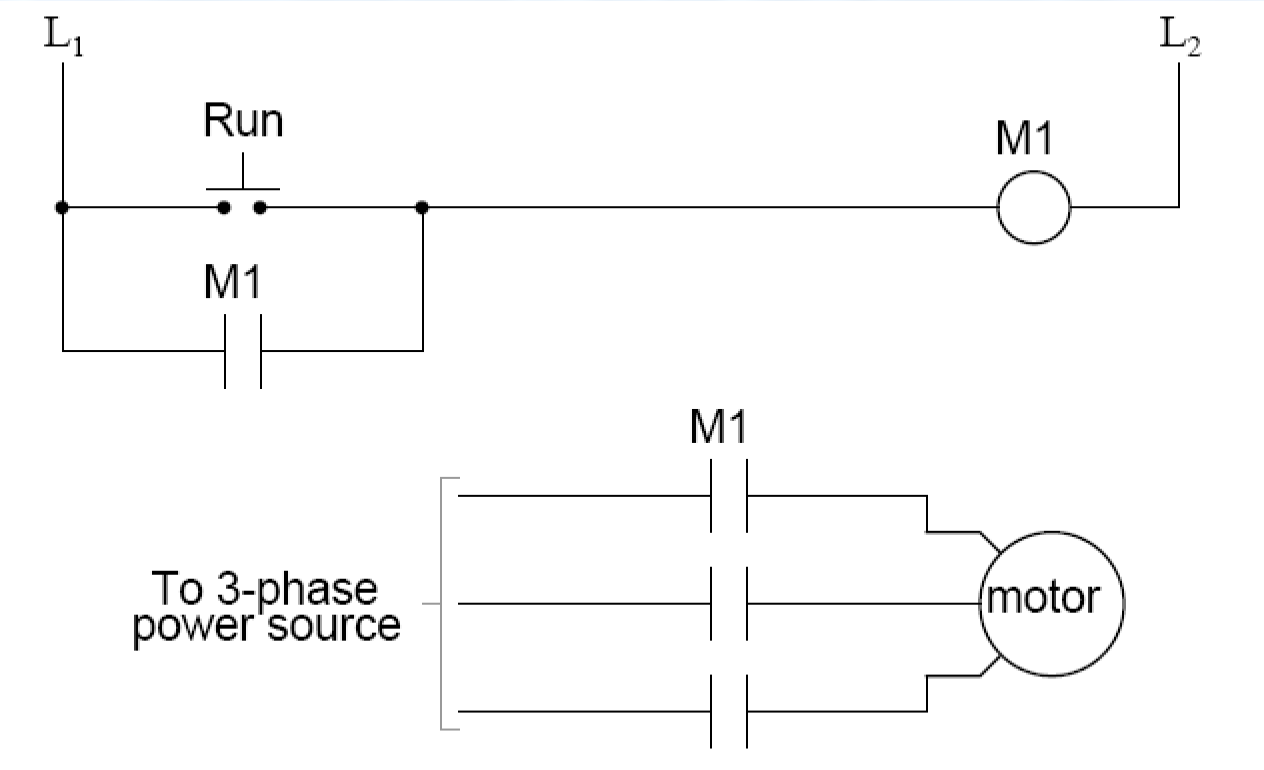


EKTS Simulation

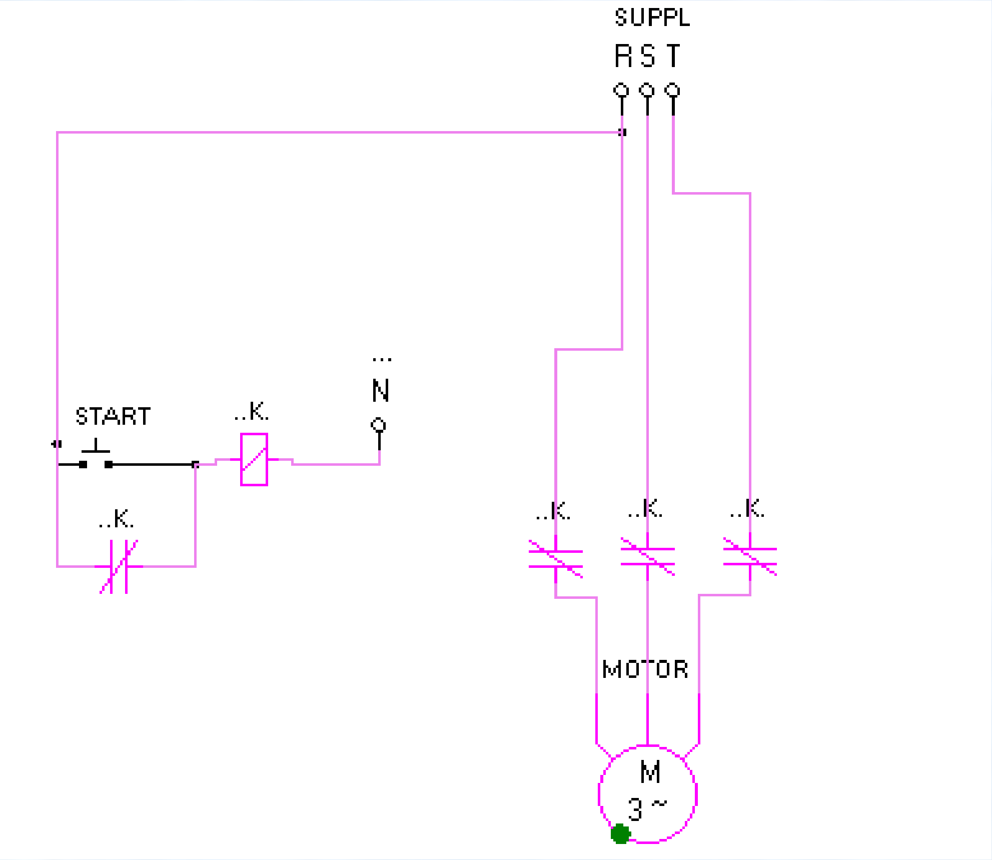


2- Motor control latched circuit

2-Wire control

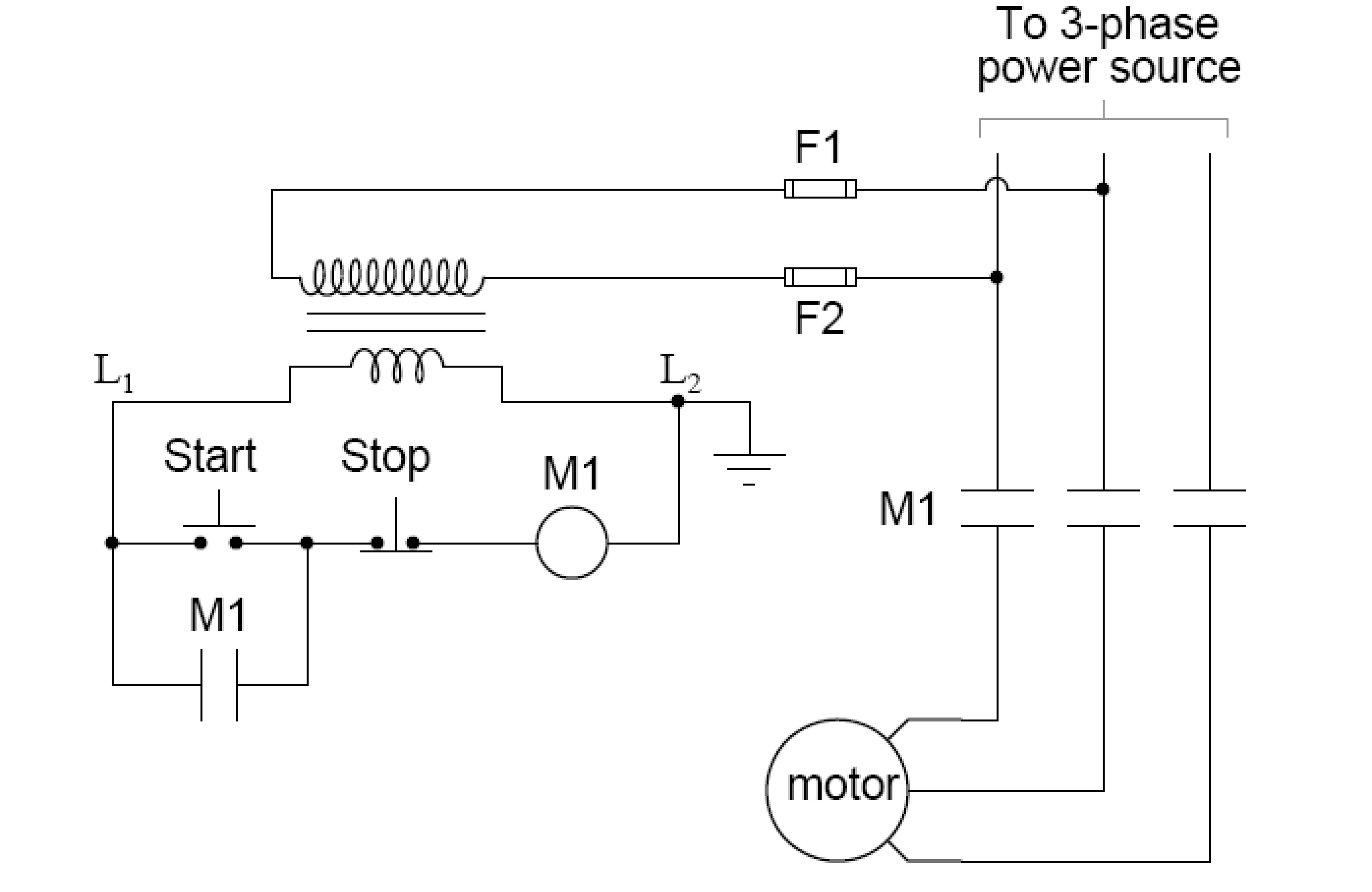


EKTS Simulation

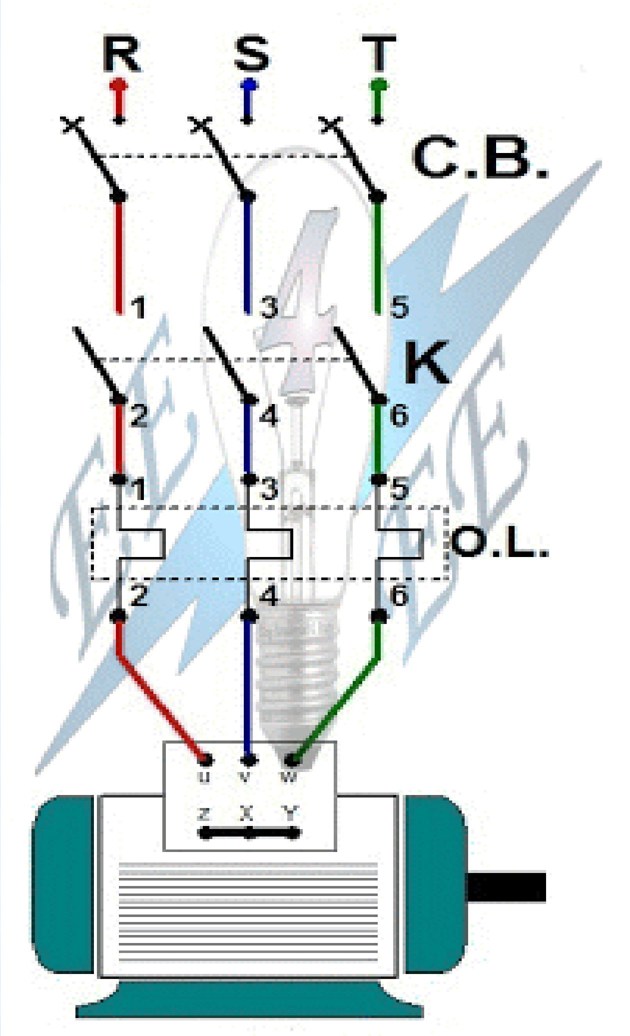


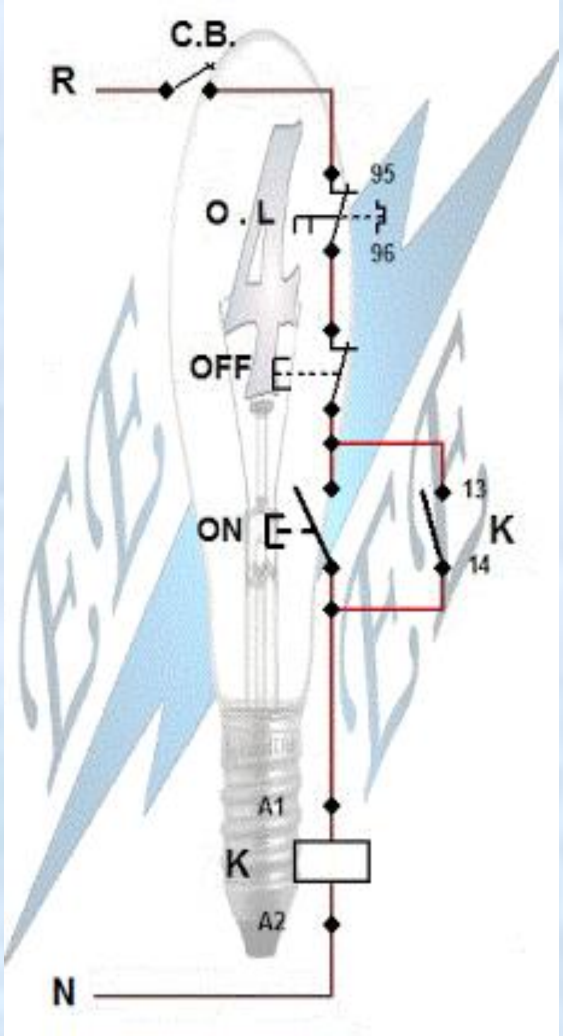
3- Start stop motor circuit

3-Wire control (380 V)



3-Wire control (220 V)





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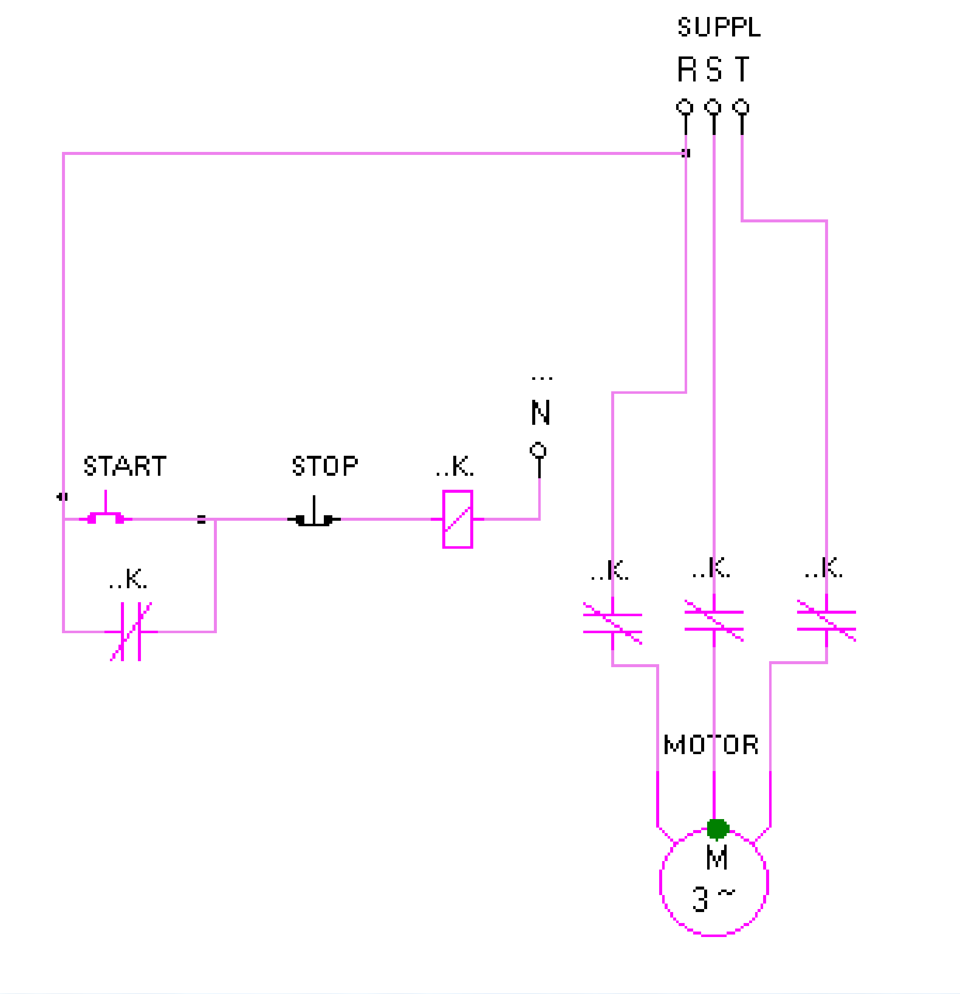
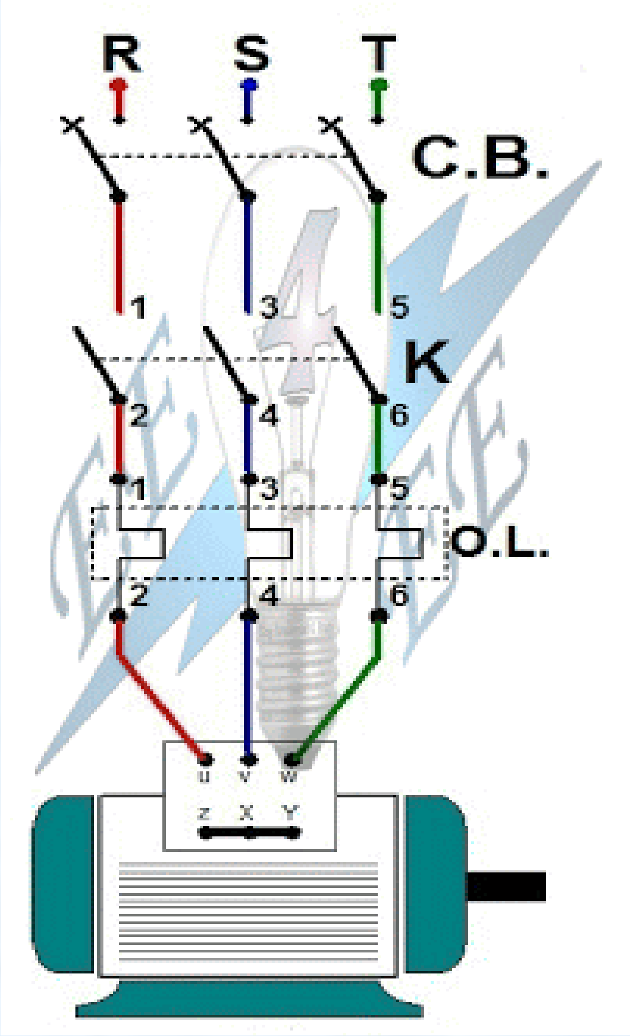
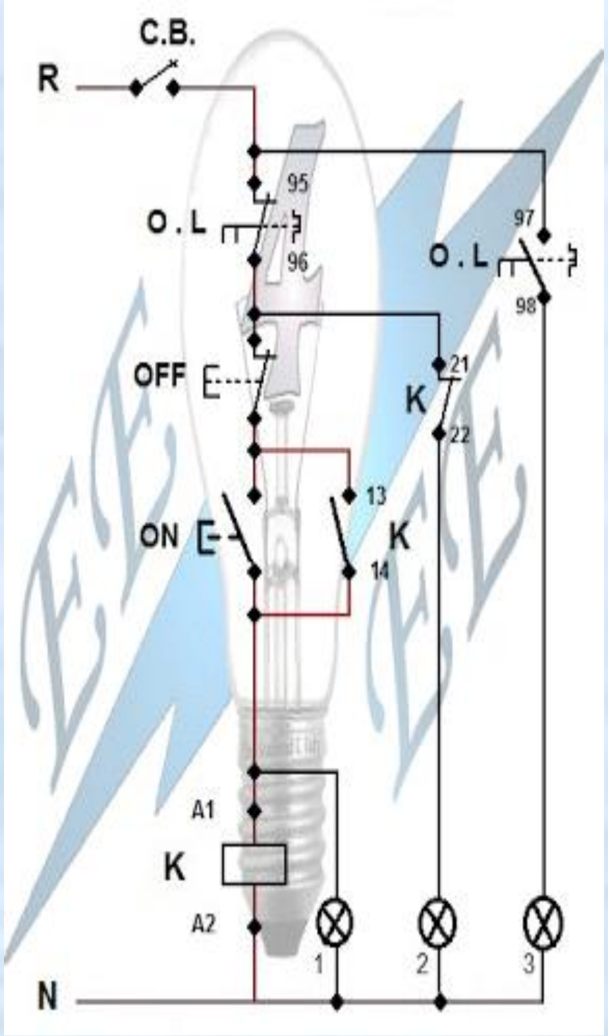


4- ON-OFF-Fault motor circuit





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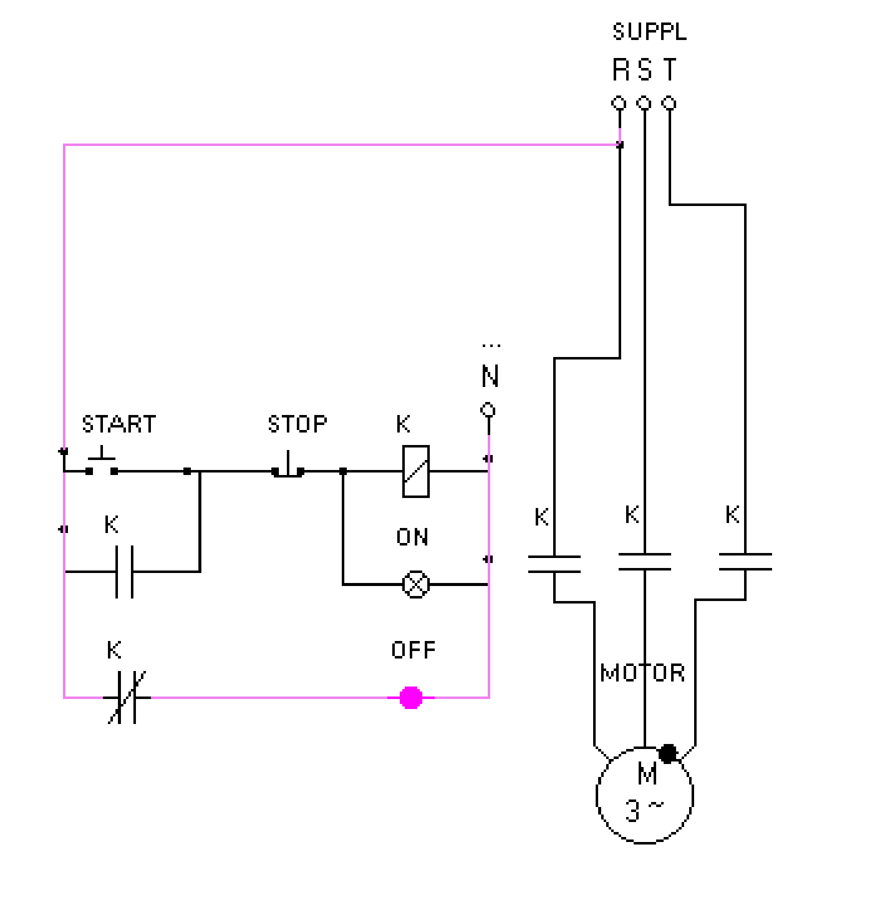
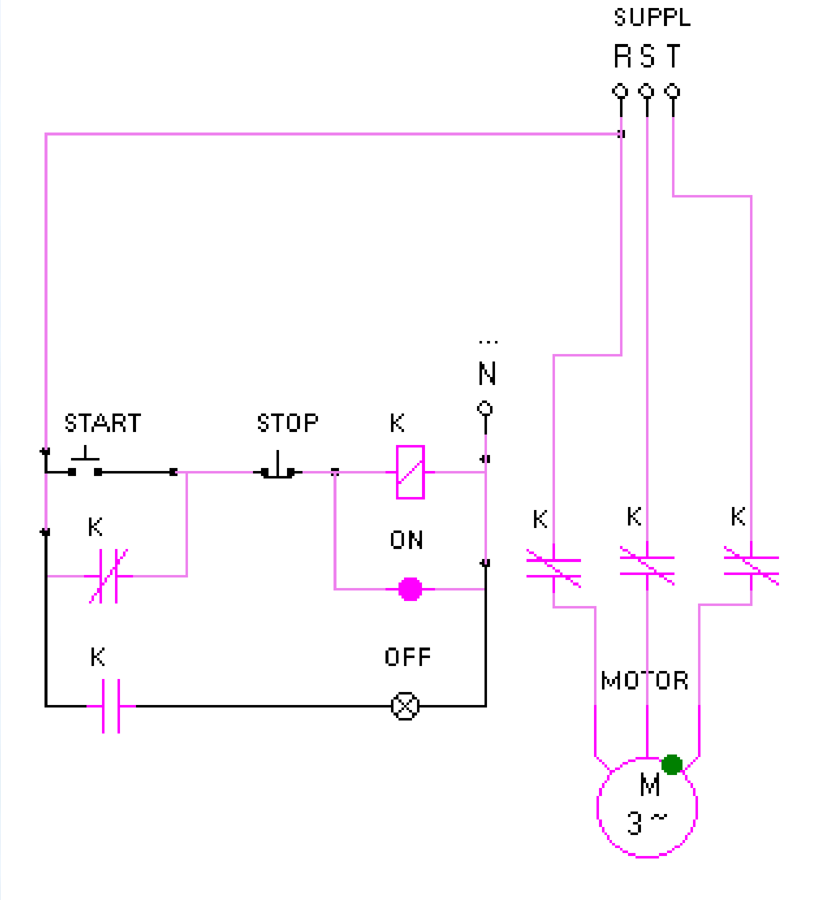
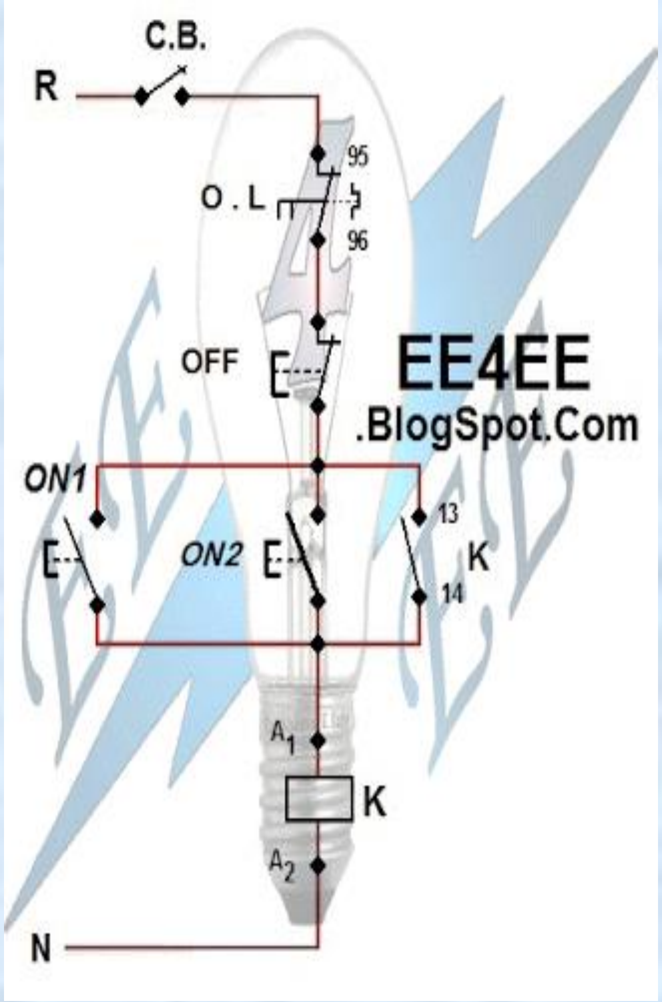
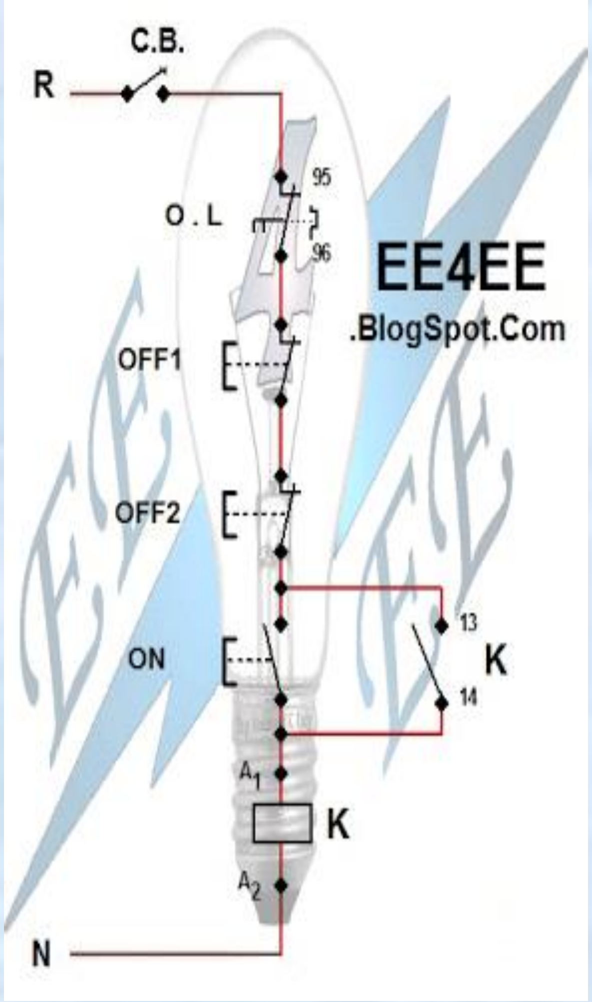




5- Different location controlling motor circuit





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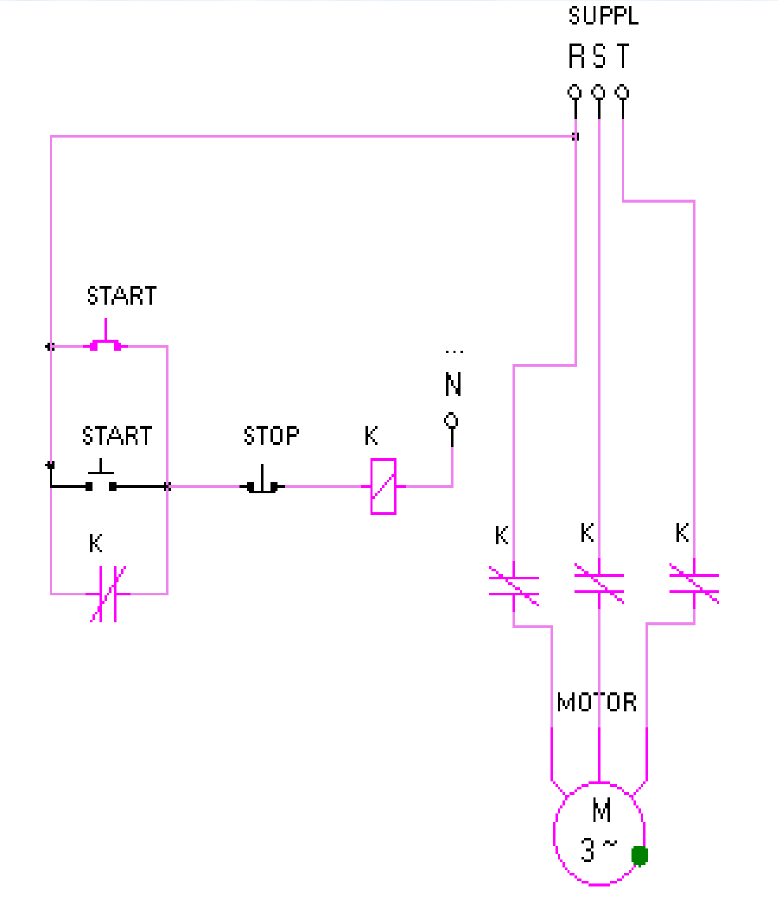
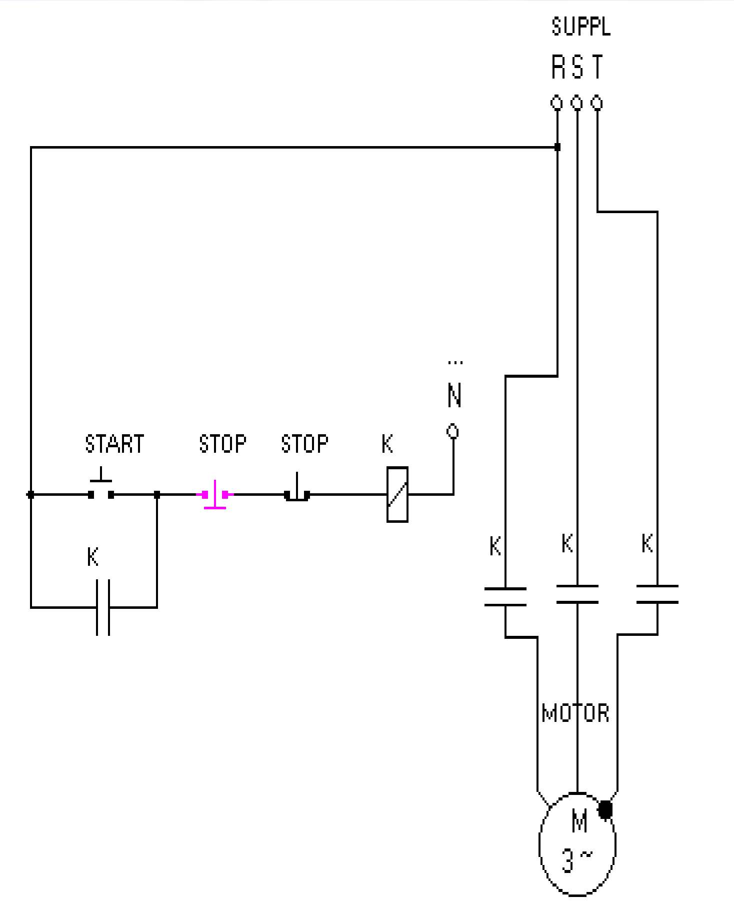
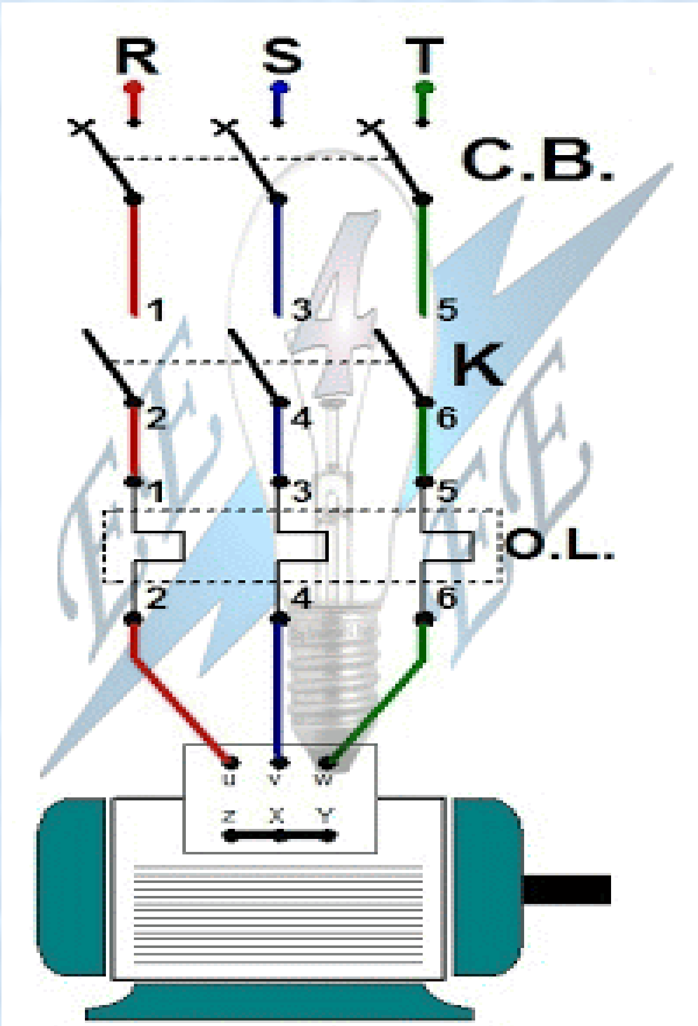
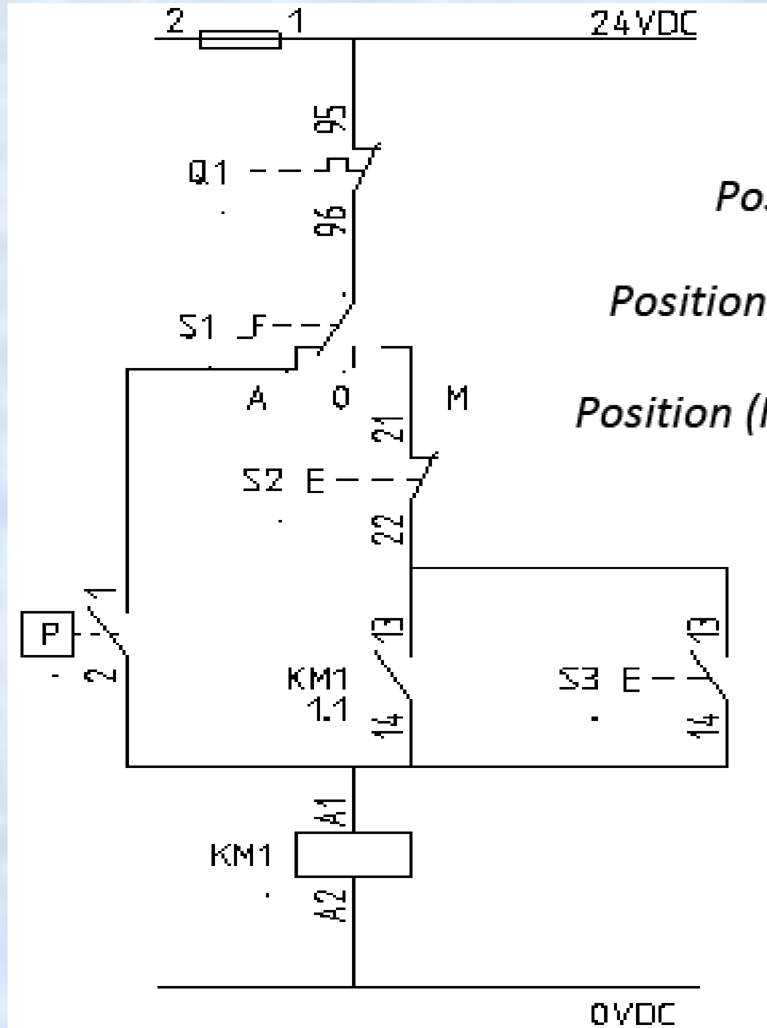




6- Manual & Automatic pump control using pressure switch



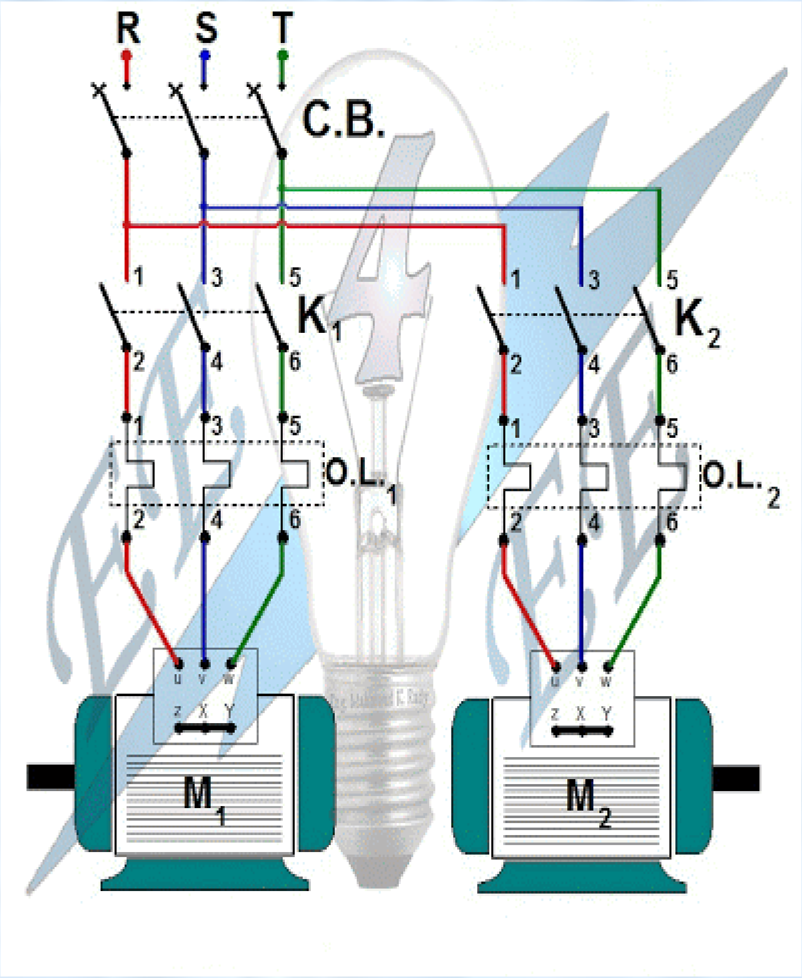


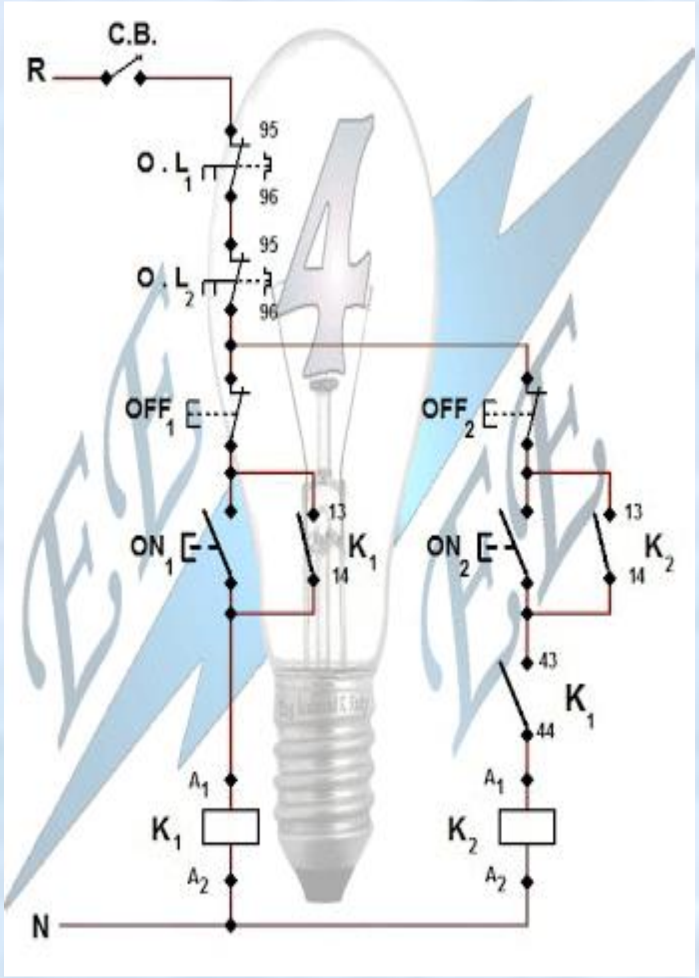
Position (0):   Stop

Position (A):   Automatic

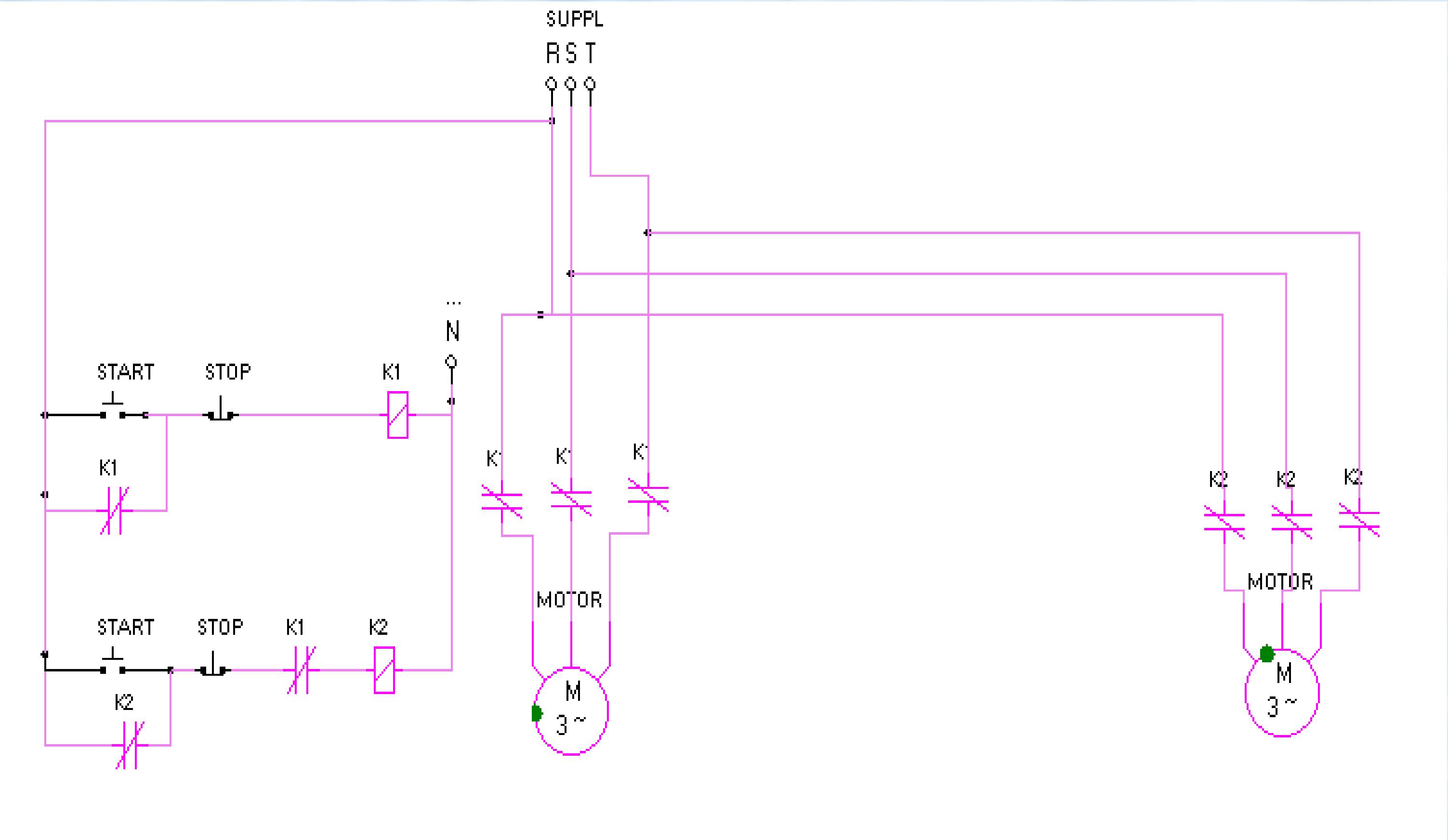
Position (M):   Manual

7- Second motor depend on first motor circuit

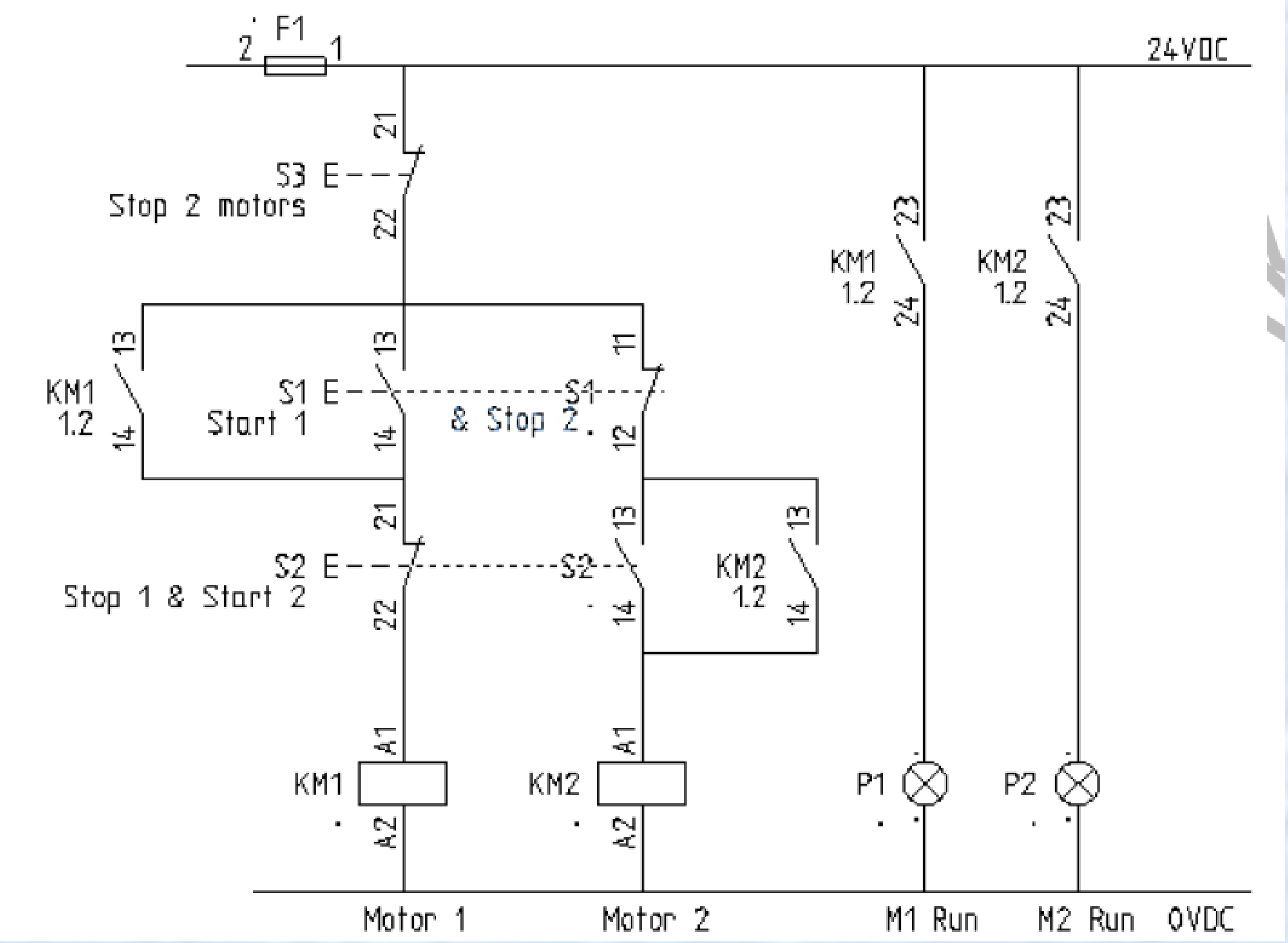




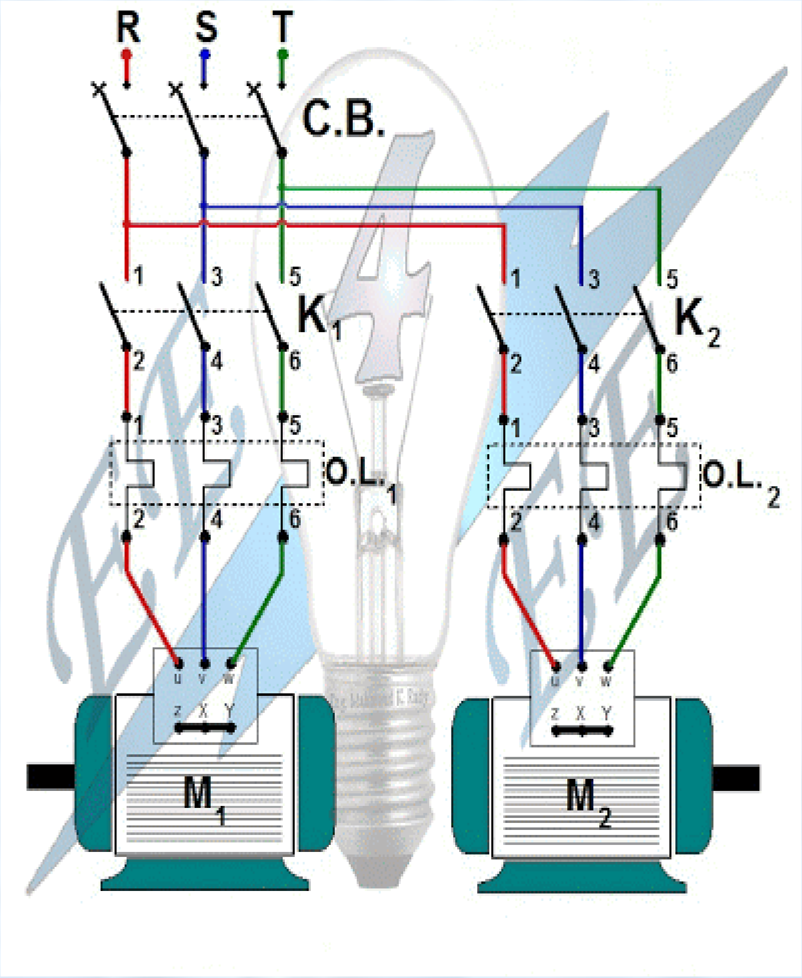
EKTS Simulation

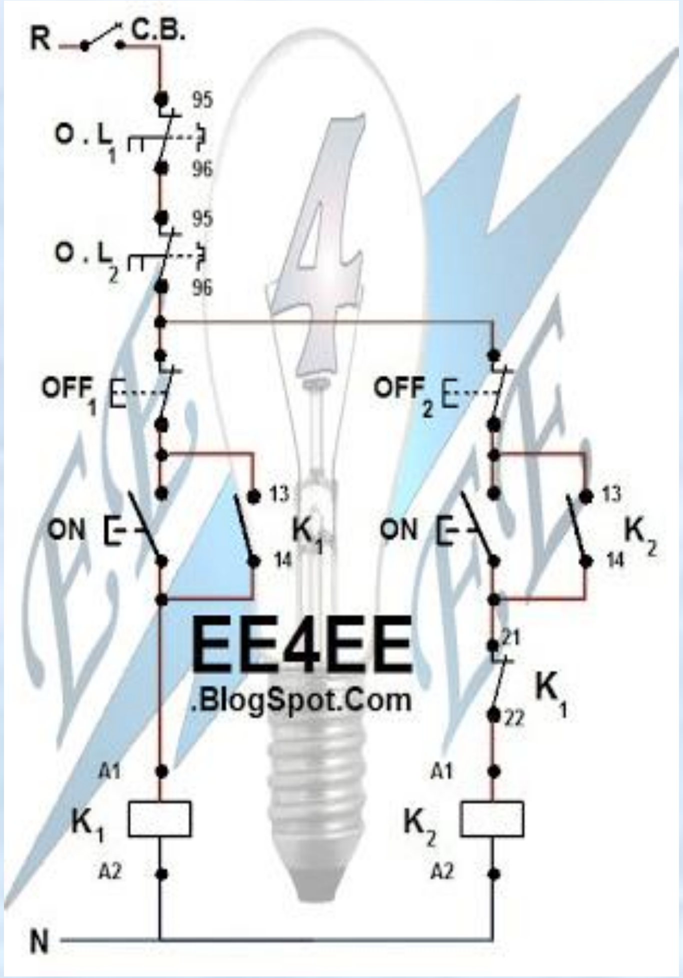


Think what does it mean ????

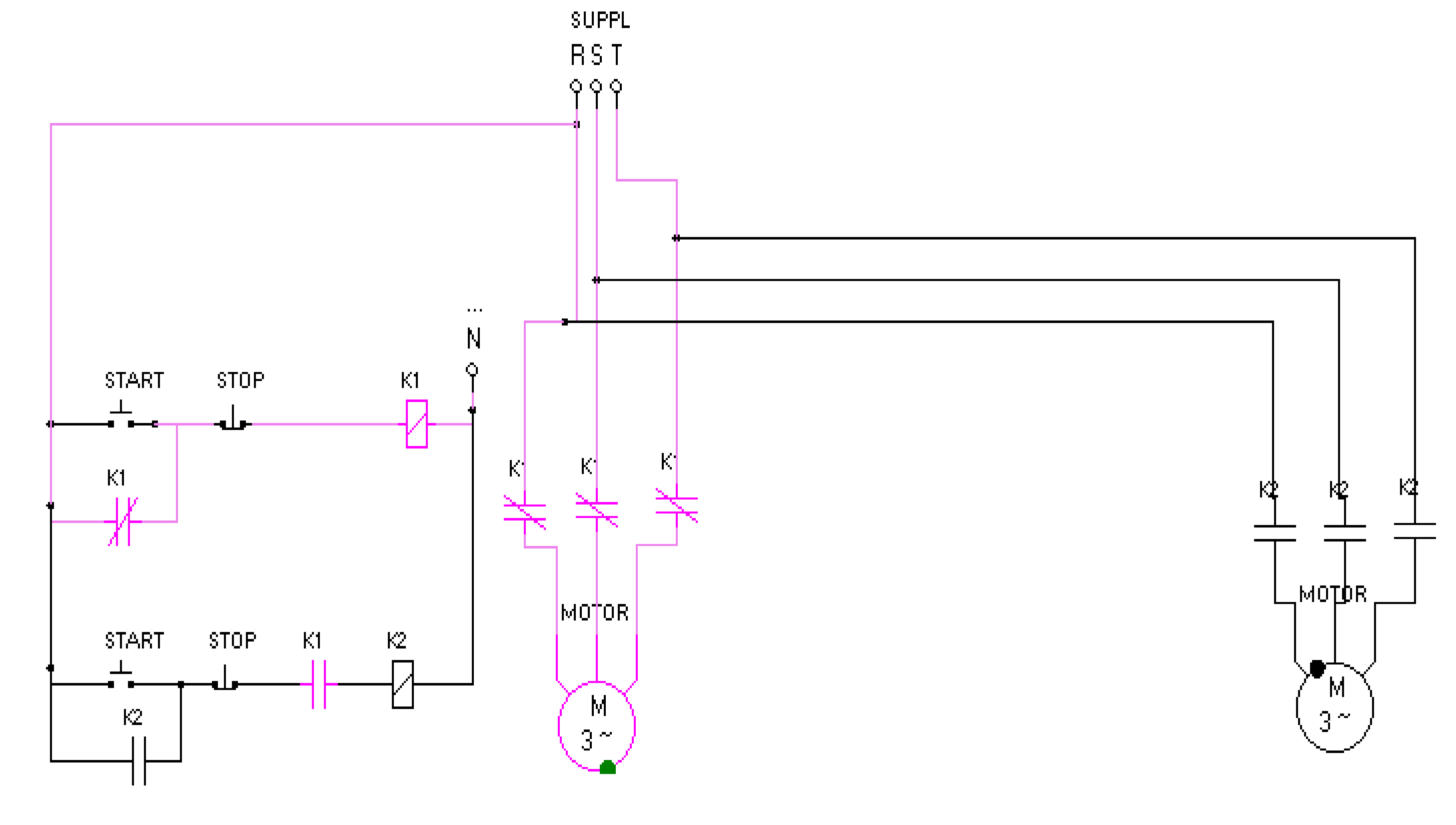


8- One out of two motor circuit

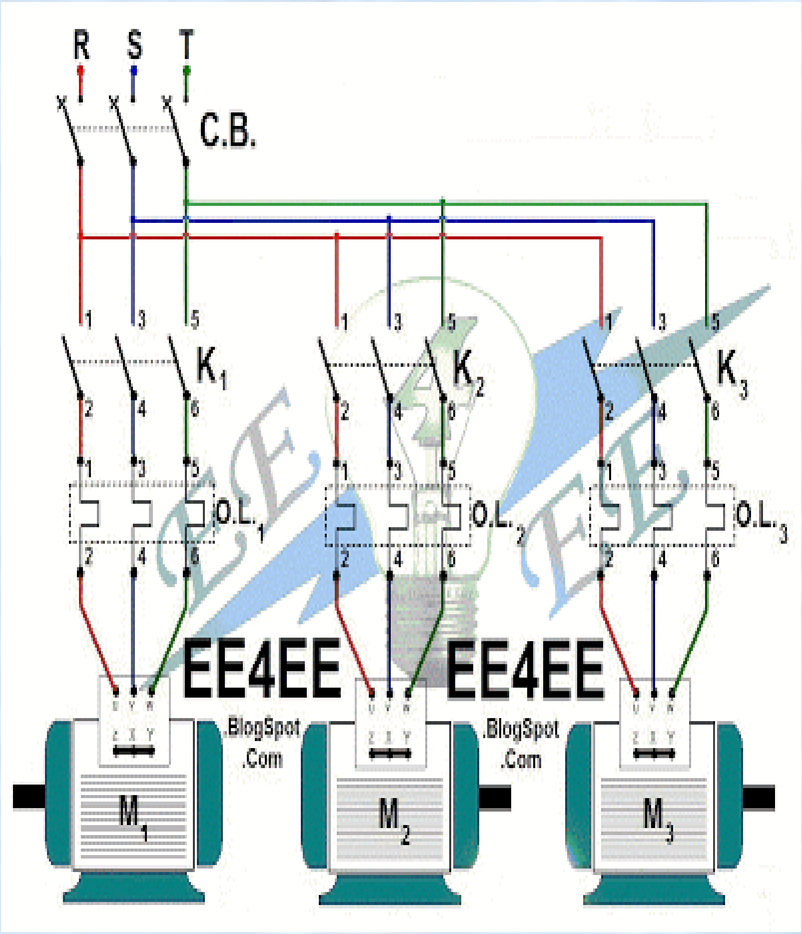


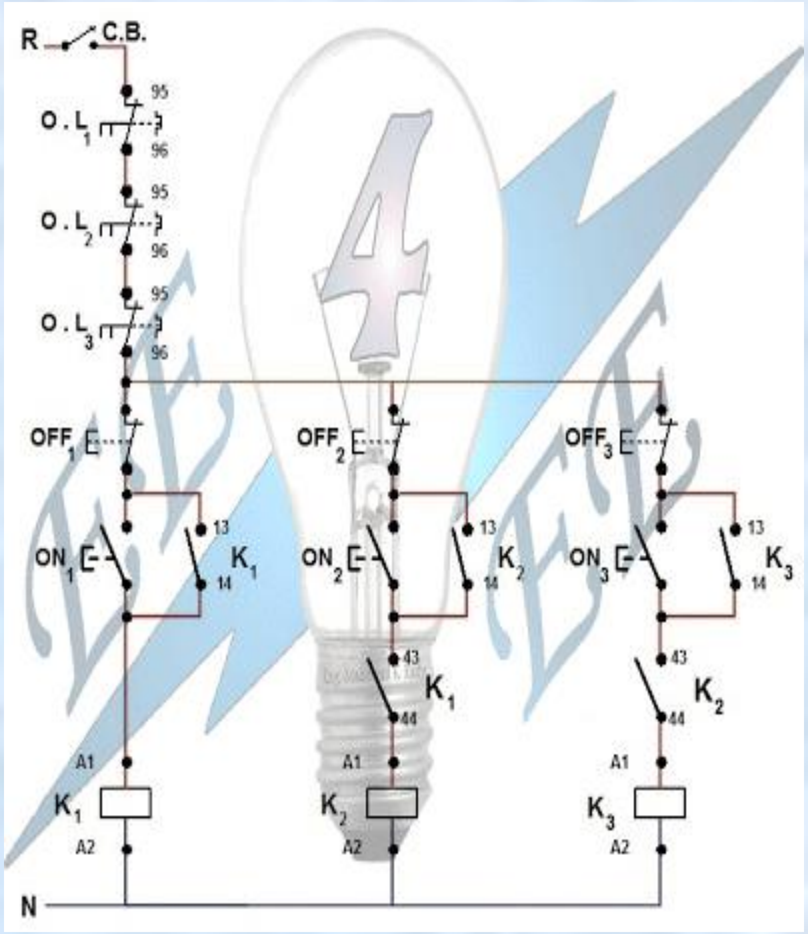


EKTS Simulation



9- Sequence of conveyors motor circuit





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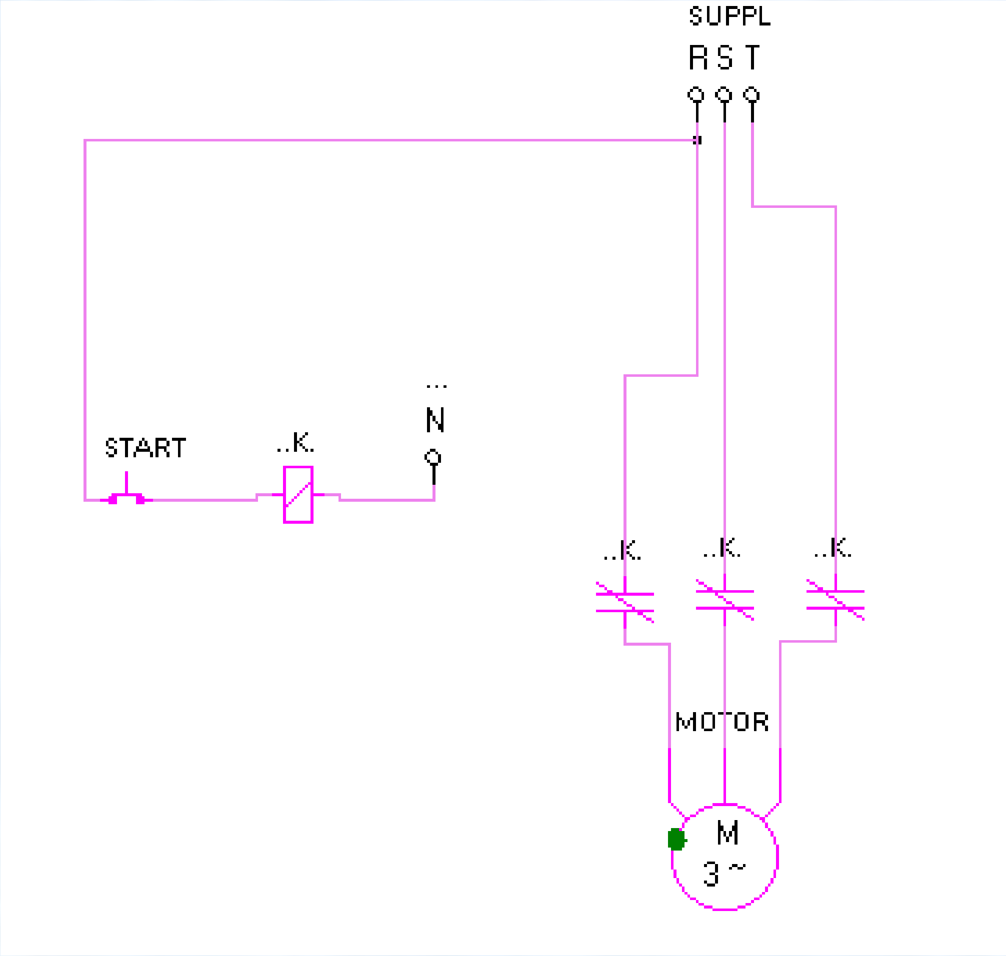
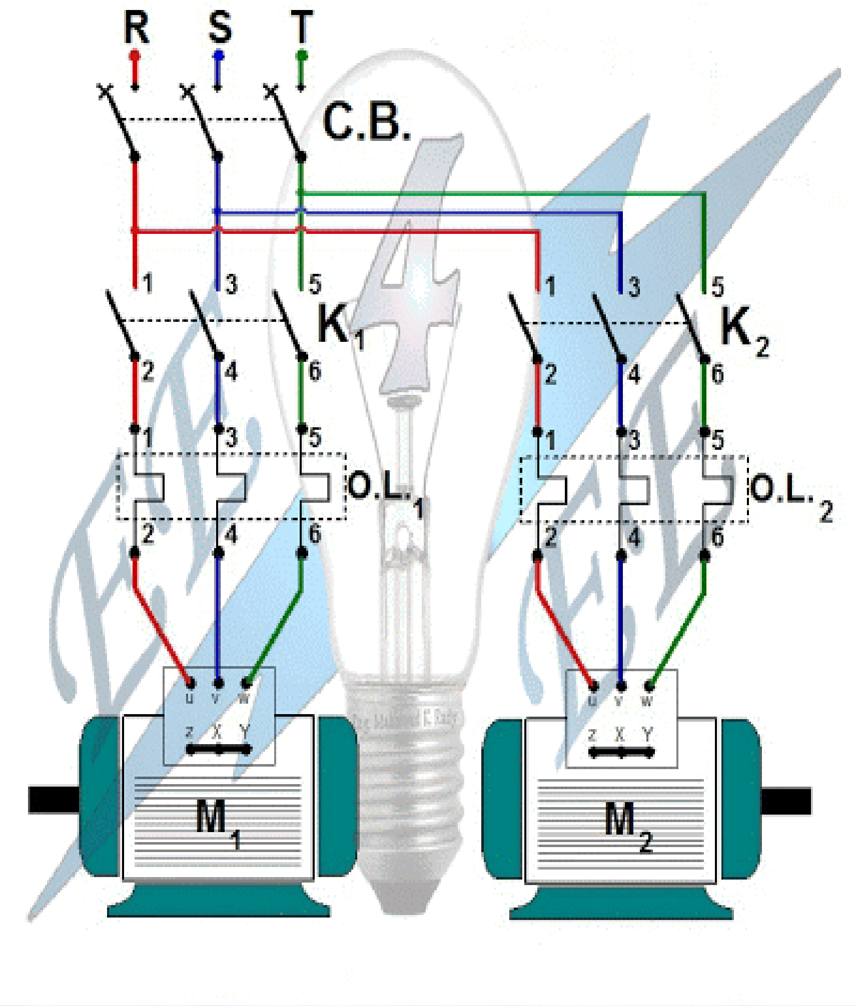
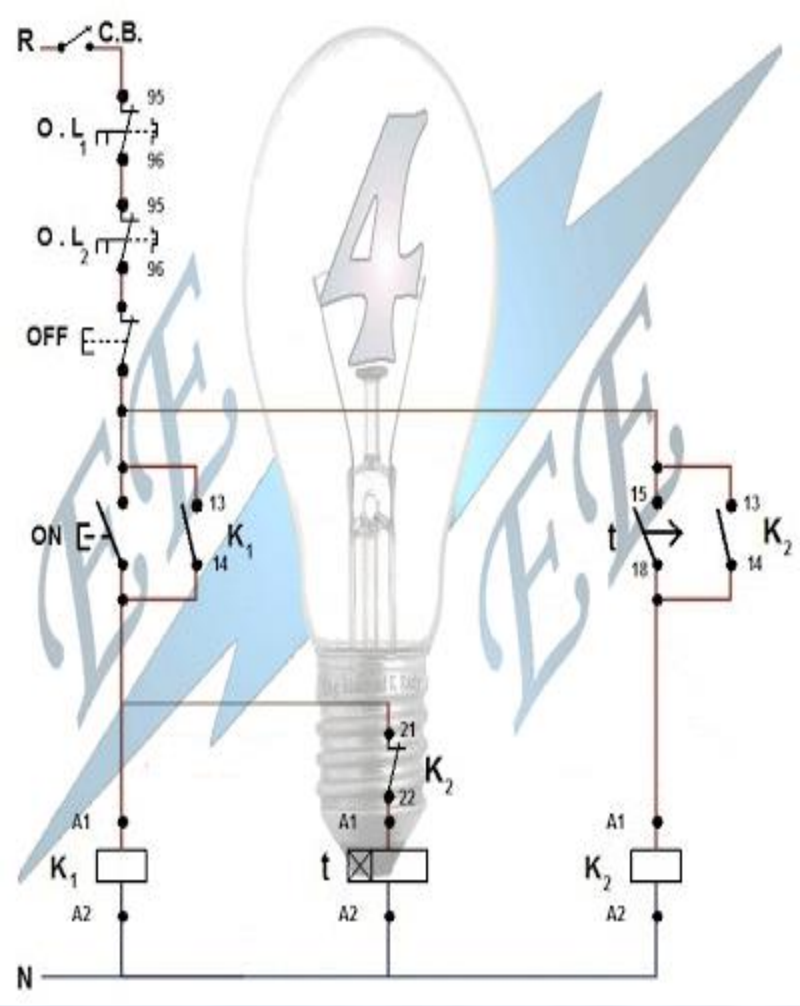


10- Automatic control with time delay motor circuit





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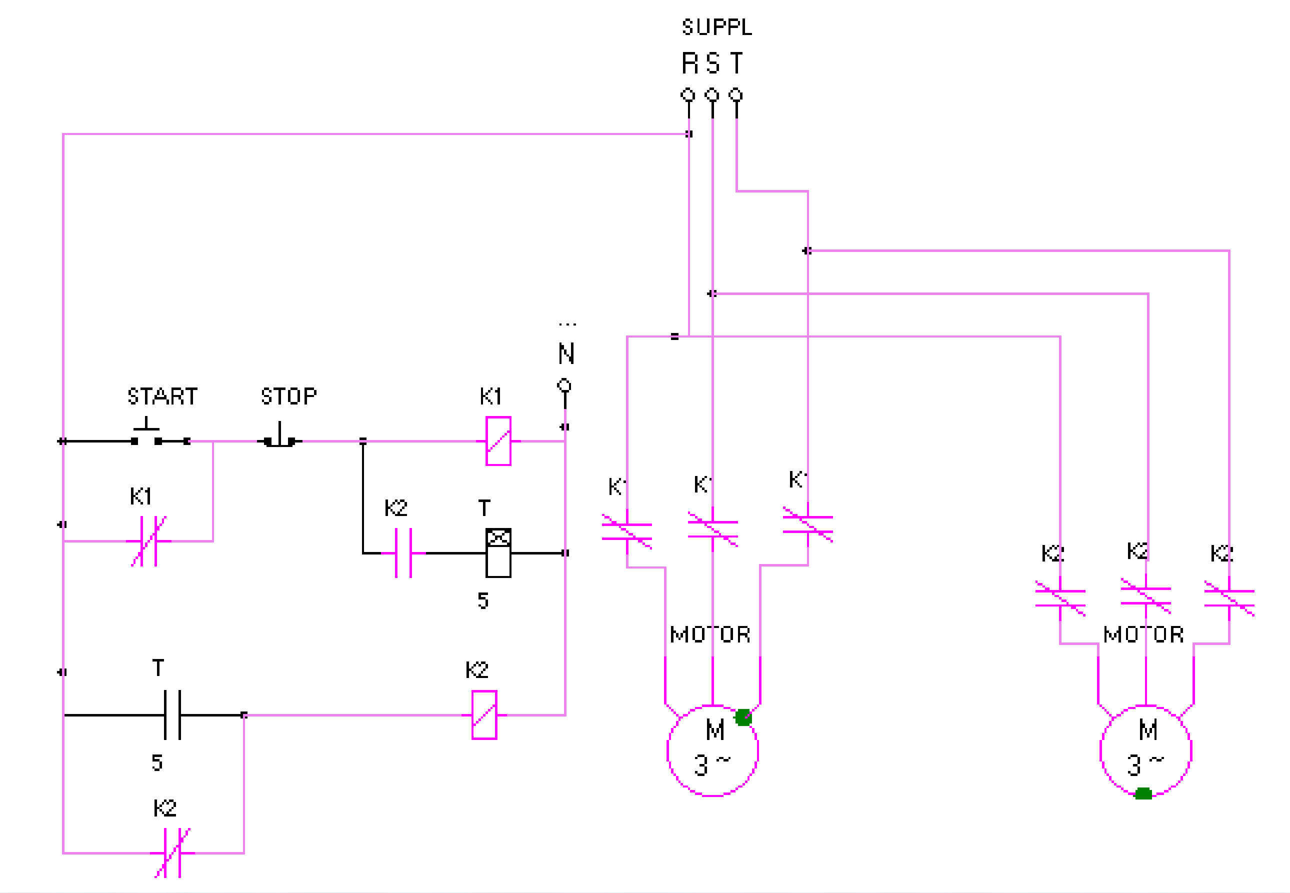
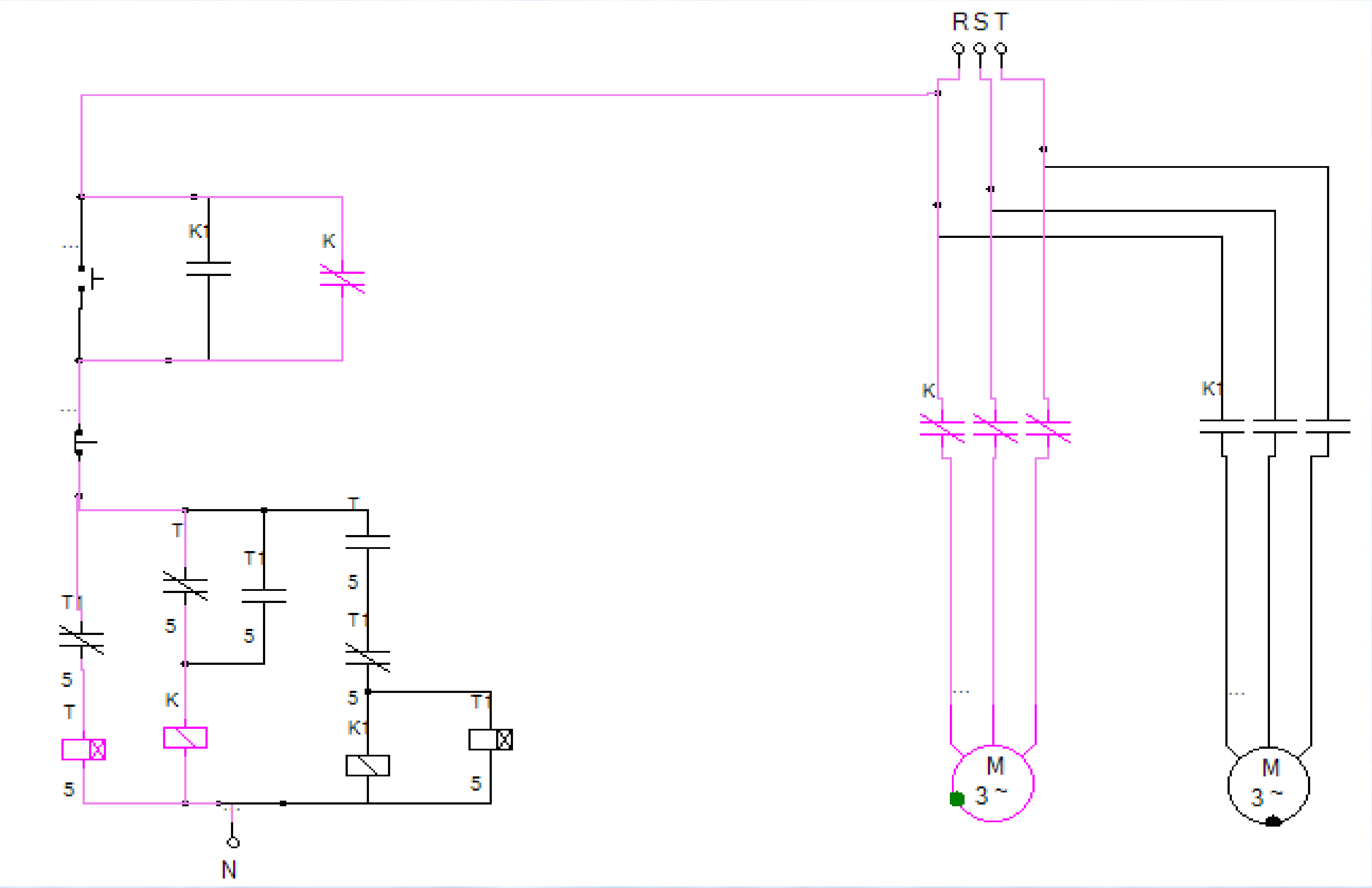
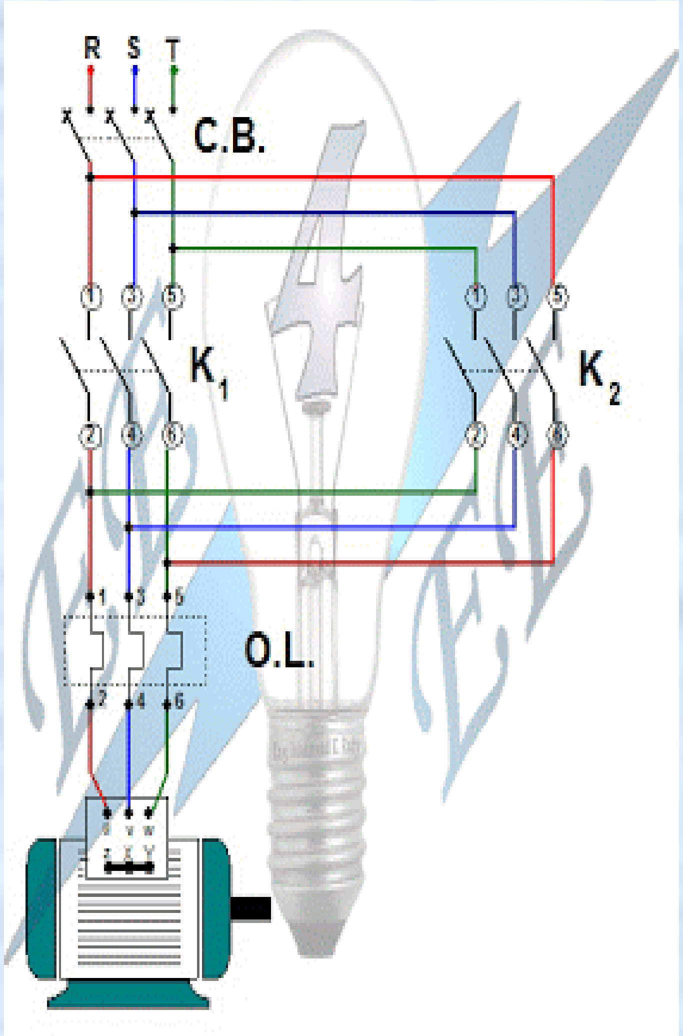
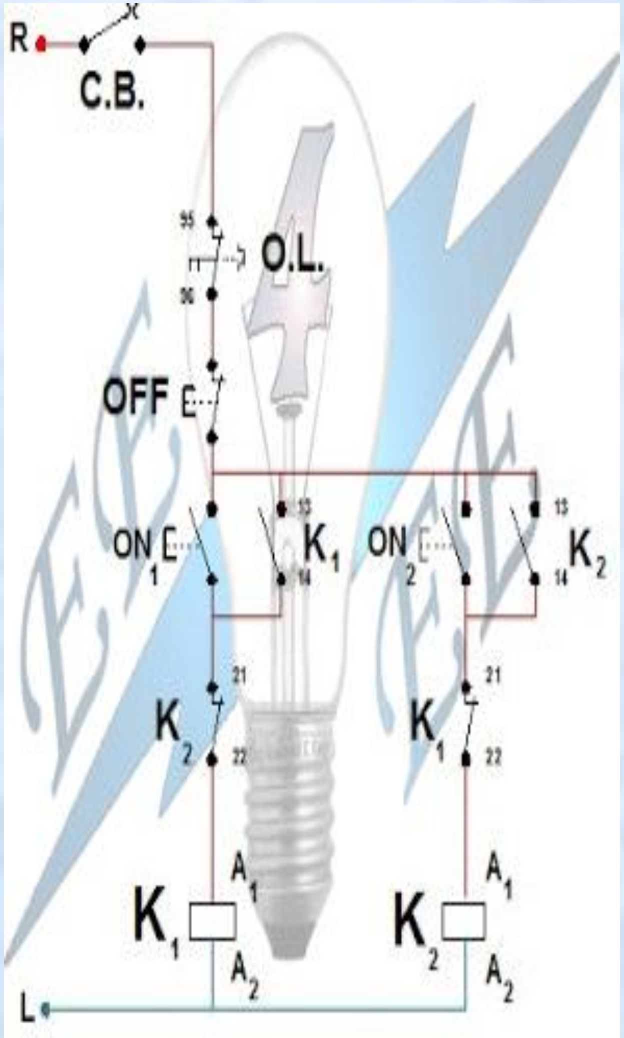


11- Automatic control of two motor with time delay motor circuit

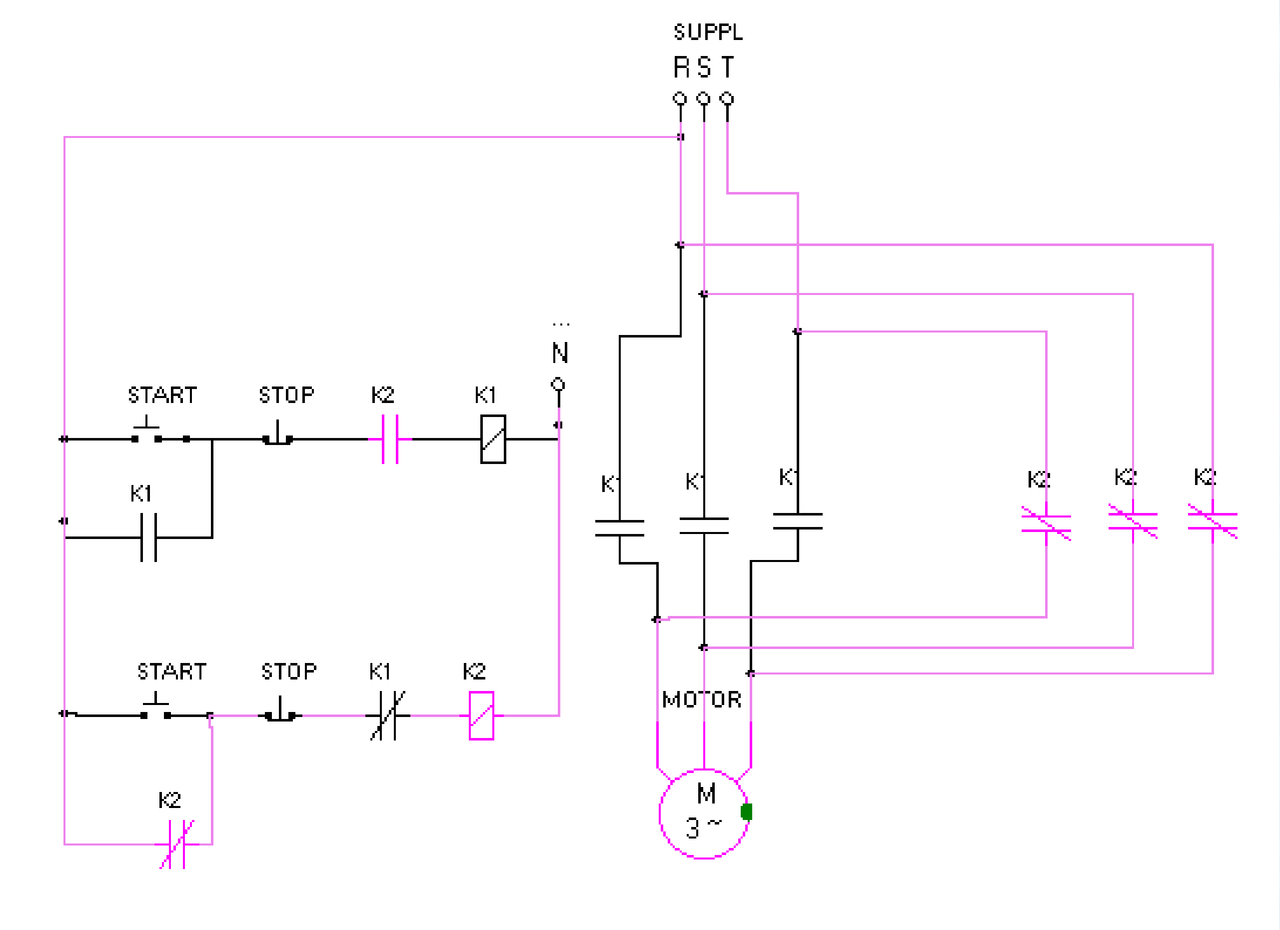


12- Forward Reverse motor circuit

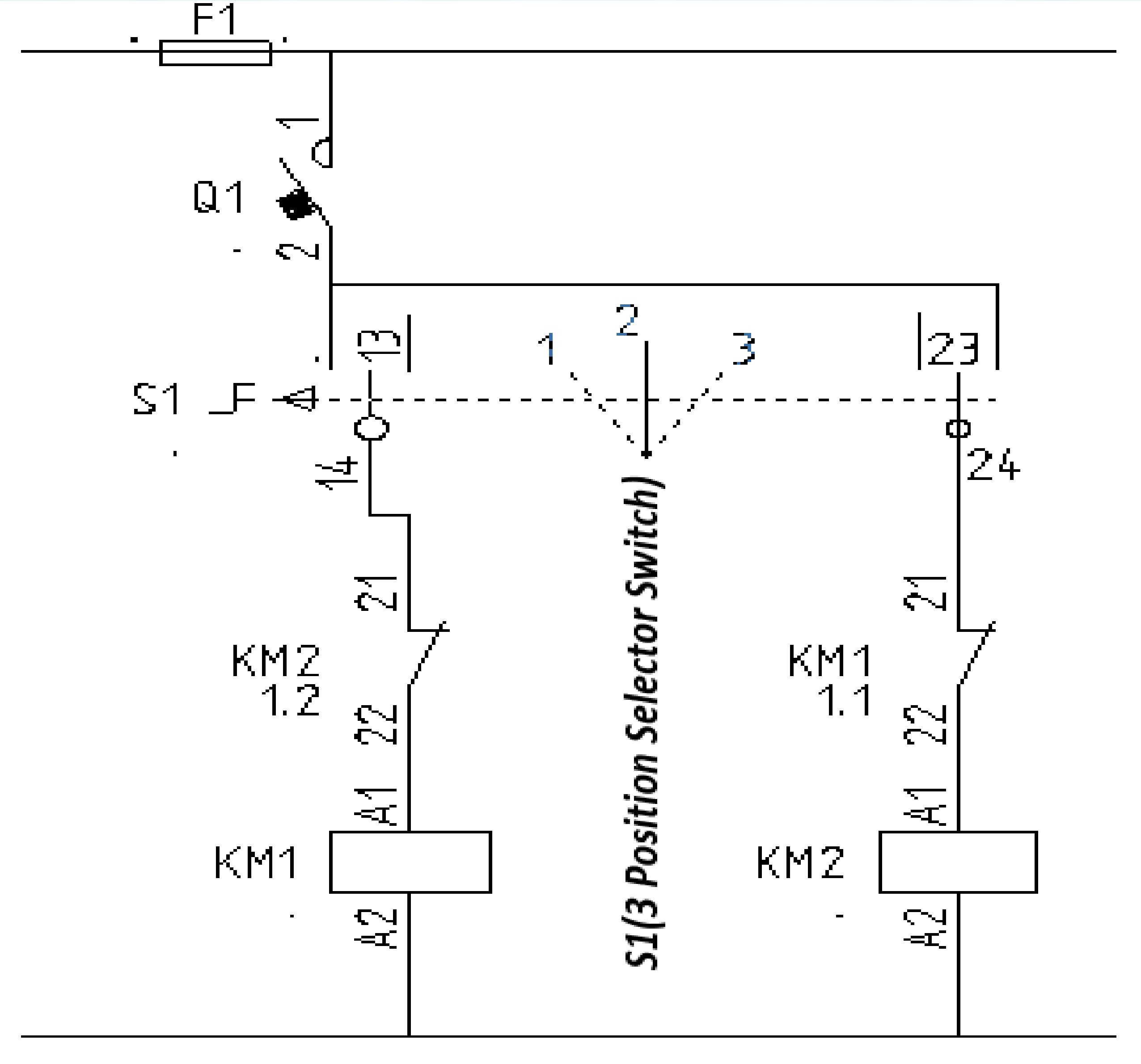




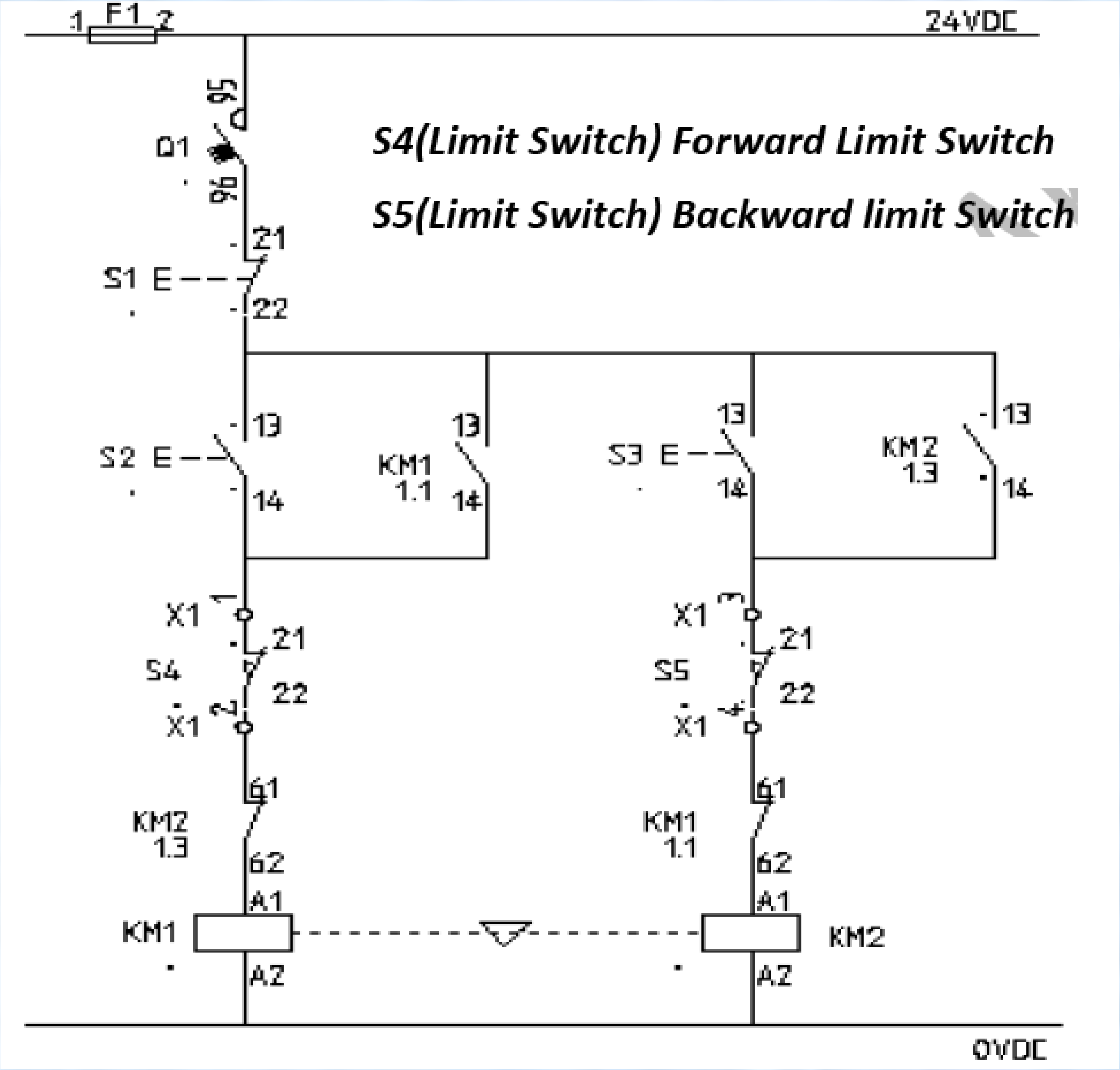
EKTS Simulation



Think what does it mean ????



Think what does it mean ????



CHAPTER 7

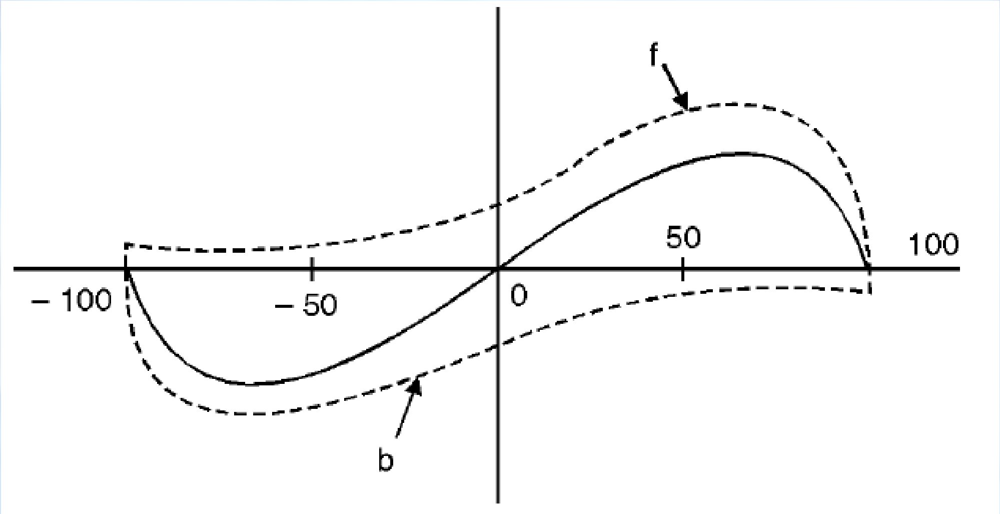
Types of Starter for Induction motors

Function of starter

- Start and stop the motor.
- Limit inrush current where necessary.
- Permit automatic control when required
- Protect motor and other connected equipments from over voltage, no voltage, under voltage, single phasing etc.

Types of 1Φ I.M starter

- Split-phase induction motor.
- Capacitor start induction motor.
- Capacitor run induction motor.
- Capacitor start capacitor run motor.
- Shaded pole induction motor.



1- Split-phase induction motor

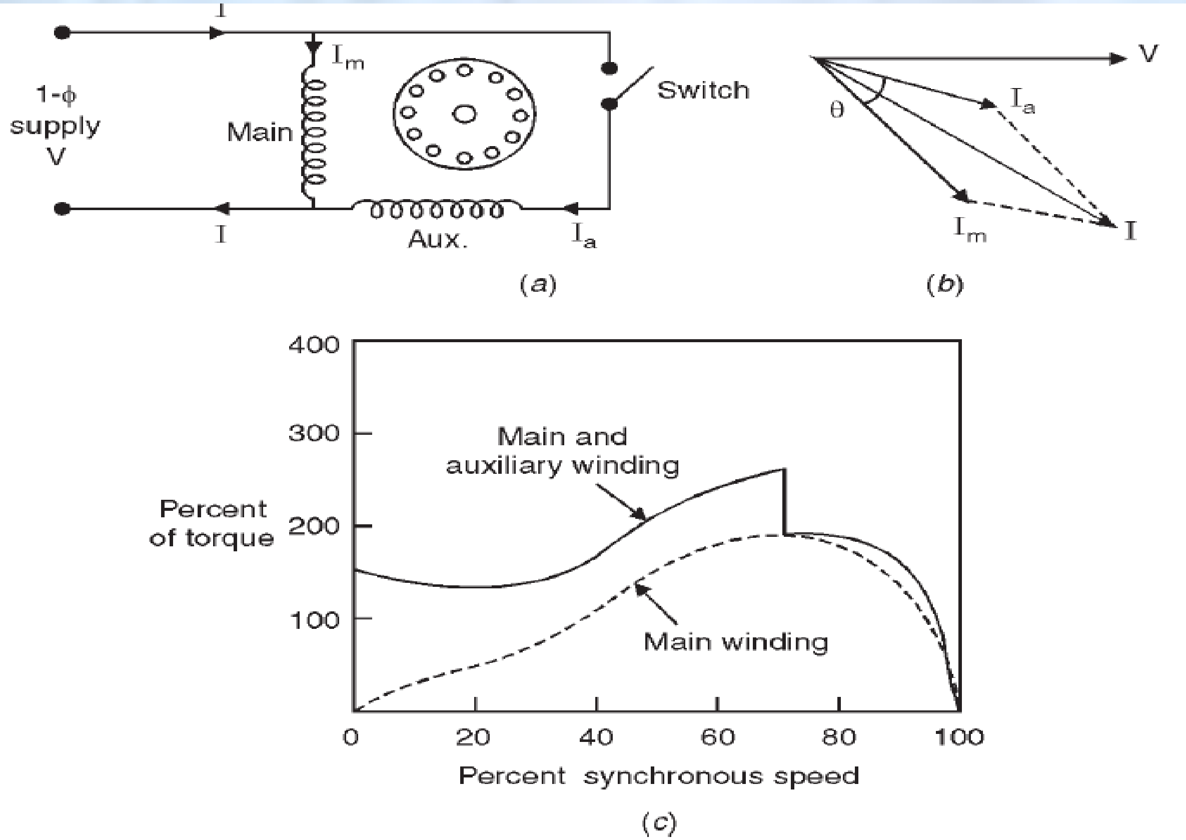
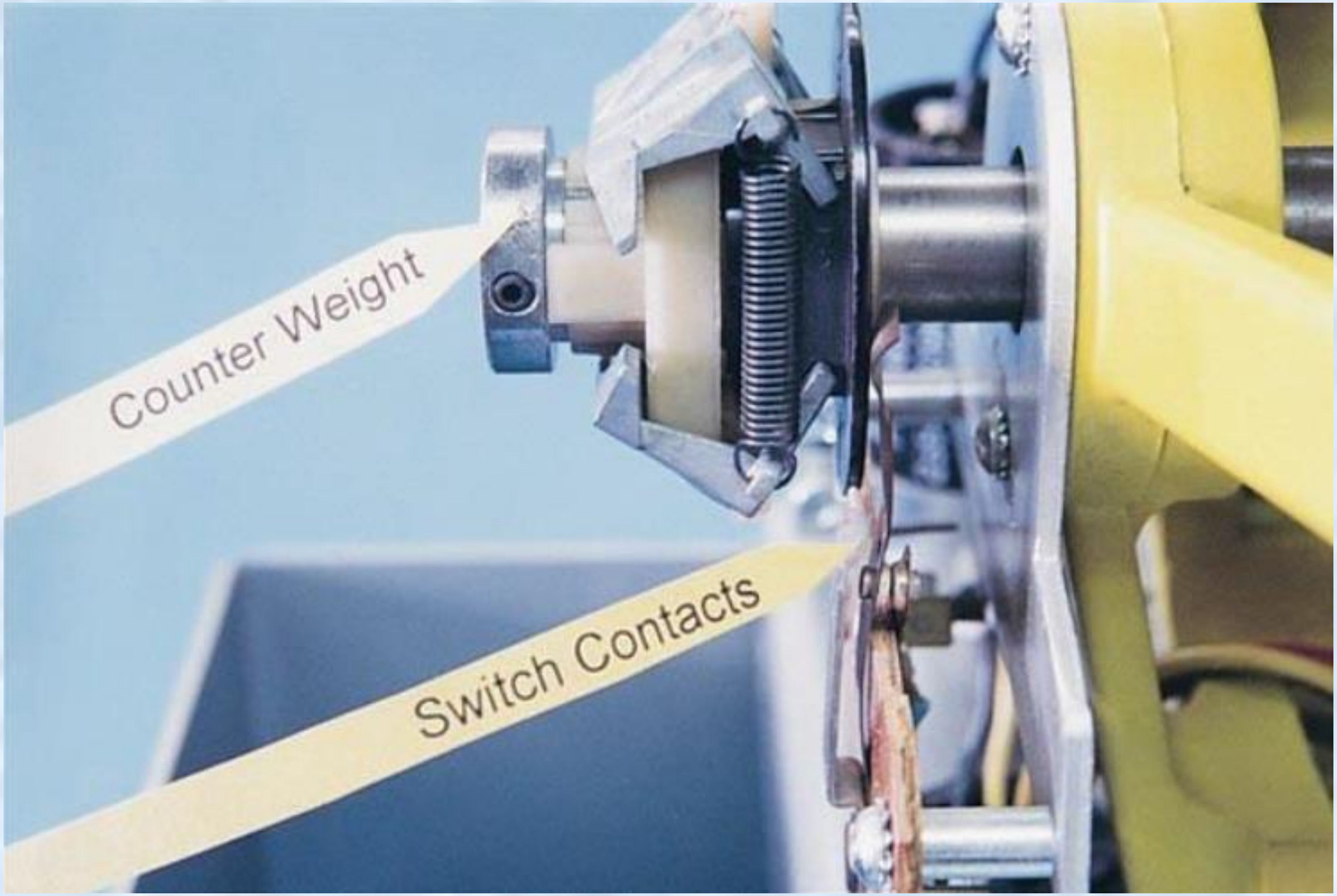


Fig. 9.5. Split phase induction motor (*a*) Connection (*b*) Phasor diagram at starting (*c*) Typical torque-speed characteristic.

The split phase induction motors are used for fans, blowers, centrifugal pumps and office equipment.

Centrifugal Switch



2- Capacitor start induction motor

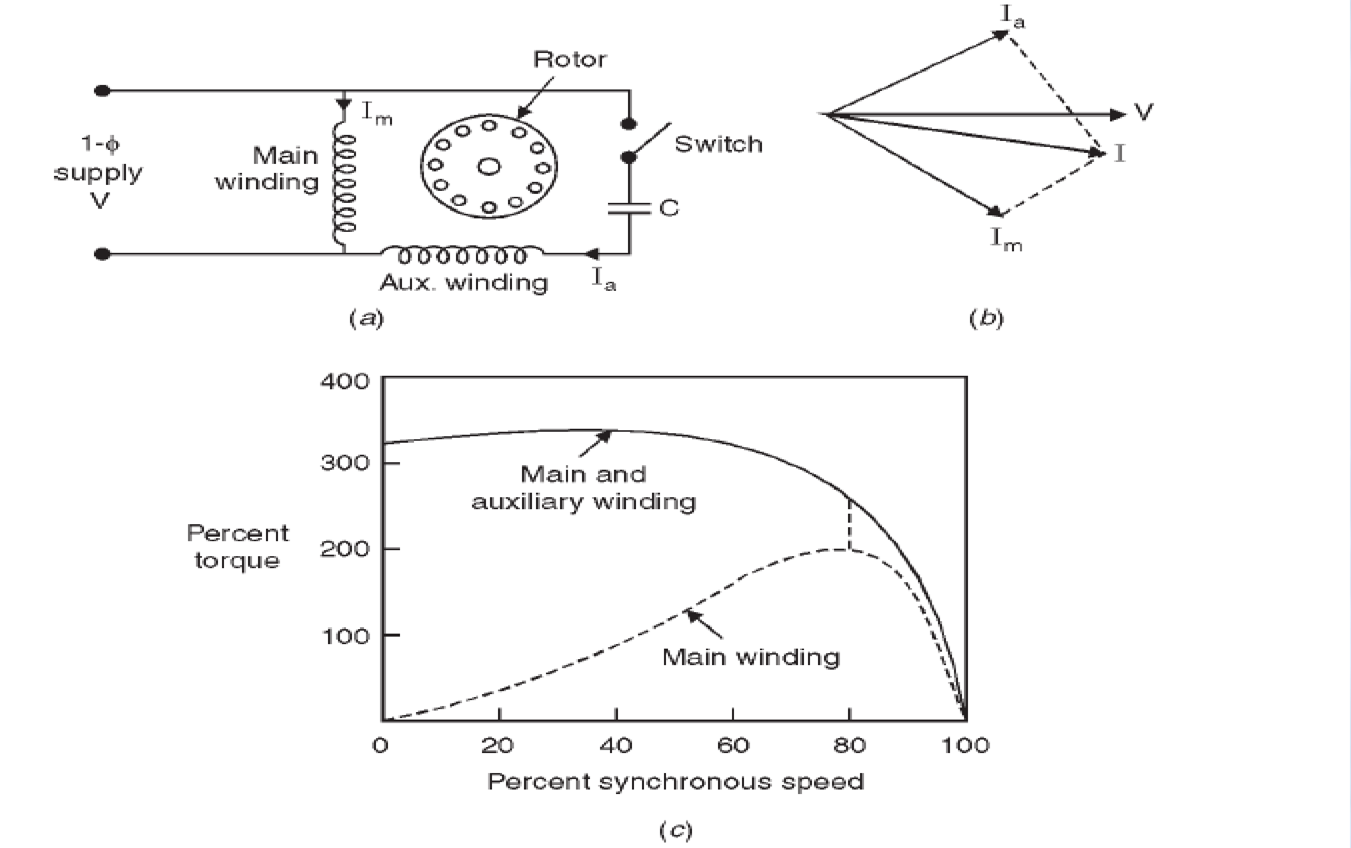


Fig. 9.6. Capacitor start motor (*a*) Connection (*b*) Phasor diagram at start (*c*) Speed torque curve.

The capacitor start motors are used for compressors, pumps, refrigeration and air-conditioning equipment and other hard to start-loads **(25 μF/HP).**

3- Capacitor run induction motor

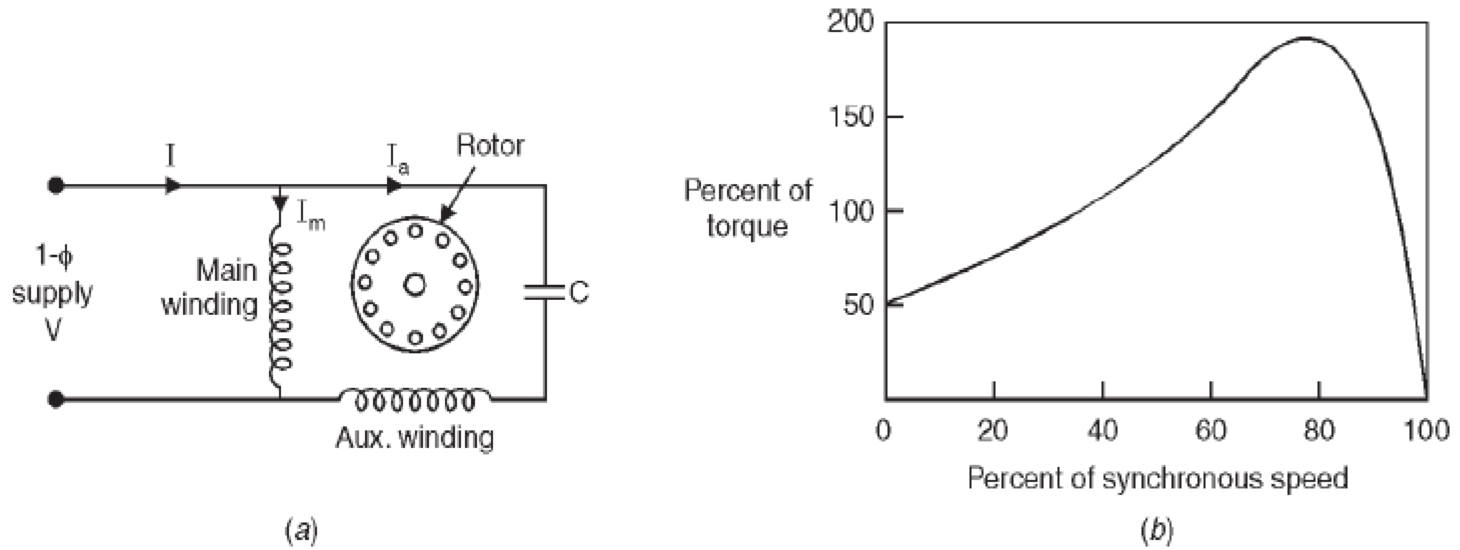


Fig. 9.7. Permanent split capacitor motor (*a*) Connection (*b*) Torque-speed characteristic.

The capacitor run induction motors are used for direct connected fans, blowers, centrifugal pumps and loads requiring low starting torque **(1.5 to 100 μF)**.

4- Capacitor start capacitor run motor

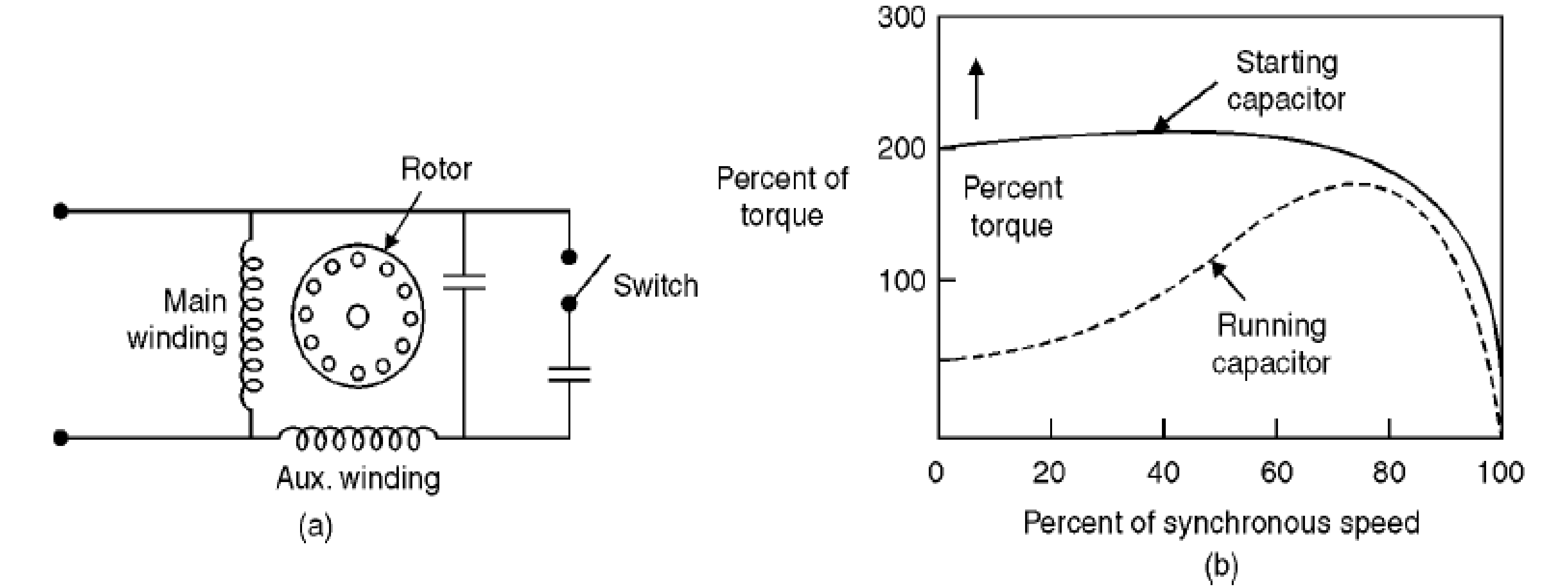


Fig. 9.8. (*a*) Capacitor start capacitor run motor (*b*) Torque-speed characteristic.

The capacitor start capacitor run motors are used in compressors, conveyors, pumps and other high torque loads.

5- Shaded pole induction motor

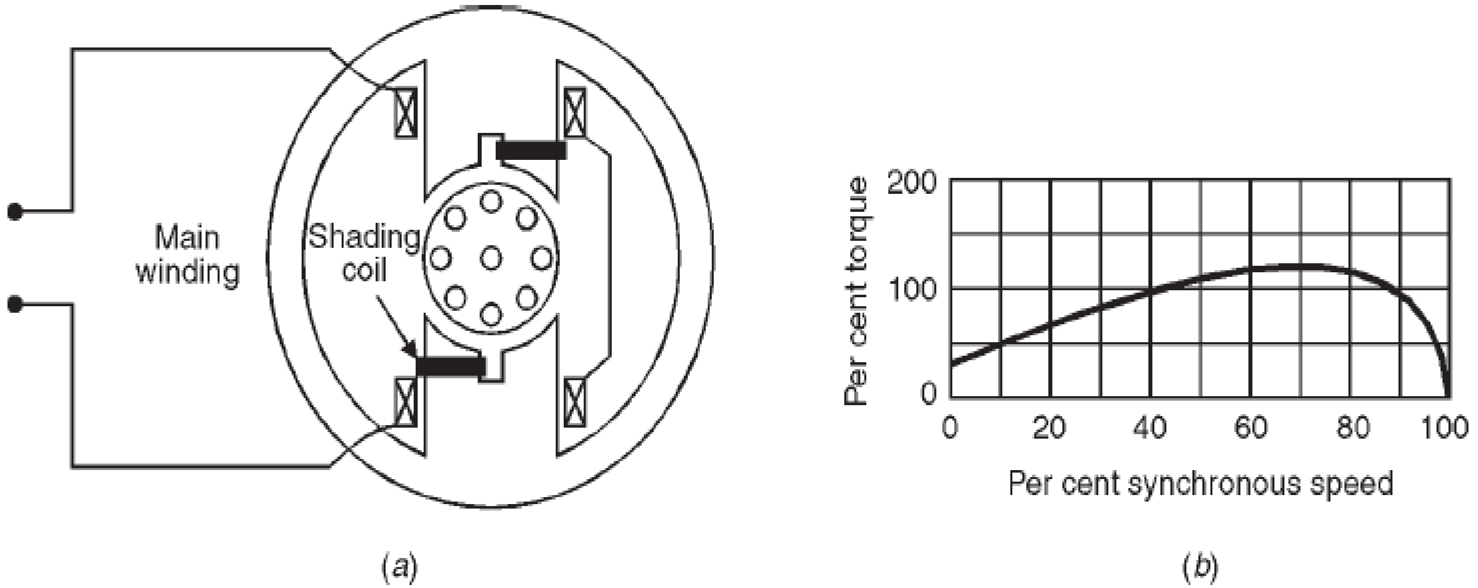
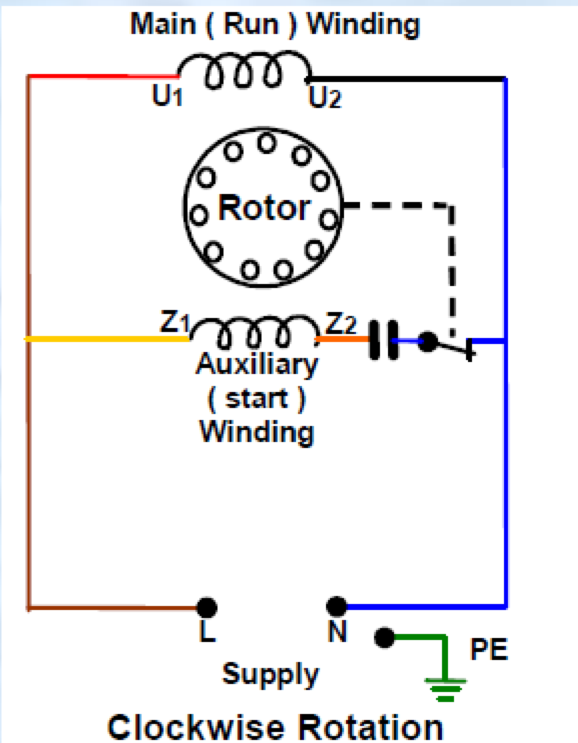


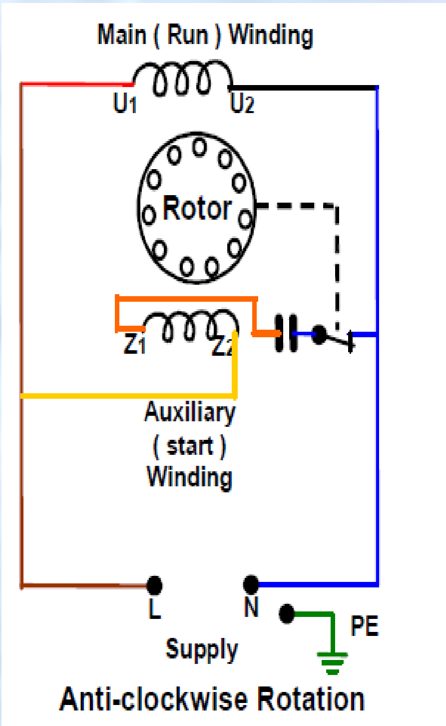
Fig. 9.9. Shaded-pole motor and typical torque-speed characteristic.

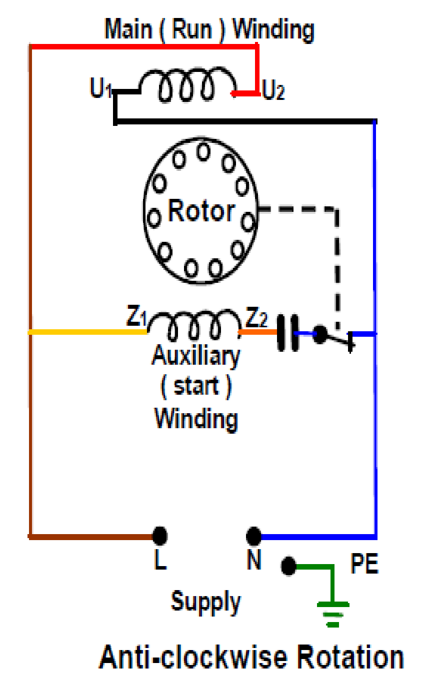
The shaded pole motors are used in toys, hair driers, desk fans etc.

Reversing the Direction of Rotation

- Reversing the direction of rotation can be accomplished by reversing either the run windings or the start windings
- Reversing the start winding connections is more common







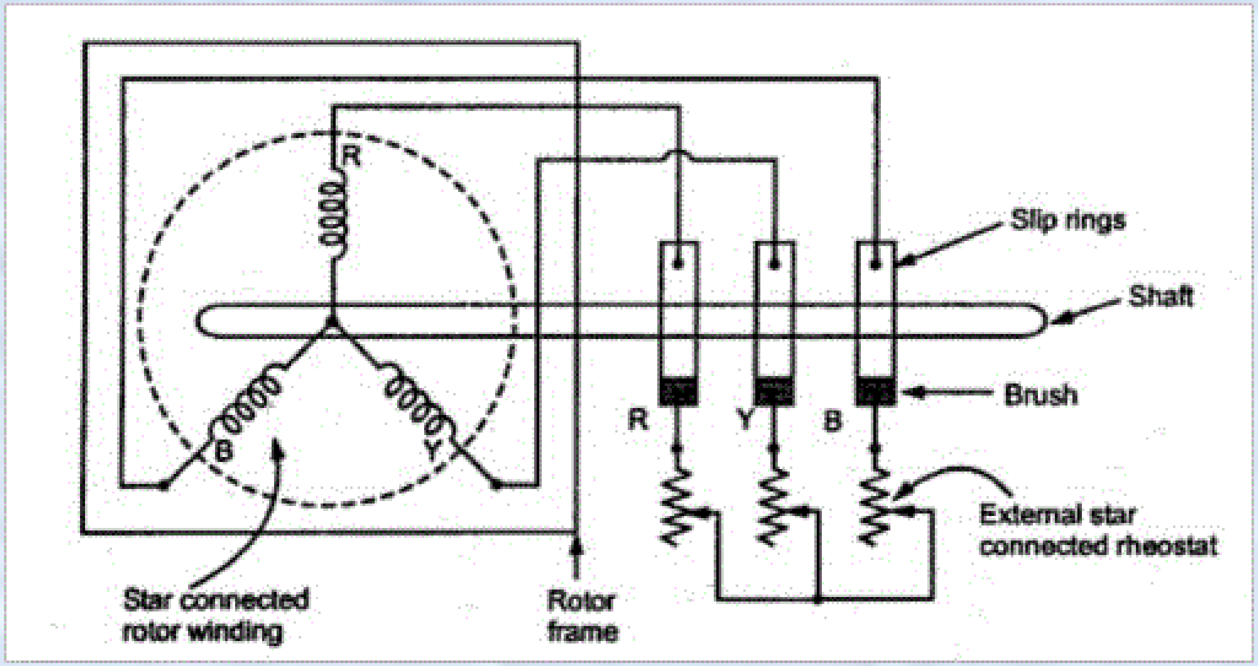
Types of 3Φ I.M starter

- **For slip-ring induction motors:**
  - Rotor rheostat starter

- **For squirrel cage induction motors:**
  - D.O.L starter
  - Primary resistance starter
  - Auto transformer starter
  - Star delta starter

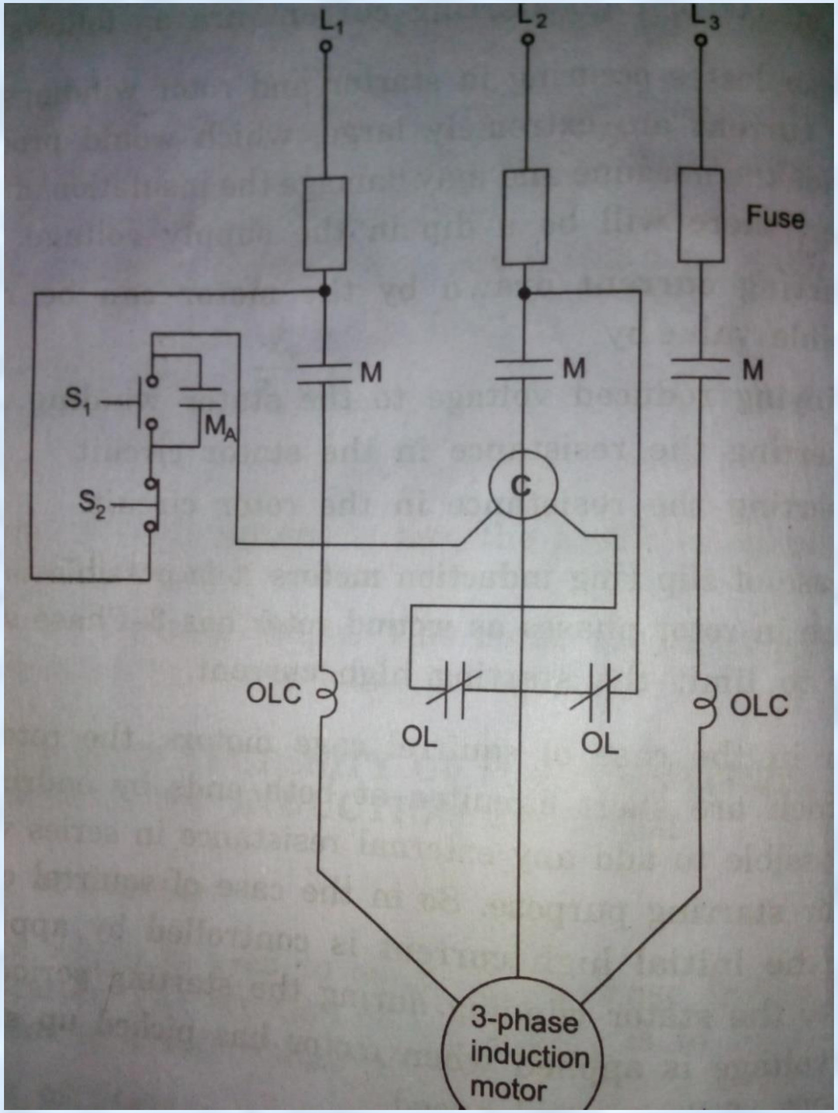
- **Other starters:**
  - Soft starters
  - Variable speed drive

1- Rotor rheostat starter



- The rotor circuit resistance is gradually cut out , as the motor speeds up and during normal running condition ,the rotor circuit resistance is completely cut out and the slip rings are short circuited **(Starting with high resistance value then decrease gradually Tmax at S=Rext/X2)).**

2- Direct-on-Line Starter (DOL)



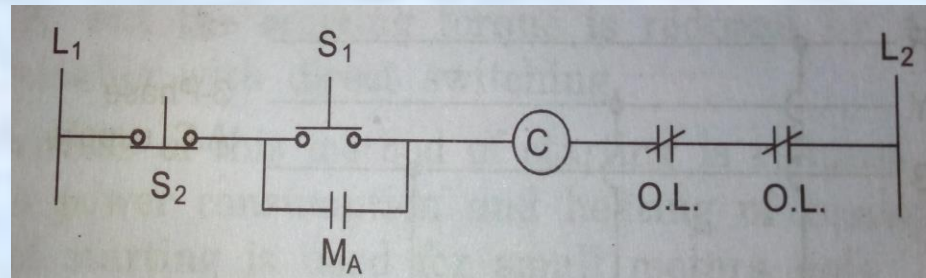
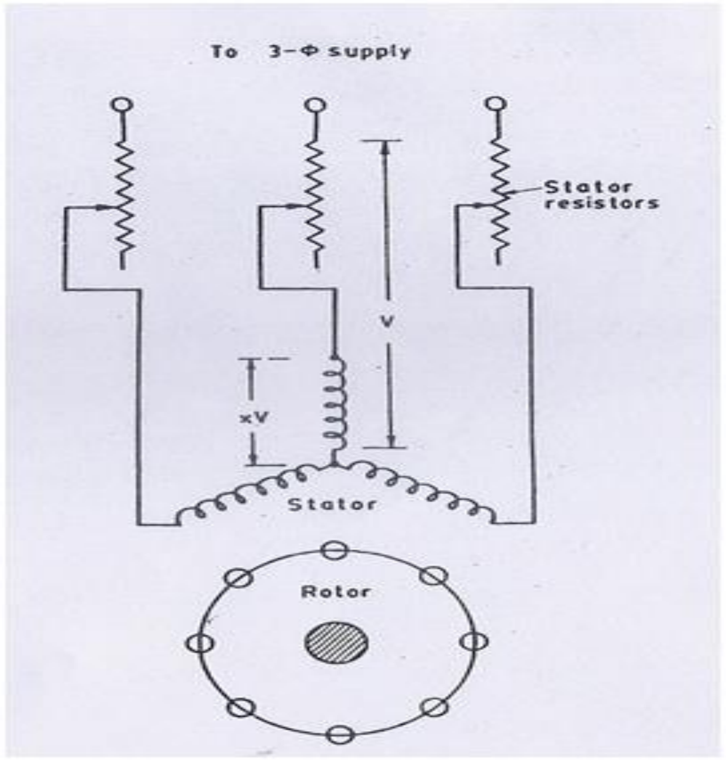


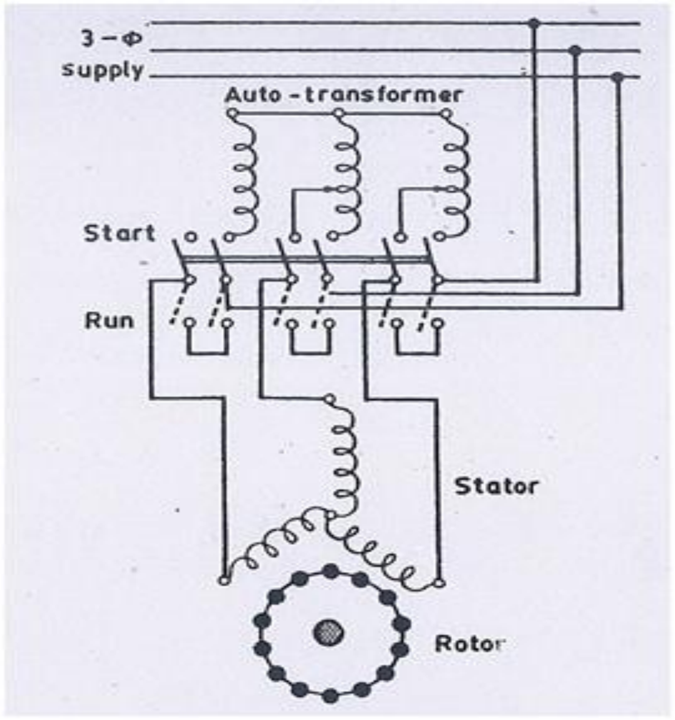
Fig.1.23 Control circuit

3- Primary resistance starter



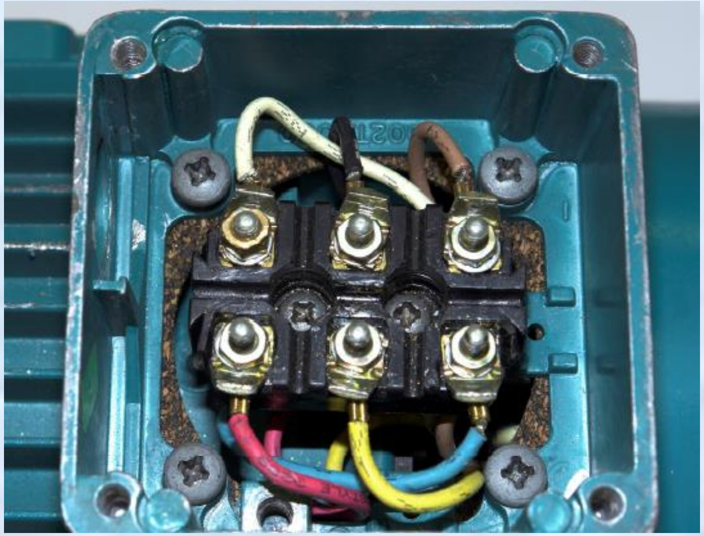
The purpose of primary or starting resistors is to drop some ❑ voltage and hence reduce the voltage applied across the motor terminals.

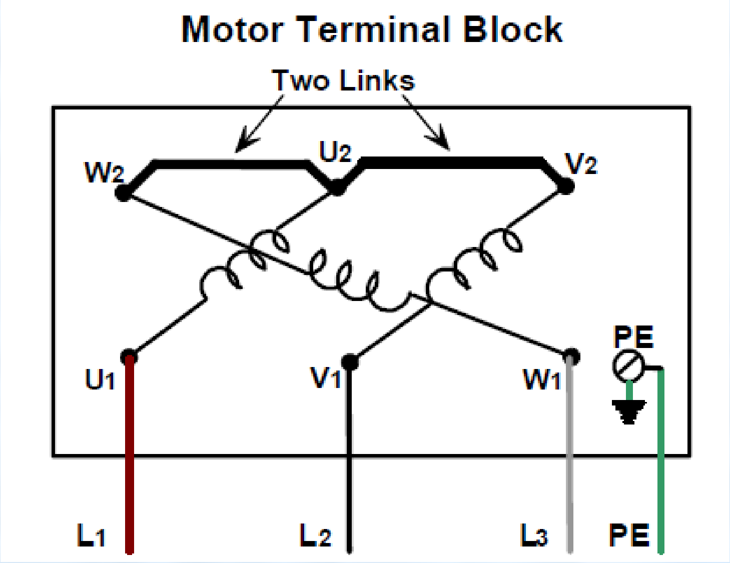
4- Auto-Transformer Starting

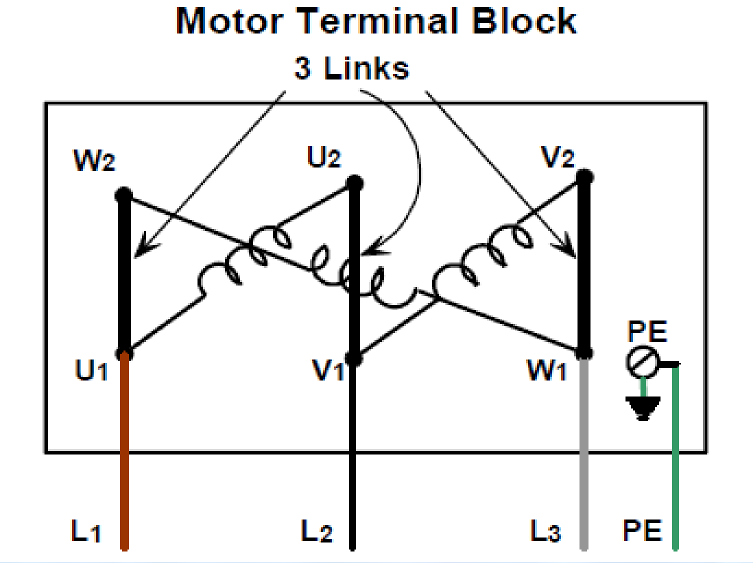


- An auto-transformer starter makes it possible to start squirrel-cage induction motors with reduced starting current, as the voltage across the motor is reduced during starting.

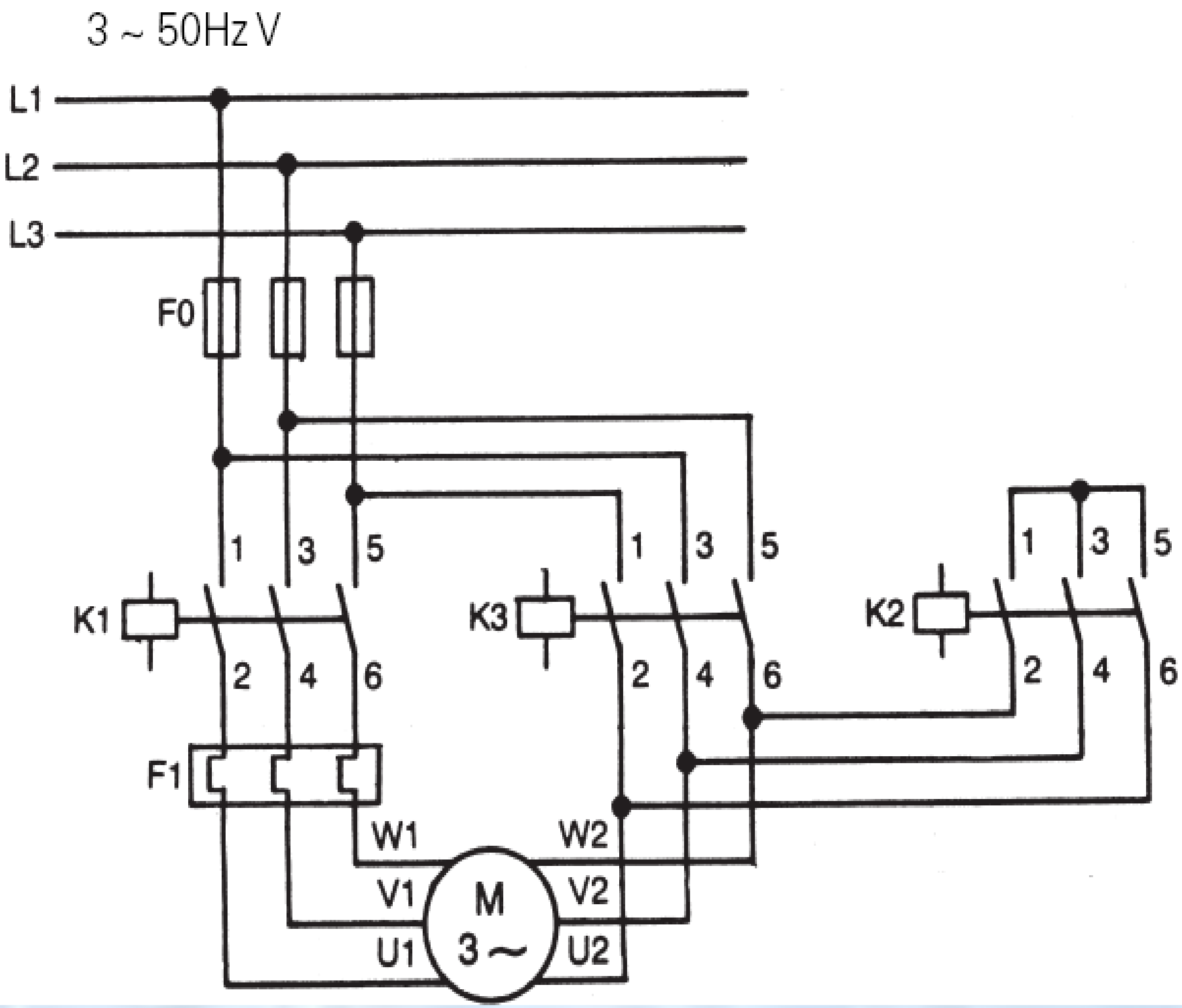
5- Star delta starting





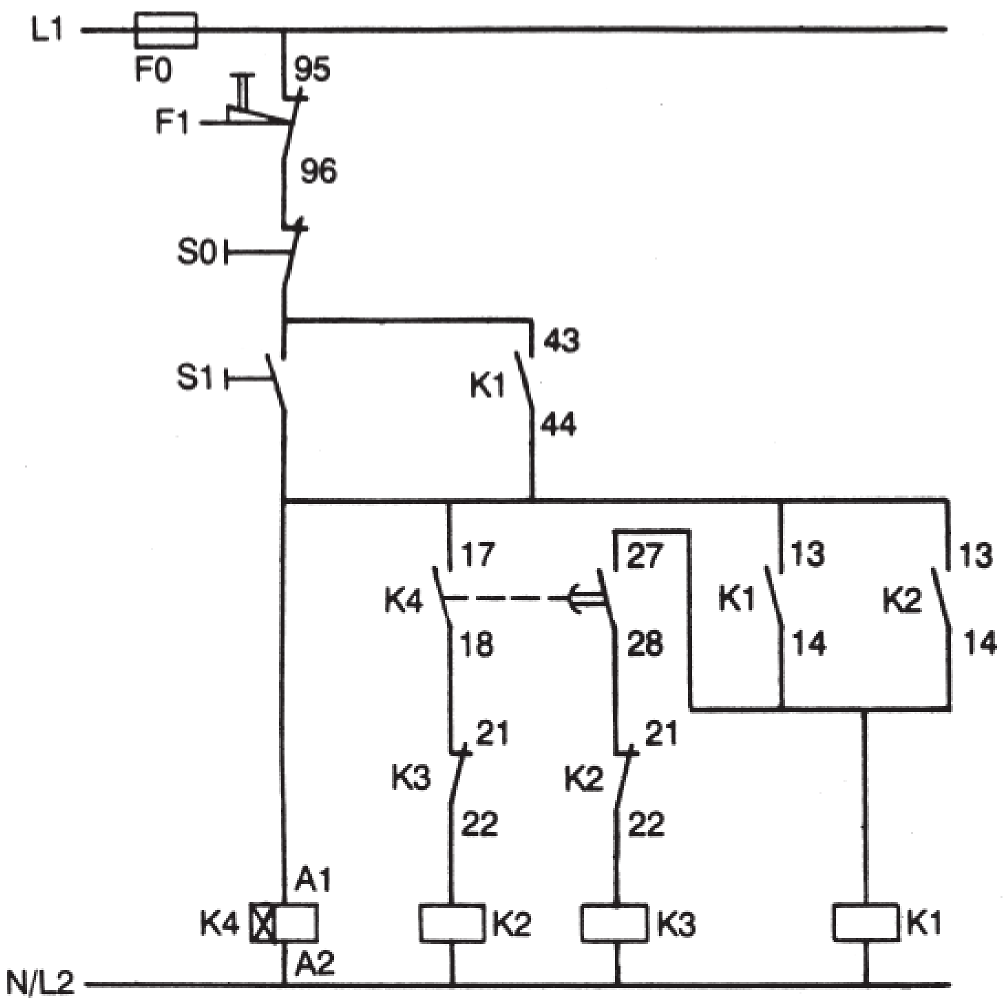


➢ Power circuit



K1 = Line Contactor
K2 = Star Contactor
K3 = Delta Contactor
F1 = Overload Relay
F0 = Backup Fuse

➢ Control circuit

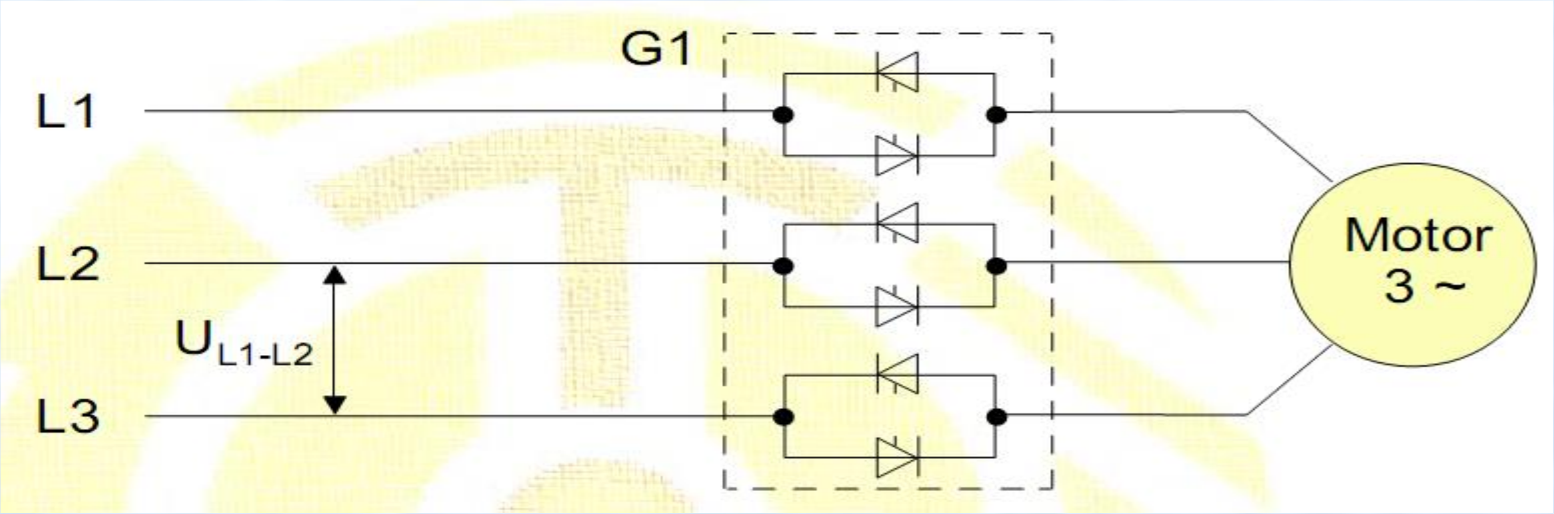


S0 = Push Button OFF (1NC)
S1 = Push Button ON (1NO)
K1 = Line Contactor with 2NO Auxiliary Contacts.
K2 = Star Contactor with 1NO + 1NC Auxiliary Contacts.
K3 = Delta Contactor with 1 NC Auxiliary Contacts.
K4 = Star Delta Timer with 1NO instantaneous and 1NO delayed Auxiliary Contacts.
F1 = Overload Relay.
F0 = Backup Fuse.

Difference between DOL/Star delta /Autotransformer

Sr.	DOL Starter	Star delta starter	Auto transformer starter
1	Used up to 5 HP	Used 5 HP to 20HP	Used above 20 HP
2	Does not decrease the starting current	Decreases the starting current by 1/3 times	Decreases the starting current as required
3	It is cheap	It is costly	It is more costly
4	It connects directly the motor with supply for starting as well as for running	It connects the motor first in star at the time of starting in delta for running	It connects the motor according to the taping taken out from the auto transformer

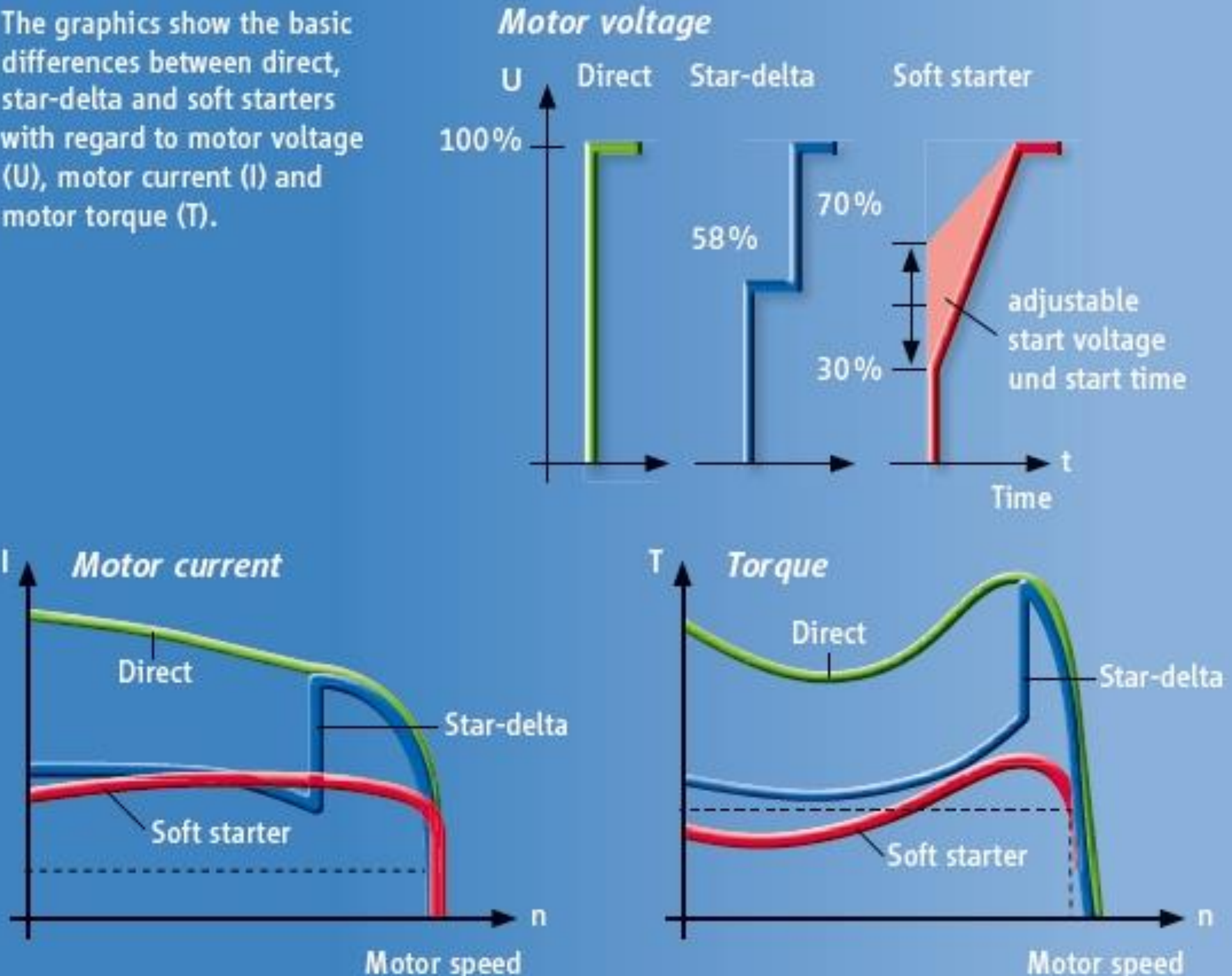
6- Soft starter starting



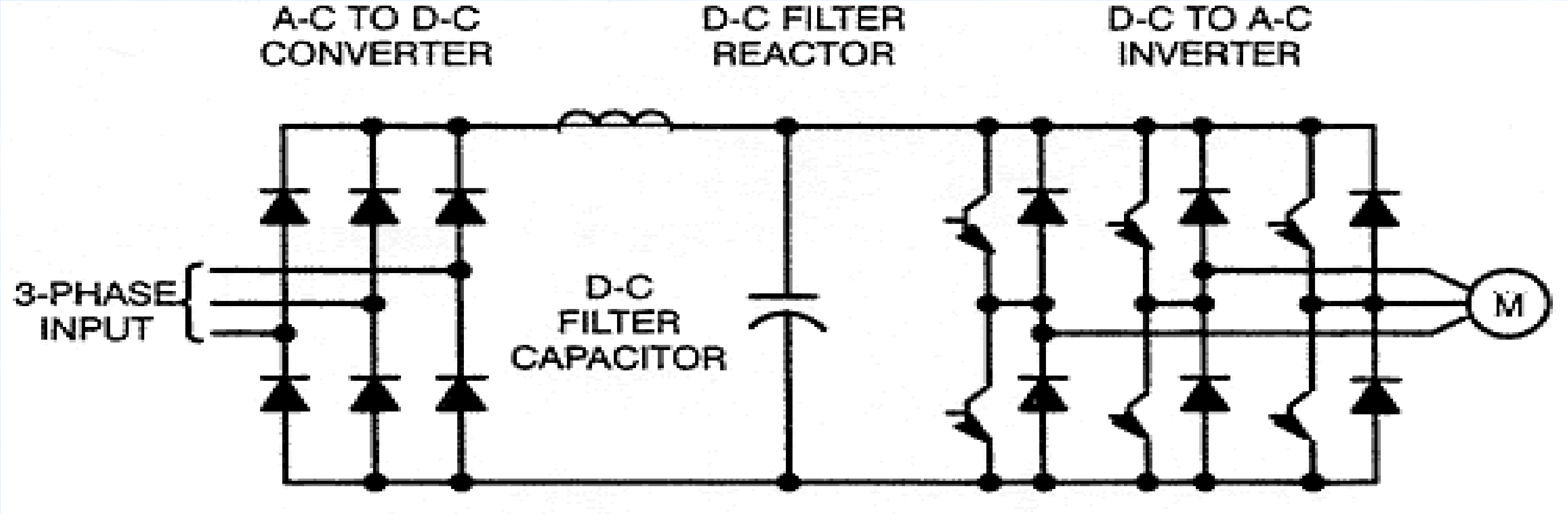
By using six SCR's in a back to back configuration , the soft starter is able to regulate the voltage applied to the motor during starting from 0 volts up to line voltage.

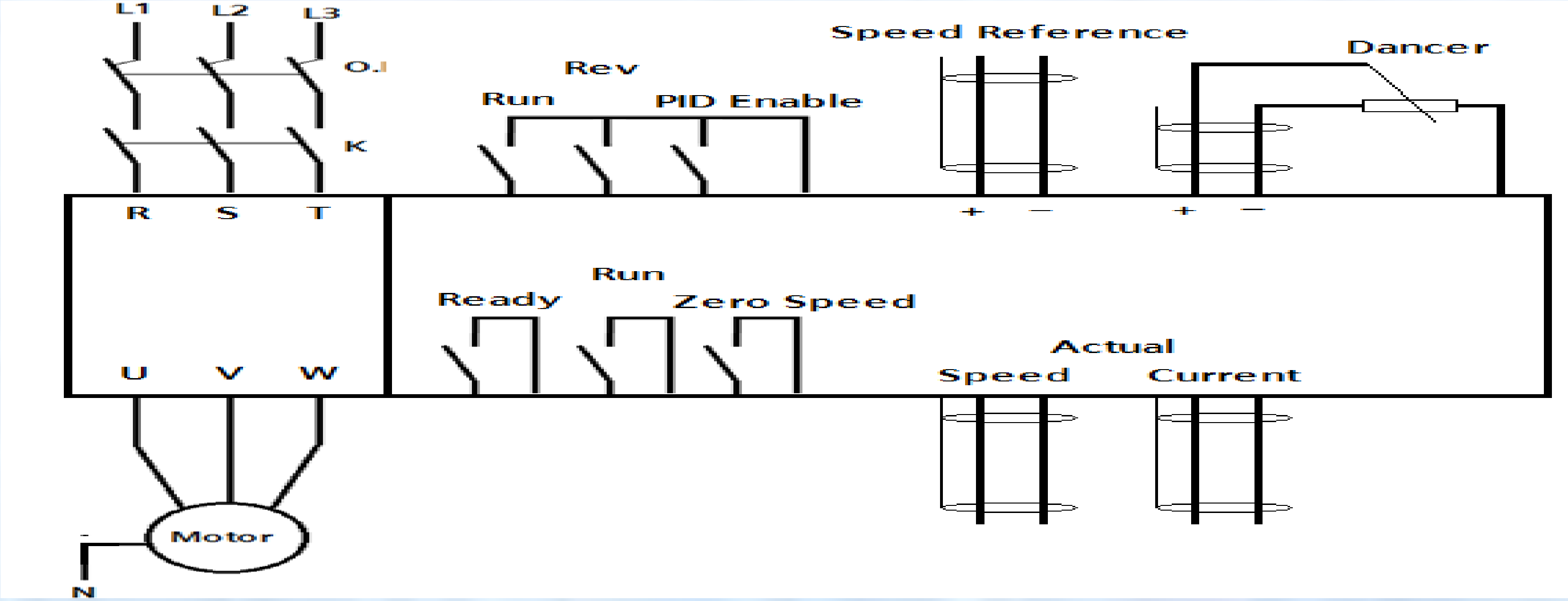
- **Frequency do not change as in VSD**
- **Only the voltage and current changes**

The graphics show the basic differences between direct, star-delta and soft starters with regard to motor voltage (U), motor current (I) and motor torque (T).



7- Variable speed drive





CHAPTER 8

Testing of Induction Motor

Testing of Induction Motor

Visual Tests

- Check that motor frame is mechanically sound.
- Remove terminal cover plate and check for ingress of foreign material, moisture etc.
- Check for signs of overheating, arcing or burning.
- Check ventilation is clear.

Electrical Tests

- Identify windings using a continuity tester.
- Measure the resistance of the windings (3 identical readings).
- Measure the insulation resistance between each winding and between windings and frame.

Mechanical Tests

- Check that the rotor is free to rotate and does so smoothly / quietly.
- Check that motor interior is free of dirt, dust, water and oil.
- Check for play in bearings.

Tests when Running

- Check run currents (If uneven check voltage at motor terminals).
- Check speed of motor at no load and full load.
- Check vibration levels and noise levels.
- Check for temperature hot spots.

Testing of Three-Phase Stator Windings

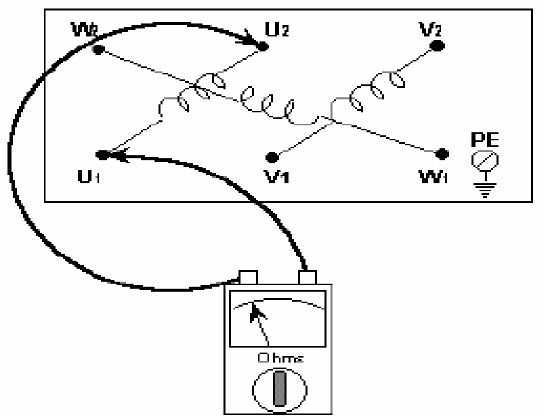
- **Step 1:** Isolate the motor electrically, and if necessary, mechanically.

- **Step 2:** Identify the way the motor terminal block is connected.

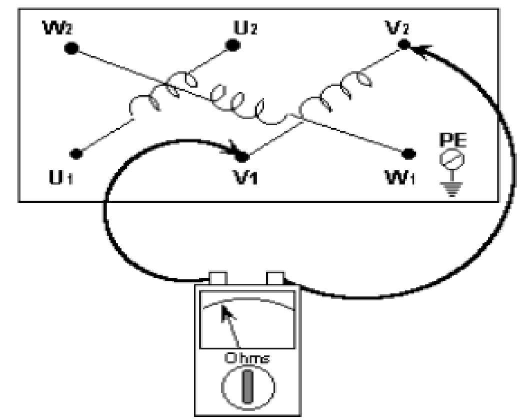
- **Step 3:** Identify the 3 stator windings - usually labelled U1-U2, V1-V2, and W1-W2.

- **Step 4:** Measure and record the resistance of each winding.

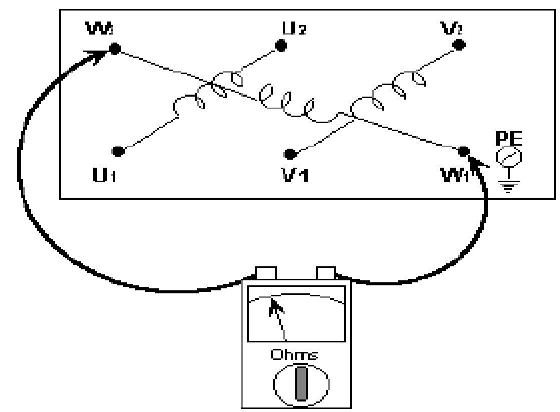
Resistance Test on Winding U

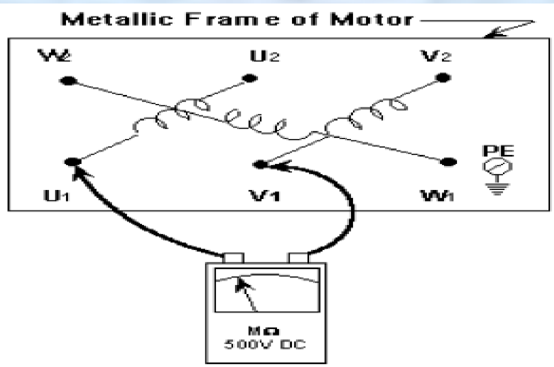


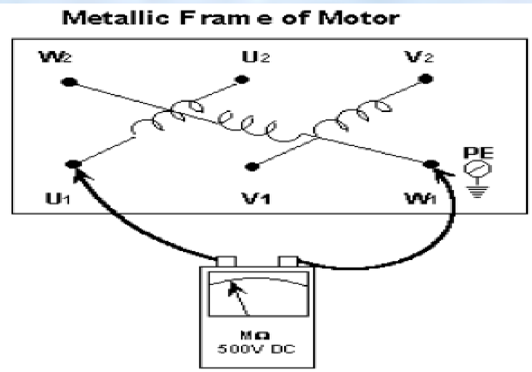
Resistance Test on Winding V

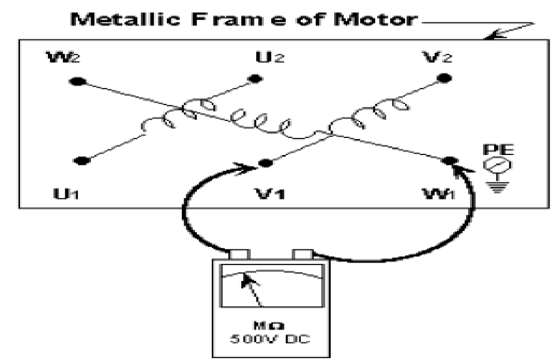


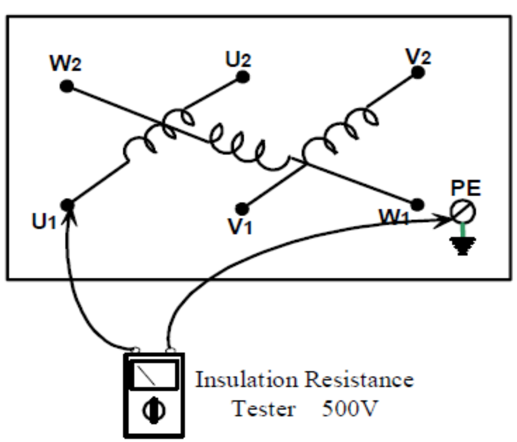
Resistance Test on Winding W

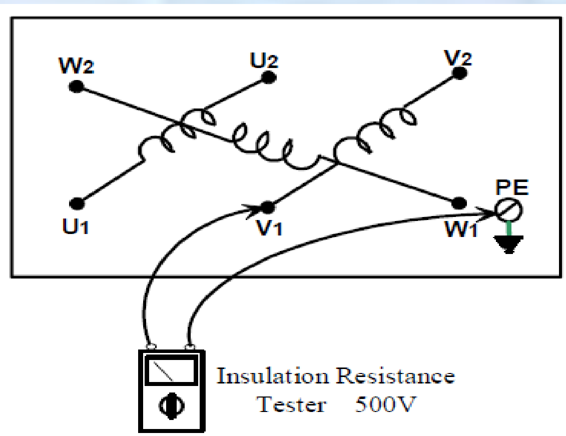


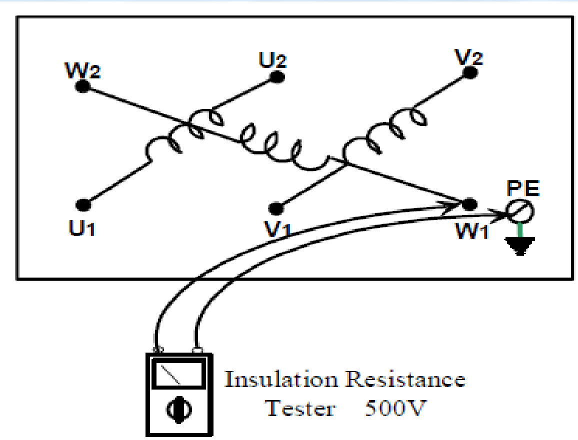






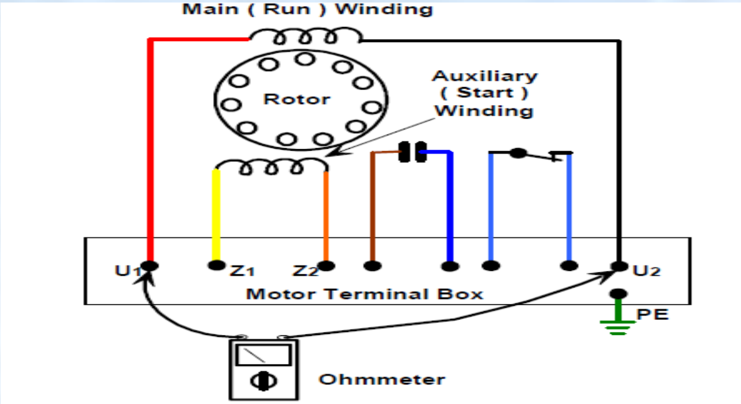


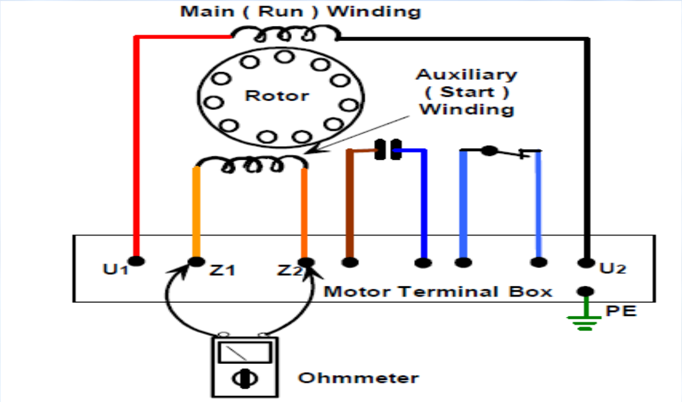


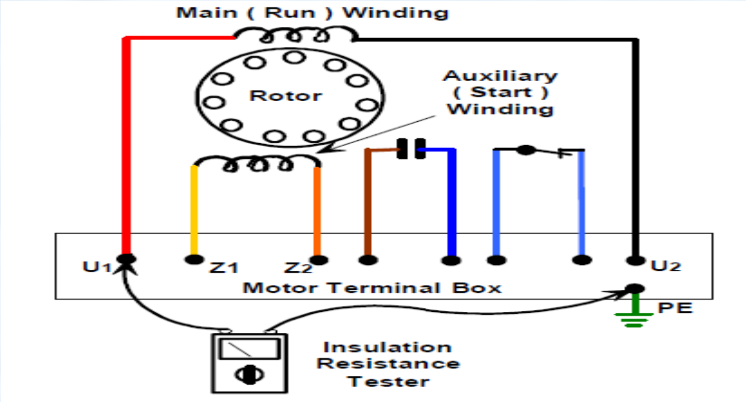


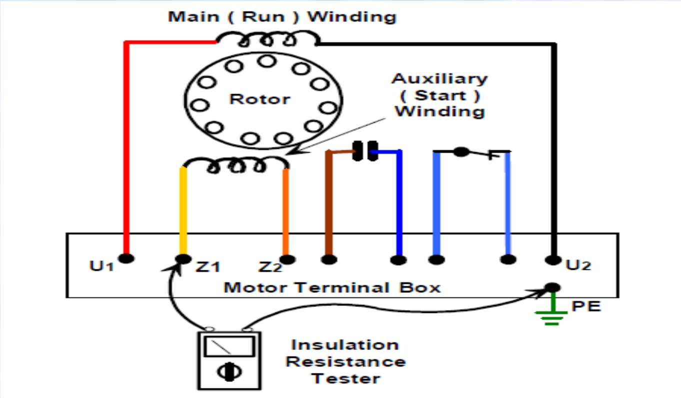
Testing of Single Phase Stator Windings

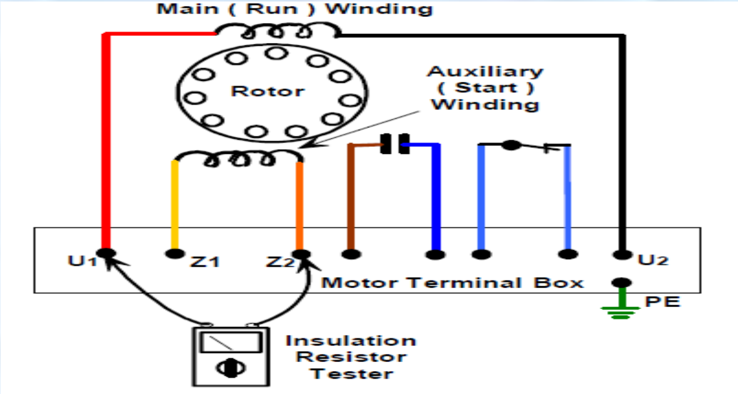
- **Step 1:** Isolate the motor electrically, and if necessary, mechanically.
- **Step 2:** Identify the way the motor terminal block is connected.
- **Step 3:** Identify the 2 stator windings - usually labelled U1-U2 and Z1-Z2.
- **Step 4:** Measure and record the resistance of each winding.


Main (Run) Winding
Rotor
Auxiliary (Start) Winding
U1
Z1
Z2
U2
Motor Terminal Box
PE
Ohmmeter


Main (Run) Winding
Rotor
Auxiliary (Start) Winding
U1
Z1
Z2
U2
Motor Terminal Box
PE
Ohmmeter


Main (Run) Winding
Rotor
Auxiliary (Start) Winding
U1
Z1
Z2
U2
Motor Terminal Box
PE
Insulation Resistance Tester

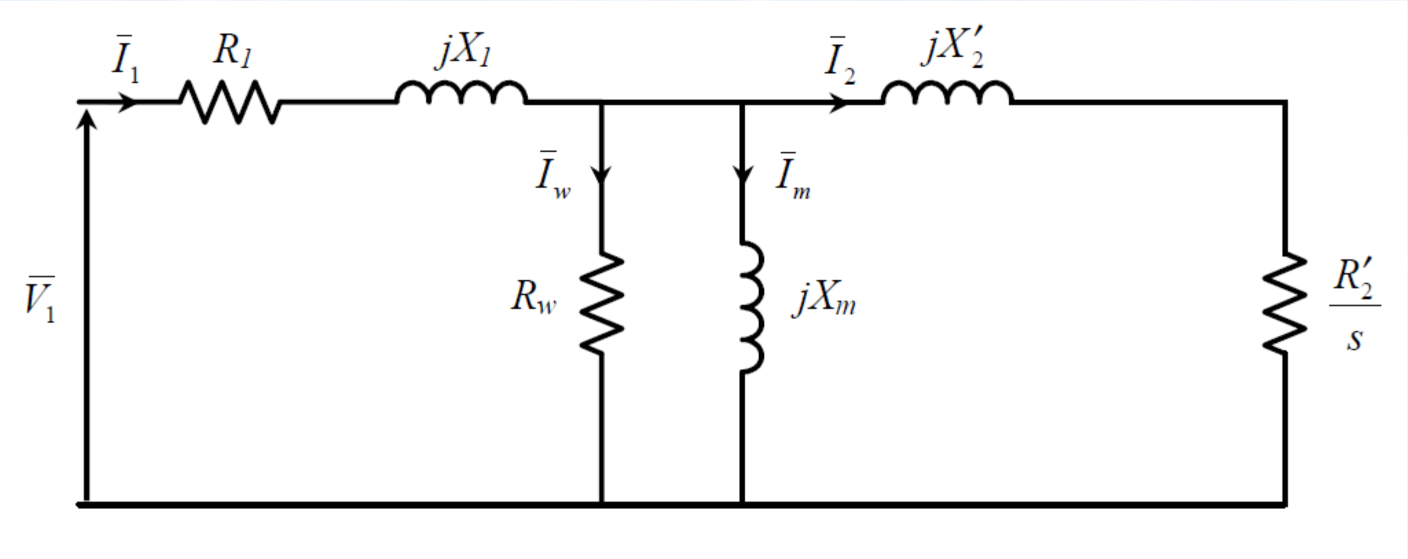

Main (Run) Winding
Rotor
Auxiliary (Start) Winding
U1
Z1
Z2
U2
Motor Terminal Box
PE
Insulation Resistance Tester


Main (Run) Winding
Rotor
Auxiliary (Start) Winding
U1
Z1
Z2
U2
Motor Terminal Box
PE
Insulation Resistor Tester


LCR
MR8/440
8µF ± 10%
440VAC 50/60HZ
-40/+85°C
00-05

Determination Of Equivalent Circuit Parameters Of Three Phase Induction Motor

- It is possible to find the parameters of the equivalent circuit of the three phase induction motor experimentally



1- The DC Test:

The DC resistance of the stator can be measured by applying DC current to the terminals of the winding of each phase and taking the reading of the voltage and the current (or using ohmmeter) and determine the DC resistance as fallows:

$$R_{iDC} = \frac{V_{iDC}}{I_{iDC}}, \text{ where } i \text{ represents the number of the winding } i \ (i = 1, 2, 3). \qquad (1)$$

After that, the average of the readings can be calculated as:

$$R_{DC} = \frac{R_{1DC} + R_{2DC} + R_{3DC}}{3} \qquad (2)$$

Then, the AC resistance is given by:

$$R_1 = 1.15\ R_{DC} \qquad (3)$$

2- The Locked Rotor Test

When the rotor is locked (i.e. prevented from running), s is equal to 1. The secondary impedance becomes much less than the magnetizing branch and the corresponding equivalent circuit becomes that of Fig.2. The readings to be obtained from this test are:

a) Three phase power $P_{3\phi\_BL}$

b) Line voltage V_{L_BL}

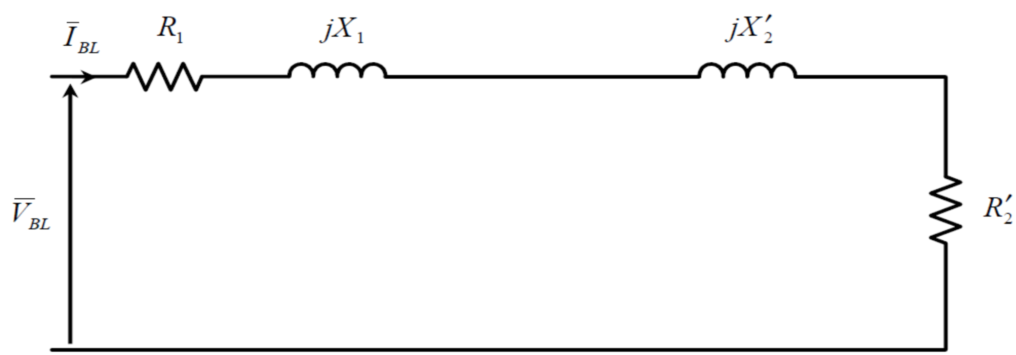
c) Line current I_{BL}

Then, R_{eq}, Z_{eq}, and X_{eq} can be obtained using the following equations:

$$R_{eq} = \frac{P_{BL}}{I_{BL}^2}$$

$$Z_{eq} = \frac{V_{BL}}{I_{BL}}$$

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$$



Separation of X_1, X_2', R_1, and R_2' can be done as follows:

$$X_1 = X_2' = \frac{1}{2} X_{eq}$$

$$R_2' = R_{eq} - R_1$$

3- The No Load Test

d) Three phase power $P_{3\phi\_NL}$

e) Line voltage V_{L_NL}

f) Line current I_{NL}

Then, R_w, and X_m, can be obtained as fallows:

$$P_{core+mechanical} = P_{NL} - I_{NL}^2 R_1$$

$$\bar{E}_1 = \bar{V}_{NL} - \bar{I}_{NL}(R_1 + jX_1)$$

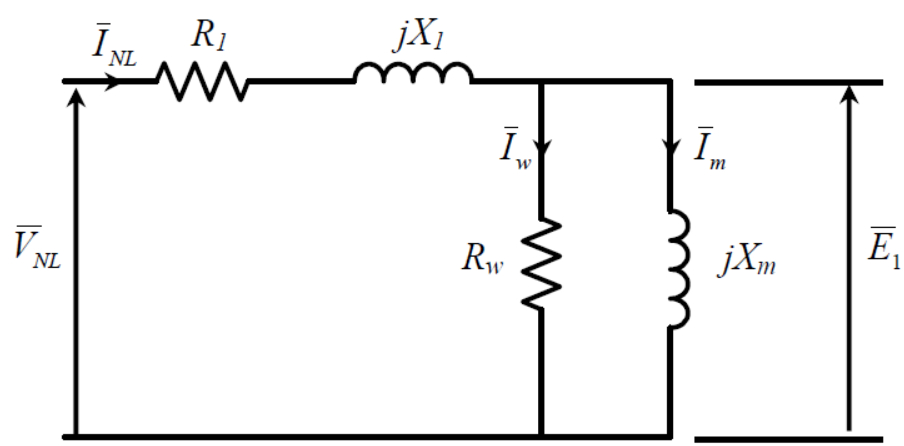
Note: $(\bar{I}_{NL} = I_{NL}\angle-\theta, \quad \theta = \cos^{-1}\dfrac{P_{NL}}{V_{NL}\ I_{NL}})$

$$R_w = \frac{|E_1|^2}{P_{core+mechanical}}$$

$$I_w = \frac{|E_1|}{R_w}$$

$$I_m = \sqrt{I_{NL}^2 - I_w^2}$$

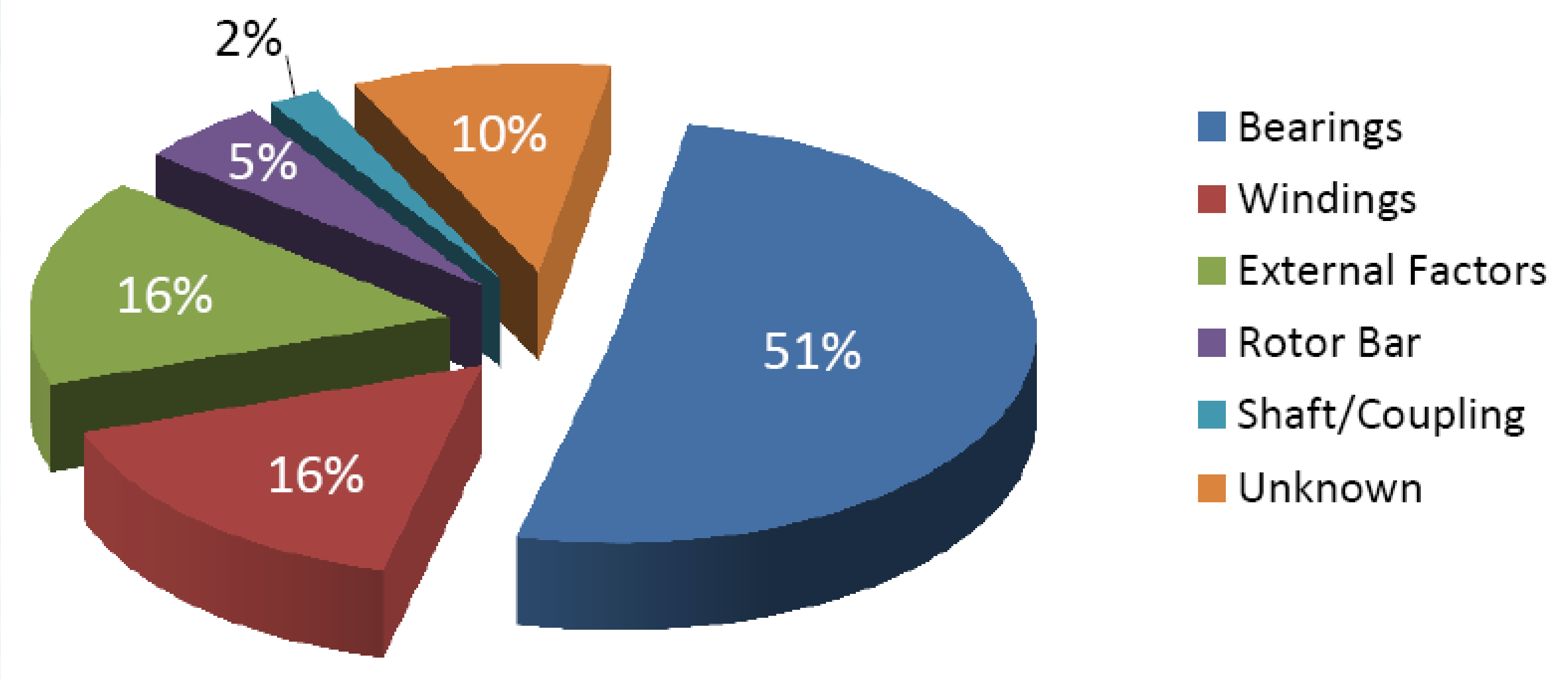
$$X_m = \frac{|E_1|}{I_m}$$

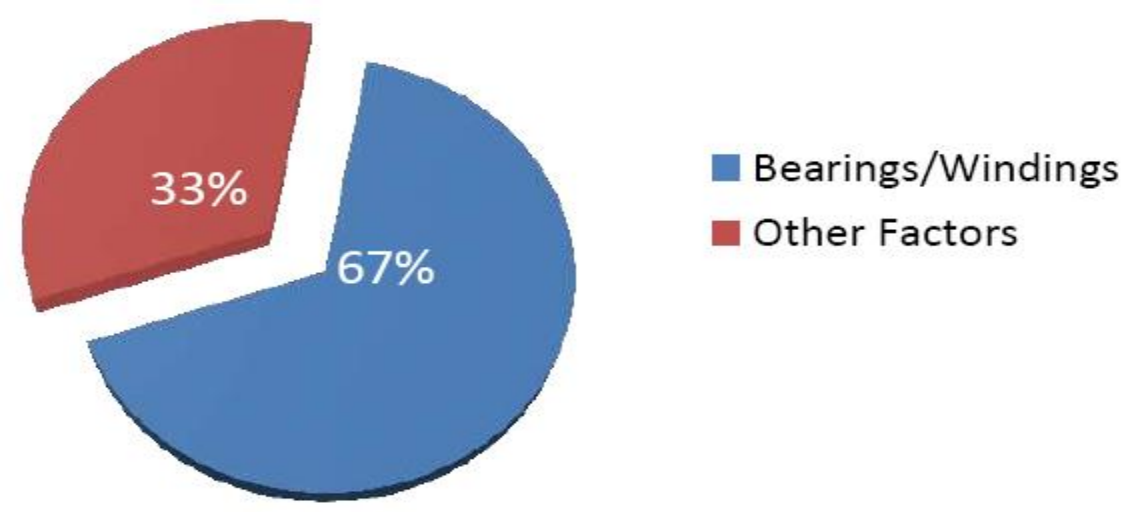


CHAPTER 9

Typical Motor Failure & Protection

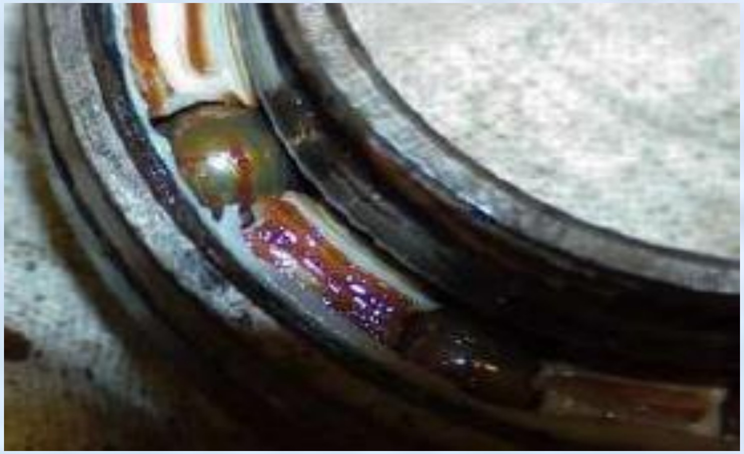
Typical motor failures





Motor failures by component

Component	% Failures	Potential Cause
Bearings	51%	Lubrication, mechanical, shaft currents, contamination
Windings	16%	Overvoltage, water, overload, undervoltage, environment
External Factors	16%	Environmental or load related
Rotor Bar	5%	Overload, locked rotor, vibration
Shaft/Coupling	2%	Mechanical, overload
Unknown	10%	No root cause determined



Bearing

Cooling

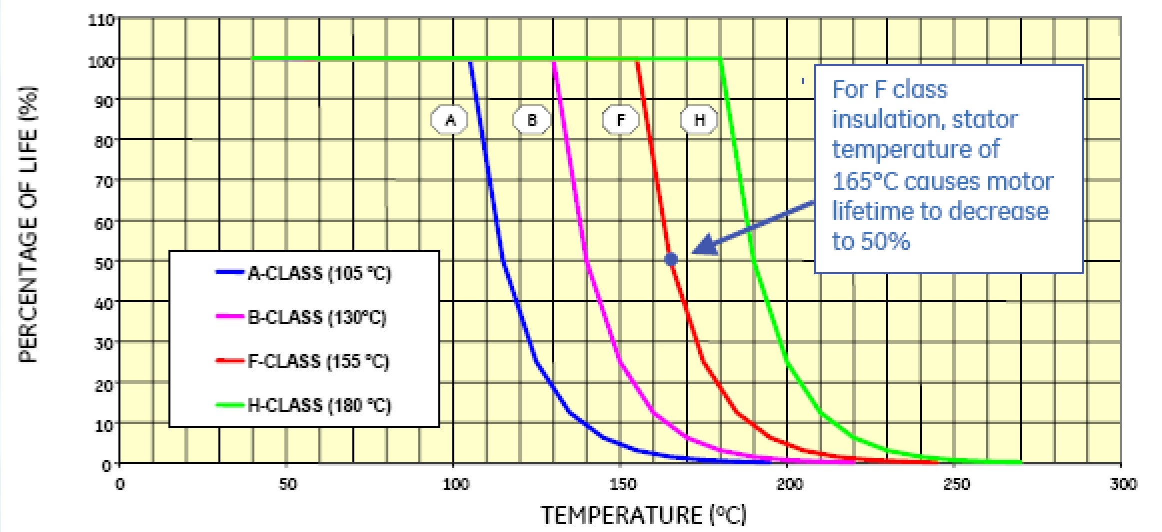
Ventilation

Motor Protection

1- Thermal Overload

- Process Caused (Excessive load)
- High Ambient Conditions (Hot, Blocked Ventilation)
- Power Supply Issues (Voltage/Current Unbalance, Harmonics)

Insulation lifetime decreases by half if motor operating temperature exceeds thermal limit by 10°C for any period of time



2- Overvoltage Protection

- The overall result of an overvoltage condition is a decrease in load current and poor power factor.
- The overvoltage element should be set to 110% of the motors nameplate.

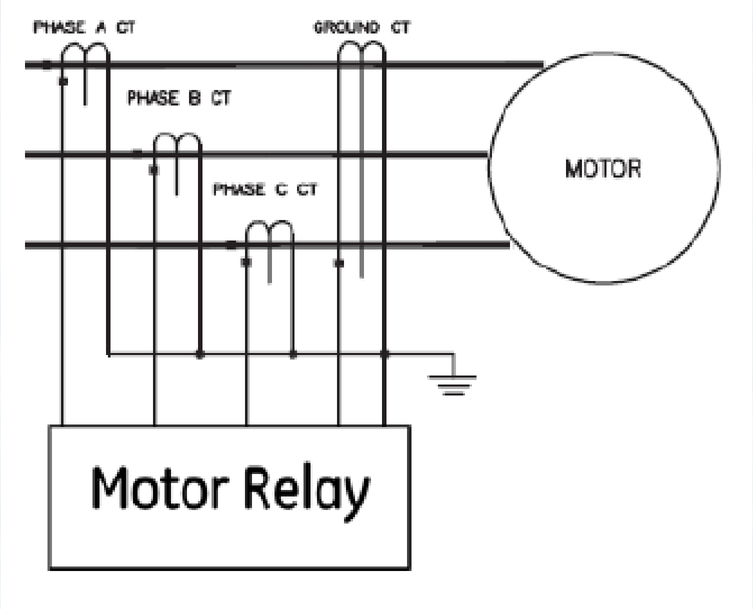
3- Undervoltage Protection

- The overall result of an undervoltage condition is an increase in current and motor heating and a reduction in overall motor performance.
- The undervoltage trip should be set to 80-90% of nameplate.

Over/Under voltage relay

4- Ground Fault Protection

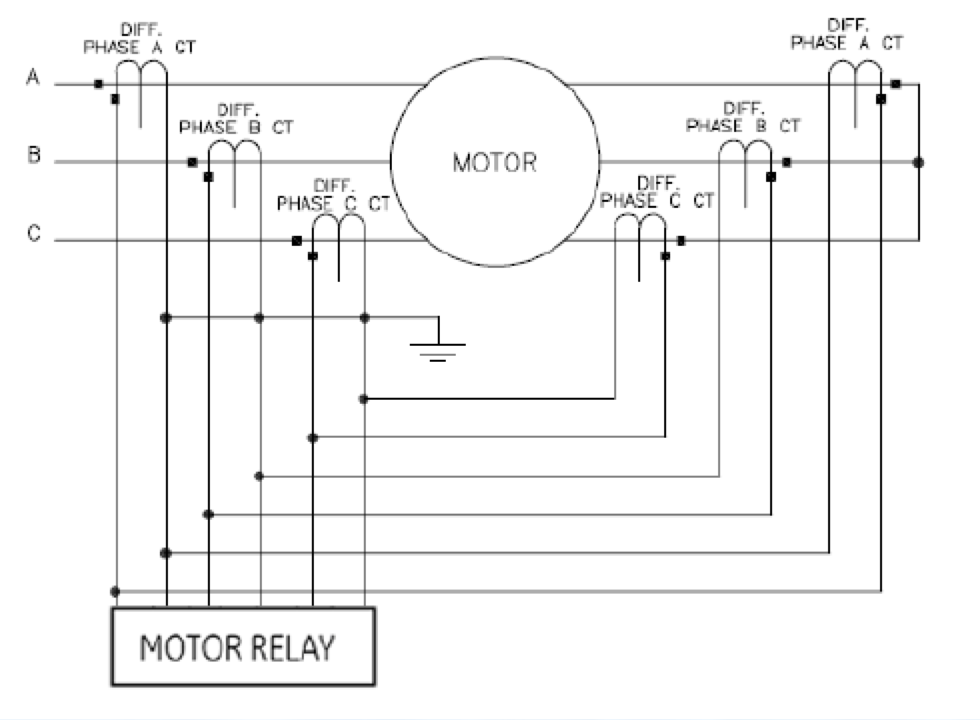
- A ground fault is a fault that creates a path for current to flow from one of the phases directly to the neutral through the earth bypassing the load
- When its phase conductor's insulation is damaged for example due to voltage stress, moisture or internal fault occurs between the conductor and ground



Zero Sequence CT Connection

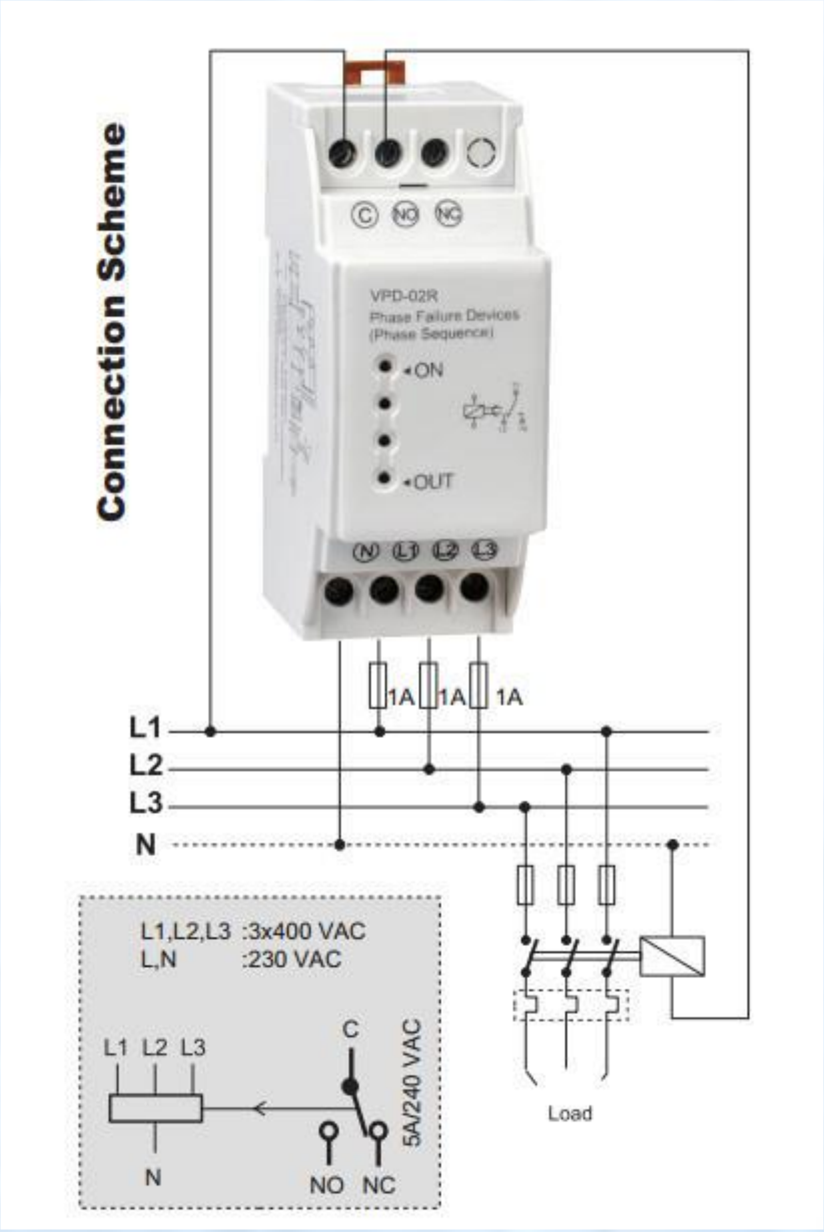
5- Differential Protection

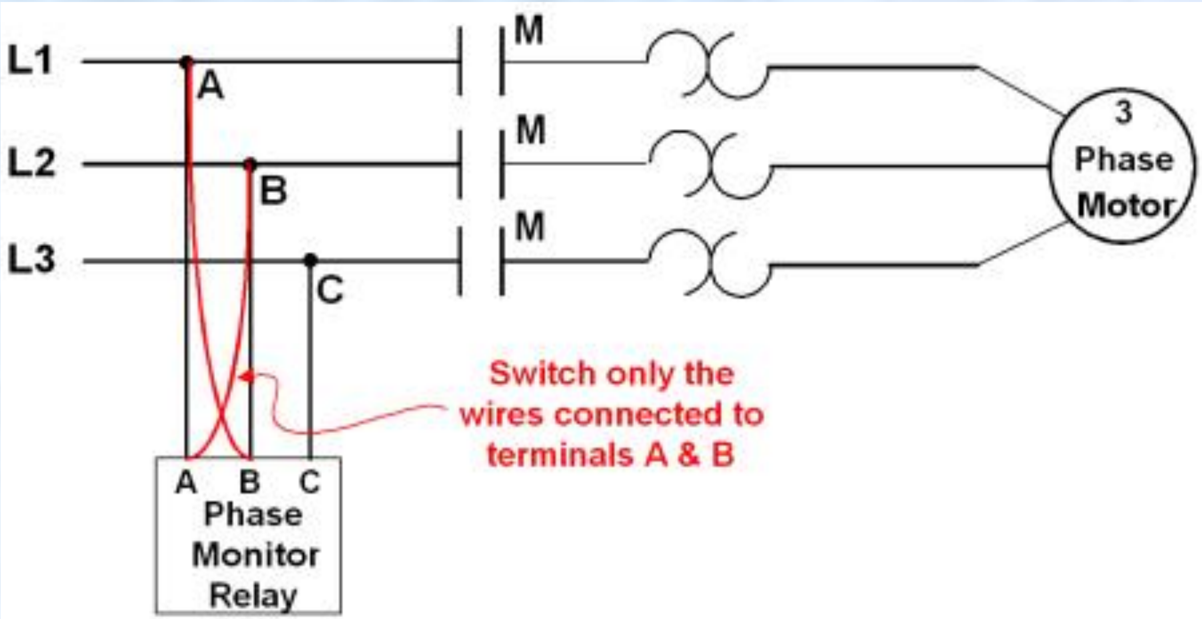
➢ Differential protection may be considered the first line of protection for internal phase-to-phase or phase-to-ground faults. In the event of such faults, the quick response of the differential element may limit the damage that may have otherwise occurred to the motor.

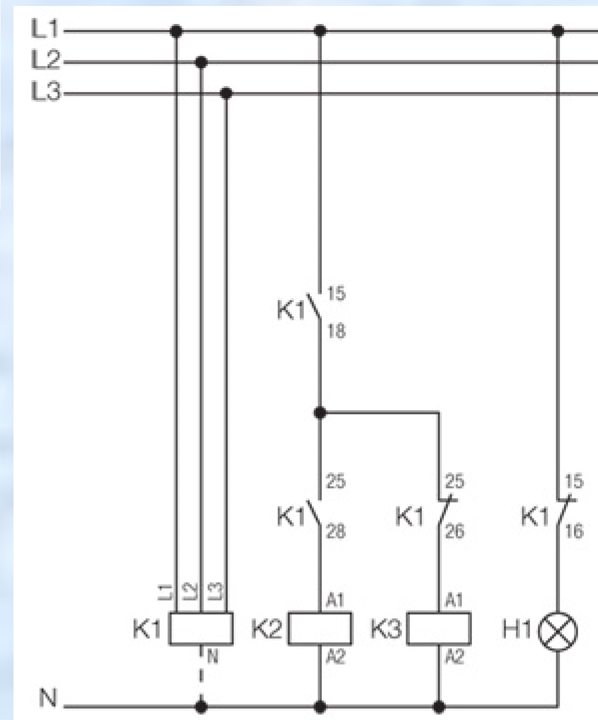


Summation method with six CTs

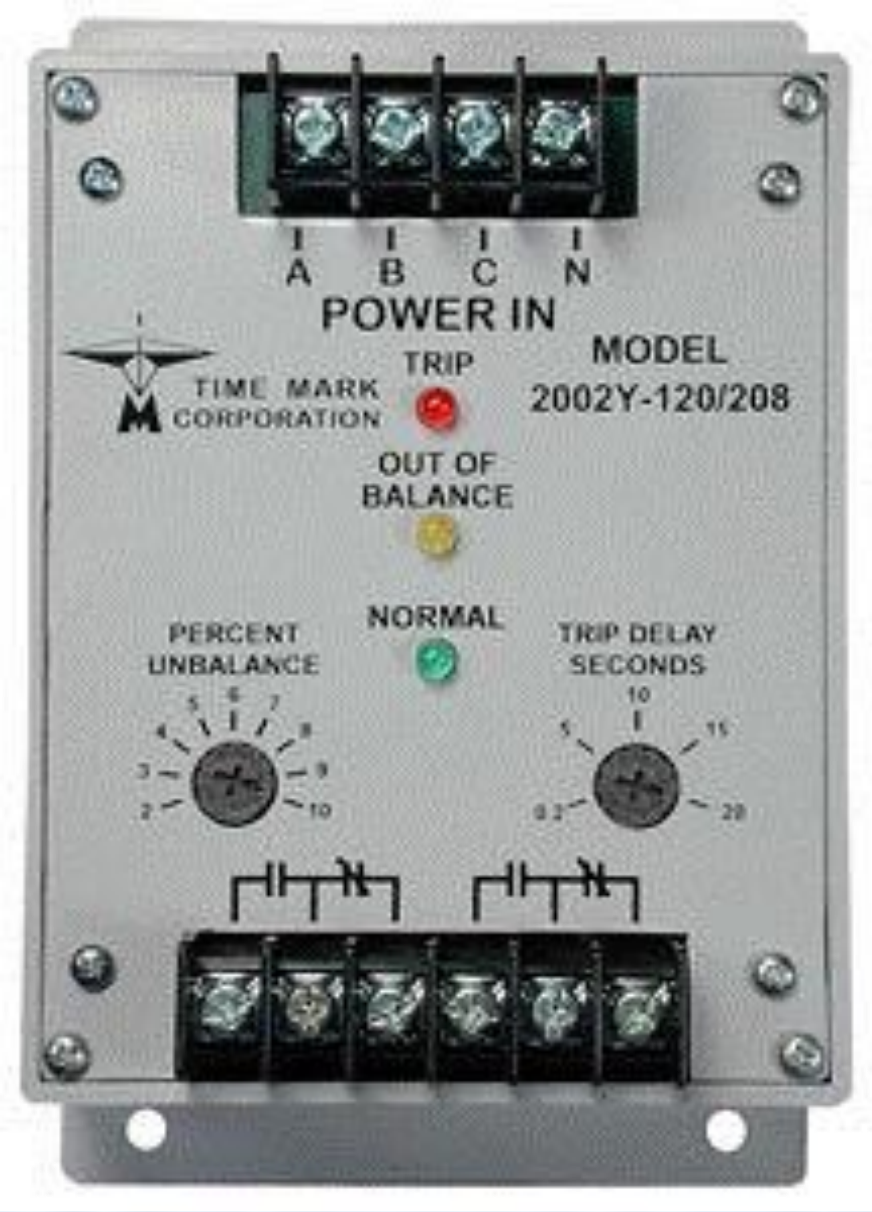
6- Phase sequence relay




L1
L2
L3
A
B
C
M
M
M
3 Phase Motor
Switch only the wires connected to terminals A & B
A B C
Phase Monitor Relay


L1
L2
L3
N
K1
15
18
25
28
26
16
K1
K2
K3
H1
A1
A2

7- Unbalance relay




Thank You


EXAM