Power Regulation Guide

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VOLTAGE, CURRENT AND POWER REGULATION

Introduction

Power Regulation: A device or circuit which maintains a desired quantity (eg. voltage, current, frequency or mechanical property) at a predetermined level usually by comparison with a reference source.

In 1837 Thomas Davenport a Vermont blacksmith built the first DC electrical rotating machine. Some time after, when Thomas Edison created the light-bulb in 1879 and subsequently illuminated 50 blocks in lower Manhattan using six 500kW steam powered generators. These were exciting days indeed.

It was only a matter of time before public buildings, such as theatres, began installing the new electrical lighting and so created a need for methods of control, primarily for dimming. The early systems comprised long lengths of resistance wire, formed into a coil with a wiper controlled by a manual lever. They were crude, large and difficult to adjust smoothly.

In Berlin REO (then known as Hase & Von Wolff G.M.B.H.) were busy producing resistors for dimming large public buildings and ballasts for arc lamps.

In 1933 General Radio announced the launch of a new product, an adjustable autotransformer called the "Variac" (short for variable AC). Eduard Karplus, a graduate of the Institute of Technology, Vienna was its creator. The first unit, the type 200-C had a current rating of 5 amperes and was used to provide an adjustable voltage from a mains supply of 115V or 230V. The output voltage range was from zero to something above line voltage and was virtually stepless. In the 1960's the Superior Electric Company produced large numbers of variable transformers under the trade names of "Luxtrol" or "Powerstat" for theatre and television applications throughout the USA and Canada.

In the meantime further uses had been found for the variable transformer and another popular, consumer, application was for speed control of model train sets, especially in the 1950's and 1960's. These transformers were essentially step-down units, the highest voltage obtainable from the secondary winding being substantially less than the primary voltage of 110 to 120 volts AC. The variable-sweep contact provided a simple means of voltage control with little wasted power; much more efficient than control using a variable resistor. There were industrial applications too and during this era variable transformers were used to control larger DC motors used in large printing and textile lines.

The invention of the transistor in 1948 by Bardeen, Brattain and Schokley brought us to the threshold of the solid-state electronics age. Then in 1956 Bell Telephone Laboratory invented the thyristor (PNPN transistor), which was later commercialized by General Electric Co. By using these devices it was possible to make much smaller and lighter power systems and so there was a natural tendency for engineers to use thyristor techniques in place of iron and copper or resistance wire.

Nowadays MosFets and IGBT's are the vogue, operating at much higher switching frequencies. The advantage being that size reduces considerably as frequency increases. Switch mode power supplies are now taking the place of thyristor controllers but there are associated problems to contend with such as harmonics and interference.

POWER REGULATION IN TODAY S ENVIRONMENT

There are many everyday applications that require a power supply with a variable, regulated output. Voltage control is the most frequently used method but often this is used in conjunction with current limiting, for system protection or safety reasons.

Variable transformers and resistors can be motorised (servo operated) and controlled from simple up/down push buttons or more sophisticated electronic modules that will compare a set point with the effective output and make an automatic correction. The controllers can be used to respond to external analogue set point signals and include PI control to give a smooth power adjustment.

Controllers based on power electronics, on the other hand, usually incorporate a microprocessor for synchronising the firing of the semi-conductors and so this intelligence can be used to provide many other operating functions, including digital set-up panels, regulation, serial interfaces and so on.

Basically there are two types of variable resistor, the rotary type (or potentiometer) and the tubular or slider type. They are often referred to as rheostats (from the Greek rheo which means stream or current and statos meaning steady or stationary). The rheostat is a device for controlling or regulating current and in the past they were often used for starting up electric motors

The potentiometer is made by winding a resistance wire onto a ceramic former. The diameter of wire is chosen to give a specific total resistance value over the turns of wire that cover the ceramic core. The diameter of the wire also determines the current carrying capacity of the resistor. A brush, or wiper, adjusted by means of a shaft through the centre of the potentiometer, is used to change the resistance value. Both ends of the winding and the brush connection are brought out to terminals for connection to the electrical circuit.

A slider resistor operates on a similar principle but the windings are held on a ceramic tube and the wiper slides along its entire length.

The resistance wire is made from constantan which has a very good temperature coefficient

Useful formulae

Everybody has heard about Ohm's Law it states that Voltage, Current and Resistance in a circuit are all related:

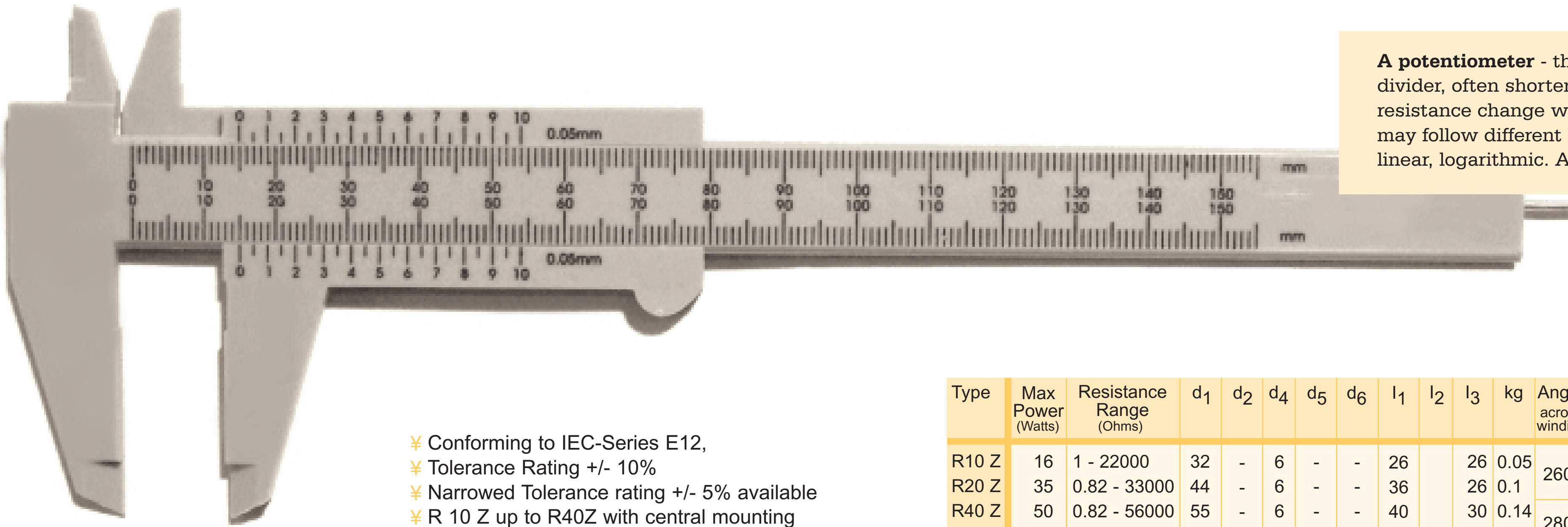
Voltage/Current = Resistance
or **V/I = R**
also,
Power = Voltage x Current
Power = Current x Resistance x Current
(because Voltage = Current x Resistance)

$$W = I^2 R$$

From this simple formula it can be seen that current has a significant effect on the total power in a circuit.

Georg Simon Ohm

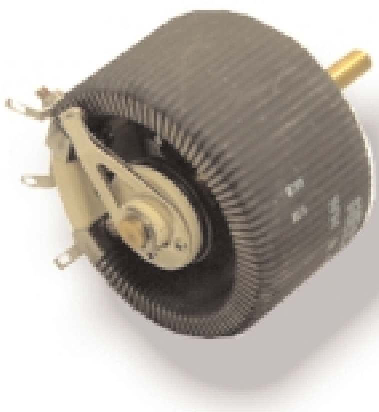
Potentiometer Dimensions



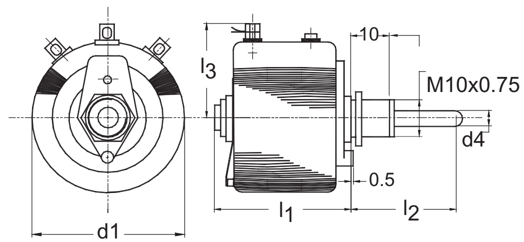
A potentiometer - three terminal voltage divider, often shortened to pot. The resistance change with shaft rotation may follow different laws - stepped linear, logarithmic. A form of Rheostat.

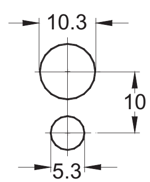
- Conforming to IEC-Series E12,
- Tolerance Rating +/- 10%
- Narrowed Tolerance rating +/- 5% available
- R 10 Z up to R40Z with central mounting
- R 75 up to R 750 with three point mounting
- R 40 Z and above available with stepped windings up to six steps, charged extra

Type	Max Power (Watts)	Resistance Range (Ohms)	d_1	d_2	d_4	d_5	d_6	l_1	l_2	l_3	kg	Angle of rotation across winding	Angle of rotation mechanical	Connection
R10 Z	16	1 - 22000	32	-	6	-	-	26	32	26	0.05	260°	280°	Solder Lugs
R20 Z	35	0.82 - 33000	44	-	6	-	-	36		26	0.1			
R40 Z	50	0.82 - 56000	55	-	6	-	-	40		30	0.14	280°	300°	
R75	100	0.68 - 56000	72	30	6	4.2	M4	58		45	0.3			
R100	125	0.68 - 56000	88	36	8	4.2	M4	70		53	0.5	286°		
R150	180	1 - 56000	88	36	8	4.2	M4	90		53	0.8			
R250	300	1 - 56000	146	60	8	4.2	M4	80		82	1.5	290°		M4 Screws
R375	450	1 - 56000	146	60	8	4.2	M4	100		82	1.7			
R500	600	1.2 - 56000	200	80	8	5.3	M5	102		110	2.7			
R750	900	1.8 - 56000	200	80	8	5.3	M5	142		110	4.0			

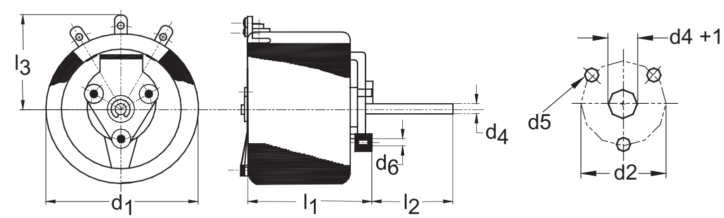


R 10 Z - R40 Z





R 75 - R750



Variable Transformers

In a similar way to resistors, variable transformers are available in two forms, toroidal and linear (or column type).

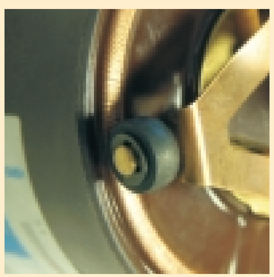
The toroidal transformer comprises copper wire wound onto a toroidal core, manufactured from electrical grade, grain oriented, strip steel. A roller brush (or wiper) is moved across the face of the windings, which have a ground finish to provide a good contact path. The brush is connected to a shaft so that it can be rotated and a second, pick-up brush in contact with a brass plate on the brush gear, allows current to flow to a terminal connected to the electrical circuit. The main winding is connected across the supply and the load is connected to the brush and supply neutral. Voltage is adjusted by rotating the shaft.

IMPORTANT FEATURES

For economy reasons the majority of variable toroidal transformers have a single winding and are used as autotransformers. Versions can be made with separate primary and secondary windings or a separate fixed transformer can be connected between the variable transformer and the load. This is referred to as "primary regulation".

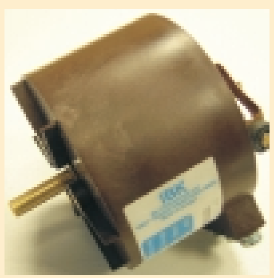
The variable, maximum, output voltage can be the same as the supply voltage or it can be up to 15% greater, which is very useful for testing equipment to ensure correct operation when it is subjected to a mains supply with an "over-voltage". Units can be ganged for three-phase operation and can be centre tapped for use in buck-boost applications such as voltage stabilisers.

The unique features found only on REO transformers include a roller type brush, instead of a wiper and a collet locking mechanism on the adjustment spindle. The roller brush greatly prolongs the operating life and the spindle adjustment allows the shaft position to be changed, quite easily using a spanner, for door or back-panel mounting.



Brush gear

Collet nut for shaft locking



Shaft set for panel mounting

Motorised Transformers

REO type DRRTMoK 3 phase motorised varible transformer

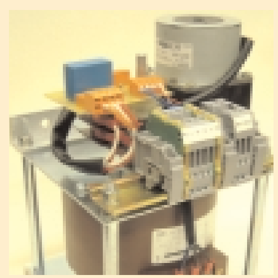
REO type NLR 546 Electronic Regulator

Both variable transformers and potentiometers can be motorised. Normally the reversible motor is powered from the mains supply and the setting time selected, from a few seconds up to several minutes duration, to suit the application requirements. It is also possible to have a DC motor, which can give a faster response time but then a separate DC power supply is required.

Cam operated micro-switches are used as end limits but it is possible to have more micro-switches fitted to the drive shaft for other functions, such as zero or maximum indication signals. REO micro-switch cams have a precision adjustment gear to provide exact, screw-driver, setting for the extra control outputs.

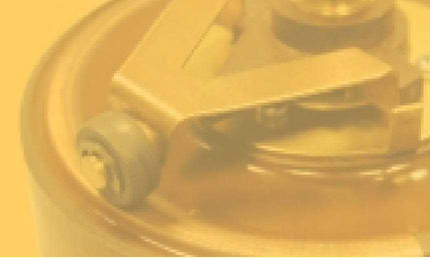
REO provide a range of electronic regulator modules to complement the servo-controlled transformers. These range in degree of sophistication but all include multi-purpose set point input, an effective value comparator, motor raise/lower outputs and sensitivity adjustment.

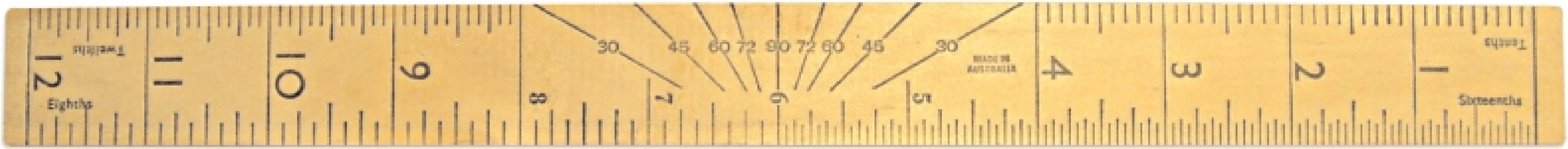
Cam Operated Micro-Switch

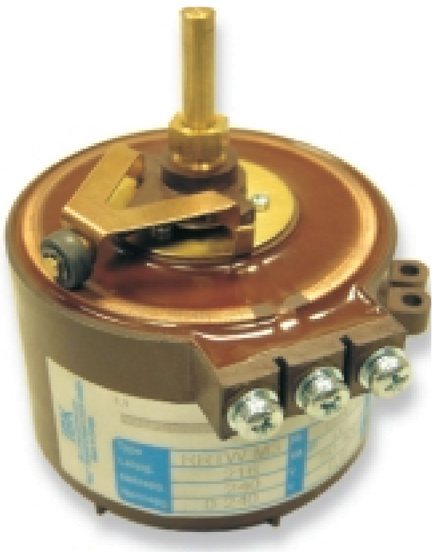


Motorised Version

Transformer Dimensions

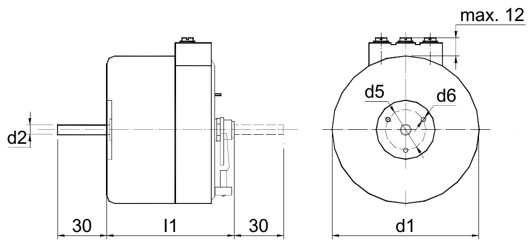




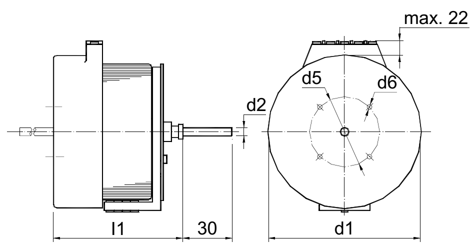


REO Type RRTWM3 Single Phase Variable Transformer

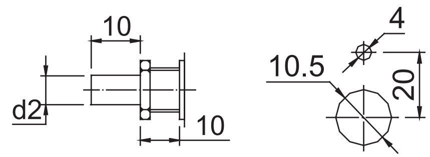
M3 - M12



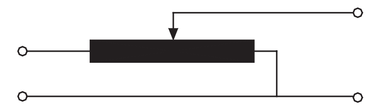
EN7 - EN10



M3Z - M4Z

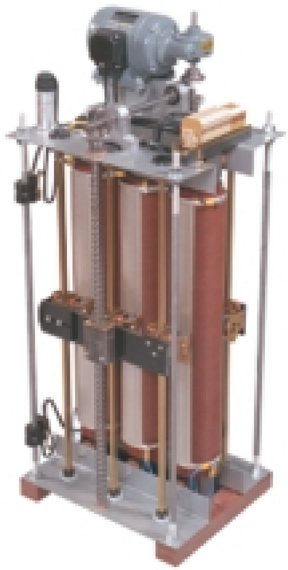


Connections



Type	0-230V A	0-230V kVA	0-260V A	0-260V kVA	Dimensions l1	Dimensions d1	Dimensions d2	Dimensions d5	Dimensions d6	Weight kg	Copper kg
M3	0.8	0.184	0.6	0.156	71	75	6	26	M4	1	0.035
M4	1	0.23	0.85	0.22	77	92	6	26	M4	1.6	0.065
M5	1.6	0.37	1.2	0.31	93	92	6	26	M4	2.1	0.9
M6	2.5	0.575	2	0.52	89	103	6	26	M4	2.8	0.14
M61	3.2	0.735	2.8	0.73	98	103	6	26	M4	3.1	0.14
M7	4	0.92	3	0.78	109	125	10	80	M6	4.1	0.23
M8	6	1.38	4.5	1.17	131	125	10	80	M6	5.4	0.45
M9	8	1.84	6	1.56	117	157	10	95	M6	7.2	0.7
M10	10	2.3	8	2.08	133	157	10	95	M6	8.8	0.9
M11	12	2.76	10	2.6	121	175	10	95	M6	9.2	1.0
M12	15	3.45	12	3.12	131	175	10	95	M6	10.5	1.2
EN 7	18	4.14	18	4.68	141	200	10	120	M6	15.1	1.9
EN 9	25	5.75	25	6.5	115	285	10	120	M6	20	2.7
EN 10	32	7.36	32	8.3	125	285	10	120	M6	21	3.3

Column Transformers



Nowadays these very large variable transformers are used mainly for test applications, where it is important to have a variable voltage with a nearly perfect sine wave. However, there are some industrial applications where a better alternative is not available and these include glass production, anodising or large power supplies requiring voltage regulation.

The column transformer comprises a number of tubes wound with copper strip, edgeways. This means that the windings are close together but because of their cross-sectional area they can carry higher currents. Brushes move across the face of the windings to give voltage adjustment.

Several columns can be connected in parallel to give higher current ratings. The brush carrier is driven up and down by a worm gear mechanism, which is very precise but does not lend itself to quick response times. However, this is often an advantage because it helps to prevent "hunting".

DOUBLE THE POWER

Because of its unique construction it is possible to handle twice the normal power load of a variable, column transformer by fitting a second set of brushes that move in the opposite direction to the first set. Effectively this produces a second voltage sine wave that is 180 degrees out of phase with the first. By connecting the output to a fixed transformer with double primary windings it is possible to double the power rating of the variable transformer. Furthermore, the variable transformer could be used in a delta configuration thereby producing the same VA but with a higher voltage and a lower current than that of a star connected unit. It is the current carrying capacity that has the greatest influence on the price and so the delta configuration offers a greater economy. Although hand operated versions are manufactured, most transformers of this type are motorised.

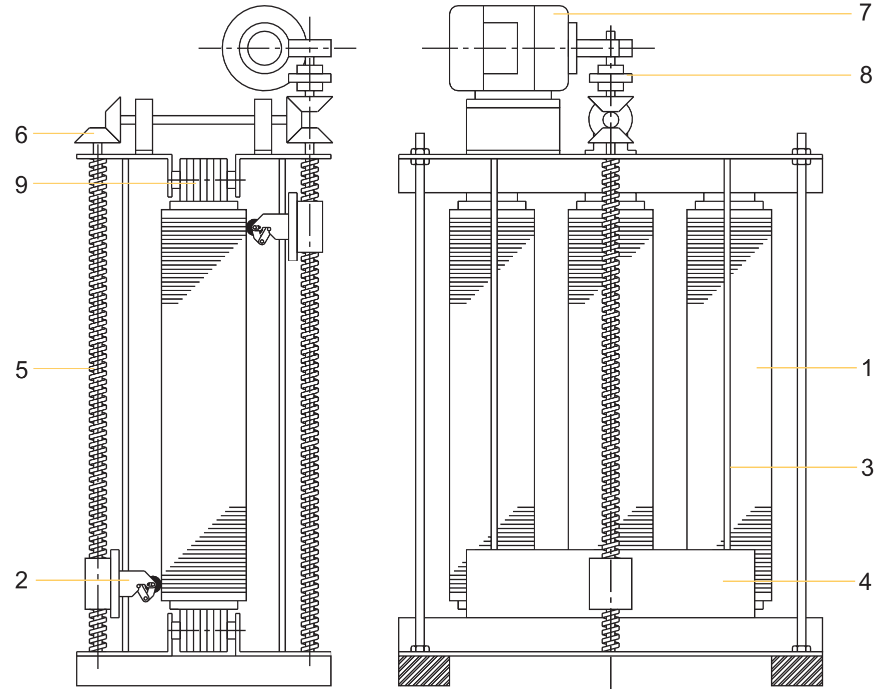


Diagram showing main components of a double brush variable column transfromer

1. Winding
2. Brush gear
3. Busbar
4. Brush gear carrier
5. Screw drive
6. Bevel gears
7. Reversing motor
8. Coupling
9. Laminated core

Double brush holder

Toggle lever & roller brush

Electronic Regulators

THYRISTOR CONTROLLERS

Thyristor regulators are used to control the energy supplied to a wide variety of loads. There are a number of circuit configurations that can be used but all methods employ self-commutating semiconductors either as single switching elements (half-controlled) but more often each phase is controlled with inverse parallel connected pairs of semiconductors (fully-controlled). Two switching methods can be employed and these are referred to as "burst fire" or "phase-angle" types.

"Burst fire" involves switching on the power with the semiconductors on full conduction for a certain time (several full mains cycles) determined by a sensor such as a thermostat. Units that work on the phase angle control principle generate an electronic firing pulse that switches the thyristor on at any point on the sine wave, thus allowing current flow for part of the mains cycle. The thyristor automatically switches off when the current falls to zero and does not conduct again until it receives the next firing pulse.

In this way it is possible to vary the output voltage but in doing so the resulting wave form resembles a saw tooth, unless the thyristor is on full conduction.

REOTRON type MDW thyristor control unit

It is possible to control currents up to thousands of amps in this way but as the power increases so does the cooling requirement.

REO manufacture stand-alone units of up to 400A per phase with water cooling. Above this current level the units tend to be purpose built and for this reason a regulating/firing module is used in conjunction with separate six-pulse thyristor stacks, using primary or secondary regulation.

SWITCH MODE POWER SUPPLIES

Most computers and television sets derive their power from a switch mode source. In industry the pattern is the same with varying levels of complexity. The main driving forces behind this revolution are reductions in price and size. To achieve these goals the switching frequencies are getting higher which results in smaller components. Unfortunately, this does create another set of challenges because higher switching frequencies mean greater distortion of the mains supply and higher losses due to the "skin effect" in conductors. However, industry is gradually providing the technology to overcome these problems.

Regulators based on the switch mode principle are now available. The main component is the IGBT (insulated gate bipolar transistor) and this is used to switch a DC power source on and off very quickly (100kHz being typical). When the power supply is applied to a load the resulting current waveform is sinusoidal. The voltage is adjusted by changing the "mark space ratio" or put simply the time that the pulses are on and off.

FIELD BUS INTERFACES

Most REO units can be supplied with INTERBUS or PROFIBUS interfaces so that several units and other devices can be controlled from a central PLC.

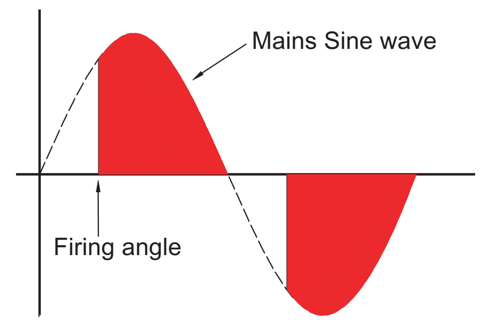


Diagram showing phase angle control

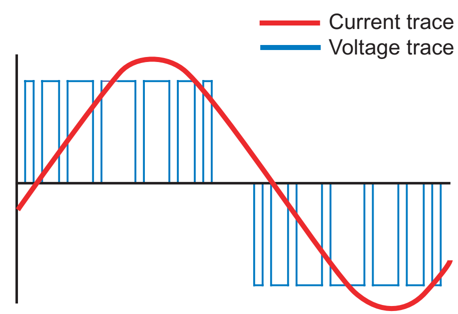


Diagram showing pulse width modulation (switch mode) control

Regulating Methods

A comparison of different regulating methods.

Method	Advantages	Disadvantages	Applications
Resistor **Potentiometers** **Rheostats**	¥Inexpensive ¥Easy to understand ¥Easy to install	¥Limited power range ¥Very high heat losses ¥Fragile ¥Bulky	¥DC Motor field control ¥Variable loads
Variable autotransformers	¥Can provide output higher than supply ¥Sine wave output ¥Easy to understand ¥Low losses ¥Robust ¥No EMC problems ¥Can be servo-controlled ¥Unity power factor	¥Require some maintenance ¥High power/weight ratio	¥Voltage stabiliser ¥Test engineering ¥Fan Control ¥Test instruments ¥Welding equipment ¥Simple power supplies ¥High voltage power supplies ¥Screened rooms ¥Anodising
Thyristor controllers	¥Compact ¥Easy to control ¥Require little or no maintenance	¥Generate RFI ¥Generate harmonics ¥Require large heatsinks ¥Non-symmetrical output ¥Not easy to understand	¥Electro-plating ¥Furnaces ¥Vacuum coating ¥Materials handling ¥Ozone generation ¥Dimmers ¥Heaters ¥Lifting magnets ¥Dryers ¥Soft starters
Switch mode controllers	¥Very compact ¥Easy to control ¥Require little or no maintenance	¥Generate RFI ¥Generate harmonics ¥Often require cooling	¥Cathodic protection ¥Electro-plating ¥Motor control

Low Voltage Directive

SAFETY OF ELECTRICAL EQUIPMENT

Within the European Economic Area (EEA) it is now a legal requirement for all electrical equipment to have the CE mark. This shows that the goods are safe and produced to standards that are accepted throughout the European Community. There are various European Commission Directives that lay down guidelines for the design, manufacture and subsequent marketing of electrical goods, including the following:-

¥Low Voltage Directive
¥Electrical Equipment (Safety) Regulations
¥EMC Directive

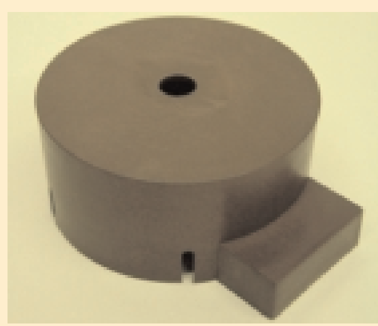
As part of the directives a statement is required from the manufacturer, or importer in the case of goods produced outside the EEA. This is referred to as a "Declaration of Conformity" and part of this is a list of the relevant standards that have been used for production of the goods. It is also necessary for the manufacturer or the supplier to be able to prove the validity of the CE mark by making available technical documentation and test reports relating to the goods.

Variable transformers do not generate any RFI nor do they distort the mains sine wave. However, the brush and track

REO single phase variable transformer complete with cover, knob and dial

windings are exposed and should be covered to protect against accidental contact. For this reason a special "slip-on" cap is available as a standard accessory.

Thyristor controls do generate RFI and so filtering is required to prevent mains borne RFI.



REO was formed in 1925 and manufactures a range of products used for power regulation. We specialise in custom designs of components and sub-assemblies, catering to both small and large orders. In other words we build what our customers want.

For more information about the Reo product range visit www.reo.co.uk