Power Quality Application Guide

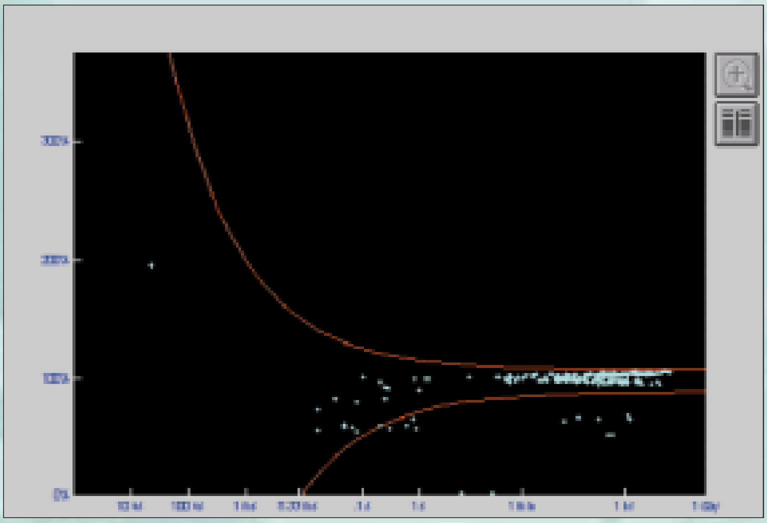
Leonardo da Vinci

Education and Culture

Voltage Dips

Voltage Dip Mitigation

5.3.2



Copper Development Association

COPPER

Voltage Dips

Voltage Dips

Voltage Dip Mitigation

Derek Maule
Claude Lyons Ltd
March 2001

(Version 0b November 2001)

European Copper Institute (ECI)

The European Copper Institute is a joint venture between ICA (International Copper Association) and IWCC (International Wrought Copper Council) contributing members. Through its membership, ECI acts on behalf of the world's largest copper producers and Europe's leading fabricators in promoting copper in Europe. Formed in January 1996, ECI is supported by a network of ten Copper Development Associations ('CDAs') in Benelux, France, Germany, Greece, Hungary, Italy, Poland, Scandinavia, Spain and the UK. It furthers the efforts initially undertaken by the Copper Products Development Association, formed in 1959, and INCRA (International Copper Research Association) formed in 1961.

Copper Development Association (CDA)

Copper Development Association is a non-trading organisation sponsored by the copper producers and fabricators to encourage the use of copper and copper alloys and to promote their correct and efficient application. Its services, which include the provision of technical advice and information, are available to those interested in the utilisation of copper in all its aspects. The Association also provides a link between research and the user industries and maintains close contact with the other copper development organisations throughout the world.

Acknowledgements

This project has been carried out with the support of the European Community and International Copper Association, Ltd.

Copper Development Association

Copper Development Association
Verulam Industrial Estate
224 London Road
St Albans AL1 1AQ
United Kingdom

Tel: 00 44 1727 731200
Fax: 00 44 1727 731216
Email: copperdev@compuserve.com
Websites: www.cda.org.uk and www.brass.org

European Copper Institute
168 Avenue de Tervueren
B-1150 Brussels
Belgium

Tel: 00 32 2 777 70 70
Fax: 00 32 2 777 70 79
Email: eci@eurocopper.org
Website: www.eurocopper.org

Voltage Dip Mitigation

Most voltage dips on the supply system have a significant retained voltage, so that energy is still available, but at too low a voltage to be useful to the load. This section discusses voltage dip mitigation equipment that deals with this type of dip. No energy storage mechanism is required; they rely on generating full voltage from the energy still available at reduced voltage (and increased current) during the dip. These devices are generally categorised as automatic voltage stabilisers. Other types of equipment are available to deal with dips where the retained voltage is zero and are described in another section of this Guide.

This section gives a basic description of each type of automatic voltage stabiliser. The advantages and disadvantages of each type have been listed to enable the appropriate choice of voltage stabiliser to be made for the particular application.

The main types of automatic voltage stabilisers are as follows:

- Electro-mechanical
- Ferro-resonant or constant voltage transformer (CVT)
- Electronic step regulators
- Saturable reactors (Transductor)
- Electronic voltage stabiliser (EVS).

An important point to note in the selection of an automatic voltage stabiliser is that the chosen solution must solve the particular problem without creating additional problems. One example of this would be to connect a ferro-resonant stabiliser to the output of an inferior generator to reduce voltage variations. The net result would be adversely affected by the frequency fluctuations of the inferior generator which would produce an AC voltage change of 1.5 % for each 1 % change of frequency.

A detailed description of each type of automatic voltage stabiliser is as follows:

Electro-mechanical

The principle of this type of stabiliser is to automatically control an internal variable transformer to compensate for the variation of input voltage from the AC supply. The output of the variable transformer feeds the primary winding of a buck/boost transformer, the secondary of which is connected in series between the supply and load to inject an aiding or opposing correcting voltage into the supply line as shown in Figure 1.

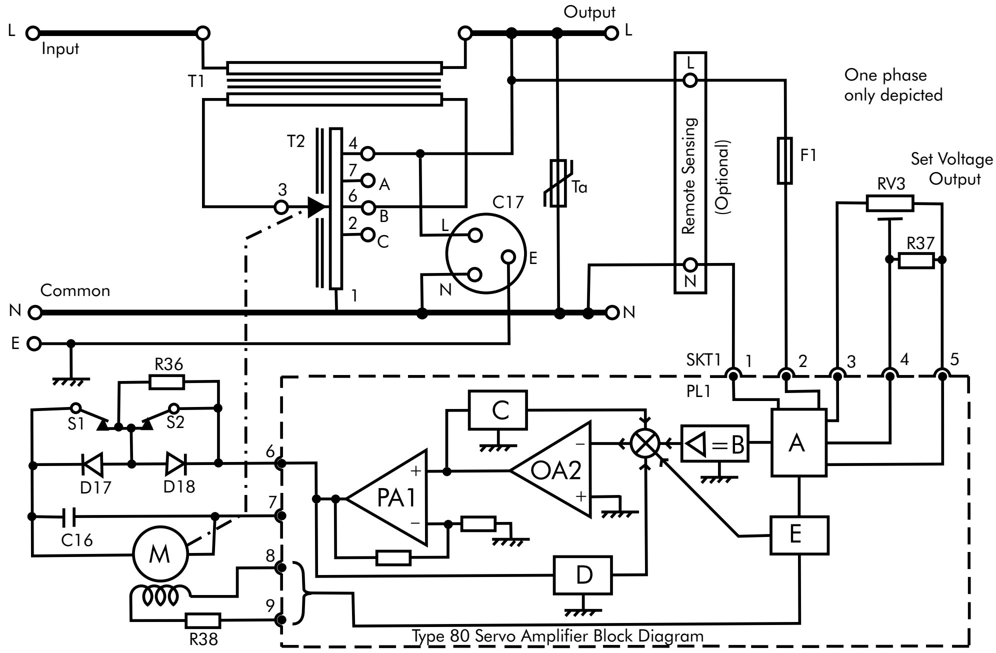


Figure 1 – Basic circuit diagram of electro-mechanical voltage regulator

One of the main advantages of this type of stabiliser is that the actual power controlled is only a small proportion of the total load power. For example, to control a load of 100 kVA for a supply voltage range of ± 10 %, the electro-mechanical voltage stabiliser would only need to handle a maximum of 10 kVA of power. The electrical nature of the power path determines that the efficiency is typically 98 % at full load. Even at light loads of say 10 % of maximum, the efficiency is still greater than 95 %.

The output voltage of the electro-mechanical stabiliser is monitored by a servo amplifier. If the stabilised output voltage deviates from the preset value due to a change in the supply voltage or the load current, the servo amplifier will drive a motor which then rotates the brush arm of the variable transformer in the required direction to boost or buck the input supply until the correct preset value of the output voltage is restored. This method of voltage stabilisation does not produce harmonics and therefore does not inject distortion into the incoming voltage supply. Figure 2 shows that the input range can be exceeded as long as the increased voltage deviation can be accepted.

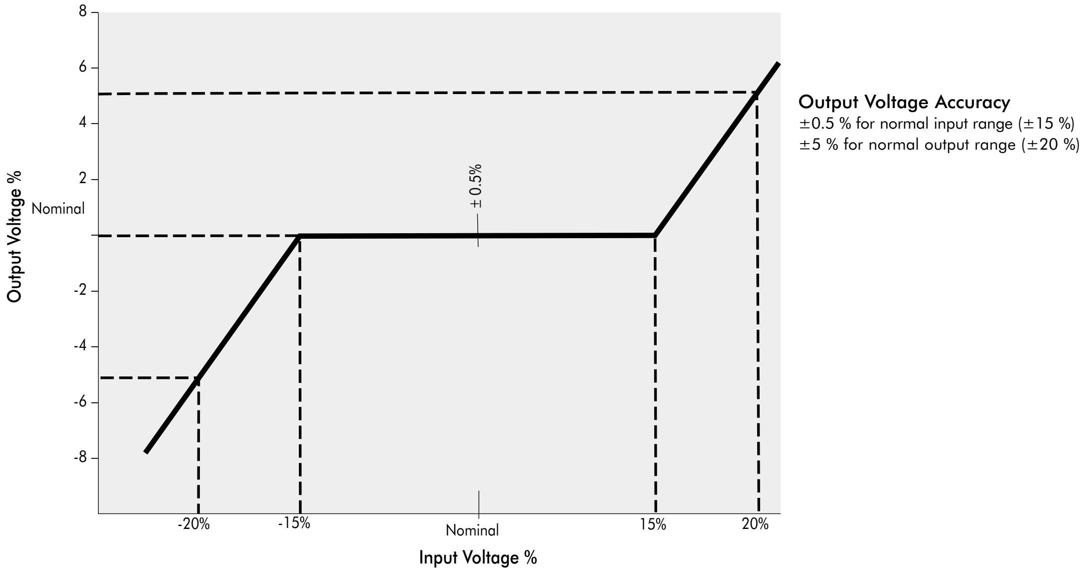


Figure 2 –Input/output characteristics for a ± 15 % stabiliser

The action of the servo system is exceptionally fast with controlled deceleration resulting in zero overshoot, Figures 3, 4 and 5. Sensing from the voltage output automatically compensates for any change in load current. Remote sensing facilities enabling the voltage to be detected at an external point allows for correction to be made for voltage drops in the cables when the load is some distance from the stabiliser.

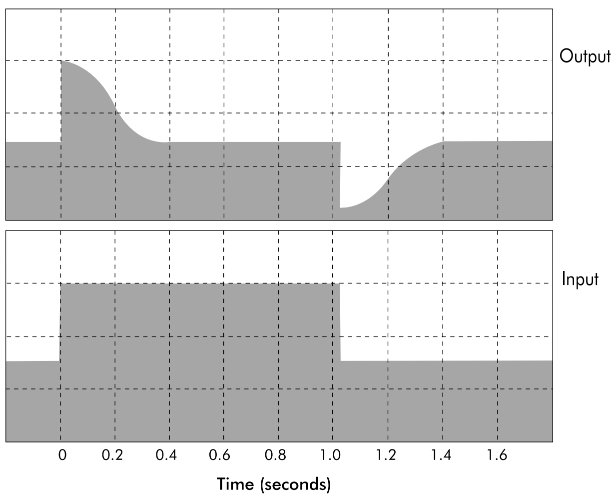


Figure 3 – Oscillogram showing typical correction time of a voltage stabiliser for a 40 volt step

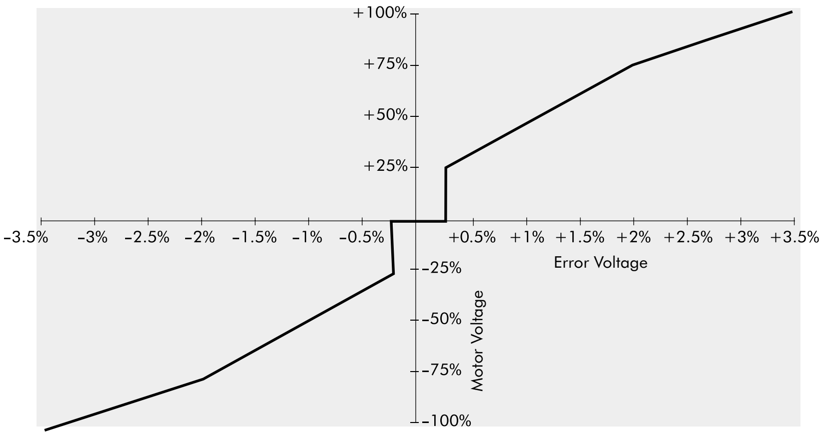


Figure 4 – The relationship between error voltage and motor voltage - Type 80 servo amplifier

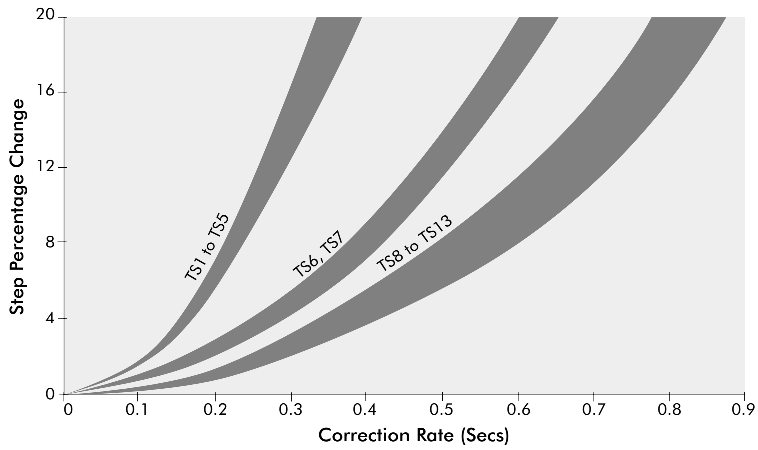


Figure 5 – Typical correction ratios against step percentage change - Type 80 servo amplifier

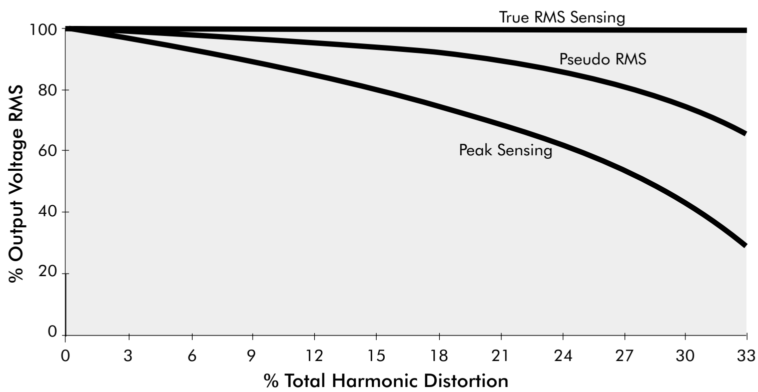


Figure 6 –Output voltage RMS against total harmonic distortion – Type 80 servo amplifier

The main advantages of the electro-mechanical voltage stabiliser are as follows:

- Simple design
- Output voltage is insensitive to load power factor
- Output voltage automatically compensates for load changes
- Very low output impedance
- High stabilisation accuracy, typically ± 0.5 %
- Completely insensitive to the supply frequency
- Relatively low cost and size
- Smooth step-less control
- Output is insensitive to supply distortion (true RMS – see Figure 6)
- Very low external magnetic fields (no magnetic currents in saturation).

The main disadvantages of the electro-mechanical voltage stabiliser are as follows:

- The stabiliser has moving parts
- The response time is typically 15 cycles (300 ms) for a 40 volt change. It is slower than an electronic step regulator or a static ferro-resonant stabiliser (CVT).

Ferro-resonant regulator or Constant Voltage Transformer (CVT)

The basic circuit of a constant voltage transformer (CVT) is shown in Figure 7 and consists of a transformer with a single primary winding and three secondary windings together with a single shunt capacitor.

The neutralising winding (N) and the secondary winding (S) are separated from the primary winding by magnetic shunts. The magnetic reluctance of these shunts is very high compared to the magnetic reluctance of the central part of the transformer core. The leakage inductance produced by these shunts, together with the capacitor (Cr), produces a resonant circuit.

As the input voltage is increased, the flux in the central part of the transformer core also increases until the inductive reactance of the secondary winding is equal to the capacitor reactance. At this point, the output voltage is high due to the resonance of the circuit even though the input voltage is quite low (Figure 8). The neutralising winding reduces the output distortion from about 20 % to less than 3 %.

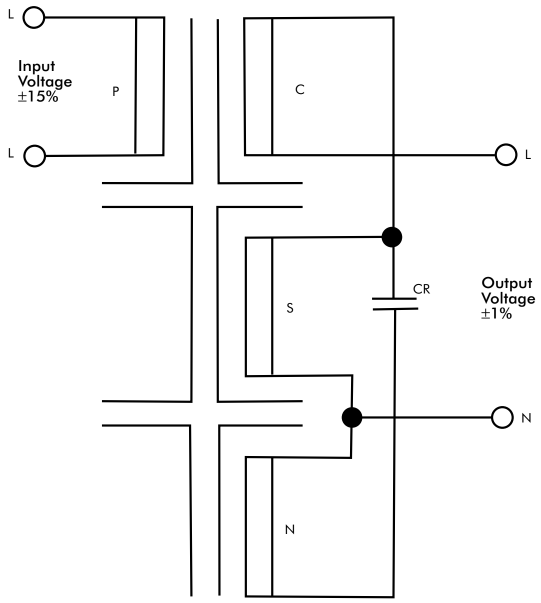


Figure 7 – Basic circuit of CVT

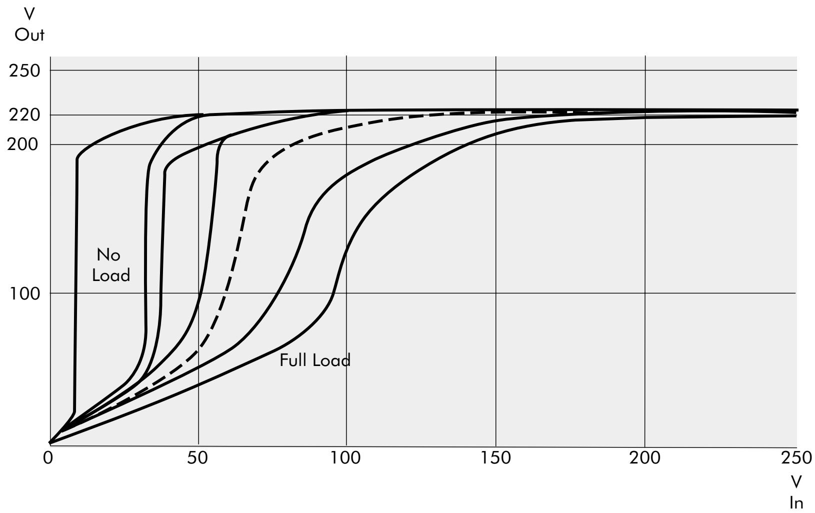


Figure 8 –CVT input/output characteristics

The total secondary circuit is resonated at the third harmonic. This cancels out most of the harmonics generated by the saturation of the core and produces a reasonably clean sinewave.

The stability of the output is determined by the flux in the transformer core and the voltage generated by the compensating winding (C). This means that the output voltage can only be changed if there are taps on the transformer.

The main advantages of the ferro-resonant stabiliser (CVT) are as follows:

- The ability at low loads to have an exceptionally wide input range. At 25 % load the output is maintained to ± 5 %, even when the input voltage is only 35 % of nominal voltage, (Figure 8).
- The output of the CVT will be automatically current limited in an overload situation.

The main disadvantages of the ferro-resonant stabiliser (CVT) are as follows:

- The feature of automatically limiting the output current (see above) can prevent loads which require start-up surges from operating correctly unless the CVT is de-rated or designed specifically for the application. Typical examples would include motor loads and switched mode power supplies.
- The transformer relies on resonance and therefore the output voltage will change by 1.5 % for each 1 % change in input frequency.
- The CVT has a modest stabilisation accuracy, typically ± 3 %.
- The transformer core relies on saturation to achieve the constant output voltage. This also produces very high magnetic fields around the transformer which can cause problems with sensitive equipment located near the CVT.
- The size and weight for a given kVA rating can be many times greater than an equally rated electro-mechanical automatic voltage stabiliser.

Electronic Step Regulators (tap changers)

Electronic step regulators operate by selecting separate taps on the input or the output of an auto transformer (Figure 9). This tap selection can be performed by relays or a semiconductor device such as a thyristor. If relays are used, they only operate at the instance of a tap change. However, if a thyristor is used, it will operate 50 times a second if selected, ie it will turn off and on each cycle of the 50Hz supply. In this application, relays have proven themselves to be more reliable.

Variations in the input voltage supply are monitored by an electronic sensor which in turn automatically selects the appropriate tap on the transformer using a relay, thus maintaining the required output voltage.

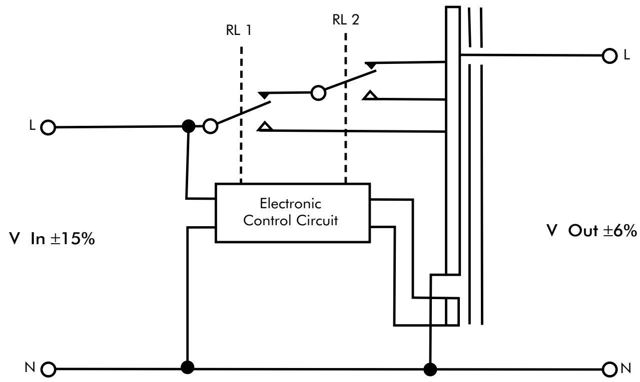


Figure 9 - Basic circuit of a step regulator

The instant of tap changing is phased by the electronic circuitry to occur very near the zero crossing of the supply voltage thus ensuring that any RF interference or switching transients are reduced to a minimum. The output voltage changes in steps, Figure 10. Therefore, this type of voltage stabilisation should not be used in lighting loads or other loads which cannot accept step changes in input voltages.

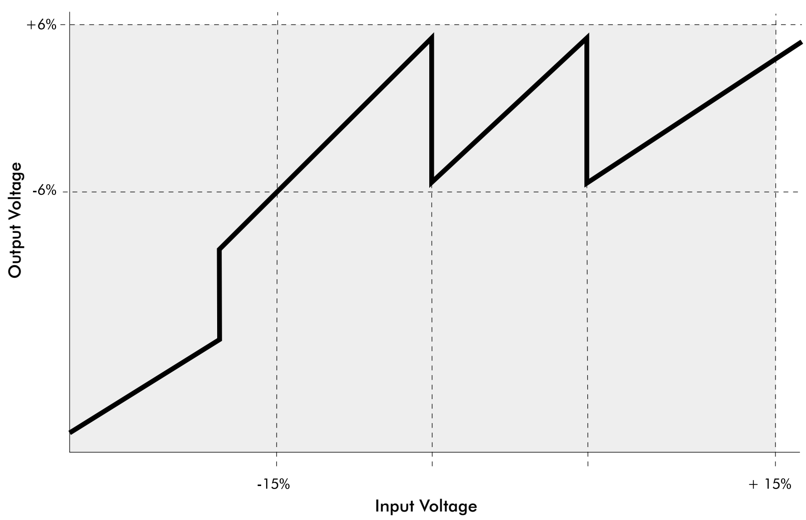


Figure 10 – Input/output characteristics for a step regulator

The main advantages of the electronic step regulator are as follows:

- Very high efficiency
- No sensitivity to frequency changes
- Small size and weight
- Insensitive to load power factor
- Insensitive to load changes
- Fast response, typically 1 – 1.5 cycles (20 – 30 ms)
- Relatively low cost.

The main disadvantages of the electronic step regulator are as follows:

- The voltage regulation (stabilisation) is in steps
- The output voltage tolerance is normally no closer than ± 3 %
- The reliability can be limited when semiconductor devices are used to switch load current.

Saturable reactor (Transductor)

The saturable reactor type of stabiliser operates by generating a magnetically controlled moving tap produced by a twin transductor assembly (T1-T2 in Figure 11). An electronic control circuit detects the output voltage and adjusts the control windings of T1 and T2 to correct for any error. The saturation of the transductors produces distortion that has to be removed with filters to ensure that a good sinewave is produced.

Even though the saturable reactor has no moving parts, its correction time can be as slow as 20 cycles (400 ms) due to the inductance of the transductors. This is much slower than a comparable electro-mechanical stabiliser.

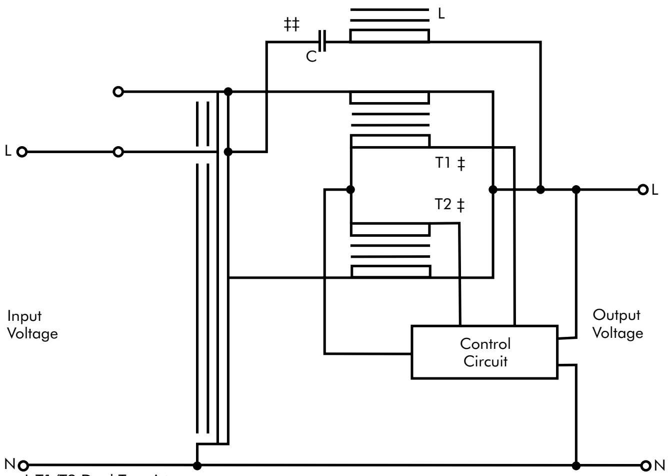


Figure 11 – Circuit of a saturable reactor regulator

The main advantages of the saturable reactor are as follows:

- No moving parts
- Smooth step-less control.

The main disadvantages of the saturable reactor are as follows:

- Large size and weight
- The response time is slower than an electro-mechanical automatic voltage stabiliser with similar capacity
- Large magnetic fields can be generated
- The voltage range is dependent on the load power factor
- High internal impedance can effect some high current loads
- The output waveform distortion is dependent on the supply frequency
- The output accuracy is dependent on the supply frequency and the load power factor.

Electronic Voltage Stabiliser

The automatic electronic voltage stabiliser is a very fast, very tolerant automatic voltage stabiliser with no moving parts and no need for tap changing.

The main component of an electronic voltage stabiliser is an electronic power controller. Depending on the model, the power controller supplies a voltage to the primary of a buck/boost transformer which is either in phase or out of phase. The secondary of the buck/boost transformer is connected between the input supply voltage and the load. The power controller can thus add or subtract a voltage to the supply or it will control the load directly through an auto-transformer.

The electronic power controller function is provided by two IGBT (insulated gate bipolar transistors) based bi-directional switches which are used to chop the input voltage at a frequency of 20 kHz with a pulse width dependent on the required output voltage. The power controller compares the 50 Hz stabiliser output voltage with that of a stable reference voltage and the error is used to control the two bi-directional switches. The high frequency pulse-width-modulated (pwm) waveform is then filtered and supplied either to the primary of the buck/boost transformer where the secondary voltage adds or subtracts an appropriate voltage to provide a stable output voltage, or directly to the load through an auto transformer.

An integral bypass circuit is used to bypass the currents in the IGBT components during output overload or a short circuit, thereby protecting the IGBTs and allowing fault currents to be cleared by fuse blowing.

The main advantages of the electronic voltage stabiliser are as follows:

- Very high stabilisation accuracy
- Very fast response, typically 0.5 cycles (10 ms)
- Wide input voltage variations without the need for tap changers
- Insensitive to input frequency variations
- Small size and weight.

The main disadvantage of the electronic voltage stabiliser is:

- More expensive than a similarly rated electro-mechanical voltage stabiliser.

Technique	Input Range	Smoothness of Control	Speed of Response	Stabilisation Accuracy	Load Regulation	Size Per kVA	Cost Per kVA	Total Out of 70	Normalise (%)
Electro Mechanical TS	10	10	6	10	10	9	9	64	91
Static Ferro-Resonant VRT	8	8 (B)	9 (B)	5	8 (D)	3	7	48	69
Electronic Step Regulator MVC	8 (A)	6 (A)	10	5 (A)	6 (C)	10	10	55	79
Saturable Reactor	8	10	5	8	8 (D)	4 (E)	6	49	70
Electronic Voltage Stabiliser EVS	10	10	10	10	10	10	8	68	97

Notes

Key: 1 – bad 10 – excellent

(A) Depends on the number of taps. (B) Depends on loading. It can over-shoot with light loads. (C) Depends on the waveform distortion and the number of taps. (D) Depends on the power factor and the type of load (resistive, capacitive, inductive). This technique can become unstable if the time constant of the load is similar to the time constant of the stabiliser. (E) The output waveform distortion is dependent on the frequency.

Table 1 - Comparison of voltage stabilisation techniques

Table 1 shows a comparison of voltage stabiliser techniques. It can be seen that the Electronic Voltage Stabiliser is the most effective method for regulating the input voltage supplying sensitive electronic equipment. The electro-mechanical automatic voltage stabiliser has become a well proven ‘standard’ for the industry. The upper limits of speed and load capacity of the electro-mechanical voltage stabiliser are restricted only by the mechanical limitations of driving the variable transformers used in the voltage regulation process. The cost-effectiveness of the different solutions available for compensating voltage dips is very much related to the value and sensitivity of the load requiring a stable voltage supply and the need to avoid introducing additional problems to the equipment through the voltage stabilisation process. Although the electronic voltage stabiliser is more expensive per kVA than the electro-mechanical stabiliser and the electronic step regulator, the future development and availability of higher power IGBTs and their inevitable reduction in cost bodes well for the future of the electronic voltage stabiliser as the fastest, most efficient and cost-effective method of stabilising the input voltage to sensitive electronic equipment.

Network Partners

Copper Benelux
168 Avenue de Tervueren
B-1150 Brussels
Belgium

Tel: 00 32 2 777 7090
Fax: 00 32 2 777 7099
Email: mail@copperbenelux.org
Web: www.copperbenelux.org

Contact: Mr B Dôme

Copper Development Association
Verulam Industrial Estate
224 London Road
St Albans AL1 1AQ
United Kingdom

Tel: 00 44 1727 731205
Fax: 00 44 1727 731216
Email: copperdev@compuserve.com
Webs: www.cda.org.uk & www.brass.org

Contact: Mrs A Vessey

Deutsches Kupferinstitut e.V
Am Bonneshof 5
D-40474 Duesseldorf
Germany

Tel: 00 49 211 4796 323
Fax: 00 49 211 4796 310
Email: sfassbinder@kupferinstitut.de
Web: www.kupferinstitut.de

Contact: Mr S Fassbinder

ECD Services
Via Cardinal Maffi 21
I-27100 Pavia
Italy

Tel: 00 39 0382 538934
Fax: 00 39 0382 308028
Email: info@ecd.it
Web www.ecd.it

Contact: Dr A Baggini

European Copper Institute
168 Avenue de Tervueren
B-1150 Brussels
Belgium

Tel: 00 32 2 777 70 70
Fax: 00 32 2 777 70 79
Email: eci@eurocopper.org
Web: www.eurocopper.org

Contact: Mr H De Keulenaer

Hevrox
Schoebroeckstraat 62
B-3583 Beringen
Belgium

Tel: 00 32 11 454 420
Fax: 00 32 11 454 423
Email: info@hevrox.be

Contact: Mr I Hendrikx

HTW
Goebenstrasse 40
D-66117 Saarbruecken
Germany

Tel: 00 49 681 5867 279
Fax: 00 49 681 5867 302
Email: wlang@htw-saarland.de

Contact: Prof Dr W Langguth

Istituto Italiano del Rame
Via Corradino d'Ascanio 4
I-20142 Milano
Italy

Tel: 00 39 02 89301330
Fax: 00 39 02 89301513
Email: ist-rame@wirenet.it
Web: www.iir.it

Contact: Mr V Loconsolo

KU Leuven
Kasteelpark Arenberg 10
B-3001 Leuven-Heverlee
Belgium

Tel: 00 32 16 32 10 20
Fax: 00 32 16 32 19 85
Email: ronnie.belmans@esat.kuleuven.ac.be

Contact: Prof Dr R Belmans

Polish Copper Promotion Centre SA
Pl.1 Maja 1-2
PL-50-136 Wroclaw
Poland

Tel: 00 48 71 78 12 502
Fax: 00 48 71 78 12 504
Email: copperpl@wroclaw.top.pl

Contact: Mr P Jurasz

TU Bergamo
Viale G Marconi 5
I-24044 Dalmine (BG)
Italy

Tel: 00 39 035 27 73 07
Fax: 00 39 035 56 27 79
Email: graziana@unibg.it

Contact: Prof R Colombi

TU Wroclaw
Wybrzeze Wyspianskiego 27
PL-50-370 Wroclaw
Poland

Tel: 00 48 71 32 80 192
Fax: 00 48 71 32 03 596
Email: i8@elektryk.ie.pwr.wroc.pl

Contact: Prof Dr H Markiewicz

Derek Maule

Claude Lyons Ltd
Brook Road
Waltham Cross
Herts EN8 7LR
United Kingdom

Tel: 00 44 1992 768888
Fax: 00 44 1992 788000
Email: pqm@claudelyons.co.uk
Website: www.claudelyons.co.uk

Copper Development Association

Copper Development Association
Verulam Industrial Estate
224 London Road
St Albans AL1 1AQ
United Kingdom

Tel: 00 44 1727 731200
Fax: 00 44 1727 731216
Email: copperdev@compuserve.com
Websites: www.cda.org.uk and www.brass.org

European Copper Institute
168 Avenue de Tervueren
B-1150 Brussels
Belgium

Tel: 00 32 2 777 70 70
Fax: 00 32 2 777 70 79
Email: eci@eurocopper.org
Website: www.eurocopper.org