

# Real-time Voltage Control to Improve Automation and Quality in Power Distribution

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*Abstract:* - A new power digital voltage controller is described able to improve quality in power distribution using real-time compensation of both slow voltage changes and quick disturbances as sags and swells. Voltage control was achieved by means of a special transformer able to change the magnetic flux linked to the secondary winding; moreover, secondary voltage was monitored through a feedback control managed by a properly programmed micro-controller. The completely automated system includes a power section, namely a special transformer, a power electronic section consisting of an inverter driven by an actuator, and a digital section involving a micro-controller with implemented software. The capabilities of the proposed voltage conditioner were verified by laboratory experimental tests performed on a specifically manufactured prototype. Experimental results are reported and the behavior of the conditioner under different working conditions is discussed.

*Key-Words:* - Electrical distribution systems, Power quality, Power systems control and automation, Voltage conditioning.

## 1 Introduction

The whole concept of voltage quality in power distribution has undergone great changes in the last few years [2], [4], [5], [6], [8], [9], [13], [14]. In the past only shifts from rated values used to be taken into account, whereas today a number of anomalies must be evaluated. These anomalies, commonly named disturbances, can be classified as follows:

- long interruptions;
- short interruptions;
- micro-interruptions;
- slow voltage changes;
- sags;
- swells;
- harmonics.

Disturbances depend on a number of events, of which the most important are:

- atmospheric phenomena such as wind, rain, snow, lightning, etc. [15];
- environmental conditions, mainly pollution;
- the diffusion of non linear loads causing harmonic distortion and voltage fluctuations.

The herein described voltage conditioner has the main aim to eliminate slow voltage changes, sags

and swells [10], [11], [12], [17]. The suggested voltage controller was derived from a power conditioner proposed in the past by the same author [1], now properly modified to achieve better performance in voltage control, with changes in both the power-unit configuration and the previously adopted processing software.

The system is arranged in three main sub-systems, namely a power electric unit, a power electronic section and a digital electronic control, and completed with a specifically implemented processing software.

Voltage control is obtained without on-load tap changers by varying the magnetic flux linked to the secondary winding of a special transformer. A digital feedback control system performs a continuous on-line supervision of all subsystems involved, and enacts voltage conditioning whenever either slow or quick changes are detected. All control actions are achieved by means of a balancing inverter automatically activated by the control system.

## 2 System description and modeling

The complete layout of the new voltage controller is shown in Fig. 1.

The power unit is controlled by a micro-processor ( $\mu\text{P}$ ) on the basis of information received from a Data Acquisition System (DAS). The  $\mu\text{P}$  drives a small inverter that, in its turn, works as an actuator. The rated power of the inverter is small when compared to that of the whole system. The power unit consists of a special transformer provided with a magnetic shunt able to deviate part of the flux generated by the primary winding, making it possible to control the magnetic flux linked to the secondary winding. The working principle of the proposed transformer is shortly described in the following, assuming a

single-phase machine for simplicity reasons. The special transformer has three legs and four windings placed around only two of the legs. Two windings, placed on the first and third legs, work as a balancing winding and a primary winding, respectively. The other two windings, also placed on the first and third legs, are connected serially forming a secondary winding. Fig. 2 shows the layout of the new electrical machine.

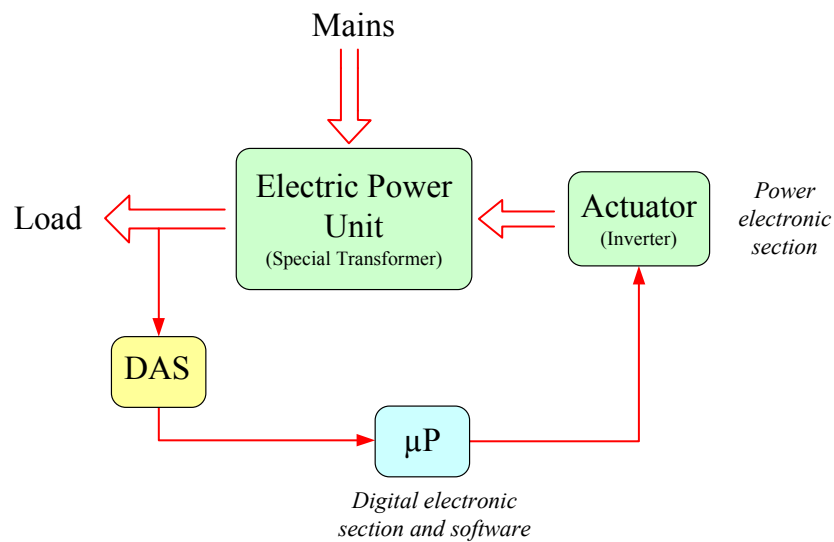


Fig.1 System layout.

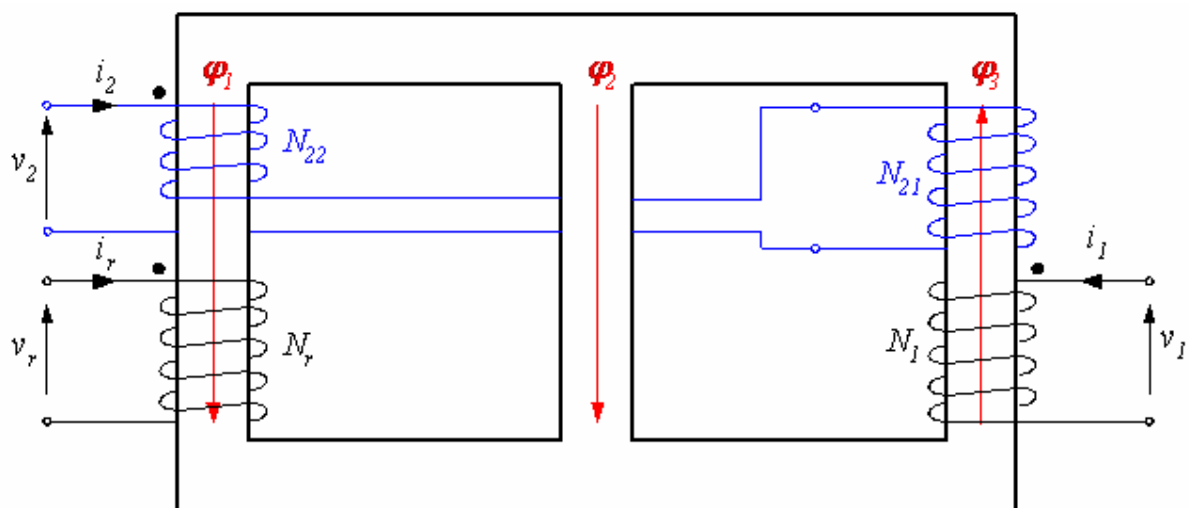


Fig.2 Layout of the power unit.

Fig. 2 also illustrates the conventional directions of both the currents and magnetic flux. The two  $N_{21}$  and  $N_{22}$  windings - together forming the secondary winding - must have same-phase electromotive forces. Assuming the electromotive forces of the  $N_{21}$  and  $N_{22}$  windings as  $e_{21}$  and  $e_{22}$ , respectively, the following relation can be written:

$$e_2 = e_{21} + e_{22}$$

In order to obtain good results, it is necessary to set the  $N_1/N_{21}$  ratio as equal to the nominal ratio. In addition, the number of coils in the  $N_r$  balancing winding must be established keeping in mind that any increase in their number implies a reduction in the magnetizing current. Finally, in order to reduce the power flow in the balancing winding,  $N_{22}$  must be much lower than  $N_{21}$ .

In order to better understand the behavior and capabilities of the proposed machine, an equivalent circuit must be defined so as to simulate the machine providing important indications for prototype design. In the first stages the proposed equivalent circuit involved an ideal transformer [3], but afterwards more precise models were built by adding a leakage flux as well as iron and copper losses.

The complete equivalent circuit of the special transformer is shown in Fig. 3, while the associated mathematical model is the following:

$$V_1^{\&} = (R_1 + j\omega L_{\sigma 1}) I_1^{\&} + E_1^{\&} = (R_1 + jX_{\sigma 1}) I_1^{\&} + E_1^{\&}$$

$$V_r^{\&} = (R_r + j\omega L_{\sigma r}) I_r^{\&} + E_r^{\&} = (R_r + jX_{\sigma r}) I_r^{\&} + E_r^{\&}$$

$$V_2^{\&} = (R_2 + j\omega L_{\sigma 2}) I_2^{\&} + E_2^{\&} = (R_2 + jX_{\sigma 2}) I_2^{\&} + E_2^{\&}$$

$$E_1^{\&} = j\omega L_{\mu 1} I_{\mu 1}^{\&}$$

$$E_r^{\&} = j\omega L_{\mu r} I_{\mu r}^{\&}$$

$$E_2^{\&} = E_{21}^{\&} + E_{22}^{\&} = \frac{N_{21}}{N_1} E_1^{\&} + \frac{N_{22}}{N_r} E_r^{\&}$$

$$I_1^{\&} = I_{\mu 1}^{\&} + \frac{I_{fe1}^{\&}}{R_{fe1}} + I_{1,21}^{\&} + I_{1,22}^{\&} = I_{\mu 1}^{\&} + I_{fe1}^{\&} + k_{r1} I_r^{\&} + k_{1,21} I_2^{\&} + k_{1,22} I_2^{\&}$$

$$I_r^{\&} = I_{\mu r}^{\&} + \frac{I_{fer}^{\&}}{R_{fer}} + I_{r,22}^{\&} + I_{r,21}^{\&} = I_{\mu r}^{\&} + I_{fer}^{\&} + k_{r1} I_1^{\&} + k_{r,22} I_2^{\&} + k_{r,21} I_2^{\&}$$

The equivalent circuit of the special transformer shown in Fig. 3 was conveniently used to optimize the prototype design.

The prototype was further improved by reducing both the power necessary for voltage control actions, and the rated power of the inverter connected to the compensating coil. Once the prototype was built, a number of significant operating conditions were investigated.

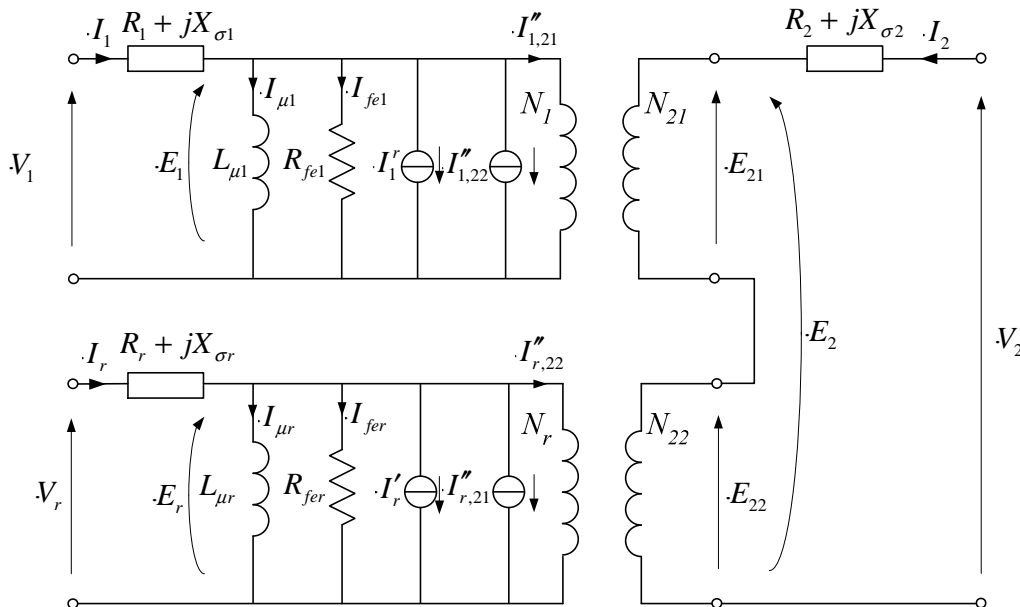


Fig.3 Equivalent circuit of the special transformer.

### 3 Evaluation of the parameters of the equivalent circuit

When the non-ideal parameters of a transformer are known, engineers can optimize design using equations rather than inefficiently wasting time in testing laboratory physical implementations, which means that designs could be optimized before any implementation took place.

With reference to the equivalent circuit of Fig. 3, the transformer parameters were evaluated by means of open circuit and short circuit laboratory tests performed directly on the built prototype.

#### 3.1 Open circuit tests

Open circuit tests allow to calculate derived parameters as  $R_{fe1}$ ,  $R_{fe2}$ ,  $X_{\mu1}$  e  $X_{\mu2}$ .

From specialized literature it is well known that an open circuit test is performed by applying rated voltage to the supplied circuit while leaving the other circuits open. Two tests were performed supplying either the primary or the compensation winding.

It is also well established that since under these conditions all series parameters and current generators can be neglected, only the values of parallel parameters need to be evaluated. As concerns the two open circuit tests, the equivalent circuits adopted are shown in Figs. 4 and 5, respectively.

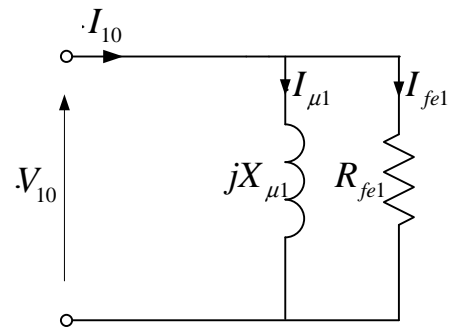


Fig.4 Equivalent circuit as “seen” by the primary when the secondary is unloaded.

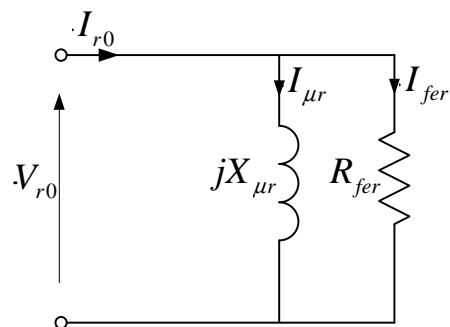


Fig.5 Equivalent circuit as “seen” by the compensation winding when the secondary is unloaded.

The two laboratory measurement diagrams adopted for the open circuit tests are shown in Figs. 6 and 7, respectively.

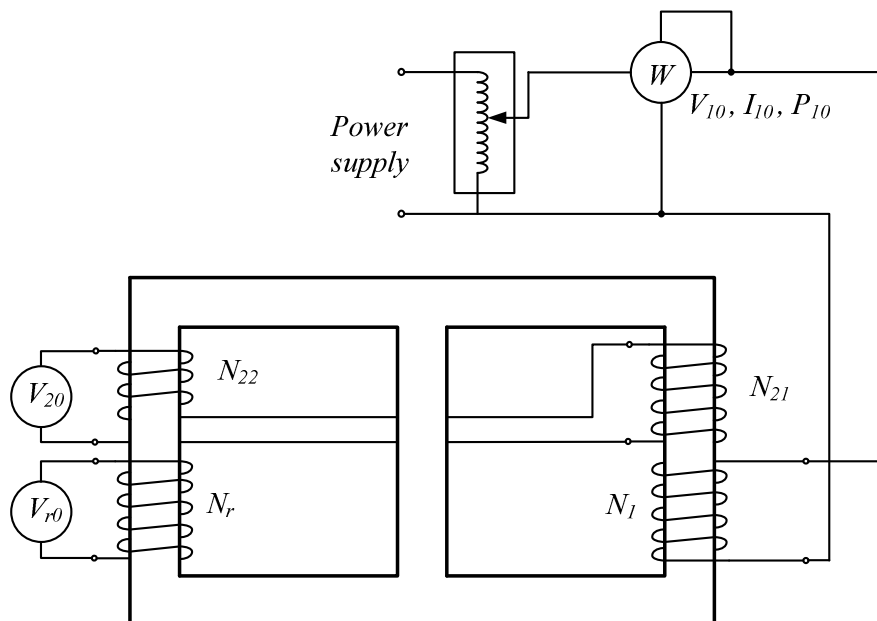


Fig.6 Electric scheme adopted for the open circuit test when the supply is on the primary.















