A new voltage digital controller for electrical distribution systems

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Abstract: - An unconventional power controller for voltage conditioning in electric power distribution is presented. The main component of the proposed system is a special transformer able to control the magnetic flux linked with the secondary winding. This special machine (also named power unit) is driven by a feed-back control applied through a properly programmed DSP (Digital Signal Processor). The whole system was optimized to balance both slow voltage changes and quick disturbances as sags and swells. Laboratory experimental tests performed on a prototype confirmed the correct behavior of the system under different working conditions.

Key-Words: Electrical distribution systems; Digital control and automation; Voltage conditioning.

1 Introduction

The idea of the suggested system derived from a previous power conditioner [1], proposed in the past by the same author, which was now properly modified to optimize performance in voltage control. This aim was reached modifying both the power-unit configuration and the previously adopted processing software.
The system is arranged in three main sub-systems:

- A power electric section (namely a special transformer).
- A power electronic section (namely an inverter).
- A digital electronic section (namely a DAS and DSP).

The system is finally completed with a specific, properly implemented processing software.
Voltage control is obtained without on-load tap changers, namely by varying the magnetic flux linked to the secondary winding of a special transformer. A digital feedback control system operates a continuous on-line supervision of all subsystems involved, by conditioning voltages in the presence of both slow and quick changes. All control actions are enacted by means of a balancing inverter automatically driven 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 DSP on the basis of information received from a Data Acquisition System (DAS), [4]. The DSP drives a small inverter that, in its turn, works as an actuator. The inverter's rated power is small if compared to that of the system. The power unit is 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. The special transformer is arranged with three legs and four windings placed around only two of the legs. Two windings, which are placed on the first and third legs, work as a balancing winding and a primary winding, respectively. The remaining two windings, which are also placed on the first and third leg, are serially connected and form the secondary winding. Fig. 2 shows the layout of the new electrical machine.

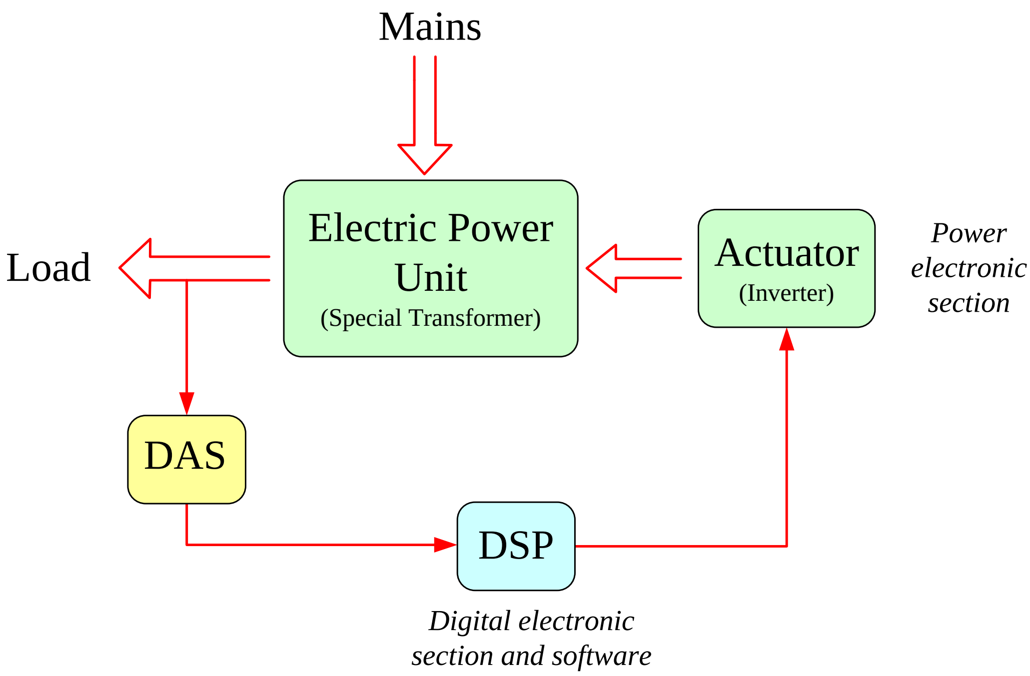

Fig. 1 - System layout.

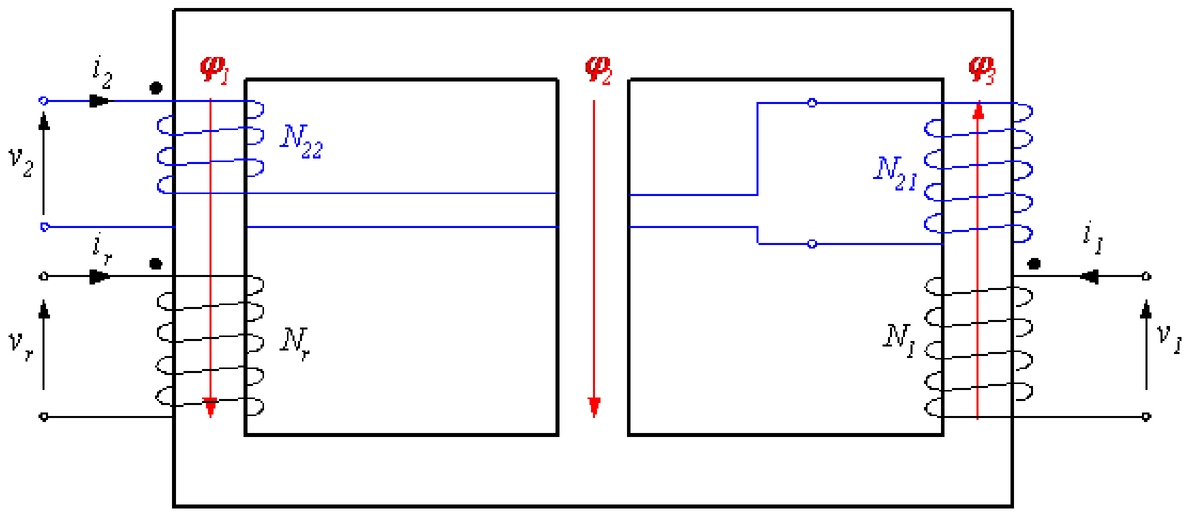

Fig. 2 - Layout of the power unit.

The same Fig. 2 illustrates the conventional directions of both the currents and magnetic flux. The two N_{21} e N_{22} windings, which together form the secondary winding, must have same-phase electromotive forces. If we denote with e_{21} and e_{22} the electromotive forces of the N_{21} and N_{22} windings, 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 the coils in the N_r balancing winding must be established keeping in mind that any increase in number implies a reduction in magnetizing current. Finally, in order to reduce the power flow in the balancing winding, N_{22} must be much lower than N_{21}.

3 Experimental tests

Laboratory experimental tests were performed on a prototype of the proposed special transformer, whose characteristics are specified in the following.

The magnetic core had the following dimensions:

- Leg cross section: 60 x 60 mm.
- Yoke cross section: 60 x 60 mm.

- Leg height: 160 mm.
- Yoke length: 240 mm.

The windings had the following number of coils:

- N_{22}=63 coils.
- N_r=222 coils.
- N_{21}=247 coils.
- N_1=247 coils.

All windings were made of copper conductors with a 5 mm^2 cross-section. Maximum allowed voltage and current for each winding were 400V and 50A, respectively. The rated power of the machine was 5 kVA.
Experimental tests were performed off-line using two variacs: the former supplies the system, the latter the balancing winding. The supply variac allowed the simulation of slow voltage changes due to both load changes and other events occurring on the primary supply network; in addition, the same variac could simulate quick voltage changes due to sags and swells.
The balancing variac, which in the off-line performed tests replaced and simulated the inverter of Fig. 1, was manually managed in order to re-establish the secondary voltage at its rated value under all working conditions.
Experimental tests allowed the investigation of the following case studies:

- Changes in the primary supply voltage.
- Changes in the secondary voltage caused by load changes.
- The compensation of sags.
- The reduction of swells.

Fig. 3 shows the arranged measurement system while Tab. I shows the results of the experimental tests performed to simulate all the different working conditions of the system, which include slow voltage changes and suddenly voltage disturbances such as sags and swells.
The earliest experimental tests were arranged in such a way to simulate secondary voltage changes due to load changes. Tab. I shows that in these cases voltage recovery required very low compensation power, that is to say from 2.3% to 3.4% of the load power.
Subsequent tests dealt with quick disturbances such as sags and swells. In these cases the required compensation power was quite greater since a compensation power of 35.5% was necessary to recover a 30% sag. As concerns the simulated swells, which reached maximum values of 30%, the required compensation power varied from 2.2% to 16.3% of the load power.
It is convenient here to recall that in order to compensate swells it is necessary to invert the terminations of compensation windings.

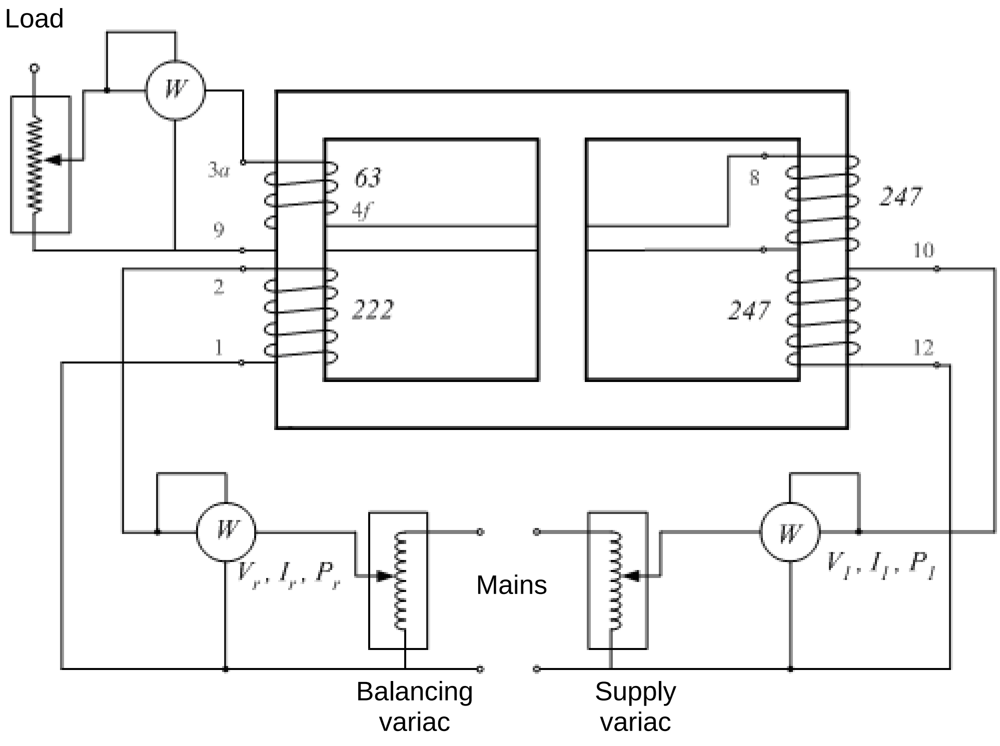

Fig. 3 - Measurement scheme of the performed laboratory tests.

Tab. I - Results of experimental tests.

	V_1 (V)	I_1 (A)	P_1 (W)	V_2 (V)	I_2 (A)	P_2 (V)	V_r (V)	I_r (A)	P_r (W)	% V_{1n}	P_r %	η
Unloaded	180.2	0.22	14.2	180.3	0.00	0.0	0.8	0.09	0.1	100.0	-	-
Load changes	180.0	4.09	730.0	180.0	3.98	716.0	26.6	0.50	13.6	100.0	1.9	0.963
	180.3	4.42	792.0	180.0	4.32	776.0	27.7	0.53	14.2	100.0	1.9	0.963
	180.3	4.65	833.0	180.0	4.54	817.0	30.7	0.56	16.5	100.0	2.0	0.962
	180.0	5.14	921.0	180.0	5.05	908.0	34.9	0.62	20.7	100.0	2.3	0.964
	180.0	5.63	1008.0	180.0	5.54	994.0	39.5	0.67	25.5	100.0	2.6	0.962
	180.0	6.05	1078.0	180.0	5.91	1064.0	43.2	0.71	29.7	100.0	2.8	0.961
Sags	180.3	5.10	913.0	180.0	5.00	898.0	30.5	0.60	17.9	100.0	2.0	0.965
	171.1	5.14	871.0	180.2	5.00	901.0	121.8	0.78	76.9	95.1	8.5	0.951
	162.4	5.52	931.0	180.0	5.00	898.0	210.1	2.27	148.0	90.2	16.5	0.917
Swells	189.5	5.09	959.0	180.0	5.00	899.0	50.6	0.55	-27.4	105.3	3.1	0.965
	198.5	5.07	999.0	180.0	5.00	899.0	134.4	0.50	-69.9	110.1	7.7	0.968
	207.8	5.06	1047.0	180.2	5.01	901.0	220.8	0.50	-101.6	115.4	11.3	0.953

If the maximum power established for the compensation winding is 20÷25% of the power unit, the built prototype is able to compensate:

- Any load changes.
- Sags up to -20%.
- Swells up to +25%.

In other words, this means that to completely compensate for the above disturbances a compensation inverter with a rated power of 20% of the system rated power is required.

4 Conclusions

The positive experimental results suggest that the power system proposed might be effectively used in the digital control of voltages in electrical distribution grids. The proposed system exhibited the following interesting features:

- substantial reduction of voltage disturbances coming from both the primary supply system and supplied load;
- high efficiency;
- good levels of robustness and reliability [5];
- reduced maintenance [6].

From an application point of view, the new power digital-controlled system can produce a number of advantages in the automatic management of electrical distribution systems, with remarkable improvements in power supply quality to customers [2], [3].

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