Doctoral school of energy and geotechnology
January 16–21, 2006. Kuressaare, Estonia

Comparison of the three-phase thyristors controlled reactors systems

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Abstract

In the following paper combined L-C scheme of reactive power compensation with Delta and Wye connected reactor circuit are compared. There is regulation ranges of the current as well as harmonic content of network current discussed. Using computer modulation we can understand, that delta scheme has wider current regulation range and network current harmonic content is better. In both cases current 5, 7, 11 and 13 harmonics must be noticed. Also approximate equitation of network current RMS value for compensator circuit is made. Approximate equitation gives good congruence with computer modulation results.

Keywords

reactors, thyristor regulator, Wye circuit, Delta circuit, harmonic analysis, distortion.

Introduction

For smooth regulation o load angle between current and voltage, combined L-C (fig. 1) system of compensation of reactive power [1,2,3,4], where capacitor banks are switched with thyristor switches and smooth regulation is achieved with thyristor regulated reactors.

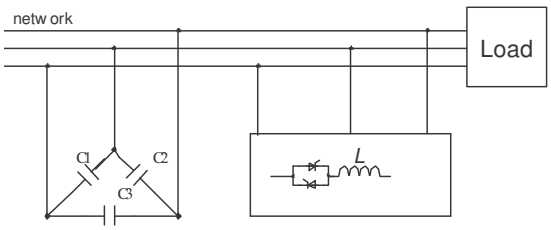


Fig. 1. Combined L-C scheme of compensation of reactive power

Creating combined combined L-C system of compensation of reactive power, it is possible to switch reactors in Wye circuit and in Delta circuit [1,2]. To ascertain the features of both possible circuits, the calculations and comparison of electromagnetic process quality is made. There are very many papers devoted to compare both schemes [1,2,3,4], but there are no researches of harmonic content in both circuits and comparison. This is the task of this paper. It is assumed that supply network is symmetric, parameters of reactors are absolutely identical and control of thyristors is symmetrical, that is all three phase thyristors are controlled with equal regulation angle α.

Comparison of electromagnetic processes in both schemes

In **Wye circuit** thyristor controlled reactor are shown in figure 2. There are two anti – parallel thyristors switched in each phase, that are regulated with time delay α for changing RMS value of current of the phase and reactor voltage [1,2]. Since there is no neutral in this scheme, there is no third as well as harmonics which divides on 3 in structure of the network current.

Applying computer modulation voltage and current instantaneous value curves (fig. 3.), as well as data of harmonic content of current are gained. As we can see the form of current is complicated, because it develops as three-phase and two-phase controlling result. The data about measurements at nominal, common power 20 kvar of reactor and line voltage 380V are given in table 1. Since current curve is symmetric towards time axis and without neutral, in current content are no pair harmonics as well as harmonics which divides on 3 (3.,9.,15. etc).

Calculations of instantaneous values in one phase are calculated such equations: in intervals, when current is conducted by two phases for example phase A concerning to voltage U_{AB} are calculated such equations

$$V_{ABm}\sin(\frac{\pi}{3}+\omega t)=2L\frac{di_A}{dt}+2Ri_A,\ i_A>0,\ \omega t\geq\alpha, \quad (1)$$

$$V_{ABm}\sin(\frac{4\pi}{3}+\omega t)=2L\frac{di_A}{dt}+2Ri_A,\ i_A<0,\ \omega t\geq\alpha, \quad (2)$$

in intervals when current is conducted by all three phases, there such equations are calculated

$$V_{Am}\sin\omega t=L\frac{di_A}{dt}+Ri_A\ ,\ i_A>0,\ \omega t\geq\alpha\ , \quad (3)$$

$$V_{Am}\sin(\pi+\omega t)=L\frac{di_A}{dt}+Ri_A,\ i_A<0,\ \omega t\geq\alpha. \quad (4)$$

In these equations L and R is inductance and active resistance of one phase reactor, angle α is deducted from the positive and negative polarity half wave beginning of the phase A and in work with reactors is bigger than 900.

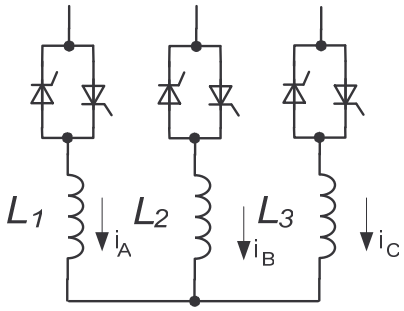


Fig. 2. Reactor scheme Wye circuit

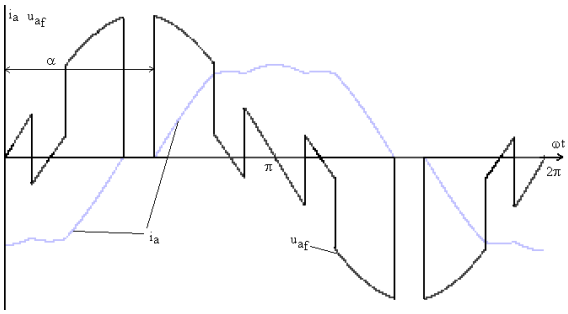


Fig. 3. Shape of current and reactor voltage in phase-A in Wye circuit scheme

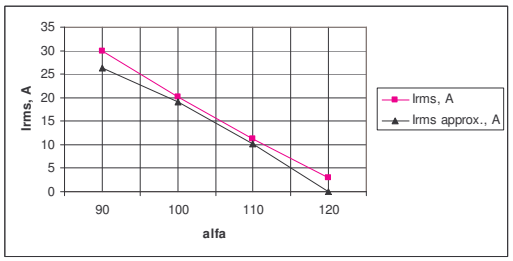
Using data of computer modulation approximate formula for calculation of reactor current RMS in wye scheme is gained:

$$I_{rms} = \frac{V_{phm}\left(1{,}5\cos\alpha + 0{,}5\sqrt{3}\sin\alpha\right)}{\omega L}\sqrt{\frac{\alpha}{\pi}} \qquad (5)$$

$$90^0 \le \alpha \le 120^0,$$

where in calculations is accepted that current shape is like trapeze. Trapeze longest length of basis is $2(\pi - \alpha)$. Each lateral margin goes on $\left(\frac{4\pi}{3} - 2\alpha\right)$.

Such expression gives small deflection from experimentally gained curve (fig. 4.). In expression U_{fm} is amplitude value of phase voltage of the network.



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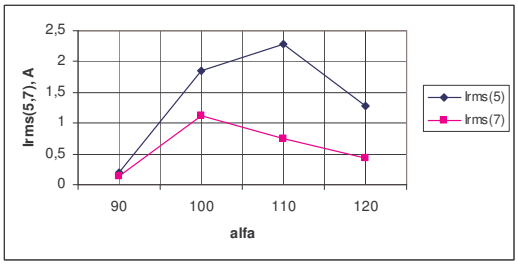

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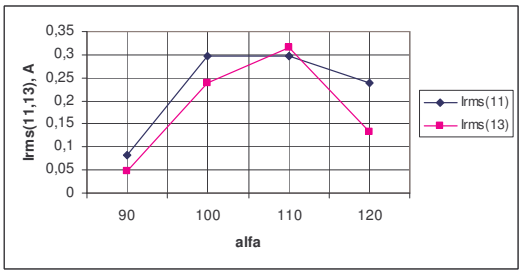

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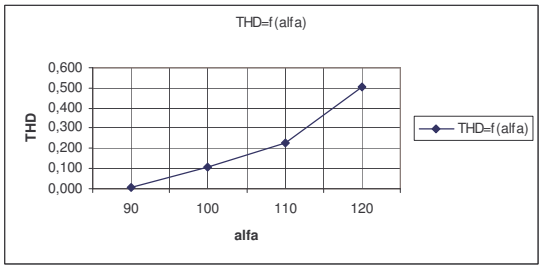


(d)

Fig. 4. Computer modulation results: reactor current (a), its harmonics (b, c), THD (d) parameter changes from α

Table 1. Resume of the results of computer modulation in Wye scheme

α, grades	90	95	100	105	110	115	120
Vf, V	218,76	199,92	179,34	157,17	132,19	103,37	66,52
I_{rms}, A	29,81	24,9	20,23	15,55	11,12	6,9	3,06
$I_{rms\ (1)}$, A	29,69	24,79	19,94	15,27	10,81	6,59	2,72
$I_{rms\ (5)}$, A	0,1961	1,087	1,844	2,25	2,269	1,918	1,273
$I_{rms\ (7)}$, A	0,146	0,7317	1,1129	1,1151	0,7539	0,165	0,4348
$I_{rms\ (11)}$, A	0,0808	0,4317	0,4447	0,1144	0,2943	0,4396	0,2368
$I_{rms\ (13)}$, A	0,0485	0,3116	0,3147	0,1024	0,3147	0,1859	0,1307
THD	0,009	0,057	0,111	0,165	0,225	0,301	0,504
Q, kvar	19,674	16,434	13,219	10,263	7,339	4,554	2,019
Q*, (Q/20)	0,984	0,822	0,661	0,513	0,367	0,228	0,101

Compensation scheme in Delta circuit

Delta circuit scheme is depicted in fig. 5. In each Delta shoulder is switched reactor L and thyristor in series with it. In such scheme each shoulder works as one phase ac regulator with supply voltage, that equal with line voltage of network. Regulation angle α working with reactor can be changed within 900 till 1800, i.e. more wider diapason than Wye circuit without neutral that is stated advantage of this circuit.

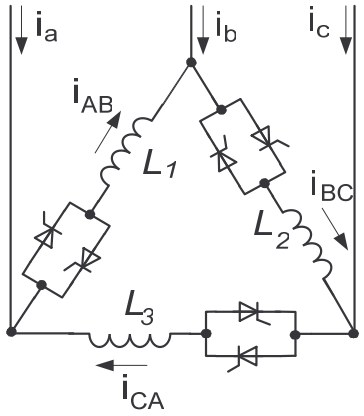


Fig. 5. Compensator reactor Delta circuit scheme

In shoulder AB are calculated such differential equitation:

$$U_{ABm}\sin\omega t = L\frac{di_{AB}}{dt} + Ri_{AB},\ \mathrm{i_{AB}} > 0,\ \omega t \geq \alpha, \qquad (6)$$

$$U_{ABm}\sin(2\pi + \omega t) = L\frac{di_{AB}}{dt} + Ri_{AB},\quad \mathrm{i_{AB}} < 0,\quad \omega t \geq \alpha, \qquad (7)$$

In such circuit the phase current of the network (for example phase A) develop as difference of two, to phase A incorporated shoulder current:

$$i_A = i_{AB} - i_{CA} \qquad (8)$$

In fig. 6 is shown the way how develop the phase A current of network in time.

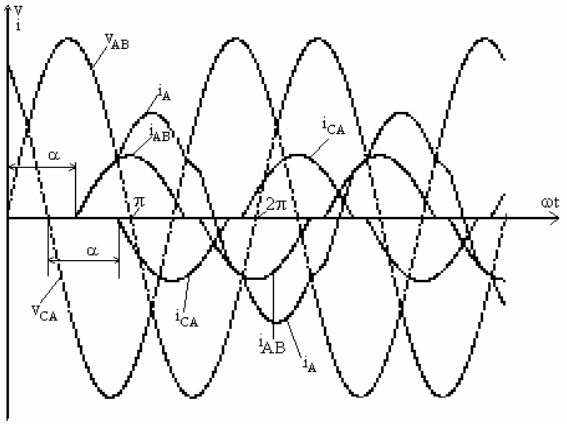


Fig. 6. Depiction of development of the current in phase-A in time

In figure 7 depicted instantaneous values of current and voltage in one shoulder of delta circuit.

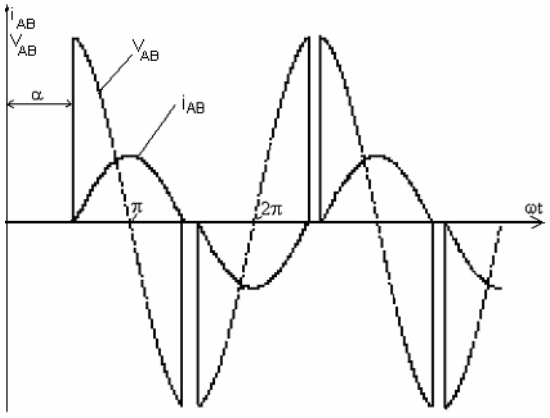


Fig. 7. The shape of current and reactor voltage in one shoulder of delta circuit

Using results of computer modulation, also in this case we can gain approximate expression for value of network current RMS calculation. Let's assume that in each shoulder, starting calculation from voltage half wave beginning current changing as half wave in interval from α till 2π- α, this half wave current vary as

$$i_{ph} = \frac{V_{lm}}{\omega L_1}\left(\cos\alpha - \cos\omega t\right), \qquad (9)$$

where L_1 in Delta circuit is 3 times bigger than in Wye, but V_{lm} is amplitude of the line voltage.

The common phase current amplitude is $\sqrt{2}I_{phm}$, but the current amplitude of shoulder

$$I_{phm} = \frac{V_{lm}}{\omega L_1}\left(1 + \cos\alpha\right) \qquad (10)$$

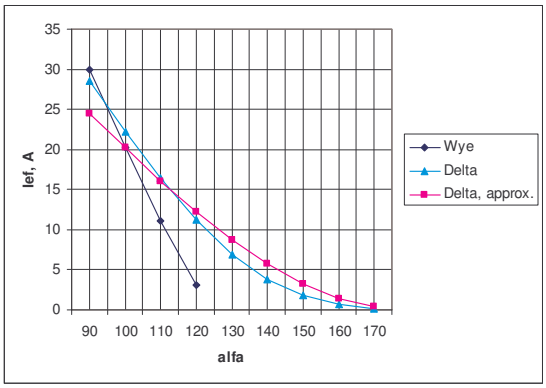
compare THD factor at these angles (the same minimal currents), then it is obvious, that THD factor in all diapason of the regulation with this and bigger current in Delta circuit is smaller than in Wye circuit i.e. network current harmonic content in delta circuit is better than in Wye circuit.

For objective evaluation of both circuit scheme impact to supply network in the process of regulation, in fig. 9. are depicted curves dependent on adjusted common power 20 kvar for reactors in both circuits.

As we can see, diapason of power changes for Wye circuit is much more smaller than in delta circuit, but THD curve at all realized values of power in delta scheme is smaller than THD curve in wye circuit.

Table 2. Resume of the results of computer modulation in Delta scheme

α , grades	90°	100°	110°	120°	130°	140°	150°	160°	170°
Vfa, V	362,15	318,3	273,07	225,8	178	131,4	87,72	49,1	18,17
Sfa	16,66	12,85	9,62	6,79	4,55	2,71	1,37	0,52	0,1
I_{rms}, A	28,51	22,19	16,38	11,19	6,9	3,84	1,87	0,7	0,13
$I_{rms(1)}$, A	28,39	22,06	16,24	11,11	6,84	3,73	1,66	0,52	0,07
$I_{rms(5)}$, A	0,013	1,12	1,41	0,79	0,21	0,825	0,78	0,38	0,065
$I_{rms\ (7)}$, A	0,034	0,68	0,47	0,28	0,58	0,17	0,27	0,26	0,06
$I_{rms(11)}$, A	0,03	0,26	0,18	0,15	0,219	0,014	0,146	0,058	0,046
$I_{rms(13)}$, A	0,018	0,18	0,19	0,091	0,07	0,133	0,087	0,009	0,04
THD	0,002	0,061	0,093	0,077	0,096	0,229	0,508	0,893	1,535



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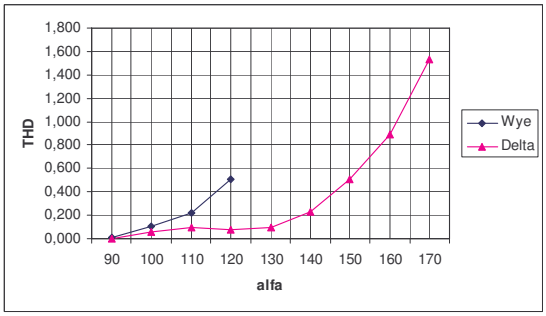

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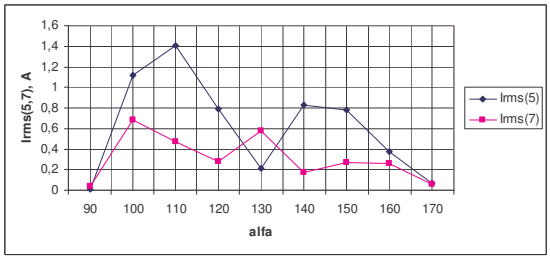

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Fig. 8. Computer modulation results: phase current, its harmonics, THD parameter changes from α in Delta and Wyes schemes

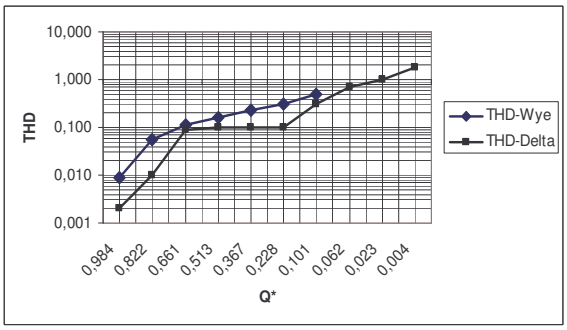

Fig. 9. Dependence of THD of supply network current on adjusted reactor power at common power 20 kvar

Conclusions

1. The diapason of the regulation in Delta circuit is wider, than in Wye circuit.

2. Harmonic content of network current is better in Delta circuit than in Way circuit.

3. Thyristor regulation of reactor delta circuit is similar to regulation of one phase ac reactor.

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