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Comparison of Thyristor Regulated Three-Phase Reactors' Schemes

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Introduction

For compensation of reactive power it's necessary to apply reactors regulated by usage of the thyristors [1,3,4]. It's well known that current consumed from network with such device has harmonics content. Taking into that it's necessary to examine an influence of system on the network. That is main goal of our investigation.

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

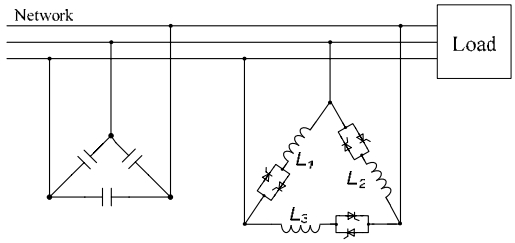


Fig. 1. Combined L-C scheme of compensation of reactive power

Creating combined 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 processes quality is made. There are very many papers devoted to comparison of the both schemes [1,2,3,4], but there are no researches of harmonic content in both circuits and its comparison. This is the task of this paper also.

Comparison of electromagnetic processes in both schemes

In **wye circuit** thyristor controlled reactors 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].

Applying computer simulation instan-taneous value curves of voltage and current (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 conductivity result. The data about measurements at nominal total power 20 kvar of reactors and line voltage 380V are presented in table 1. Since current curve is symmetric towards time axis and without neutral point, in current content are no pair harmonics as well as harmonics which divides on 3 (3.,9.,15. etc).

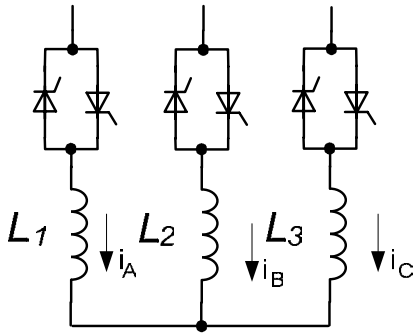


Fig. 2. Reactor scheme wye circuit

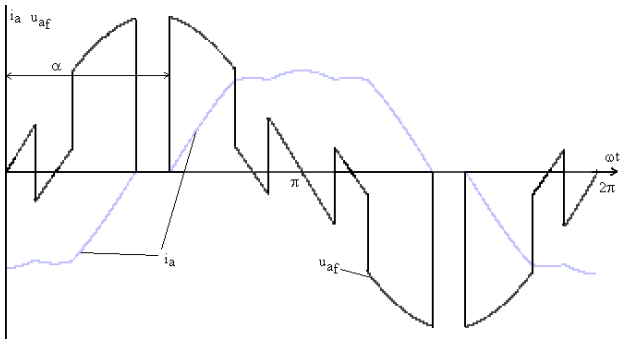


Fig. 3. Shape of current and reactor voltage in phase-A in wye circuit scheme

Table 1. Resume of results of computer simulation in wye schem

α , deg.	90	100	110	120
V_{fa},V	218,76	179,34	132,19	66,52
I_{ef}, A	29,94	20,23	11,17	3,07
$I_{efh(1)}$, A	29,81	20,03	10,85	2,73
$I_{efh(5)}$, A	0,1961	1,844	2,279	1,279
$I_{efh(7)}$, A	0,145	1,117	0,757	0,436
$I_{efh(11)}$, A	0,081	0,295	0,295	0,237
$I_{efh(13)}$, A	0,0487	0,2386	0,3161	0,1313
THD	0,009	0,109	0,225	0,505

Table2. Resume of the results of computer simulation in delta scheme

α , deg.	90	100	110	120	130	140	150	160	170
V_{fa},V	362,15	318,3	273,07	225,8	178	131,4	87,72	49,1	18,17
$I_{Sh.\ fa}$ A	16,66	12,85	9,62	6,79	4,55	2,71	1,37	0,52	0,1
I_{ef}, A	28,51	22,19	16,38	11,19	6,9	3,84	1,87	0,7	0,13
$I_{efh(1)}$, A	28,39	22,06	16,24	11,11	6,84	3,73	1,66	0,52	0,07
$I_{efh(5)}$, A	0,013	1,12	1,41	0,79	0,21	0,825	0,78	0,38	0,065
$I_{efh(7)}$, A	0,034	0,68	0,47	0,28	0,58	0,17	0,27	0,26	0,06
$I_{efh(11)}$, A	0,03	0,26	0,18	0,15	0,219	0,014	0,146	0,058	0,046
$I_{efh(13)}$, 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

In accordance with data of table, the current and harmonic RMS value curves in dependence on regulation angle α are shown in fig.4. Admittedly, angle α can be changed only within 90^0 (it's work with ideal inductance) till 120^0. The biggest limit of the angle α can be equated till 150^0, but then thyristor control realization is inconvenient. This is one of the serious controllability restrictions of wye circuit. In fig. 4. is shown also THD change related on changes of regulation angle.

As we can see the RMS value of the current decreases approximately linearly if angle α grows up. Fifth harmonic maximum is at $\alpha=110^0$, but seventh at $\alpha=100^0$. Parameter THD growths if α growth too, reaching value 0.5 at 120^0.

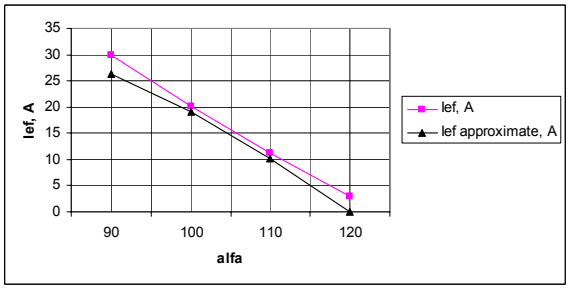
Using data of computer modulation approximate formula for calculation of reactor current RMS in wye scheme is gained:

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

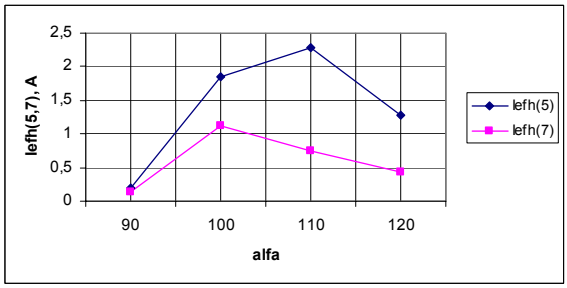
where $90^0 \le \alpha \le 120^0$ in calculations is accepted that current shape is like trapeze. Trapeze's longest length of basis is $2(\pi-\alpha)$. Each lateral margin go on interval $(\frac{4\pi}{3}-2\alpha)$. Such expression gives small deflection from experimentally gained curve (fig.4.). In expression U_{fm} is amplitude value of phase voltage of the network.

Compensation scheme in delta circuit

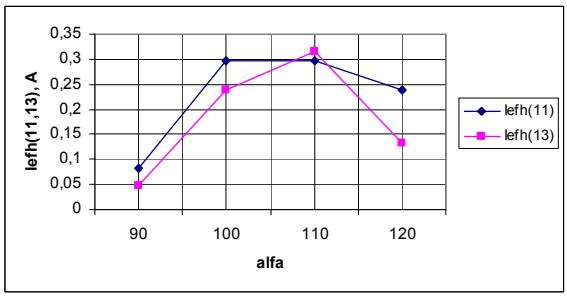
Delta circuit scheme is depicted in fig.5. In each delta shoulder is switched reactor L and thyristor in series with it. In such scheme each shoulder works as single phase AC regulator with supply voltage, that equal with line voltage of network. Regulation angle α working with reactor can be changed within 90^0 till 180^0, i.e., more wider diapason than in wye circuit without neutral is obtained, which is certain advantage of this circuit.



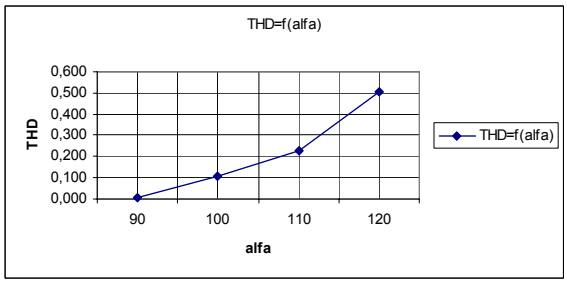
(a)



(b)



(c)



(d)

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

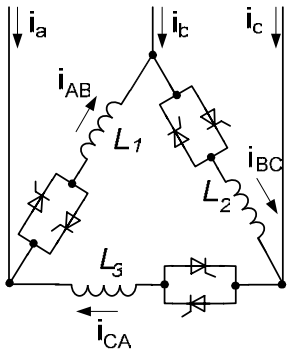


Fig. 5. Compensator reactor Delta circuit scheme

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

$$i_A = i_{AB} - i_{CA}. \qquad (2)$$

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

Using results of computer simulation, 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

$$i_p = \frac{V_{lm}}{\omega L_1}(\cos\alpha - \cos\omega t); \qquad (3)$$

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

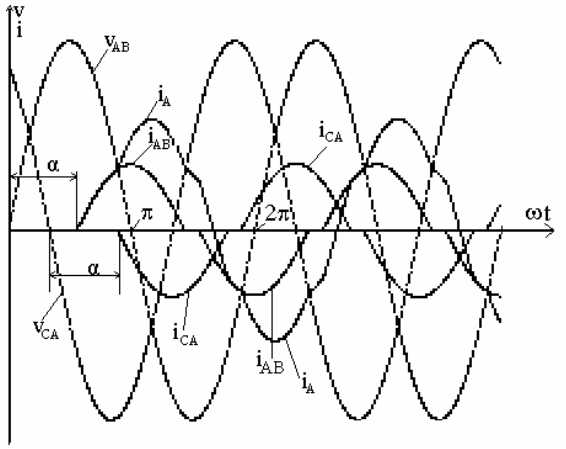


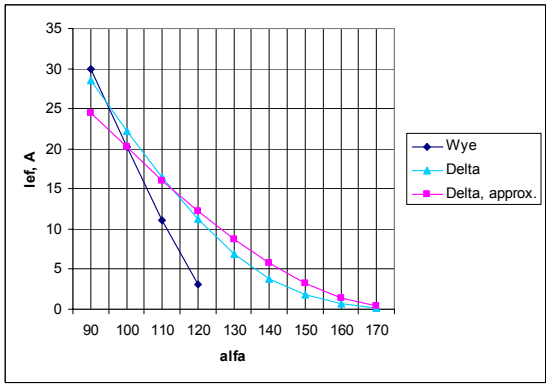
Fig. 6. Depiction of development of the current in phase-A in time

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

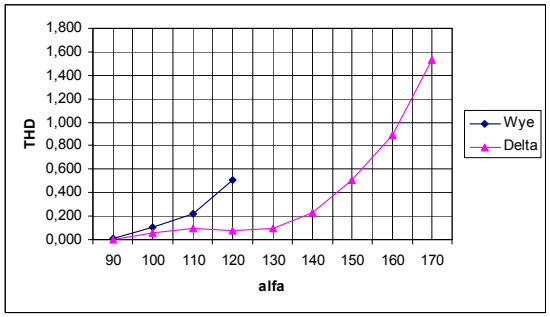
$$I_{pm} = \frac{V_{lm}}{\omega L_1}(1 + \cos\alpha); \qquad (4)$$

Then RMS value of the phase current, approximately considering current sinusoidal, is approximately equal with I_{pm}.

Obviously, in fig. 7. a, it is easier to regulate current in delta scheme than in wye scheme, because changing α in delta scheme current is changing flatter. Besides, at $\alpha=90^0$ current is bigger in wye scheme, but already at $\alpha=95^0$ current is bigger in delta scheme. The same minimal current in wye circuit is at 120^0, but in delta circuit – at 140^0. Approximate calculation of current RMS value in delta circuit differs very few from calculation of current RMS value in computer modulation. If 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.



(a)



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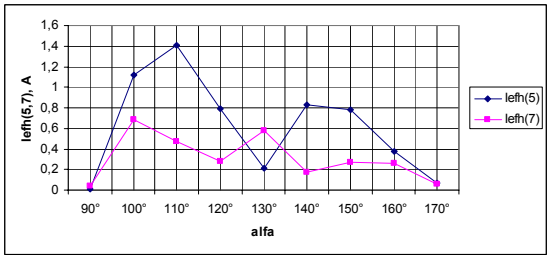

(c)

Fig. 7. Computer simulation results: phase current (a), its harmonics (c), THD (b) parameter changes from α in delta and wye schemes

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 wye circuit.
3. Thyristor regulation of reactor in delta circuit is similar to regulation of single phase AC reactor.

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J. Zakis, O. Plataiskalns, I. Rankis. Trifazių reaktorių sistemų valdomų tiristoriais palyginimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2005. – Nr.3(59). – P.84-87.

Pateikiamas kombinuotų reaktyvinės galios reguliavimo schemų, kurių reaktoriai sujungti žvaigžde arba trikampiu, palyginimas. Sujungimas trikamiu užtikrina tolygesnį valdymą dideliame diapazone nei žvaigždinis sujungimas. Panaudotas abiejų schemų tipų kompiuterinis modeliavimas, modeliavimo rezultatai patvirtina trikampio sujungimo pranašumus. Abiem atvejais turi būti įvertinamos 5-oji, 7-oji ir 13-oji srovės fazės harmonikos.Gautos supaprastintos išraiškos skirtos apytiksliam abiejų shemų fazių srovių skaičiavimui. Skaičiavimo rezultatai gerai sutampa su eksperimentiniais rezultatais. Il. 7, bibl. 4 (anglų kalba, santraukos lietuvių, anglų ir rusų k.).

J. Zakis, O. Plataiskalns, I. Rankis. Comparison of Thyristor Regulated Three-Phase Reactors' Schemes // Electronics and Electrical Engineering. – Kaunas: Technologija, 2005. – No. 3(59). – P.84-87.

In the following paper combined L-C scheme of reactive power compensation with Delta and wye connected reactor circuit are compared. There are 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. Ill. 7, bibl. 4 (in English, summaries in Lithuanian, English, Russian).

Я. Закис, О. Платаискалнс, И. Ранкис. Сравнение управляемых тиристорами трехфазных систем реакторов // Электроника и электротехника. – Каунас: Технология, 2005. – № 3(59). – С.84-87.

В работе проведено сравнение комбинированных схем управления реактивной мощностью, где реакторы соединены или звездой или треугольником. При соединении треугольником можно обеспечить более плавное управление в большем диапазоне чем при соединении звездой, а также улучшается гармонический состав тока фазы. Применено компьютерное моделирование обеих схем, результаты моделирования подтвердили преимущество соединения треугольником, поскольку упрощается также алгоритм реализации системы управления. В обеих случаях 5-ая, 7-ая,11-ая и 13-ая гармоники тока фазы должны быть учтены. Получены упрощенные выражения для приближенного расчета действующих значений токов фаз обеих схем хорошо совпадающие с результатами экспериментального исследования. Ил. 7, библ. 4(на английском языке; рефераты на литовском, английском и русском яз.).