Principles of Realization of Control System for a Compensator of Reactive Power on Base of Gate Commutated Thyristors

Olegs Vasilevičcs[1], Ivars Rankis[2], [1-2]*Riga Technical University*

Abstract **– This paper deals with reactive power compensation system on base of capacitor banks and reactors current of which can be regulate by means of semiconductor devices. In the ordinary case they are Thyristors that don't allow provide efficient regulation with good compatibility with supply voltage. Application of Gate Commutated Thyristors is proposed which allows to provide PWM modulation of reactor current at high frequency. Control system is proposed and it is investigate using PSIM simulation package. Good results are obtained and it allows recommend such system for further investigations.**

Keywords **– Thyristor, reactor, capacitor, power, balance, control, sensor, supply**

I. Introduction

In the paper the basic control principles of reactive power compensation system realization using the new generation of Gate Commutated Thyristors GCT is described. As main target of the investigation is elaboration of proper control system and its investigation for fast-responsible reactive power compensation system on base of sheme capacitor – switched by GCT reactor, which allows operate repeatedly in duration of half cycle of supply voltage.

II. Control Principles of Existing Thyristor Controlled Reactors

The classical scheme of flexible reactive power compensation with capacitor and reactor is presented in Fig. 1 [1,4]. Reactor L1 is chosen taking into account consumption of reactive energy generated by capacitor C1 and in case of necessity – also extra reactive capacitive power generated by loadи.

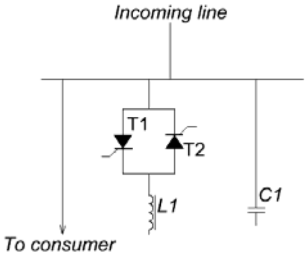

Fig. 1. Application of thyristor regulated reactors as compensators of reactive power.

Generally the maximal reactive power consumed by reactors Q_{L1m} can be:

$$Q_{L1m} \geq Q_{C1} , \qquad (1)$$

where Q_{C1} - reactive power generated by capacitors. Usually it's accepted an equality of the both reactive powers [1]. Control of thyristors is realized using switching angle delay principle [1,4] and at that system initially is balanced in such way that all power generated by reactors are consumed by reactors: i.e. $Q_{L1} = Q_{C1}$ and equality of currents consumed by the both systems have to be provided. It means that in respect to one phase at full (half-cycle) conductivity interval of thyristor for the reactive equipment have to be provided connection between parameters as

$$\omega^2 L_{ph} C_{ph} = 1 , \qquad (2)$$

where ω is angular frequency of supply voltage, L_{ph} and C_{ph} – respectively inductance and capacitance of compensator parts per phase. If reactors are connected in the „star" scheme but capacitors in the „delta"scheme, as it's often done, then capacitance for one leg is $C_l = L_{ph}/3$.

If initial balancing is realized at full (half-cycle) conductivity interval of thyristor (i.e. at the minimally possible delay angle for thyristors which in the case is 90^0) then regulation of reactor current at load's reactive power compensation process is provided increasing delay angle over 90^0, at lowering current consumed by rectors under the initial balancing value.

Simplified scheme of control of such compensation system is represented in Fig. 2. It comprises a sensor of reactive power Qsens1 of load, proportional calibration device P1, summator SUM1 with two input signals – one from device P1 about actual reactive power of all system compensator-load, other as reference signal CONST1, which regards to the initial balancing conditions, and delay angle contro system for thyristors PAC1. At zero value of the summary reactive power signal at input of PAC1 is equal to the CONST1, which provides $\alpha = 90^0$.

In the system at increasing of reactive power of load the signal of sensor Qsens1 calibrated by P1 is rising and summating with CONST1 increase control voltage of the PAC1 and as result delay angle is decreased and current through reactors L1 decreases too. Operation of the scheme trends to keeping common reactive power on level $Q = 0$.

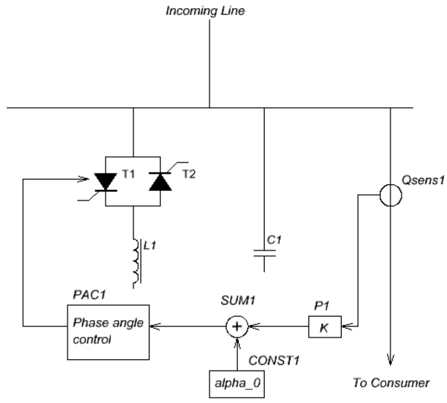

Fig. 2. Simplified control circuit of thyristor controlled reactor.

Main disadvantages of the system are

- bad shape of current consumed by reactors as result of thyristor controlled regulation [1,5];
- slow response reaction time which is connected with control and operation principles of the TCR when reaction can influence balance of reactive powers only after half-cycle of supply voltage [1,5].

Above mentioned disadvantages are restrictions for application of the TCR for compensation of fast processes as it is for instance in electrical arc furnaces [4].

III. Realization of Control Principles for GCT Thyristor Commutated Reactors

Similar principles as presented in the part I should be applied also in system with gate commutated thyristors GCT [2,3]. The main difference will be in possibility to provide high-frequency Pulse Width Modulation of thyristors in each half-cycle of voltage applied to reactors and that allow decrease response time and introduce Low-Pass Filter - obtain good shape of consumed by reactors current.

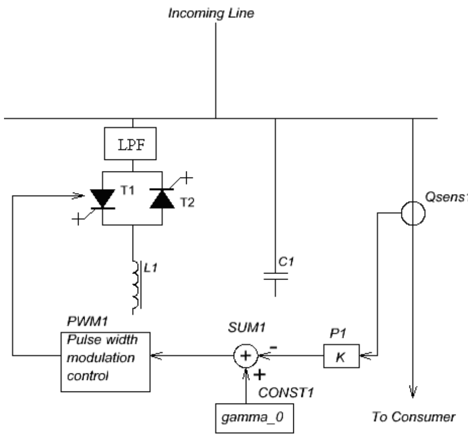

Fig. 3. GCT Thyristor controlled reactor simplified control circuit.

Simplified control system for application of GCT thyristors is represented in Fig. 3. Here instead of delay angle control unit is applied PWM control unit which determines duty ratio D for thyristors turn-on interval duration to switching cycle of each thyristor, only here summator SUM1 has inverse input in respect to signal of sensor Qsens1. As result control signal for PWM device formates as

$$\gamma = \gamma_0 - k \cdot Q, \qquad (3)$$

where γ_0 is initial control signal which defines initial duty ratio D_0 for control which at balancing conditions mentioned above should be equal to the unity value; k - coefficient for calibration; Q - signal which is proportional to the load reactive power.

Fast-operation of system can be evaluate by number of switching pulses of switching semiconductor device per half-cycle of supply voltage. For system with ordinary thyristors is possible only one switching per half-cycle and only on regard to on-switching. In the case when GCT is applied number of available switching depend only on characteristics of the element. For most of GCT the maximal frequency can be up to 800 Hz, but at introducing of proper snabber circuits frequency can be rised up to 10 kHz and compensator's time constant will be:

$$\tau = \frac{1}{f_{\lim}}, \qquad (4)$$

where $f_{\lim}$ - maximal switching frequency of GCT.

In such case parameters of the compensation system will be much better as at using ordinary thyristors when contro impact is possible only by $\tau \geq 10 \cdot 10^{-3}\, s$.

IV. Model of GCT Thyristor Controlled Reactors Compensation System

For simulation of the scheme a package PSIM 9.0 is applied. Simulation scheme for the system in Fig.3 is presented in Fig. 4 This model is constructed for symmetric load which in step-mode can be changed with given ferquency. Elements VSIN1, R1, R2, R3 are substituting a supply network, R14, R15, R16, L7, L8, L9 are modeling an active-reactive load which is on-turned to the supply through switch SSWI31, controled by link C9-TD1-TD2-NOT3-AND1-ON10, forming time delay on turn-on and turn-off of the load. At adopted parameters load is turned-on by 1 s from initial start and then in 0.5 s – turned-off. Compensation device comproses reactors L1, L2, L3, switches SS1, SS2, SS3, which connect reactors to the supply and ones SS7, SS8, SS9, by-passing reactors when logical sygnal of PWM regulator is 0.

Resistors R8, R9, R10 are modeling internal resistances of reactors. Reactors are really connected to the supply through Low-pass filter on base of elements L4, L5, L6, C5, C6, C7, and it's tuned on adopted switching frequency of thyristors 5 kHz.

Current consumed by reactors is balancing current of capacitors C1, C2, C3. Reactive power consumed by load is measured using sensor combined on elements VSEN1, ISEN1, MULT1, ABS1. According to the block-scheme described in the part III the signal from the sensor in summator SUM1 is subtracted from initial duty ratio signal γ_0, generated with junction C8. Obtained control signal is applied to the PWM regulator on base of linear rising saw-tooth voltage generator VSAW1 and comparator COMP1. Comparators output controls turn-on of introduced in reactors line thyristors but inverse signal – thyristors by-passing reactors.

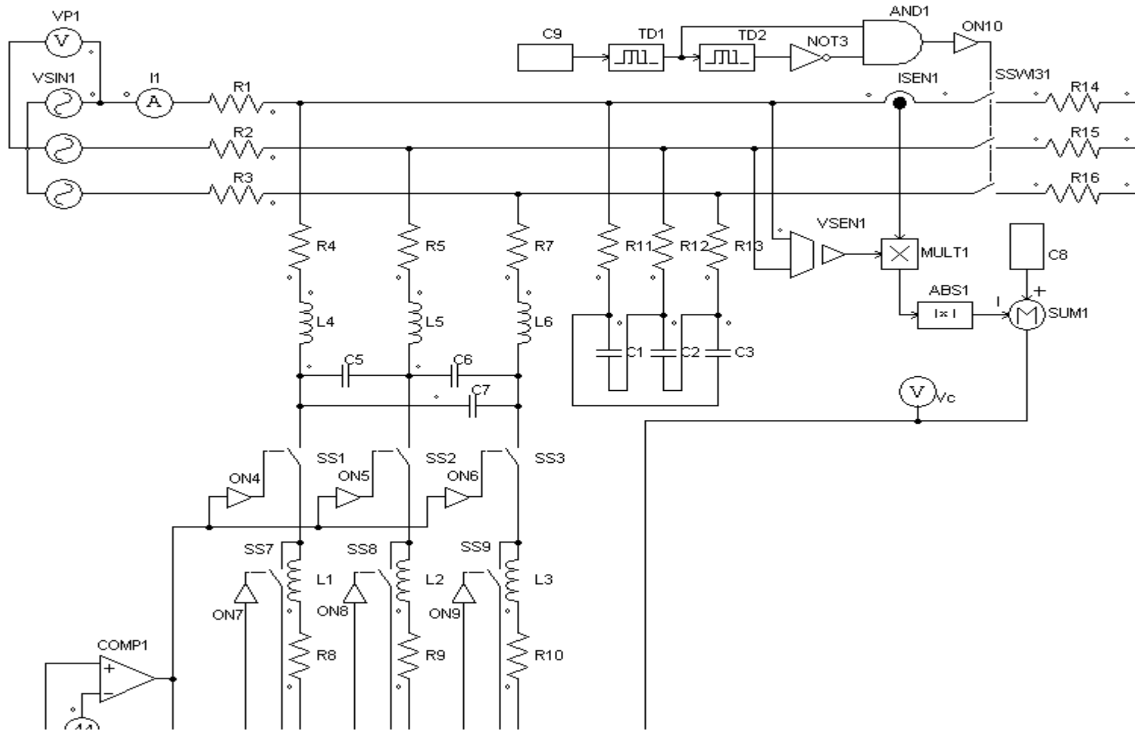

Fig.4. Simulation scheme for the considered system

The rated parameters of elements of the system are presented in Table I.

TABLE I

ELEMENTS PARAMETER VALUES USED IN MODEL

Designation	Parameter value
R1 – R13	10 mΩ
R14 – R16	12 Ω
L1 – L3	3 mH
L4 – L6	0.1 mH
L7 – L9	5 mH
C1 – C3	1000 µF
C5 – C7	100 µF
VSIN1	400 V 50 Hz

Using parameters it can be possible state that maximum reactive power compensated by system at duty ratio $\gamma = 0$ (reactors are at turn-off constant position) is $Q_C = 150.79k$ var, but initial duty ratio can be installed $\gamma_0 = 0.918$.

V. INVESTIGATION OF TRANSITION PROCESSES OF MODELED COMPENSATION SYSTEM

The first transient process is at initial turn-on all compensation utility to supply network. It comprises initial charging of capacitors and magnetizing of reactors at duty ratio γ_0. This process is represented in Fig. 5. Length of transient process is 0.6 s but initial current reaches up to $361A$. At end of the transient process sinus shape current which is in phase with supply voltage wave – it means that utility is in balance of reactive powers and consumed current is of active mode compensating losses of power in resistances of reactive elements of utility.

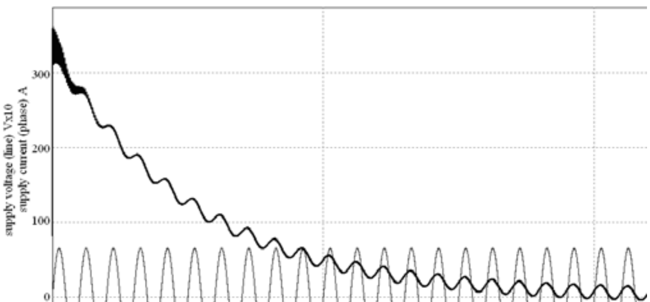

Fig. 5. Transient process of switching on the compensation utility. Bold line shows current I1, regular line shows voltage VP1 multiplicated by 0.2.

At turn-on and off of an active-reactive load take place transient processes presented in Fig. 6. At turn-on of load (simulation time: 1s) control voltage at input of comparator COMP1 is decreasing step-wise. As result duty ratio of switching is decreased and current of reactors too. Capacitors are interchanging reactive power between themselves and reactive elements of load. Current of supply is directly in phase with voltage, i.e. supply is providing only active power.

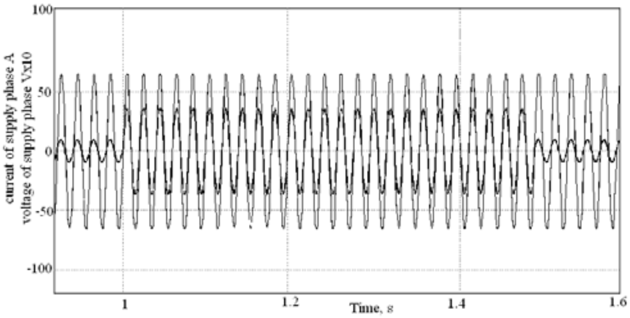

Fig. 6. Transient process of switching on and off active-reactive load to the grid. Bold line shows current I1, regular line shows voltage VP1 multiplicated by 0.2.

Duration of transient process is negligible small and at simulation step $1 \cdot 10^{-5} s$ there are no any delays at changes of current in respect to supply voltage. Shape of current in supply phase cioincides in full extent with one of phase voltage. Rised magnitude of current can be explained with risng consuming of an active power from supply.

VI. Conclusions

1. Flexible system of reactive power compensation is elaborated using Gate Commutated Thyristors and examined using computer simulation.
2. Results of computer modeling show on possibility to practical realize such flexible reactive power compensation system using system reactor-fast switched reactors.
3. Proposed system is not complex and only distinction from ordinary systems is in high-frequency switching of GCT, i.e. existing systems of flexible reactive power compensation can be improved applying elaborated principles.
4. High switching frequency allows use efficents Low-pass filters for providing of sinus shape of reactors' current.

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Ivars Rankis, professor, Hab.Dr.sc.eng. He graduated from Riga Polytechnical institute in 1960 as engineer-electromechanic. Defended his first degree of Dr.sc. (candidate of technical sciences) in 1970. Defended his second degree Hab.Dr.sc.eng. in 1992 at Riga Technical university. From 1958-1966 he worked as engineer at Riga Electrical machine building company. From 1966 he started studies as doctoral student, but from 1970 – as teacher of different subjects of electrical engineering at Riga Technical university. Research interests are connected with Power electronics and Industrial automation. Now is professor at departement of Industrial electronics and electrical technologies of Riga Technical university. Riga Technical university, Institute of Industrial Electronics and Electrical Engineering

Address: Kronvalda 1, LV1048,Riga.

Phone +371 67 089 917, rankis@eef.rtu.lv

Olegs Vasilevics, engineer, has defended a Master of sc. Degree at RTU in 2011, now working as Automation Engineer at **JSC "Liepajas Metalurgs"** factory.

Address: Brivibas 93, LV-3401, Liepaja.

Phone: +37122318749,

oleg.vasilevich@metalurgs.lv

Oļegs Vasiļevičs, Ivars Raņķis. Uz pilnīgi vadāmu tiristoru bāzes izveidotas reaktīvās jaudas kompensācijas sistēmas vadības principu realizācija

Publikācijā aprakstīti ātrdarbīgas reaktīvās jaudas kompensācijas iekārtas vadības principi. Piedāvāts veidot iekārtu pēc shēmas "ar tiristoru komutējams reaktors", izmantojot jaunas paaudzes brīvi komutējamos tiristorus – GCT. Atšķirībā no klasiskās shēmas ar tiristoriem, kuriem regulēšanas efekts sasniedzams tikai ar regulēšanas leņķa izmaiņu, pielietojot GCT ir iespējams izmantot tiristoru vadībai augstfrekvences impulsa-platuma modulācijas principu, palielinot reaktoru komutācijas skaitu viena tīkla sprieguma pusperioda laikā. Tādējādi var ievērojami palielināt sistēmas ātrdarbību. Pie tam regulējošais efekts šādā sistēmā tiek panākts, proporcionāli aktīvi-induktīvās slodzes patērētajai reaktīvajai jaudai mainot tiristoru vadāmības realatīvo laiku pārslēgšanas periodā. Ieviešot augstfrekvences filtru, iespējams panākt augsti kvalitatīvu reaktoru patērēto maiņstrāvu ar niecīgiem harmoniskajiem kropļojumiem. Izveidota pilna datormodeļa shēma, veikti parametru izvēlei nepieciešamie aprēķini. Teorētiskā izpēte ir veikta ar pārejas procesu datormodelēšanas paņēmienu slodzes pēkšņu izmaiņu laikā, izmantojot programmatūru PSIM 9.0. Iegūtie rezultāti liecina par piedāvātās shēmas realizācijas iespēju, kā arī ļoti augsto ātrdarbību, kas ļauj praktiski momentāni izmainīt kompensācijas režīmu.

Олег Василевич, Ивар Ранькис. Принципы реализации системы управления компенсатором реактивной мощности на базе коммутируемых управляющим электродом тиристоров

В статье описаны принципы управления быстродействующей системой компенсации реактивной мощности, построенной по схеме «реактор, управляемый тиристором». В отличие от классической схемы, где эффект достигается изменением угла регулирования обычных тиристоров, предлагается использовать запираемые тиристоры нового поколения – GCT, что позволяет применить широтно-импульсный метод высокочастотного управления ими, и увеличив количество коммутаций реактора за время протекания одного полупериода сетевого напряжения, достичь большего быстродействия системы. При этом, используя фильтр высоких частот, возможно обеспечить потребляемый реакторами от сети ток с очень низкими гармоническими искажениями, что было невозможно в системе с обычными тиристорами. В предлагаемой системе эффект регулирования достигается изменением ширины импульсов переключения тиристорв пропорционально потребляемой нагрузкой системы отстающей реактивной энергии. Теоретическое исследование проводилось методом компьютерного моделирования переходных процессов с помощью программного обеспечения PSIM 9.0. Полученные результаты свидетельствуют о возможности реализации предложенной схемы и показали возможность достичь очень высокого быстродействия системы компенсации.