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An Innovative TCR Compensator for Closed Loop Reactive Power Compensation of Dynamic Loads

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Abstract: Topology for closed loop reactive power compensation suitable for dynamic loads using TCR is presented. Firing angle range of TCR is selected in such a way to keep the harmonic content at a minimum level. Simulation results show that the proposed scheme can achieve reactive power compensation in less than a half cycle and the harmonics contents of source are maintained at insignificant levels due to delta connection of TCR and appropriate firing angle range selection of TCR.

Keywords: Reactive Power Compensation, SVC, TCR, harmonics, power factor, firing angle

I. INTRODUCTION

Any power problem manifested in voltage, current, or frequency deviations that result in failure, misoperation or even damage of customer equipment is considered as a power quality problem [1, 2]. Different power quality problems are power frequency disturbances, power system transients, electromagnetic interference, electrostatic discharge, power system harmonics, poor Power Factor (P.F.), grounding and bonding problems etc. [3]. Many big industries, commercial and industrial electrical loads include power transformers, welding machines, arc furnaces, induction motor driven equipment such as elevators, pumps, and printing machines etc., which are mostly inductive in nature. These loads create serious power quality problems. Low power factor is the predominant problem nowadays. Poor P.F. has various consequences such as increased load current, large KVA rating of the equipment, greater conductor size, larger copper loss, poor efficiency, poor voltage regulation, reduction in equipment life etc. Therefore it is necessary to solve the problem of poor P.F. Static VAR Compensator (SVC) provides a better solution to improve the power factor. SVC consists of standard reactive power shunt elements (reactors and capacitors) which are controlled using thyristors to provide rapid and variable reactive power. They can be grouped into two basic categories; Thyristor switched capacitor (TSC) and Thyristor controlled reactor (TCR). TSCs can be arranged in steps to provide reactive power compensation (only leading). By controlling the gate pulses of thyristors, the reactive power can be controlled. Capacitor bank step values can be chosen in binary sequence weights to make the resolution small. If such 'n' capacitor steps are used then 2^n different compensation levels can be obtained [4]. Capacitors can provide only leading reactive power. In order to absorb the excess leading reactive power supplied by the capacitors TCR is connected in conjunction with TSCs. Controller determines the value of reactive power required to achieve the desired power factor and then generates the control signals (gate signals) which can be given to TSC banks and TCR. By coordinating the control between TCR and TSC, it is possible to obtain fully stepless control of reactive power in closed loop. In the proposed paper closed loop operation of TCR to achieve dynamic reactive power compensation is presented. The connection of TCR Compensator with dynamic load and source is shown in Fig.1.

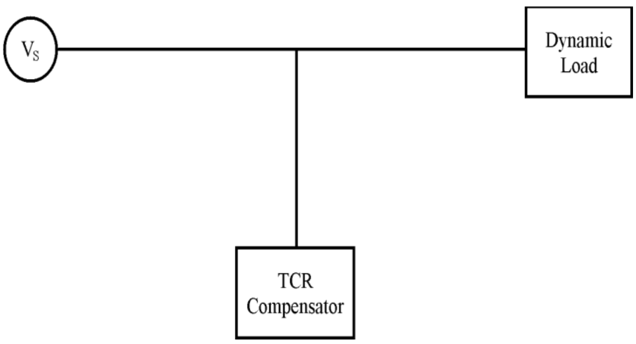

Fig. 1 Proposed Topology

II. TCR

Reactors may be both switched and phase-angle controlled [5], [6], [7]. When reactors are phase-angle controlled then that reactor is called as TCR (Thyristor Controlled Reactor). Whereas when reactors are switched (i.e. either fully on or fully off) then that reactor is called as TSR (Thyristor Switched Reactor) [8]. A basic TCR consists of an anti-parallel connected pair of thyristor valves in series with a reactor. The anti-parallel connected thyristor pair acts like a bidirectional switch. TCR behaves like a

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variable susceptance. Variations in the firing angle, α changes the susceptance and, consequently, the fundamental current component I_1 which is shown by equation (1) [8].

$$I_1(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha\right) \quad (1)$$

Where, V - Peak value of the supply voltage
ω - Angular frequency of supply voltage
Variation in the fundamental current component leads to variation of reactive power absorbed by the reactor. Thus by changing the firing angle of thyristors stepless variation of reactive power can be achieved. If firing angle is increased beyond 90^0, the current becomes non sinusoidal and odd harmonics are generated [9]. TCR is connected in delta so as to prevent the odd tripplen harmonics from entering into the transmission lines. The inductor in each phase is split into two halves, one on each side of the anti-parallel connected thyristor pair, to prevent the full ac voltage appearing across the thyristor valves and damaging them if a short-circuit fault occurs across the reactor's two end terminals [8]. A three phase, six pulse TCR comprises three single phase TCRs connected in delta, as shown in Fig. 2. The inductor in each phase is split into two halves (not shown in the Fig. 2) one on each side of the anti-parallel connected thyristor pair, to prevent the full ac voltage appearing across the thyristor valves and damaging them if a short-circuit fault occurs across the reactor's two end terminals. The delta connection of the three single-phase TCRs prevents the triplen (i.e., multiples of third) harmonics from percolating into the transmission lines [8].

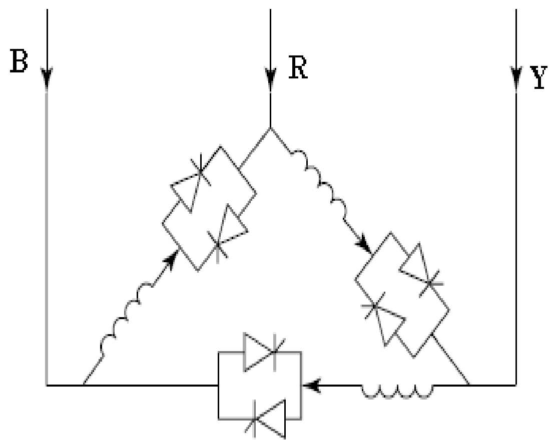

Fig. 2 Three phase delta connected TCR

TCR has following advantages: ability to perform stepless reactive power compensation, maximum delay of one half cycle and practically no transients. However it has few disadvantages like generation of low frequency harmonic current components, higher losses when working in the inductive region (i.e. absorbing reactive power) [5]. To overcome these disadvantages in proposed scheme, TCR firing angle range is selected in such a way that harmonic level at the point of common coupling (PCC) is maintained at minimum value and resistance value associated with reactor is kept minimum to reduce the losses.

III. TCR CONTROLLER

A block diagram of reactive power compensator using TCR is shown in Fig. 3. Reference reactive power, Q_{Ref} is compared with the actual reactive power at PCC, Q_{Actual}. The error signal is converted to the TCR firing angle using lookup table method. In this way closed loop operation of TCR for capacitive reactive power absorption is achieved.

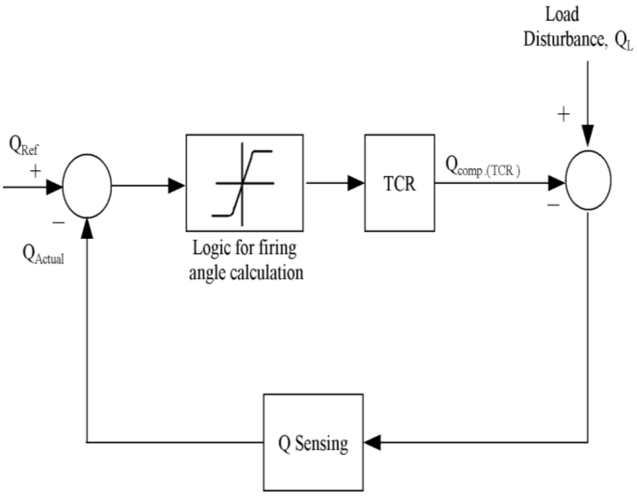

Fig. 3 TCR closed loop operation

IV. SIMULATION OF CLOSED LOOP OPERATION USING TCR

To verify the performance and accuracy of the proposed technique, extensive simulation studies are carried out using MATLAB/Simulink software.

A. Simulation Parameters-

Data used in simulation is shown below.
Source:-
V_s = 400 V, R_s = 0.0287 Ω, L_s = 0.20471mH
TCR Data:-
Each coil have R = 9 Ω and L = 300mH. This will provide reactive power absorption of 2.5 KVAR.

B. Simulation of three phase dynamic load:-

Three-phase three-wire dynamic load is simulated to get a continuously changing reactive power. Active power P and reactive power Q vary as function of positive-sequence voltage. The load impedance is kept constant if the terminal voltage V of the load is lower than a specified value V_{min}. When the terminal voltage is greater than the V_{min}, the active power P and reactive power Q of the load vary as follows:

$$P(s) = P_0 \{V/V_0\}^{n_p} \frac{(1 + T_{p1}s)}{(1 + T_{p2}s)}$$

$$Q(s) = Q_0 \{V/V_0\}^{n_q} \frac{(1 + T_{q1}s)}{(1 + T_{q2}s)}$$

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Where,
P_o and Q_o- Initial active and reactive powers at the initial voltage V_o
V - Positive-sequence voltage
V_o - Initial positive sequence voltage
n_p and n_q - Exponents that controls the nature of load
T_{p1} and T_{p2} - Time constants that controls the dynamics of active power P
T_{q1} and T_{q2} - Time constants that controls the dynamics of reactive power Q

Here n_p =1, n_q =1, T_{p1} = 0, T_{p2} = 0, T_{p2} = 0, T_{q2} = 0

Parameters of three phase dynamic load block are adjusted such that Q_L varies continuously from $Q_{Min.}$ = 260 VAR to $Q_{Max.}$ = 2500 VAR with base load, $Q_{Base.}$ = 1500 VAR. Look up table method is used to achieve the closed loop operation of TCR.

C. *Firing angle range selection:-*

Table I shows for various firing angles α, the fundamental line and phase currents $I_1(\alpha)$ in ampere, % Total Harmonic Distortion (THD_I) values in line and phase and reactive power Q in VAR. From Table I it can be concluded that,

a. Reactive power Q can be varied by changing the firing angle α.

b. THD_I values in line are less than that of phase. This is due to the fact that all triplen harmonics get circulated through phase and they do not enter into the line side because of delta connection of TCR.

c. As the firing angle α approaches to 180^0, the THD_I goes on increasing. It is observed that the safest region of TCR operation without significant harmonics is in between 85^0 to 140^0. This firing angle range is used to avoid the large harmonic distortion. TCR will provide reactive power compensation from 260 VAR to 2500 VAR in stepless manner.

TABLE I. SIMULATION RESULTS OF TCR

Sr. No.	α in Degrees	Q in VAR	% THD $_I$		$I_1(\alpha)$	
			Line	Phase	Line	Phase
1	85	2500	0.63	1.11	3.53	2.04
2	95	1780	9.27	16.69	2.58	1.48
3	105	1514	11.48	23.46	2.19	1.26
4	115	975	10.48	39.41	1.41	0.81
5	125	685	11.66	51.98	0.99	0.57
6	135	358	26.30	75.78	0.51	0.29
7	145	172	54.89	106.71	0.24	0.14
8	155	43	152.9	214.45	0.06	0.035

D. *Dynamic reactive power compensation:-*

Waveforms of load reactive power Q_L, reactive power given by TCR $Q_{comp.(TCR)}$ and actual reactive power Q_{Actual} at point of common coupling (PCC) are shown in Fig. 4. From simulation results it is seen that $Q_{comp.(TCR)}$ closely follows Q_L and actual reactive power Q_{Actual} at PCC is approximately zero at all times i.e. power factor is maintained at unity.

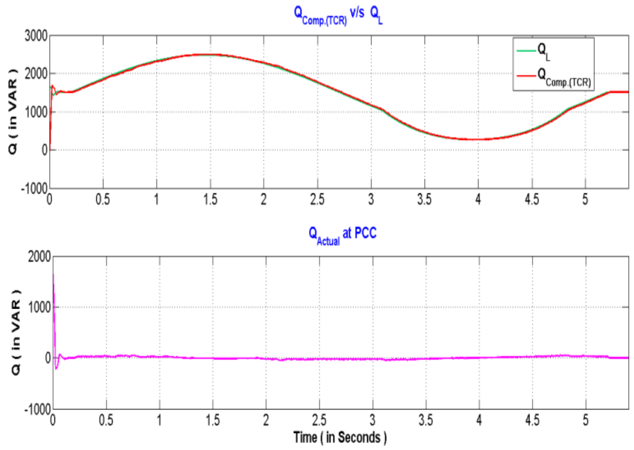

Fig. 4 Simulation results of TCR

E. *Source current waveform:-*

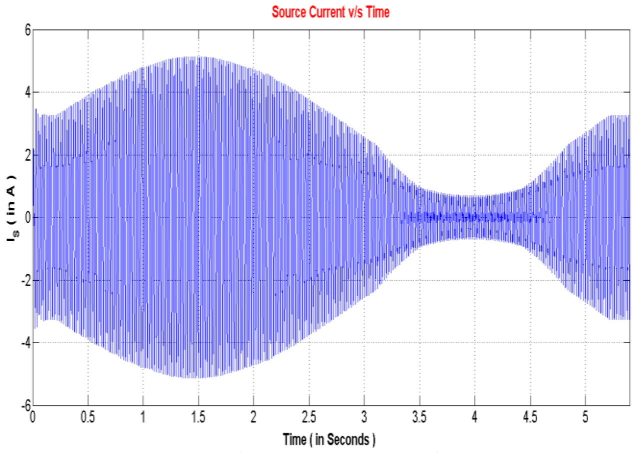

Fig. 5 Current waveform through source (of R phase only)

Current waveform through source (of R phase) is shown in Fig. 5 which is transient free.

V. CONCLUSION

A topology using TCR was presented. Due to delta connection of TCR and firing angle range control it was possible to keep the harmonics content at the minimum level. TCR controller is designed in such a way to provide the closed loop reactive power compensation. Simulation results show that the operating time of TCR is less than one cycle. The presented scheme can be used in conjunction with the TSCs to achieve stepless reactive power compensation of dynamic loads. By using TSC-TCR compensator one can operate the system at any desired power factor with minimum harmonics generation. TSC-TCR scheme can also be used for starting of induction motors with voltage sag mitigation.

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BIOGRAPHIES

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U. Gudaru, aged 73 years has obtained his B.E. in 1962, M.E. in 1966 and Ph.D in 1983. He published three papers at International level, and presented / published 32 other papers at National seminars / Journals. After superannuation in 1999, the All India Council for Technical Education (AICTE) has awarded Emeritus Fellowship for carrying out research work on the topic, “Measures for Power Quality Improvement”. The author is a Fellow of Institution of Engineers (India) in their Computer Engineering Division. He is a member of IEEE in their power engineering society since 2000.