Analysis and Minimization of Harmonics of Thyristor Controlled Reactor (TCR)

Yadav Pratibha Subhashrao
Research scholar
Annasaheb Dange College of Engg & Technology,Ashta
Sangli, India

Dr. Mulla Anwar Mubarak
Principal
Annasaheb Dange College of Engg & Technology,Ashta
Sangli, India

Abstract— **This paper proposes a firing angle range control and minimization of harmonics in thyristor controlled reactor (TCR). A typical Static Var Compensator generally consists of a Thyristor Controlled Reactor (TCR) & a Thyristor Switched Capacitor (TSC) which compensates loads through generation or absorption of reactive power. The operation of Thyristor Controlled Reactors at appropriate conduction angles can be used advantageously to meet the phase-wise unbalance and varying load reactive power demand in a system. However, such an operation deteriorates the quality of power supply through percolation of harmonic currents into the mains.**

This paper presents an approach to minimize harmonic generation internally by different combinations of Delta connected TCR by using MATLAB SIMULATION. In particular harmonics will be investigated and range of firing angle fixed for satisfactory operation.

Keywords—- TCR, Harmonics, Firing angle.

I. INTRODUCTION

The electrical power system plays a very important role in our day to day life. Now a day due to modernization there is increase in the industrial load on system which mainly consists of non-linear load. The dynamic nature of industrial loads such as arc furnaces, traction loads, mills, single phase fluctuating loads and saturated transformers cause unbalance on the system due to which the power quality of supply deteriorates, leads to fluctuation in supply voltage which may cause flicker, sag, swell, noise and disturbance which are undesirable to consumers. The result of all these is it introduces harmonics in system and reactive power is also serious problem associated with it. The presence of harmonics and reactive power is harmful because it causes undesirable effects such as over current, extra power loss, interference with telecommunication system and malfunctioning of system components [1][2].

To improve the power quality of the system a Flexible AC Transmission system (FACTS) devices are widely used. The SVC's are preferred over traditional Var compensators such as saturable reactors, switched capacitors or combination of both due to additional advantages like fast response, high reliability, flexibility and low maintenance cost[3].

A Static Var Compensator generally consists of a Thyristor Controlled Reactor (TCR) & a Thyristor Switched Capacitor (TSC). It compensates loads through generation or absorption of reactive power. A thyristor –controlled reactor (TCR) is one of the FACTS device used to improve power quality. It can absorb a continuous reactive power at fundamental frequency of the power system network, but it introduces harmonic currents into the power supply system. In such cases, it becomes necessary either to minimize harmonic generation internally or provide external harmonics filters [4][5].

Today, a number of methods have been proposed to address this phenomenon. One conventional method is the application of LC passive filter. However, LC passive filter has disadvantages: The designing form is large and weight to filter low frequency harmonic current order. The LC filter which to filter harmonic current needs specific value of LC for each order harmonic. Beside this, The LC filter has a problem formulation due to the system impedance variation and resonance condition. The other method in reducing harmonic is Active Power Filter (AFP). The active power filter is a PWM inverter current source[1]-[2]. Therefore, it is very difficult used for high capacity and more expensive. The other disadvantage of PWM inverter is that it generate high order harmonic current which can distorted the telecommunication systems, audio and video system.

II. PROPOSED SYSTEM

The objective of this work is to analyze the harmonics generated in TCR with the firing angle control method. The harmonics produced can be minimized by following methods -

- By splitting the TCR in equal steps, and controlling only one step.
- By using Binary sequential steps for the TCR.

This will be investigated through simulation

A. By splitting TCR in equal steps-

Fig.1 shows the delta connected TCR divided into number of steps. Each step having equal value of all reactors. L=74.59mH and R=1Ω and reactive power of 12 KVAR. In this paper three equal steps are used.

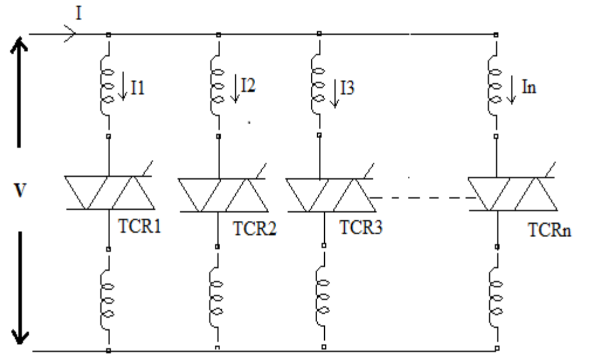

Fig.1 Equally Splitted TCR bank To Achieve Harmonic Reduction.

This method is advantageous for high power applications, employs 'm' (m≥2) parallel connected TCRs, each with 1/m of the total rating required. The reactors are sequentially controlled, that is only one of the 'm' reactors is delay angle controlled and each of the remaining 'm-1' reactors is either fully 'on' or fully 'off' depending on total reactive power required[7-8].

B. By using binary sequential steps-

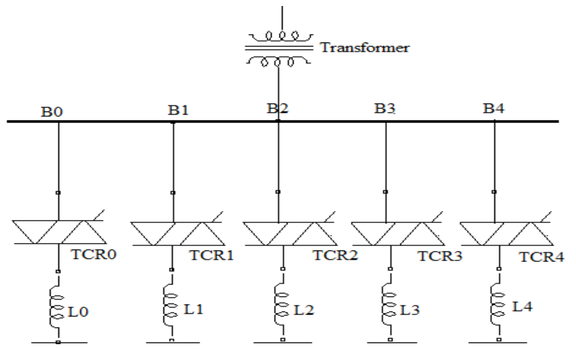

Fig.2 TCR In Binary Sequential Steps

Fig.2 shows Delta connected TCR divided into binary sequence steps. Here TCR is divided into four steps of 2.5, 5, 10, 20KVAR.

For 2.5 KVAR L=350mH & R=1Ω.

For 5 KVAR L=170mH & R=1Ω.

For 10 KVAR L=85.51mH & R=1Ω.

For 20 KVAR L=42.75mH & R=1Ω.

$$Q = 2^nL + 2^{n-1}L + \dots\dots\dots + 2^2L + 2^1L + 2^0L$$

In this method reactor bank step values are chosen in binary sequence weights to make the resolution small. The Q can be arranged in binary sequential 'n' steps, satisfying the above equation [1].

III. SIMULATION MODEL

The fig(3) shows the single Delta connected TCR configuration which consists of six RL branches having value 1Ω and 25.4mh respectively, & switches, pulse generator with three phase 440volt AC supply. It is designed for 36 KVAR reactive power requirements. This simulation model is designed for harmonics analysis study.

The reactor coil in the phase is split in two halves to prevent the full AC voltage appearing across the thyristor. The entire Simulink model has been shown in the Fig.(3) The Table 1 shows the various fundamental rms magnitudes as well as percentage of harmonic current generated with respect to fundamental component of the current for firing angle α varying from 72° to 171°. The data for various firing angles α was collected. The various parameters noted are fundamental current component to the 12th harmonic component. The plot of magnitude of the entire harmonics v/s firing angle is depicted in Fig.(a) to Fig.(i). and the FFT Analysis of harmonic spectrum for firing angles is shown in Fig.(A) to Fig (F).

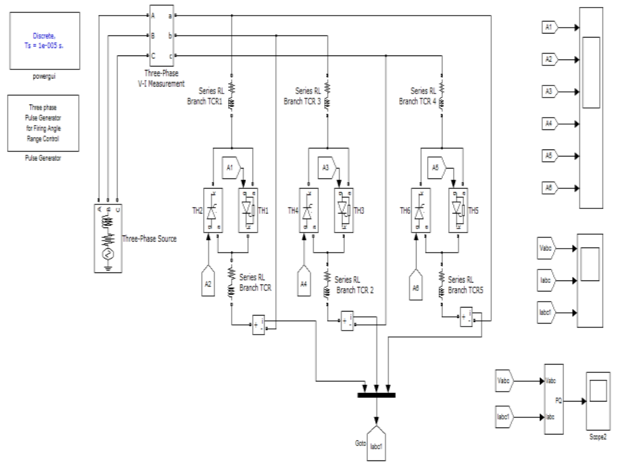

Fig. 3 Open loop simulation model of Three phase Delta connected TCR

IV. SIMULINK MODEL RESULT

TABLE 1- SIMULATION RESULTS OF TCR FOR VARIOUS FIRING ANGLES

Sr.No	Firing Angle (α)	%THD			Fundamental Current		
		Single TCR	Equally Stepped	Binary TCR	Single TCR	Equally Stepped	Binary TCR
1	72	6.43	5.75	5.28	43.65	45.18	49.7
2	81	6.71	5.92	5.34	43.2	45.01	49.66
3	90	7.86	6.01	5.39	36.6	44.61	49.61
4	99	10.28	6.06	5.38	29.46	41.24	49.25
5	108	11.35	6.03	5.33	22.63	38.62	48.17
6	117	10.05	5.91	5.31	16.44	36.27	47.88
7	126	12.48	6.06	5.35	11.12	34.25	47.33
8	135	21.45	6.21	5.38	6.826	32.64	46.96
9	144	40.57	6.22	5.36	3.643	31.45	46.73
10	153	73.14	7.47	5.34	1.551	28.35	46.54
11	162	127.45	7.28	5.32	0.4162	27.94	46.46
12	171	1184.02	7.19	5.31	0.00887	27.78	46.43

DC Current Component			%H2			%H3		
Single TCR	Equally Stepped	Binary TCR	Single TCR	Equally Stepped	Binary TCR	Single TCR	Equally Stepped	Binary TCR
6.3	15.02	21.83	4.82	4.36	3.9	2.36	2.1	2
3.517	12.94	21.14	5.14	4.51	3.95	2.39	2.14	2.02
2.724	11.41	20.45	5.35	4.62	3.99	2.4	2.17	2.04
2.171	11.22	20.47	5.55	4.63	4	2.48	2.17	2.04
1.654	11.01	20.43	5.77	4.63	3.99	2.6	2.17	2.04
1.185	10.82	20.37	5.98	4.6	3.96	2.77	2.17	2.04
0.7844	10.67	20.34	6.13	4.54	3.95	3.01	2.15	2.03
0.4732	10.55	20.32	6.22	4.47	3.94	3.33	2.13	2.03
0.2502	10.47	20.3	6.26	4.4	3.92	3.8	2.1	2.03
0.1074	14.06	20.29	6.28	6.37	3.92	4.58	1.38	2.02
0.03134	14.03	20.28	6.66	6.42	3.91	6.48	1.41	2.02
0.00338	14.02	20.28	31.73	6.44	3.91	55.55	1.43	2.02

%H4			%H5			%H6		
Single TCR	Equally Stepped	Binary TCR	Single TCR	Equally Stepped	Binary TCR	Single TCR	Equally Stepped	Binary TCR
1.87	1.64	1.43	1.45	1.33	1.33	0.87	0.76	0.9
1.96	1.7	1.45	1.28	1.29	1.33	0.92	0.78	0.91
2	1.72	1.46	2.33	1.17	1.33	0.82	0.82	0.92
1.98	1.73	1.46	6.26	0.97	1.29	0.81	0.75	0.92
1.87	1.7	1.46	8.3	1.32	1.16	1.01	0.76	0.9
1.59	1.64	1.44	6.15	0.97	1.13	1.34	0.82	0.91
1.06	1.57	1.43	2.98	1.25	1.23	1.58	0.85	0.94
0.26	1.53	1.42	17.66	2.27	1.44	1.75	0.84	0.94
0.9	1.52	1.42	38.64	2.68	1.52	2.78	0.81	0.93
2.19	1.36	1.42	63.53	2.9	1.49	4.96	0.62	0.92
3.83	1.4	1.43	94.28	2.19	1.41	8.15	0.61	0.92
25.93	1.42	1.43	574.62	1.75	1.36	52.49	0.61	0.92

%H7			%H8			%H9		
Single TCR	Equally Stepped	Binary TCR	Single TCR	Equally Stepped	Binary TCR	Single TCR	Equally Stepped	Binary TCR
0.92	0.77	0.64	0.85	0.75	0.66	0.7	0.61	0.58
1.05	0.83	0.66	0.81	0.75	0.67	0.72	0.63	0.59
2.79	0.81	0.67	0.86	0.75	0.67	0.73	0.64	0.6
4.14	1.05	0.58	0.9	0.77	0.67	0.67	0.63	0.59
2.34	0.88	0.56	0.84	0.78	0.67	0.65	0.62	0.59
3.14	0.92	0.64	0.66	0.74	0.68	0.65	0.61	0.59
8.61	1.49	0.84	0.41	0.7	0.67	0.6	0.6	0.59
8.17	1.27	0.8	0.46	0.71	0.66	0.65	0.61	0.59
4.88	0.68	0.63	1.37	0.77	0.66	1.27	0.63	0.59
32.09	0.18	0.53	3.27	0.47	0.67	1.99	0.54	0.59
73.91	0.23	0.6	5.86	0.45	0.67	3.29	0.52	0.59
554.55	0.53	0.63	35.34	0.42	0.67	46.47	0.51	0.59

%H10			%H11			%H12		
Single TCR	Equally Stepped	Binary TCR	Single TCR	Equally Stepped	Binary TCR	Single TCR	Equally Stepped	Binary TCR
0.66	0.59	0.53	0.53	0.48	0.52	0.5	0.42	0.43
0.62	0.58	0.53	0.56	0.49	0.52	0.59	0.46	0.44
0.65	0.58	0.53	1.89	0.56	0.53	0.57	0.46	0.44
0.69	0.59	0.53	1.2	0.89	0.52	0.46	0.46	0.44
0.66	0.61	0.53	1.33	0.42	0.54	0.43	0.4	0.44
0.52	0.58	0.53	0.85	0.32	0.56	0.57	0.41	0.44
0.36	0.55	0.53	3.46	0.67	0.55	0.58	0.44	0.44
0.61	0.58	0.53	2.76	0.75	0.51	0.59	0.43	0.44
1.41	0.62	0.53	6.48	0.44	0.52	0.62	0.41	0.44
1.76	0.64	0.53	5.47	0.3	0.54	1.54	0.26	0.44
0.26	0.61	0.53	33.83	0.52	0.53	3.43	0.27	0.44
17.88	0.61	0.53	507.05	0.45	0.52	47.38	0.26	0.44

A. *The comparative plot of Firing Angle V/S different components of TCR for various Combinations.*

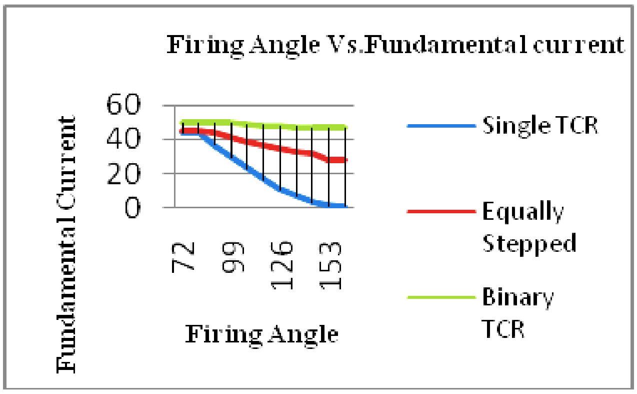

Fig.(a) Fundamental component of line current for TCR.

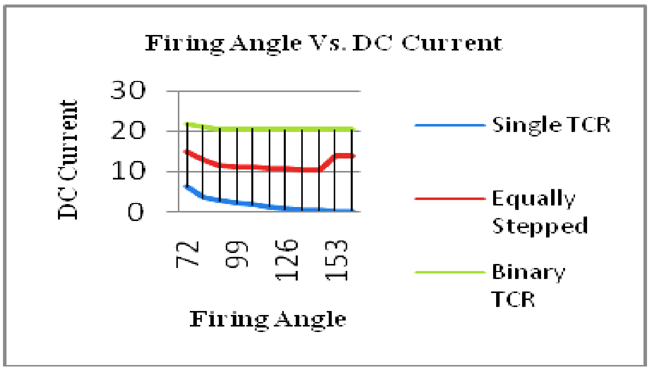

Fig.(b) D.C. components of TCR

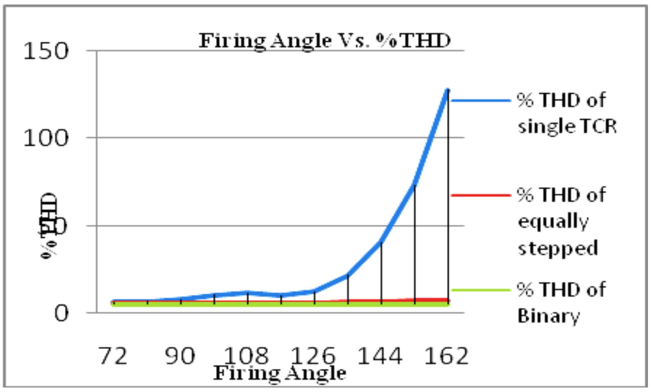

Fig.(c) Total THD components of TCR.

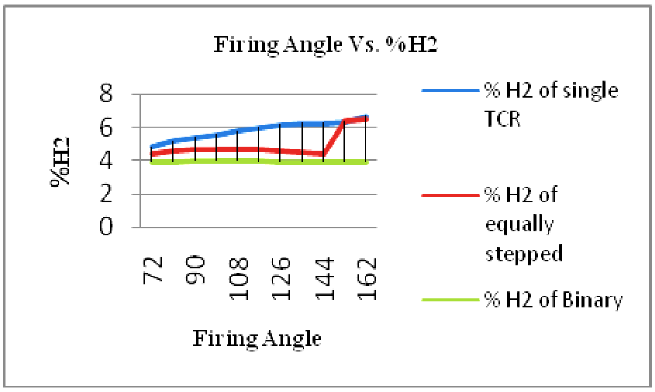

Fig. (d) Even harmonics of TCR for H2

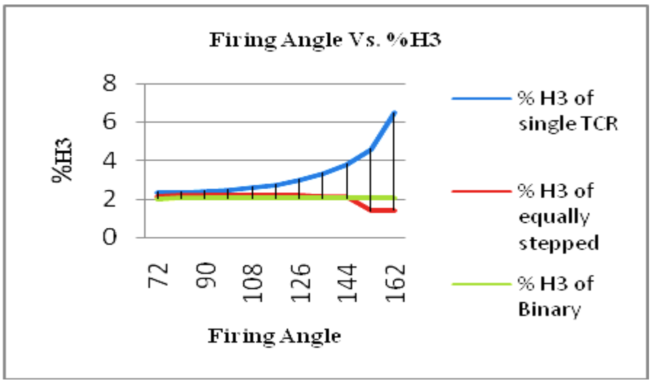

Fig. (e) Triplen harmonics of TCR for H3

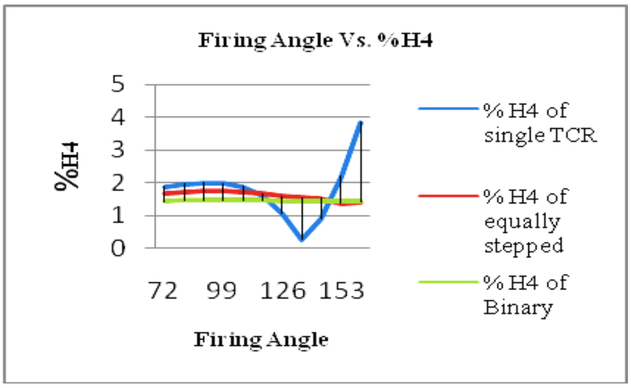

Fig. (f) Even harmonics of TCR for H4

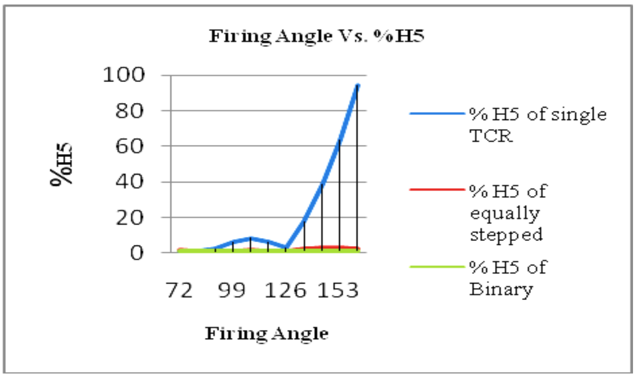

Fig. (g) Odd harmonics of TCR for H5

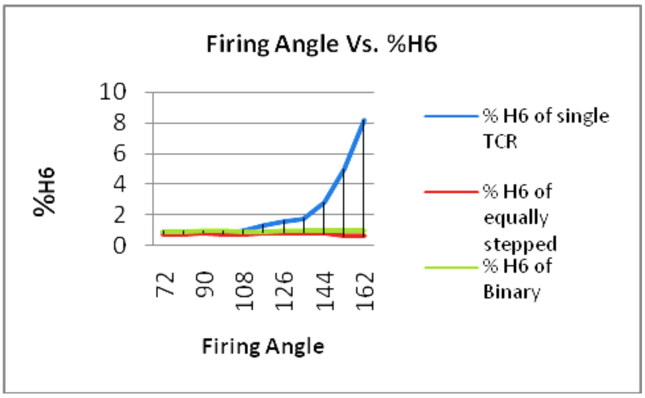

Fig. (h) Triplen harmonics of TCR for H6

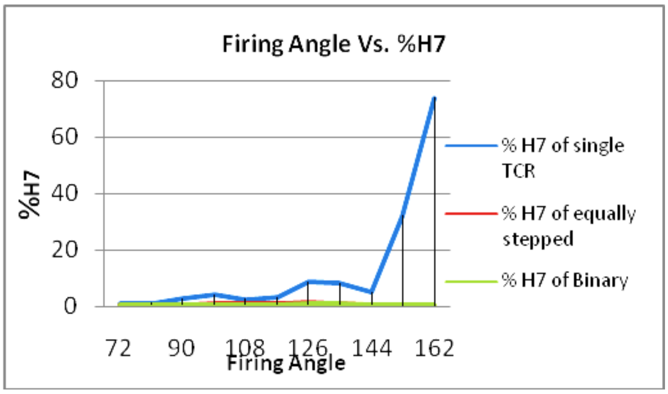

Fig. (i) Odd harmonics of TCR for H7

B. FFT Analysis Harmonic Spectrum of line current for firing angles

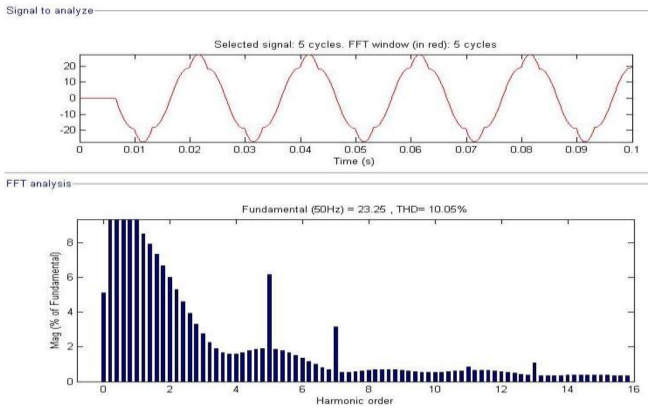

Fig.(A) Harmonic spectrum for line current for α=117°(single TCR)

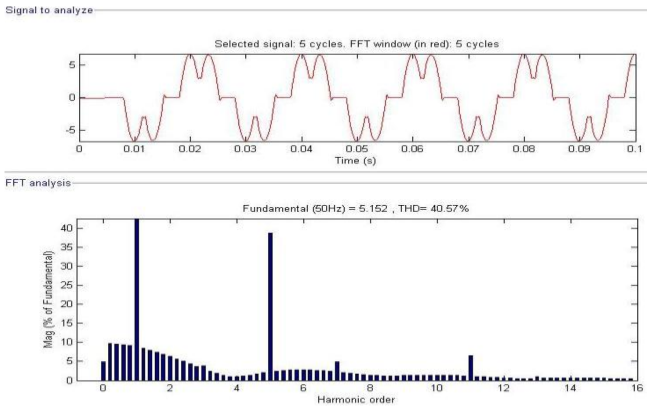

Fig.(B) Harmonic spectrum for line current for α=144°(single TCR)

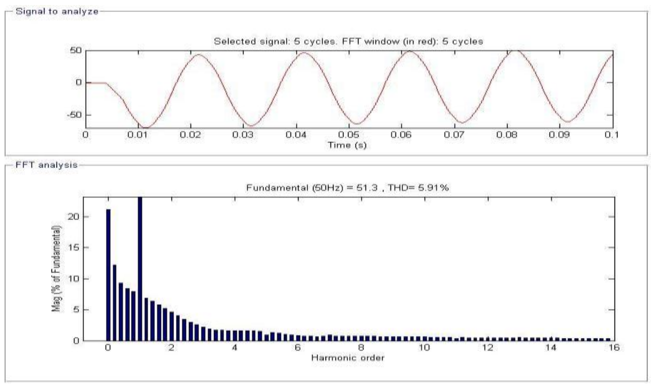

Fig.(C) Harmonic spectrum for line current for α=117°(Equally Stepped TCR)

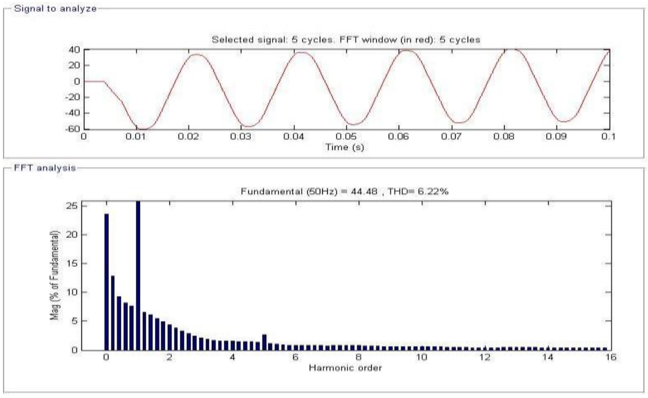

Fig.(D) Harmonic spectrum for line current for α=144°(Equally Stepped TCR)

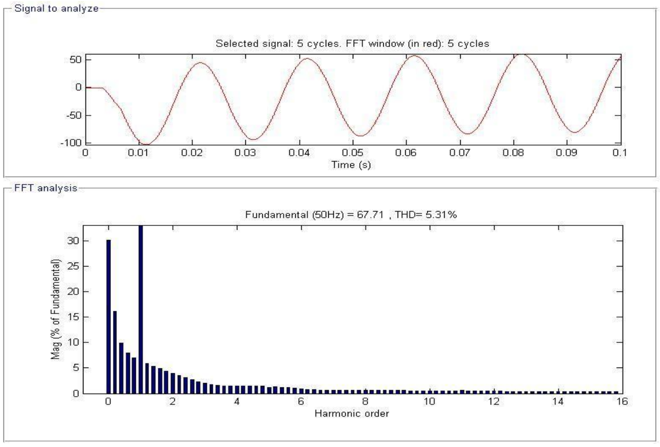

Fig.(E) Harmonic spectrum for line current for α=117°(Binary TCR)

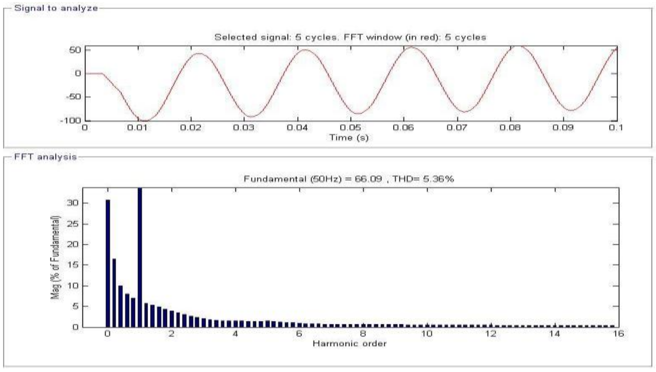

Fig.(F) Harmonic spectrum for line current for α=144°(Binary TCR)

V. CONCLUSION

TCR is a heart of a typical static var compensator and problem of harmonics is much severe. The operation of TCR at various conduction angles can be used advantageously to meet the unbalanced reactive power demand in a system. The compensator operation beyond certain range may increase the harmonic components which are harmful to system.

The proposed approach can be effectively used to minimize the harmonics generated in TCR. Here two methods are used for minimizing harmonics. The basic method is single delta connected TCR that produces large numbers of harmonics compared to other two methods but reduces odd number of harmonics. Second method is equally stepped method that reduces the harmonics upto 30% to 40% as compared to single delta connected TCR and third method is Binary sequential steps that reduces the harmonics upto 50% as compared to first method TCR and 30% as compared to second method. From analysis out of these two methods the thyristor binary controlled reactor (TBCR) is best method to minimize harmonics as it gives step less operation.

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