

Harmonic Reduction in TCR and TSC Using Artificial Neural Network

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Abstract - One of the most important parameters of Reactive Power Compensators is minimum production of harmonics. Nowadays by considering the improvement of power systems in power quality and the importance of harmonics in power quality, compensators by minimum harmonic distortion should be designed. In this paper the issue of harmonic reduction in determining the fire angle of TCR¹ and TSC² that are very important in FACTS³, is proposed. Determination of optimum angles for minimizing the THD⁴ is investigated and finally for online control and faster decision, Artificial Neural Network has been used and satisfactory results have been obtained and to have minimum THD, existence of maximum possible capacitors for both negative and positive reactive power is calculated.

I. INTRODUCTION

One of the most important concepts of power systems is load flow. So reactive power control is very important and by consideration of high speed power electronic switches, FACTS are using to achieve this goal. Most important static compensators are TSC and TCR [1,2,4,10,11, 12]. In this paper shunt combination of TCR and TSC is used. At the beginning a TSC and a TCR with constant capacitor and reactor are supposed. As we know, minimum THD is very important in power quality concepts. Fire angles of TCR and TSC are α and β respectively and they are determining so that TCR and TSC combination has the minimum harmonic distortion [2,4,7,8,9,10,11]. In the next stage, capacitor bank has been used; then α and β are calculated for another time in case that they minimize the harmonic distortion [1,3,4,5,6,13]. Data obtained from these two stages have been used for neural network training and trained neural network is used for making fast decisions and making an online variations.[1,2]

It should be mentioned that in both considered cases, negative and positive reactive power compensators are equal and they could be different in many places. They can differ from each other. It should also be said that the harmonics are assumed without filtering and only the harmonic output of TCR and TSC are considered. [1,2,4,6,7,9,11]

II. SOLUTION ALGORITHM

As we know static reactive power controller is like fig.1 and voltage of these two elements at fire angles α and β are as fig. 2 and fig. 3. The goal is determination of α and β for a requested reactive power in case that minimum harmonic is injected to system.

Fourier series are used to obtain these injected currents. Fourier series of voltages of capacitor and reactor are according to (1).

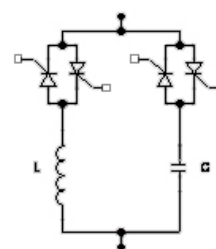


Fig. 1- TSC & TCR combination

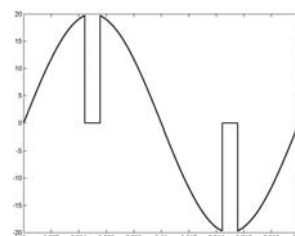


Fig. 2- reactor voltage for $\beta=100$

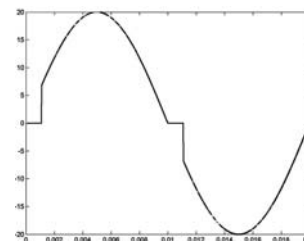


Fig. 3- capacitor voltage for $\alpha=20$

¹ Thyristor Control Reactor

² Thyristor Switch Capacitor

³ Flexible AC Transmission System

⁴ Total Harmonic Distortion

$$V_c(t) = \frac{1}{2}a_0 + a_n \cos(n\omega t) + b_n \sin(n\omega t)$$

$$a_n = \frac{2}{T} \int_0^T V_c(t) \cos(n\omega t) dt$$

$$b_n = \frac{2}{T} \int_0^T V_c(t) \sin(n\omega t) dt$$

$$a_0 = \frac{1}{T} \int_0^T V_c(t) dt$$
(1)

For example Fourier series coefficients of reactor voltage are given by figure 4. In this figure Fourier series coefficients are rms values of a_n and b_n together.

By coefficients of Fourier series and specifically first coefficient, injected power of capacitor and absorbed power of reactor are calculated. After computing the Fourier coefficients, by considering the relations, currents of reactor and capacitor could be calculated according to (2).

$$I_c = c \frac{dV_c}{dt} = c \frac{d}{dt} \left(\frac{1}{2} a_{0c} + a_{nc} \cos(n\omega t) + b_{nc} \sin(n\omega t) \right)$$

$$\Rightarrow I_c = cn\omega (b_{nc} \cos(n\omega t) - a_{nc} \sin(n\omega t))$$
(2)

$$I_L = \frac{1}{L} \int V_L dt \dots$$

$$\Rightarrow I_L = \frac{1}{Ln\omega} \left(\frac{1}{2} a_{0L} T + a_n \sin(n\omega t) - b_n \cos(n\omega t) \right)$$

Fourier coefficient are rms values of a_n and b_n together. Using these coefficients THD is calculated. For different values of α and β injected and absorbed powers are calculated. For a specific reactive power, those α and β are accepted that they minimize the THD. This algorithm is repeated for all values of powers and then the best α and β are chosen.

III. OBTAINED RESULTS

First a TSC with a 10MVar capacitor and a TCR with a 10MVar reactor are supposed. For a positive and negative requested reactive power all α s and β s that produce requested power, are calculated. Then those α and β that cause in minimum THD, are chosen. For example α s and β s are shown for specific requested powers of ± 5 MVar in table 1 and table 2.

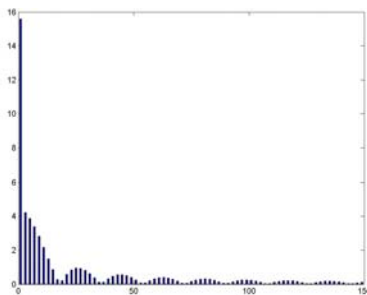


Fig. 4- Fourier coefficients of reactor voltage

The accordance of generated power is because of discrete values of α and β . As we see the THDs are in case that capacitor has been switched at $\alpha=0$ for positive reactive power (injection of power) and case that isn't switched at all for negative reactive power (absorption of power).

TABLE 1
 α AND β VALUES FOR REQUESTED REACTIVE POWER OF -5MVar

α	β	THD	Q
82.5	91.5	3.5985	-5.0002
90	93.5	3.6289	-5.0007
99.5	96	3.5783	-4.9945
103.5	97	3.5284	-5.0024
105.5	97.5	3.4961	-5.0042
112.5	99	3.3527	-4.9939
115	99.5	3.2885	-5.0013
117.5	100	3.2179	-4.998
132	102	2.6948	-5.0065
137	102.5	2.4765	-4.9983
144.5	103	2.106	-4.9995
169.5	103.5	0.66205	-4.9912
170	103.5	0.63215	-4.9914
171	103.5	0.56472	-4.9917
171.5	103.5	0.5347	-4.9918
172.5	103.5	0.47455	-4.992
173	103.5	0.44443	-4.9921
173.5	103.5	0.41428	-4.9921
174.5	103.5	0.34639	-4.9922
175	103.5	0.3162	-4.9923
176	103.5	0.25582	-4.9923
177	103.5	0.18801	-4.9923
177.5	103.5	0.15798	-4.9923
178.5	103.5	0.098541	-4.9923
179.5	103.5	0.043002	-4.9923
180	103.5	0.026626	-4.9923

TABLE 2
 α AND β VALUES FOR REQUESTED REACTIVE POWER OF +5MVar

α	β	THD	Q
0	103.5	0.026626	5.0077
1	103.5	0.06968	5.0077
2	103.5	0.12811	5.0075
2.5	103.5	0.15799	5.0074
3	103.5	0.18802	5.0071
4.5	103.5	0.28602	5.0057
5	103.5	0.31622	5.005
6.5	103.5	0.41431	5.0016
7	103.5	0.44446	5.0001
9	103.5	0.56478	4.9922
21	104	1.2979	4.9995

25.5	104.5	1.5634	4.9999
29	105	1.7595	4.9977
34	106	2.0319	5.0082
36.5	106.5	2.1562	4.9931
40.5	107.5	2.3587	4.9951
42	108	2.4274	5.0073
45	109	2.5655	4.9995
56	114	3.0109	5.0084
57	114.5	3.0445	4.9939
62	118	3.2072	5.0056
64	119.5	3.2622	5.005
64.5	120	3.2786	4.9989
65	120.5	3.2915	5.0045
70	126	3.4101	5.0044
73	131	3.4702	4.996
73.5	132.5	3.4811	5.0086
75	136.5	3.5056	5.003
75.5	138	3.5133	4.9953
76	140.5	3.5207	5.0029
76.5	144	3.5296	4.9949
76.5	144.5	3.5296	5.0019
77	149.5	3.5365	4.9948

So the best state to have minimum THD is obtained when capacitor is switched at $\alpha=0$ for positive requested power and when capacitor isn't switched at all for negative requested power. For another example when -3MVar reactive power is needed, the most optimum state is in case that capacitor isn't switched and β is chosen to produce 3MVar.

When capacitor is switched on, $\alpha=0$ and β is chosen such that TCR produces -7MVar and TCR and TSC totally produce 3MVar. Now suppose a condition that a bank of capacitor is available. Suppose the bank has six capacitors. 10MVar is divided to six equal shunt capacitors.

In this case the number of switched capacitors is shown by n and for different α and β , current Fourier coefficients, THD and power of compensator are obtained. For a requested power, possible combination of n , α and β are calculated and among them, that combination is chosen that produces minimum THD. Possible combinations of n , α and β are shown in tables 3 and 4.

As shown in table 3 and 4, in each situation, minimum harmonic distortion is obtained when maximum possible number of capacitors exists in circuit. As is shown in table 4 and 5 for 0.2MVar requested power 6 capacitors exist in circuit and $\beta=90.5^\circ$ and for -2.5MVar requested reactive power 4 capacitor should be switched and $\beta=91.8^\circ$.

TABLE 3
NUMBER OF CAPACITOR AND β VALUE FOR REQUESTED REACTIVE POWER OF 0.2 MVar

N. Cap.	α	β	THD	Q
1	0	120.1	0.63675	0.21024
1	0	120.2	0.6411	0.20689
1	0	120.3	0.64605	0.221
1	0	120.4	0.6505	0.21215
1	0	120.5	0.65499	0.20139
1	0	120.6	0.66009	0.21483
1	0	120.7	0.66468	0.22684
1	0	120.8	0.66931	0.23878
2	0	110.5	0.57879	0.19865
2	0	110.6	0.58529	0.19232
2	0	110.7	0.59116	0.21325
2	0	110.8	0.5971	0.2241
2	0	110.9	0.60387	0.24743
3	0	104	0.5608	0.20987
3	0	104.1	0.56908	0.19895
3	0	104.2	0.57751	0.22671
4	0	98.8	0.56096	0.20124
4	0	98.9	0.57609	0.20724
4	0	99	0.58993	0.24066
5	0	94.4	0.62658	0.19153
5	0	94.5	0.65918	0.22976
6	0	90.4	0.47969	0.20124
6	0	90.5	0.47867	0.20112

TABLE 4
NUMBER OF CAPACITOR AND β VALUE FOR REQUESTED REACTIVE POWER OF -2.5 MVar

N. Cap.	α	β	THD	Q
0	0	113.6	0.27614	-2.5414
0	0	113.7	0.27739	-2.5234
0	0	113.8	0.27864	-2.5054
0	0	113.9	0.28005	-2.4854
0	0	114	0.28131	-2.4676
1	0	106.3	0.24867	-2.5253
1	0	106.4	0.25073	-2.4967
1	0	106.5	0.25256	-2.4714
2	0	100.7	0.21058	-2.5169
2	0	100.8	0.21298	-2.4854
2	0	100.9	0.2154	-2.4541
3	0	96	0.15489	-2.5194
3	0	96.1	0.15794	-2.4828
4	0	91.8	0.063599	-2.5495
4	0	91.9	0.067349	-2.5087
4	0	92	0.071619	-2.4628

IV. USING ARTIFICIAL NEURAL NETWORK

In this stage of project neural network is used for determining the α , β and n (in case that bank of capacitor is exist). Use of neural network is because of increasing the response speed and making online decisions. First for a system with a fix capacitor, using the obtained data that minimize THD from previous stage, a neural network is trained and this network is used to obtain β and as said $\alpha=180$ for negative requested power and $\alpha=0$ for positive requested power. Fig.5 shows the employed system in this stage. Table 5 is brought for comparing the neural network outputs and the quantities that are obtained from analytical method.

In second stage another neural network is trained for determination of β and n . Considering the results obtained from previous discussion, minimum THD takes place in cases that $\alpha=0$ and $\alpha=180$.

Considering this fact in case of existing a capacitor $\alpha=0$. Figure 6 shows the construction of the neural network and its outputs in case of existing a bank.

It should be said that because of the discrete nature of n , it should be rounded. Table 6 shows the outputs of neural network without rounding n and the quantities that are

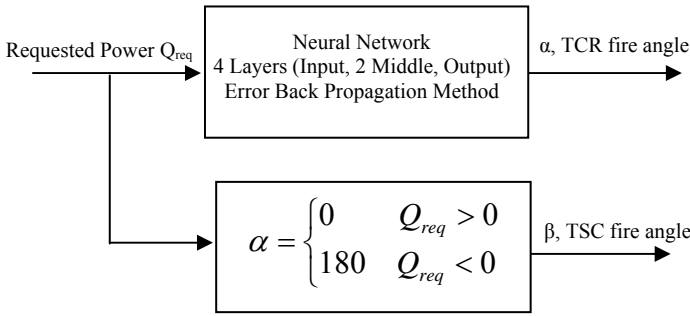


Fig. 5- System employed for determining α and β

TABLE 5
COMPARISON OF α AND β OBTAINED FROM ANN AND ANALYTICAL METHOD

α	β using analytic method	β using neural network	Q
180	90	90	-10
180	93.5	93.5	-8.5139
180	97	96.991	-7.157
180	101.5	101.52	-5.5839
180	106.5	106.5	-4.1513
180	113	113	-2.6464
180	123	123	-1.171
0	91.5	91.5	0.63004
0	95	95	2.1108
0	99	99	3.5759
0	104	104.01	5.184
0	109.5	109.47	6.5901
0	118	117.99	8.1906
0	136.5	136.8	9.7252

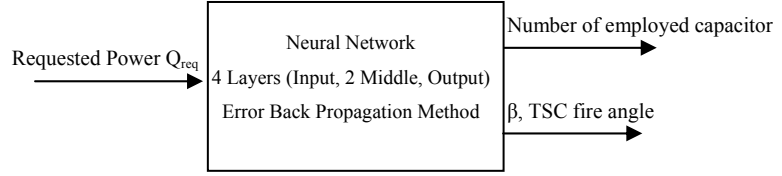


Fig. 6- System employed for determining α and β

TABLE 6
 β AND N VALUES OBTAINED FROM ANN FOR A REQUESTED REACTIVE POWER AND COMPARING IT WITH ANALYTICAL METHOD OUTPUT

N. cap. Analytic Method	N. cap. Neural network	β Analytic meth.	β ANN	Q
0	-0.0221	90	90.038	-10
0	-0.0358	93.5	93.649	-8.505
0	0.2452	97	92.248	-7.1452
2	2.1266	92.5	92.508	-5.5887
3	2.905	92	92.102	-4.1295
4	3.8969	91.5	93.743	-2.6779
6	6.0037	91.5	91.613	0.65545
6	6.0285	95	94.942	2.0955
6	6.0583	99	98.953	3.574
6	5.9073	104	104.02	5.1711
6	5.9477	109.5	109.51	6.6012
6	6.0066	118	118.01	8.1935
6	6.0047	135.5	136.26	9.6894

obtained from analytical method. As shown, there is negligible difference between them.

V. CONCLUSION

In case of existing only one capacitor, if requested reactive power is positive, capacitor should be switched and β should be determined for minimizing the THD; and if requested reactive power is negative, capacitor shouldn't be switched on and β should be calculated for minimizing the THD.

And in case of existing a bank, if requested power is positive, maximum capacitors should be switched on and β should be determined to supply requested reactive power, and when requested power is negative, although reactor is needed, maximum capacitors should be used subject to have a reactor that by adding it to capacitors, the requested reactive power is obtained.

VI. REFERENCES

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