ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 1, Issue 7, October 2013

Genetic Algorithm Based SVC Switching for Harmonic and Reactive Power Compensation

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Abstract: Reactive power compensation in a power distribution network plays a vital role in improving voltage and power system stability. Flexible AC transmission system (FACTS) devices like Static Var Compensators (SVCs) are used to control reactive power generation or absorption in long transmission line. However, these SVCs will introduce harmonic current in to the system due to the operation of thyristor controlled reactors (TCR). This paper proposes a modified genetic algorithm approach to minimize the harmonics injected into the systems with the operation of TCR-FC type SVC used in conjunction with fast-changing loads. Optimum triggering delay angles used to trigger thyristors in TCR are calculated using the proposed genetic algorithm to achieve better, smooth and adaptive control of reactive power as well as harmonics. This approach can be effectively used to limit the THD as well as receiving end voltage within the acceptable range for linear as well as nonlinear load condition.

Keywords: Genetic Algorithm, Harmonic Distortion, Optimization, Reactive power Compensation, TCR-FC.

I. INTRODUCTION

To improve voltage stability and power system stability in long transmission line reactive power need to be compensated. The Power electronic based Flexible AC transmission system (FACTS) devices are employed at strategic locations to enhance power system stability [1, 2] in addition to their main function of power flow control. These devices can supply or absorb the reactive power at receiving end bus or at load end bus in transmission system which helps in achieving better economy in power transfer.

Thyristor-controlled static var compensators (SVCs) are the commonly used FACTS device in modern power-supply systems for compensating loads due to low cost and simple control strategy. An SVC can consist of a thyristor controlled reactor (TCR) and a fixed capacitor (FC) and compensates loads through the generation or absorption of reactive power [3]. A continuous range of reactive power consumption is obtained by the operation of TCRs at appropriate conduction angles. However this operation results in the injection of harmonic currents into the power-supply system.

There are various techniques available in the literature to reduce the harmonics injected by TCR into the power system. Simplest method is to use appropriate harmonic filters with the TCR or introduce some technique to minimize harmonic generation internally [6]. It is obvious that the inclusion of harmonic filters associated with additional investment.

The authors A. Luo *et al.* [7] have proposed a combined system consisting of SVC and active power filters (APF). This system can eliminate harmonics generated by nonlinear loads and the TCR and compensate reactive power dynamically but with an additional cost of APF.

D. Thukaram *et al.* [8] discussed an optimum firing angle calculation approach to compensate reactive power while keeping the harmonics injection to the power system within the limit. But when the harmonic content is more beyond some range of firing angle, the compensator reactor value should be selected based on the overall requirement of meeting the loads.

D. B. Kulkarni *et al.* [5] have developed an ANN based SVC approach for low voltage distribution systems to reduce the reactive power drawn from the source while keeping the harmonic injection into the power system within the limit. But they concluded that the limitation of the system is the inability to filter load harmonics.

In this paper a modified genetic algorithm technique is used to determine the optimized triggering angle which minimizes the harmonics internally in the existing SVCs.

Genetic Algorithm is a computational procedure that mimics the natural process of evolution. It works by evolving a set of solutions called population over a number of generations. For each generation, good solutions are selected from the population based on their fitness value which is evaluated using error criteria. These solutions by crossover (merging previous solutions) and by mutation (modifying the solutions) generate new population. Since it searches many peaks in parallel, the trapping at local minima is avoided [9].

A modified genetic algorithm with a suitable fitness function is proposed in this paper for the calculation of optimum firing angle which minimizes both the reactive power drawn from the supply and the harmonics injected into the system.

II. STATIC VAR COMPENSATOR (TCR-FC TYPE)

Static Var Compensators are shunt connected static generators / absorbers whose outputs are varied so as to control voltage of the electric power systems. In its simple form, SVC is connected as Thyristor Controlled Reactor-Fixed Capacitor (TCR-FC) configuration as shown in Fig. 1.

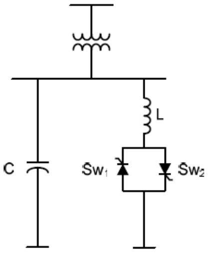

Fig. 1. Basic SVC

The current in the reactor is varied by the method of firing delay angle control method. The constant capacitive var generation (Q_C) of the fixed capacitor is opposed by the variable var absorption (Q_{TCR}) of the thyristor controlled reactor, to yield the total var output (Q) required. At the maximum capacitive var output, the thyristor-controlled reactor is off [11-13].To decrease the capacitive output, the current in the reactor is increased by decreasing delay angle α. At zero var output, the capacitive and inductive currents become equal and thus both the vars cancels out. With further decrease of angle α, the inductive current becomes larger than the capacitive current, resulting in a net inductive output.

The single line diagram of the system under consideration is shown in Fig. 2. Let the source voltage be V_S , receiving end voltage be V_r , the reactance of transmission line be X and δ be the angle between V_s and V_r. The relation between reactive power 'Q_r' and voltage at receiving end is given by :

$$Q_r = \frac{V_r(V_r - V_S Cos\ \delta)}{X} \qquad (1)$$

From the equation (1) it is clear that by compensating this reactive power consumed by the transmission line, it is possible to control V_r. This can be achieved by the shunt connection of TCR-FC. For a given load power demand , by calculating the Q_r value using equation 1 and by setting the values for Q_C of the FC, the reactive power absorbed by the TCR-FC can be calculated from the equation (2).

$$Q = Q_{TCR} - Q_C \qquad (2)$$

Q_{TCR} can be determined from the fundamental component of TCR current, $I_{LF}(\alpha)$ and is given by the equation (3)[2].

$$I_{LF}(\alpha) = \frac{V_r}{\omega L}\left(1 - \frac{2\alpha}{\pi} - \frac{Sin\ 2\alpha}{\pi}\right) \qquad (3)$$

where, α is firing angle of TCR, L is fixed value of reactance for TCR.

From the equation (3) it is clear that when α=0, maximum reactive power can be compensated. Thus, by considering zero firing angle under no load condition, inductor of the TCR can be designed. When the transmission line is loaded, reactive power compensation can be done by varying the firing angle along with the FC. However as α is increased from 0° to 90°, TCR current becomes more distorted.

The performance index THD is given by

$$THD = \frac{1}{I_{LF}}\sqrt{\sum_{h=2}^{m} I_h^2} \qquad (4)$$

Where I_{LF} is the fundamental current calculated from equation (3) and I_h is the harmonic line current calculated by the following equation.

$$I_h = \frac{4V_s}{\pi\omega L}\frac{(Sin\alpha\ Cosn\alpha - nCos\alpha\ Sinn\alpha)}{n(n^2-1)} \qquad (5)$$

A Genetic algorithm based controller is designed to calculate optimal firing angle which can simultaneously keep desired receiving end voltage and harmonics within limit.

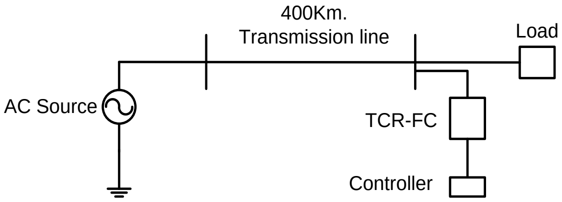

Fig. 2. Single line diagram of the system

III. THE PROPOSED GENETIC ALGORITHM

The objective of the Genetic algorithm (GA), based on the natural process of evolution, is to find the optimal solution to a problem. GA works on a collection of several alternative solutions called population. Each solution or individual in the population is called chromosome and individual character in this is called genes. To obtain better solutions (population) from existing one, a new generation is evolved in each iteration of the GA [10].

Generation of a new population involves various steps. First evaluate each individual of the population by a user defined fitness function, which can be the opposite of the error function. Then highly fit individuals are selected from the population for reproduction. Selected individuals form pairs called parents. Different operations for reproduction are crossover and mutation [9].

In the crossover operation, portions of two parents are combined to produce two new individuals, called offspring. This provides a mechanism for the chromosomes to mix and match their desirable qualities in forming offspring. For each pair of parents, crossover is performed with a crossover probability Pc. New features can be introduced into a population by mutation. It produces random changes in the offspring with a probability called mutation probability, PM. Crossover is the main operation to search the solution space, but does not guarantee the reachability of the entire solution space with a finite population size. Mutation improves search space by introducing new genes into the population.

With crossover and mutation there is a high risk that the optimum solution could be lost as there is no guarantee that these operators will preserve the fittest string [4]. To counteract this, in the proposed algorithm a mechanism is used in which, the best individual from a population is saved in the new population.

In GA the initial generation can be random or user specified. After the reproduction, new generation will replace the old one and evolve until some stopping criterion is met.

IV. SVC CONTROL USING GENETIC ALGORITHM

When applied to the reactive power compensation problem, the genes are the firing angles to be determined. Each chromosome contains the gene needed to define uniquely a trial solution. The fitness of each chromosome is evaluated using the error criterion, which is used as the basis of selection for the chromosomes in the next generation.

Consider 20 possible solutions of firing angle from 0^o to 90^o as the initial population. Evaluate all solutions in the population by a fitness function which can be considered as the reciprocal of the error function as given by the equation (6).

$$E = \sqrt{(Q_{r\_reqd} - (Q_{r\_actual} - Q_c))^2 + (THD_{\lim} - THD_{actual})^2} \quad (6)$$

Where Q_{r_reqd} is the required reactive power to be compensated, Q_c is the VAR compensation by the FC and Q_{r_actual} is the reactive power calculated from the solution. Similarly THD_{lim} is the limit in the THD and THD_{actual} is the THD calculated from the solution.

In the next step sort the individuals according to their calculated fitness values. Then select the best solutions for reproduction based upon their rank in the sorted list. As a crossover operation take the average of the selected solutions to generate the new set of solutions in the neighbourhood of the best solutions. As a mutation modify some of the solutions by adding a small value which depends upon the difference in the consecutive solution. To preserve the fittest solution in the new population maintain the best solution of the current population in the new set of solutions also.

Now continue the process of fitness evaluation, reproduction etc., with the new set of population for a fixed number of generations to get a better solution. Algorithm can be summarized as,

1. Measure receiving end voltage, Vr.
2. Calculate required Qr using equation (1)
3. Vary Q_C in steps. Each step of Q_C do the following:
➢ *Initialize the population;*
➢ *while predetermined termination condition not satisfied;*

■ *Calculate Q_{r_actual} and THD_{actual} for each solution in the population.*
■ *Evaluate all these solutions with the fitness function, which can be the reciprocal of error function given in equation (6).*
■ *Select some highly fit solutions.*
■ *Pair them as parents and perform crossover operation to generate offsprings.*
■ *Perform mutation by slightly changing some random solution.*
■ *Preserve the best solution.*
■ *Replace the entire population with these offsprings after crossover mutation while preserving the best solution.*

➢ *Save the highly fit solutions calculated by the above process and go to step 3.*
4. Compare the fitness of saved solutions in each capacitor value Q_C and select the best solution.

V. SIMULATION RESULTS

A 400 kV, 400 km, 50 Hz transmission line is modelled using Matlab. The static VAR compensator was considered consisting of a FC that can vary through 8 steps: 0, 10, 20, 30, 40, 50, 60, 70 MVAR per pahse and thyristor controlled reactor with L=3.66H. The various parameters of transmission line are assumed as given in Table I.

TABLE I DISTRIBUTED PARAMETERS FOR 400 KV TRANSMISSION LINE

Sending end voltage (kV)	Distributed parameters			Length of transmission line (km)
	R (Ω/km)	L (mH/km)	C (nF/km)	
230	0.01273	0.9337	12.74	400

Under various loaded conditions with a sending end voltage of 230kV/phase, the modeled system is simulated in Matlab and the results without optimization techniques are shown in Table II. For each load data receiving end voltage V_r before compensation is measured . Firing angle α for TCR and the capacitor value for FC for maintaining the receiving end voltage $V_r \approx 230$ kV is calculated and the corresponding THD is observed. It is clear from the table that THD is more than 5% which is an assumed THD_{limit}.

TABLE II
SIMULATION RESULTS FOR THE SYSTEM BEFORE OPTIMIZATION

Load (MW)	**Vr before Comp. (kV/phase)**	**Before Optimization**			
		Alpha (Deg.)	**Cap value (MVAr)**	**THD**	**Vr After Comp. (kV/phase)**
50	251.30	10.6	0	8.88	230.3
70	249.10	16.49	0	9.813	230.2
80	247.87	19.2	0	7.98	230.4
95	245.73	24.55	0	9.88	230.6
100	245.01	25.025	0	8.88	230.2
110	243.30	28.3	0	8.69	229.8
115	242.55	30.5	0	7.77	230.4
220	220.90	45.58	50	5.56	230.6
230	218.63	54.2	50	4.98	230.4
240	216.20	21.5	60	5.09	230.1

By using the genetic algorithm optimized firing angle and capacitor value for maintaining both voltage stability and THD within specified limit are calculated and the results are as shown in Table III.

TABLE IIII
SIMULATION RESULTS FOR THE SYSTEM AFTER OPTIMIZATION WITH GA

Load (MW)	**Vr before Comp. (kV/phase)**	**After Optimization with GA**			
		Alpha (Deg.)	**Cap value (MVAr)**	**THD**	**Vr After Comp. (kV/phase)**
50	251.30	0.28	0	2.52	227.30
70	249.10	5.01	0	1.83	225.60
80	247.87	8.08	0	1.87	224.75
95	245.73	2.79	10	1.67	227.69
100	245.01	14.51	0	1.15	223.04
110	243.30	18.14	0	2.5	223.70
115	242.55	20.04	0	3.21	223.63
220	220.90	1.39	60	3.38	231.72
230	218.63	15.35	50	4.07	227.61
240	216.20	9.30	60	2.92	227.69

The receiving end voltage before compensation and after optimized compensation with GA is shown in Fig. 3. It is seen that variation of receiving end voltage is maintained within the limit (near 230 kV) with optimal control of firing angle of TCR.

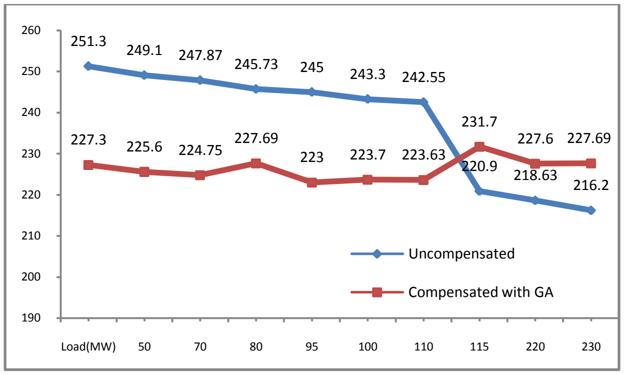

Fig.3. Optimized and uncompensated receiving end voltage

Table IV shows the similar results for various inductive loads. The case study proves that the percentage THD under the optimized condition is much less than the percentage THD under the unoptimized condition.

TABLE IV
SIMULATION RESULTS FOR THE SYSTEM UNDER VARIOUS INDUCTIVE LOADS BEFORE AND AFTER OPTIMIZATION WITH GA

Load (MW)	**Vr before Comp. (kV)**	**Before Optimization**			**After Optimization with GA**		
		Alpha (Deg.)	**THD**		**Alpha (Deg.)**	**THD**	**Vr(KV)**
10+j1	253.5	4.8	16.9	230.6	0	2.1	228.7
40+j5	249.3	13.5	16.5	230.5	5.2	1.9	225.4
100+j0.1	244.9	25.5	7.97	230.1	5	1.2	227.0
100+j1	244.4	28.5	9.5	230.6	15.6	2.2	223.8
200+j10	221.4	39.8	4.88	230.7	.93	4.3	233.0
200+j20	217.4	7.8	5.26	230.7	7.9	5.0	230.2
140+j60	211.9	36.5	9.17	230.1	8.45	3.9	221.9

Fig. 4. shows a reduction in THD using modified GA compared to unoptimized operation. It is found that the THD with optimized control is reduced and is within the specified limit while maintaining the receiving end voltage within the allowable value.

Proposed genetic algorithm based approach can be effectively used to improve the voltage stability under various loaded conditions while keeping the harmonic injection into the power system within specified limit.

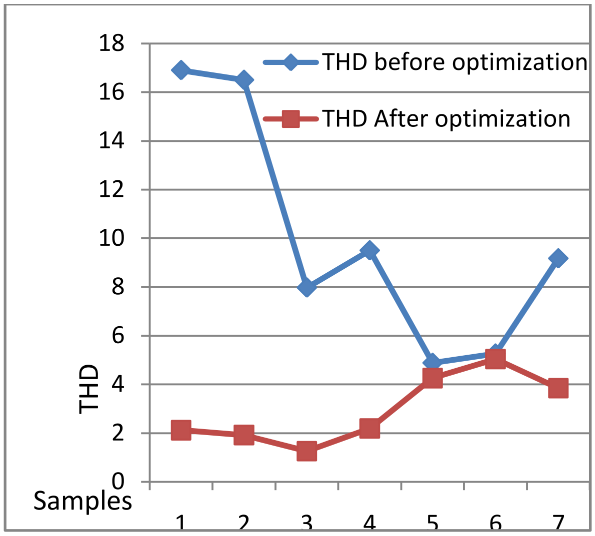

Fig. 4. Comparison of THD before and after optimization

V CONCLUSION

The operation of thyristor controlled reactors with fixed capacitors (TCR-FC) at various firing angles can be used advantageously to meet the reactive power demands in a fluctuating load environment. It is observed that as firing angle increases, TCR pollutes the power system by injecting harmonic current in to the system. This deteriorates the power quality of the system. In this paper a three phase system with a resistive and reactive load is tested for compensation of the current harmonics and reactive power demand using modified genetic algorithm. It is clear that the implemented genetic algorithm approach can be effectively used to limit the THD as well as receiving end voltage within the acceptable range. The case study proves that the percentage THD under the optimized condition is much less than the percentage THD under the unoptimized condition. It is a simple way of controlling the reactive power of transmission line. The advantage of this scheme is that it can be effectively used at TCR-FC installations for linear or nonlinear load to reduce the harmonics injections.

REFERENCES

[1] D. P. Kothari, I. J. Nagrath, Modern Power System Analysis ,Tata McGraw-Hill Education, 01-Oct-2003

[2] N. G. Hingorani and L. Gyugyi, *Understanding* FACTS. Piscataway, NJ: IEEE Press, 2001

[3] T.J.E Miller , Reactive power control in electric systems , a wiley Interscience publication, 1982

[4] Sincy George , Vivek Agrawal, "Effect of harmonics on reliability of electrical equipm*ent", International Conference on Quality, Reliability and Control*, ICQRC 2001, pp. R68-1

[5] Deepak Balkrishna Kulkarni and G. R. Udupi*, "*ANN-Based SVC at Distribution Level for Minimal-Injected Harmonics ," *IEEE Tran. On Power Delivery*, Vol. 25, No. 3, pp. 1978 - 1985, July 2010

[6] C. S. Indulkar, "Required shunt compensation for an EHV transmission line," *IEEE Power Engg. Review*, pp. 60-64, September 1999

[7] A.Luo, Zhikang Shuai, Wenji Zhu, and Z. John Shen, "Combined System for Harmonic Suppression and Reactive Power Compensation," *IEEE Tran.on Industrial Electronics*, Vol.56, No.2, pp. 418- 427, Feb 2009

[8] D. Thukaram, H. P. Khincha, and B. Ravikumar, "Harmonic minimization in the operation of static VAR compensators for unbalanced reactive power compensation," *presented at the Int. Conf. Power System Technology*, Singapore, 2004.

[9] K.F. Man, K.S. Tang, and S. Kwong, Genetic algorithms: concepts and applications, IEEE Transactions on Industrial Electronics, 43 (1996), 5, pp. 519 -533.

[10] M. Gen, and R. Cheng, "Genetic algorithms and engineering design", (John Wiley & Sons, Inc., 1997).

[11] 11. Gutierrez, J, Montano, J.C, Castilla, M. and Lopez, A. 'Power-quality improvement in reactive power control using FCTCR circuits'IECON 08, Industrial Electronics Society, IEEE 2008, 28th Annual Conference, Volume 2, 5-8 pp.:880 - 885 vol.2.

[12] T. Y. Gelen, "Analysis of TSR-based SVC for a three-phase system with static and dynamic loads," in Proc. of the IEEE Int. Conf. on Electrical Engineering, ICEE'07, 6 pp., Lahore, Pakistan, 11-12 Apr.2007.

[13] T.Vijayakumar, .A.Nirmalkumar," Harmonics Analysis of Thyristor controlled Reactor circuits", International Journal of Computer and Electrical Engineering, Vol. 2, No. 1, February, 2010.