Umm Al-Qura Univ. J. Eng.& Arch. Vol. 4, No.1, pp. 29-35 (2011)

Mixed Shunt and Series Capacitance for a Practical 380 kV System

Abdulrahman. H. Almasoud
EE Dept., Faculty of Engineering
King Abdulaziz University
Jeddah, Saudi Arabia
Email: amasoud@kau.edu.sa

الملخص

بات من المعروف أن استخدام وحدات المكثفات بطريقة التوازي أو الطريقة التسلسلية على شبكات الطاقة الكهربائية التي لها تأثيراتها الايجابية الاجتماعية والاقتصادية. ترفع هذه الوحدات من قدرة المولدات الكهربائية على إنتاج الطاقة الحقيقية، وبالتالي تسمح باستيعاب عدد أكبر من مستهلكي الطاقة الكهربائية، وبالتالي زيادة دخل شركات الكهرباء. توصل وحدات المكثفات التسلسلية على خطوط نقل الطاقة، بينما توصل وحدات المكثفات المتوازية على محطات نقل مختارة بحيث تعطى أكبر قدر ممكن من توفير الطاقة المهدرة. ويمكن تحقيق هذا بعدة طرق منها الطريقة الجينية، والطريقة الجينية المهجنة، وطريقة المحاولة والخطأ. في هذا البحث تم عرض دراسة مقارنة للطرق الثلاث وتم إيجاد مقدار التوفير الناتج من استخدام وحدات المكثفات على شبكات ٣٨٠ ك. ف. المقامة في المنطقة الغربية من المملكة العربية السعودية.

Abstract

It is well known that mixed shunt and series capacitance are both socially and economically beneficial to power system network. These devices improve the capability of power transfer and reduce the apparent power (s) which is produced by generators allowing more customers to be served and increasing the income of electrical companies.

Series compensation units have to be connected to transmission lines whereas shunt compensation units have to be connected to carefully selected substations to result in a high degree of reactive power compensation. This can be done by several methods, such as the Genetic Algorithm (GA), Hybrid of GA or Trial and Error heuristic method (called proposed method in the tables). In this paper, we present a comparison of the three algorithms to determine the amount of savings that can be achieved by each algorithm. The system under investigation is a real 380 kV system, operating in the Western Region of Saudi Arabia, and the results reflect experimental data on this system.

Keywords: series capacitance; shunt capacitance; reactive compensation; 380 kV; saving; Saudi Arabia.

Introduction

The placement of a mixed shunt and series capacitor within a power system network is not a trivial task. Several methods have been published to determine optimal mixed shunt and series capacitor placement, such as the Trail and Error heuristic method, Artificial Neural Networks (ANN) method and Genetic Algorithm (GA) [1-29]. Because substations yield different reactive power savings, the proposed methods are useful in determining which substation would yield the greatest reactive power savings as a result of mixed shunt and series capacitance placement.

In this paper, we present a comparison of the three algorithms to determine which algorithm would yield the greatest reactive power savings. The three methods were applied to a load flow computer program on a real power system network, containing several generators and 48 transmission lines (110kV). The 380 kV system compensation scientific paper was published elsewhere [30].

Genetic Algorithm (GA)

Genetic Algorithm (GA) is a global search technique based on mechanics of natural selection and genetics. It is a general-purpose optimization algorithm that is distinguished from conventional optimization techniques by the use of concepts of population genetics to guide the optimization search. Instead of point-to-point search, GA searches from population to population. Genetic algorithms use biological evolution to develop a series of search space points toward an optimal solution. This approach involves coding of the parameter set rather than working with the parameters themselves. GA's operate by selecting a population of the coded parameters with the highest fitness levels (i.e., parameters yielding the best results), and performing a combination of mating, crossover, and mutation operations on them to generate a better set of coded parameters. Genetic algorithms are simple to implement and capable of locating the global optimal solution.

The key advantages and features of applying the genetic algorithm can be summarized as follows:

1. The algorithm is a multi-path that searches many peaks in parallel, and hence reducing the possibility of local minimum trapping.
2. GA works with a coding of parameters instead of the parameters themselves. The coding of parameter will help the genetic operator to evolve the current state into the next state with minimum computations.
3. GA evaluates the fitness of each string to guide its search instead of the optimization function. The genetic algorithm only needs to evaluate objective function (fitness) to guide its search. There is no requirement for derivatives or other auxiliary knowledge. Hence, there is no need for computation of derivatives or other auxiliary functions.
4. GA explores the search space where the probability of finding improved performance is high.

On the other hand, the main disadvantages and shortcomings of using the GA approach can be summarized as follows:

1- It requires a tremendously long time.
2- The tuning of the algorithm parameters to produce a high quality solution is a difficult and time-consuming task

Artificial Neural Networks (ANN)

An artificial neural network is the connection of artificial neurons which simulates the nervous system of a human brain. ANN are mainly categorized by their architecture (number of layers), topology (connectivity pattern, feed forward or recurrent etc.), and learning regime. Artificial neural networks are useful for mapping nonlinear relationships between inputs and outputs. An ANN typically consists of three types of layers: an input layer, one or more hidden layers, and an output layer.

This arrangement is shown in fig. 1. The input layer is a buffer that presents data to the network. The top layer is the output layer, which presents the output response to a given input. The other layer is called the middle or hidden layer because it usually has no connections to the outside world. The ANN accepts known input data and minimizes the difference between the known outputs and the generated outputs. The relationship between the inputs and the outputs are embedded as parameters in the hidden layer. Correct output patterns can be generated by the ANN providing that there are enough hidden layers and nodes to encode the input–output pattern, and enough known data to train the ANN. Once an ANN is trained, it can provide very fast results given a set of inputs. Most of the applications of the ANN in the power systems use multi-layer feed forward network.

The learning capability of the ANN spurred a surge of interest in employing artificial intelligence (AI) for the on-line solution of different power system problems. Furthermore, any modelling deficiency in applying algorithmic or rule based approaches to power systems may cause the corresponding approach to deteriorate. However, failures of some neurons in the ANN may only degrade its performance, it may recover completely from such failures with additional training.

The key advantages of applying the Artificial Neural Networks can be summarized as follows:

1. It is fast.
2. It possesses learning ability.
3. It adapts to the data.
4. It is robust.
5. It is appropriate for non-linear modelling.

On the other hand, the main disadvantages of using the ANN approach can be summarized as:

1. Large dimensionality as it need huge amount of data.
2. Selection of the optimum configuration.
3. The choice of training methodology. In addition to that, the training time required for the neural networks may be immense.
4. The ‘black-box’ representations of ANN – they lack explanation capabilities, so decisions are not audible.
5. The fact that results are always generated even if the input data are unreasonable.

380 kV System Topology

The system under investigation supplies a number of big cities in the Western region of Saudi Arabia as outlined in fig. 2. The Western power system network, fig. 3, can be represented in terms of power production conditions, as shown in Table 1, by assuming that the cost of the production of each kWh is equivalent to $0.06 (6 cents). Three loading times were also considered (i.e.. peak, medium and light loading times). There are one hundred and thirty seven substations (110/13.8 kV) supplying loads through the four major cities.

Mixed Shunt and series Capacitance Compensation

Shunt and series capacitance units were placed on different substations (buses) according to the following categories: Three algorithms (Trail and Error heuristic, Artificial Neural Networks (ANN) and Genetic Algorithm (GA)) are applied in order to find out the optimal places for shunt capacitance and then calculate the saving as a result. The calculations were carried out on three different loading times. That is to say when system loads are light, medium and peak. Saving have been found on three different times of loading throughout a year of consuming loads. The second major benefit of adding shunt capacitance is to reduce the distribution current throughout the power system network. This will reduce the power loss on transmission lines and cables. Thus more power can be transmitted via transmission lines and more customers can be accommodated as a result of adding shunt capacitances. Thirdly, shunt capacitances help stabilize buses voltages during heavy loaded system. The series capacitance are applied to all transmission lines indicated in the network in order to enhance the capability of transmitting power.

Single Mixed Shunt and series Capacitance Compensation

In this case, the computer program places series capacitor to a transmission line (between 30-70% of the line inductance in 1% increment), shunt capacitor to a substation and increase their values until the highest compensation of reactive power on the network is achieved (in 0.5 MVAR increment), provided that the generators are not converted to capacitive power generation. This routine is repeated for all single-bus utile finding the best bus that can give a high degree of compensation. Table 2 shows that transmission line No. 30-1250 and substations No. 970 yield the highest compensation during peak loading conditions which results in a 829.6 MVAR reduction of inductive production by the generators, corresponding to a 41.36 % reduction in total generation (MVAR).

Double Mixed Shunt and Series Capacitance Compensation

In this case the computer program places series capacitors to two transmission lines and shunt capacitors to two substations and increase their values up to the highest compensation of reactive power on the network is achieved, provided that the generators are not converted to capacitive power generation. This routine is repeated for all double-bus utile finding the best two buses that can give a high degree of compensation. Table 3 shows that transmission lines No. 1102-1250 and 20-500 and substations No. 500 and 970 yield the highest compensation during peak loading conditions, which results in a 930.6 MVAR reduction of inductive production by the generators, corresponding to a 46.39 % reduction in total generation (MVAR).

Double Series and Triple Shunt Capacitance Compensation

In this case the computer program found that the optimal solution is to place series capacitors to two transmission lines and shunt capacitors to three substations and increase their values until the highest compensation of reactive power on the network is achieved, provided that the generators are not converted to capacitive power generation. This routine is repeated for all triple-bus utile finding the best triple buses that can give a high degree of compensation. Table 4 shows that transmission lines No. 20-500 and 900-1500 and substations No. 500, 970 and 20 yield the highest compensation during peak loading conditions which results in a 918.00 MVAR reduction of inductive production by the generators, corresponding to a 45.76 % reduction in total generation (MVAR).

Economic consideration

The three aforementioned methods, namely the Trial and Error heuristic method (proposed method), GA and GA + Hybrid, were applied to different transmission lines and buses of different city network to determine the greatest reduction of total MVAR generation during peak loading conditions. Using the results, the money savings for each method was calculated. Table 4 shows that for a system with 7705 MVAR total generation, the proposed method yields savings equivalent to $656,610 per year, GA method yields savings equivalent to $652,847 and GA+ Hybrid methods yield savings equivalent to $655,056 per year. Moreover, the additional benefit for adding shunt and series capacitors is to transmit more power and allow the system to accommodate more customers, thus increasing the total income of the electrical company and improving the capability of the system to withstand dip voltages.

Conclusions

It is well known that mixed shunt and series capacitances add value to power system networks. The 380 kV system under investigation represents a real system, operating in the Western region of the Kingdom of Saudi Arabia, with the capacity of 7705MVA in 2003. The three methods investigated show savings ranging according to the results shown in Tables 2-4. Based on study, it is recommended that the electrical companies have to consider applying mixed shunt and series capacitors to their electrical substations. It is recommended that the series and shunt capacitances should be of automatic variable values in order to suit different time of loading and to keep the generating system to be reactive power production and not capacitive power production. This study indicates that if the data of the system are for this year, the compensation will be bigger than that calculated and the savings. The study was not an easy task since the collecting data took time and the programming also took some time, and the program testing took yet longer time in order to check the results coming out of the load flow computer program to be matched with the results of the load flow of the Saudi electrical company. This check is important as the first step to start to use the developed computer program in applying series and shunt compensation and finding the optimal buses that can be used for compensation and trusting the results.

Acknowledgements

The author would like to thank the Saudi Electrical Company (Western Region) for their help in providing the researcher with the necessary data to complete the research and yield valuable results.

References

1. H. Duran, "Optimal number, location and size of shunt capacitors in radial distribution feeders, a dynamic programming approach", IEEE Trans. (PAS). 1968; 87: 1769-74.
2. R.M. Malisizewski, L.L. Graver and A.J. Wood, "Linear programming as an aid of planning kilo var requirements" IEEE Trans. (PAS). 1968; 87: 1963-8.
3. J.B Young, "Optimal static capacitor allocation by discrete programming development of theory" IEEE Trans. (PAS). 1970; 89: 1688-97.
4. K. Raman Nair and A. Kuppurajulu, "Optimization of static capacitors installations and switching schedule in distribution systems", proc. IEE. 1975; 4: 415-8.
5. K.R.C Mandur and R.D Chenoweth, "Optimal control of reactive power for improvement in voltage profile and for real power loss minimization ", IEEE Trans. (PAS). 1981; 90: 2498-508.
6. William D. Stevenson, "Elements of power system analysis", McGraw- Hill. international editions, 1982.
7. M. Kaplan, "Optimization of number, location, size, control type and control setting of shunt capacitors on radial distribution feeders," IEEE Trans. On PAS. 1984; 103(9): 2659-65.
8. S. Rama Iyer, K. Ramachandran and S. Hariharan, "Optimal reactive power allocation for improved system performance", IEEE Trans. (PAS). 1984; 103: 1509-15.
9. N. I. Santoso and O. T. Tan, "Neural-net based real-time control of capacitors installed in distribution systems" IEEE Trans. Power Delivery. 1990; 5 (1): 266-72.
10. Haido-Dong Chiang, "Optimal capacitor placement in distribution systems: Part 2: Solution algorithm and simulation results", IEEE Trans. PWRD. 1990; 5 (2): 643-649.
11. M. M. A. Salama and A. Y. Chikhani, "An expert system for reactive power control of a distribution systems, Part 1: System configuration" IEEE Trans. Power Delivery. 1992; 7(2): 940-5.
12. Swann, D.E.; Larsen, E.V.; Piwko, R.J. “Major benefits from thyristor controlled series capacitors”**,** International Power Technology. 1993: 109-12.
13. Kingston, R.; Holmberg, N.; Kotek, J.; Baghzouz, Y., “Series capacitor placement on transmission lines with slightly distorted currents”, IEEE Power Eng. Soc. April 1994: 10-15.
14. Masayuki Abe, Nobuo Ostsuzuki, Tokuo Emura, Masayasu Tekeuchi, “Development of a new fault location system for multi-terminal single transmission lines”, IEEE. 1994: 259-68.
15. Prabha Kundur, "Power system stability and control", McGraw-Hill Inc., New York, USA, 1994.
16. John J. Grainger, William D. Stevenson, "Power system analysis", McGraw-Hill. international editions. 1994.

17. S. Sundhararajan and A. Pahwa, "Optimal selection of capacitors for radial distribution systems using a genetic algorithm" IEEE Trans. Power Systems. 1994; 9 (3): 1499-1507.
18. C. H. Chen, C. T. Hsu and Y.H. Yan, "Optimal distribution feeder capacitor placement considering mutual coupling effect of conductors", IEEE Trans. Power Delivery. 1995; 10 (2): 987-994.
19. J. R. P. R. Laframboise, G. Ferland, A. Y. Chikhani, and M. M. A. Salama, "An expert system for reactive distribution systems, Part 2: System implementation" IEEE Trans. Power Systems. 1995; 10 (3): 1433-41.
20. Wanhong Deng and Lie, T.T, "Optimal compensation of variable series capacitors for improved economic dispatch in power systems" IEEE Trans. Power Delivery. 1995; 2: 732-7.
21. Yang Chang Huang , "Solving the capacitor placement problem in radial distribution systems using Tabu Search approach", IEEE Trans. (PAS). 1996; 11 (4): 1868-73.
22. T. Anathapadmanabha, A. D. Kulkarni , A. S. Gopala Rao, and K. Raghavendra Rao, " Knowledge-based expert system for optimal reactive power control in distribution system", Electrical Power and Energy Systems. 1996; 18 (1): 27-31.
23. K. N. Miu, H. D. Chiang, and G. Darling, "Capacitor placement, re-placement and control in large-scale distribution systems by a GA-based two-stage algorithm", IEEE Trans. Power Systems. 1997; 12 (3): 1160-6.
24. R.Rajaraman, F. Alvarado, A.Maniaci, R. Camfield, and S. Jalali, "Determination of location and amount of series compensation to increase power transfer capability", IEEE Transaction on Power Systems. 1998; 13 (2): 294.
25. Hadi Saadat, "Power System Analysis", McGraw-Hill. International editions. 1999.
26. N. Ng, M.A. Salama, A.Y. Chikhani, "Classification of capacitor allocation techniques", IEEE Transaction on Power Delivery. 2000; 15 (1): 387.
27. S. Gerbex, R. Cherkaoui, and A. J. Germond, "Optimal location of multi-type FACTS devices in a power system by means of genetic algorithms," IEEE Trans. Power Systems. 2001; 16: 537-44.
28. Edimar J. and de Olivera, "Series compensation device allocation under contingency constraints," IEEE Power Tech Conference Proceedings. 2003; 4: 5.
29. Cai L.J., Erlich I. and Stamtsis, G., "Optimal choice and allocation of FACTS devices in deregulated electricity market using genetic algorithms" IEEE Power Systems conference and exposition. 2004; 1: 201-7.
30. Almasoud A.H. "Shunt Compensation for practical 380 kV system" IJECS/IJENS Journal. 2009: 23-27.

Received 10/2/1432;14/1/2011, accepted 14 /11 /1432; 12/10/2011