International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-1 Issue-6, August 2012

Optimal Solution Of 14 Bus System using MATLAB Simulation Incorporating with FACTS Devices

Nanda Kumar Easwaramoorthy, R. Dhanasekaran

Abstract - This research work presents a new approach for optimal location of FACTS controllers in a multi machine power system using MATLAB coding. Using the proposed method, the location of FACTS controller, their type and rated values are optimized simultaneously. Among the various FACTS controllers, Thyristor Controlled Series Compensator (TCSC) and Unified power Flow Controller (UPFC) are considered. Optimal Power Flow (OPF) is one of the most important processes in power system, which improves the system performance by satisfying certain constraints. Generally, different optimization methods are used in the literature to solve the OPF problem. In some research works, the optimization process is done by considering total fuel cost or by considering the environmental pollution that occurs during power generation. But in some other research works, FACTS controllers are used to improve the power flow without considering the power generation cost.

The OPF problem is one of the most extensively studied topics in the power system community. In power system operation, OPF is an extended problem of economic dispatch (ED) which consider several parameters such as generator voltage, transformer tap change, SVC, and include constraints such as transmission line and transformer loading limits, bus voltage limit, and stability margin limit . The main function of OPF is to select the optimal operation state of a power system, in the time of meeting some particular constraints. OPF study plays a key role in the Energy Management System (EMS), where the entire operation of the system is regulated in each possible real time intervals.

Key words: OPF, EP, TS, SA, ITS, IEP, TCVR, FACTS controller, SVC, UPFC

I. INTRODUCTION

This paper proposes an OPF problem which is realized by means of Particle Swarm Optimization algorithm. Particle Swarm Optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity.

The equality constraints are the nodal power balance equations, whereas the inequality constraints are the limits of all control or state variables. The physical laws controlling the power generation of transmission systems and the operating limitations of the equipment are the constraints involved for optimizing the objective function. OPF is the evaluation of the best settings of the control variables such as the Active Power and Voltages of Generators, Discrete variables like Transformer taps, Continuous variables like the Shunt reactors and Capacitors, and other continuous and discrete variables, in order to achieve a common objective such as reduction of operating cost or Social Welfare while respecting all the system limits for secure operation.

The possibility of operating power systems at the lower cost, while satisfying the given transmission and security constraints is one of the main current issues in elongating the transmission capacity through the use of FACTS devices. FACTS devices can direct the active and reactive power control and flexible to voltage-magnitude control simultaneously, because of their adaptability and fast control characteristics. With the aid of FACTS technology, namely Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) etc., the bus voltages, line impedances and phase angles in the power system can be controlled quickly and flexibly.

The possibility of operating power systems at the lower cost, while satisfying the given transmission and security constraints is one of the main current issues in elongating the transmission capacity through the use of FACTS devices. FACTS devices can direct the active and reactive power control and flexible to voltage-magnitude control simultaneously, because of their adaptability and fast control characteristics. With the aid of FACTS technology, namely Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) etc., the bus voltages, line impedances and phase angles in the power system can be controlled quickly and flexibly.

II. FACTS DEVICES TO BE NCORPORATED TO OPF PROBLEM

2.1 TCSC

The TCSC can serve as the capacitive or inductive compensation respectively by modifying the reactance of the transmission line. In this paper, the reactance of the transmission line is adjusted by TCSC directly. The rated value of TCSC is a function of the reactance of the transmission line where the TCSC is located.

$$X_{ij} = X_{Line} + X_{TCSC},\ X_{TCSC} = rtcsc.\ X_{Line}$$

where XLine is the reactance of the transmission line and rtcsc is the coefficient which represents the compensation degree of TCSC.

Manuscript received on August 25, 2012

Nanda Kumar Easwaramoorthy, Dept. of E.E.E., Sri Krishna College of Technology, Kovaipudur, Coimbatore.

R. Dhanasekaran, Director- Research, SyedAmmal Engineering College, Ramnad.

To avoid over compensation, the working range of the TCSC is between 0.7 XLine and 0.2 XLine.

2.2 UPFC

The UPFC is a combination of shunt and series controller. It has three controllable parameters namely, the magnitude of the boosting injected voltage (UT), phase of this voltage (ØT) and the exciting transformer reactive current (Iq).

III. IMPROVEMENTS IN POWER SYSTEM STABILITY

The cost of losing synchronous operation through a transient instability is extremely high in modern power systems. Consequently, utility engineers often perform a large number of stability studies in order to avoid the problem. Since different operating points of a power system have different stability characteristics, stability can be maintained by searching for one point that respects appropriate stability limits. In the past three decades, power system stabilizers (PSSs) have been extensively used to increase the system damping for low frequency oscillations. However, there have been problems experienced with PSSs over the years of operation. Some of these were due to the limited capability of PSS, in damping only local and not inter area modes of oscillations. In addition, PSSs can cause great variations in the voltage profile under severe disturbances and they may even result in leading power factor operation and losing system stability. Flexible AC transmission systems (FACTS) have gained a great interest during the last few years, due to recent advances in power electronics.

IV. OPTIMAL POWER FLOW WITH FACTS CONTROLLERS

The formulation of the optimal allocation of FACTS controllers can be expressed as

Minimize $C_{Total} = C_1 (f) + C_2 (PG)$

Subjected to **$E(f,g) = 0$**

$B_1 (f) < b_1, B_2 (g) < b_2$

Where

C_{Total} : the overall cost objective function which includes the average investment costs of FACTS devices C_1 (f) and the generation cost C_2(PG).

E (f.g) : the conventional power flow equations.

B_1 (f) and B_2 (g) are the inequality constraints for FACTS controllers and the conventional power flow respectively.

f and PG are vectors that represent the variables of FACTS controllers and the active power outputs of the generators.

g represents the operating state of the power System.

The unit for generation cost is US$/Hour and for the investment cost of FACTS controllers are US$. They must be unified into US$/Hour. Normally the FACTS controllers will be in service for many years. However only a part of its life time is employed to regulate the power flow. In this paper three years is employed to evaluate the cost function. Therefore the average value of the investment costs are calculated as follows

$C_1(f) = C(f) / \{8760 \times 3\}$

As mentioned above, power system parameters can be changed using FACTS controllers. These different parameters derive different results on the objective function. Also, the variation of FACTS locations and FACTS types has also influences on the objective function. Therefore, using the conventional optimization methods are not easy to find the optimal location of FACTS devices, types and control parameters simultaneously.

V. OPTIMIZED SETTINGS OF FACTS DEVICES

In this paper UPFC is modeled as combination of a TCSC in series with the line and SVC connected across the corresponding buses between which the line is connected. After fixing the location, to determine the best possible settings of FACTS devices for all possible single and multiple contingencies, the optimization problem will have to be solved using Fuzzy Controlled FACTS controller technique.

The objective function for this work is,

Objective = minimize {SOL and IC}

$$SOL = \sum_{C=1}^{M} \sum_{k=1}^{n} a_k (P_k / P_{k_{max}})^4 \quad \text{……….. (4)}$$

where,

m- Number of single contingency considered

n- Number of lines

ak- weight factor=1.

P_k- real power transfer on branch k.

P_k^{max}- maximum real power transfer on branch k.

IC - Installation cost of FACTS device

SOL - Represents the severity of overloading

$$C_{TCSC} = 0.0015S^2 - 0.71S + 153.75(US\$/\ \ KVAR)$$

----------------------- (5)

$$C_{UPFC} = 0.0003S^2 - 0.2691S + 188.22(US\$/\ \ KVAR)$$

---------------------- (6)

Where, S - Operating range of UPFC in MVAR

$$S = |Q_2 - Q_1|$$

Q1 – MVAR flow through the branch before placing FACTS device.

Q2 - MVAR flow through branch after placing FACTS device.

VI. VARIOUS CONSTRAINTS OF POWER FLOW PROBLEM

6.1 Voltage Stability Constraints

VS includes voltage stability constraints in the objective function and is given by,

$$VS = \begin{cases} 0 & \text{if } 0.9<vb<1.1 \\ 0.9 - vb & \text{if } vb<0.9 \\ Vb - 1.1 & \text{if } vb>1.1 \end{cases} \quad \text{-----------------(7)}$$

Vb - Voltage at bus B

6.2 FACTS Devices Constraints

The FACTS device limit is given by,

$$-0.5\, X_L < X_{TCSC} < 0.5\, X_L$$

$$-200 \text{ MVAR} \le Q_{SVC} \le 200 \text{ MVAR}$$

------------ (8)

Where,

X_L - original line reactance in per unit

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

X_{TCSC} - reactance added to the line where UPFC is placed in per unit

Qsvc- reactive power injected at SVC placed bus in MVAR.

6.3 Power Balance Constraints

While solving the optimization problem, power balance equations are taken as equality constraints. The power balance equations are given by,

$\Sigma P_G = \Sigma P_D + P_L$ ----------- (9)

Where,ΣP_G– Total power generation

ΣP_D– Total power demand

PL – Losses in the transmission network

$P_i = \Sigma / E_i / / E_k / [G_{ik} \cos (\theta_i - \theta_k) + B_{ik} \sin (\theta_i - \theta_k)$ ------ (10)

$Q_i = \Sigma / E_i / / E_k / [G_{ik} \sin (\theta_i - \theta_k) + B_{ik} \cos (\theta_i - \theta_k)$ ------ (11)

where

Pi – Real power injected at bus i.
Qi– Reactive power injected at bus i.
θ_i ,θ_k– The phase angles at buses i and k respectively.
E_i,E_k– Voltage magnitudes at bus i and k respectively.
G_{ik}, B_{ik}– Elements of Y – bus matrix.

VII. FUZZY CONTROLLER AND ITS OPERATION

The collection of rules is called a rule base. The rules are in the familiar if-then format, and formally the if-side is called the *condition* and the then-side is called the *conclusion* (more often, perhaps, the pair is called *antecedent - consequent* or *premise - Conclusion).*

A preprocessor, the first block in the structure conditions the measurements before they enter the controller. The first block inside the controller is fuzzification, which converts each piece of input data to degrees of membership by lookup in one or several membership functions. The rules may use several variables both in the condition and exclusion of the rules. The controllers can therefore be applied to both multi-input-multi-output (MIMO) problems and single-input-single-output (SISO) problems.

VIII. OPF WITH FACTS CONTROLLER USING SIMULATION

Optimal power flow is one of the important methods used to increase the power flow between the buses. OPF is not only to increase the power flow in the system, but also to generate power based on the requirement with low cost. The power flow between the buses can also be increased by connecting FACTS controller in suitable places. By considering the above problems, here a new method for OPF with FACTS controller using MATLAB Simulation was proposed. Initially, the load flow between the buses is calculated using Newton raphson method and then the amount of power to be generated by each generator is computed using PSO. Finally, the FACTS controller is placed in a suitable location using PSO and Fuzzy Controller to increase the power flow between the buses. The process that takes place in the proposed method is explained briefly in the below sections.

IX. LOAD FLOW CALCULATIONS

The load flow calculation is important to compute the power flow between the buses. In our method Newton raphson method is used for load flow calculation. Newton Raphson method is commonly used technique for load flow calculation. The real and reactive power in each bus is computed using equation 1 & 2.

$$P_i = \sum_{k=1}^{N} V_i * V_k \left(G_{ik} * \cos\theta_{ik} + B_{ik} * \sin\theta_{ik} \right) \qquad \textbf{(1)}$$

$$Q_i = \sum_{k=1}^{N} V_i * V_k \left(G_{ik} * \sin\theta_{ik} - B_{ik} * \cos\theta_{ik} \right) \qquad \textbf{(2)}$$

where, N is the total number of buses, V_i & V_k are the voltage at i & k bus respectively, θ_{ik} is the angle between i & k bus, G_{ik} & B_{ik} are the conductance and susceptance value respectively.

After computing the power flow between the lines, the amount of power to be generated for the corresponding load with low cost is identified using PSO. In our method, there are two stages of PSO and a neural network is used. Here, PSO is used for generating training dataset to train the neural network. In the first stage, the amount of power generated by each generator for a particular load is computed using PSO and in the second stage, the bus where the FACTS controller is to be connected is identified and using this data, the neural network is trained. From the output of neural network, the amount of power to be generated by each generator for the given load and the location of FACTS controller to be connected are obtained.

X. IDENTIFYING UPFC CONNECTING BUS

In the testing stage, if a bus number except the slack bus given as input, it checks the lines which are connected in that bus and based on the reduce in cost and increase in power flow, the next bus where the UPFC is to be connected and the corresponding voltage and angle to be injected in that bus are obtained as output by the neural network.

By injecting the voltage and angle value to the line that are identified by the network, and using the amount of power generated by each generator that are obtained as an output from the first stage of PSO, the power flow is optimal and reduce in line losses.

XI. RESULT AND DISCUSSIONS

The proposed technique was implemented in the working platform of MATLAB 7.11 and tested using IEEE 14 bus system. The IEEE 14 bus system used in our proposed method is shown in fig below.

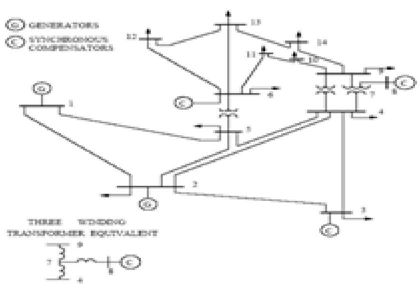
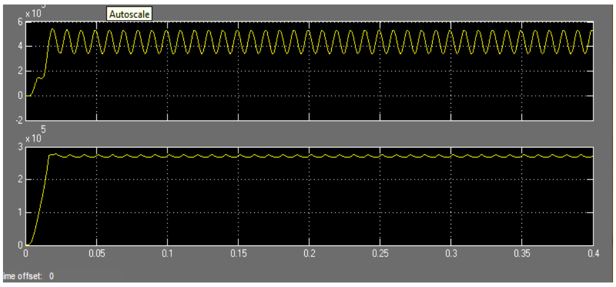


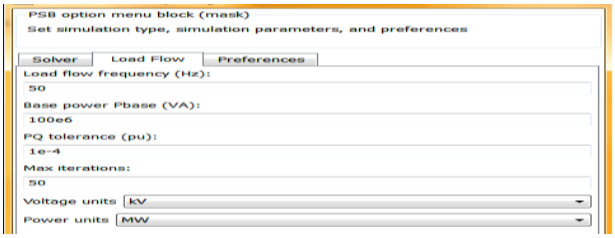
Figure 1: IEEE 14 bus system.

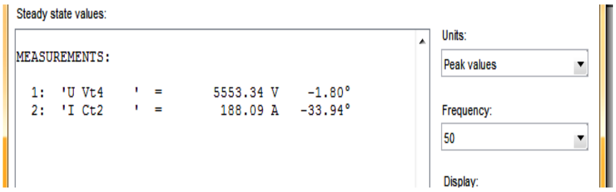
Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

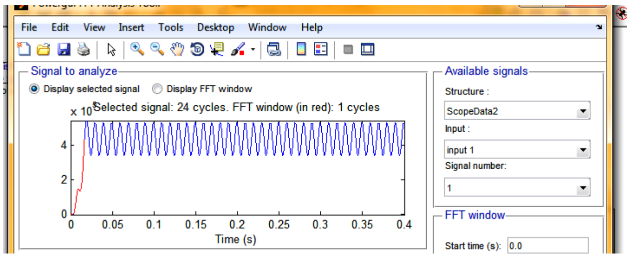
In the test system, bus 1 is considered as the slack bus and the base MVA of the system is 100. Bus 2, 13, 22, 23 and 27 are generator bus and all other buses are load bus.

1) 14 bus system with open loop and SVC

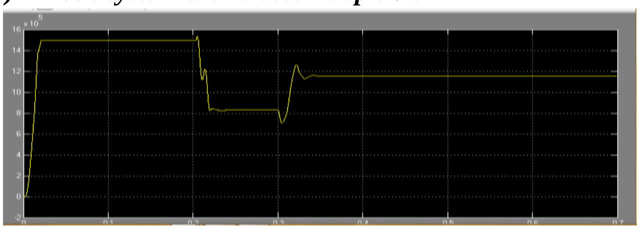


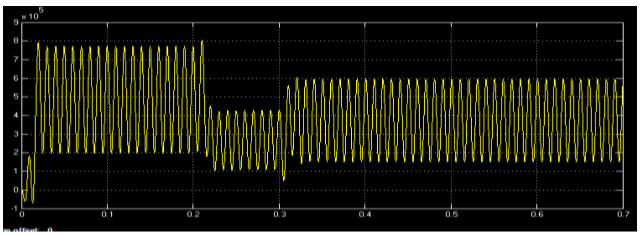


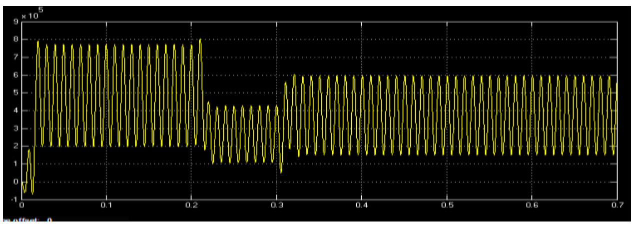




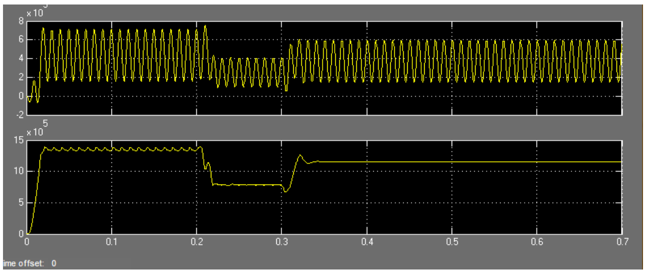
2) 14 bus system with closed loop SVC

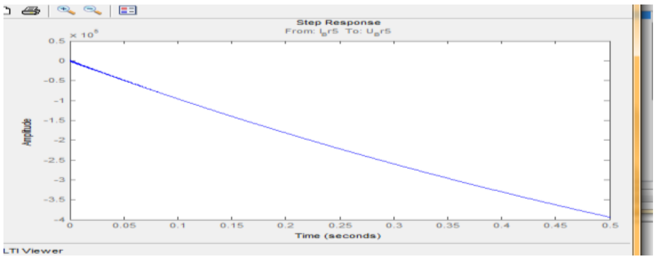


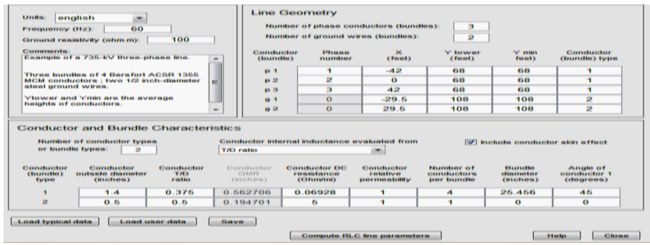




3) 14 bus system with closed loop and TCVR







XII. CONCLUSION & FUTURE SCOPE

In this paper, the proposed method was tested for **IEEE 14 bus system** and FACTS controller used in our method is **SVC and TCVR**. From the above results it is clear that our method has reduced the power losses as well as the total cost in the system. This method to be tested for IEEE 30 & 50 bus systems also in future. Also various FACTS controllers like Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) etc., also to be incorporated likely.

REFERENCES

1. MithunBhaskar M, SrinivasMuthyala and SyduluMaheswarapu, "Security Constraint Optimal Power Flow (SCOPF) – A Comprehensive Survey", International Journal of Computer Applications, Vol. 11, No.6, pp. 42-52, Dec 2010.
2. K. Mani Chandy, Steven H. Low, UfukTopcu and HuanXu, "A Simple Optimal Power Flow Model with Energy Storage", In Proceedings of IEEE Conference on Decision and Control, Atlanta, pp. 1051-1057, Dec 2010.
3. Brahim Gasboui and Boume diene Allaoua, "Ant Colony Optimization Applied on Combinatorial Problem for Optimal Power Flow Solution", Leonardo Journal of Sciences, Issue. 14, pp. 1-17, June 2009.
4. Hongye Wang, Carlos E. Murillo-Sanchez, Ray D. Zimmerman and Robert J. Thomas, "On Computational Issues of Market-Based Optimal Power Flow", IEEE Transactions on Power Systems, Vol. 22, No. 3, pp. 1185-1193, Aug 2007.
5. Zwe-Lee Gaing; Rung-Fang Chang, "Security-constrained optimal power flow by mixed-integer genetic algorithm with arithmetic operators", In Proceedings of IEEE Power Engineering Society General Meeting, pp. 1-8, Montreal, 2006.
6. N. G. Hingorani and L. Gyugyi, Understanding FACTS concepts and technology of flexible AC transmission systems. New York: IEEE Press, 2000.

7. R. M. Mathur and R. K. Varma, Thyristor-based FACTS controllers for electrical transmission systems. Piscataway: IEEE Press, 2002.
8. Y.-H. Song, Flexible ac transmission systems (FACTS). London: The Institution of Electrical Engineers, 1999.
9. P. Moore and P. Ashmole, "Flexible AC transmission systems. III. Conventional FACTS controllers," Power Engineering Journal, vol. 11, pp. 177-183, 1997.
10. J. Carpentier and A. Merlin, "Optimization methods in planning and operation," International *Journal of Electrical Power and Energy Systems*, vol. 4, pp. 11-18, 1982.
11. M. Noroozian, L. Ängquist, M. Ghandhari, and G. Andersson, "Improving power system dynamics by series-connected FACTS devices," *Power Delivery, IEEE Transactions on*, vol. 12, pp. 1635-1641, 1997.
12. H. Ambriz-Perez, E. Acha, and C. R. Fuerte-Esquivel, "Advanced SVC models for Newton-Raphson load flow and Newton optimal power flow studies," *Power Systems, IEEE Transactions on*, vol. 15, pp. 129-136, 2000.
13. T. Orfanogianni, "A flexible software environment for steady-state power flow optimization with series FACTS devices." Diss. ETH Zurich, 2000, pp. 135 S.
14. TarekBouktir and Linda Slimani, "Optimal Power Flow of the Algerian Electrical Network using an Ant Colony Optimization Method", Leonardo Journal of Sciences, Issue. 7, pp. 43-57, Dec 2005.
15. TarekBouktir and Linda Slimani, "A Genetic Algorithm for Solving the Optimal Power Flow Problem", Leonardo Journal of Sciences, Issue. 4, pp. 44-58, June 2004.
16. Mithun M. Bhaskar, SrinivasMuthyala MaheswarapuSydulu, "A Novel Progressively Swarmed Mixed Integer Genetic Algorithm for Security Constrained Optimal Power Flow (SCOPF)", International Journal of Engineering, Science and Technology, Vol. 2, No. 11, pp. 34-40, 2010.
17. KeeratiChayakulkheeree and WeerakornOngsakul, "Optimal Power Flow Considering Non-Linear Fuzzy Network and Generator Ramprate Constrained", International Energy Journal, Vol. 8, pp.131-138, 2007.
18. C. Thitithamrongchai and B. Eua-Arporn, "Self-adaptive Differential Evolution Based Optimal Power Flow for Units with Non-smooth Fuel Cost Functions", Journal of Electrical Systems, Vol. 3, No. 2, pp. 88-99, 2007.
19. P. K.Roy, S. P. Ghoshal and S.S. Thakur, "Biogeography Based Optimization Approach for Optimal Power Flow Problem Considering Valve Loading Effects", International J. of Recent Trends in Engineering and Technology, Vol. 3, No. 3, pp. 177-181, May 2010.
20. S. Jaganathan, S. Palanisamy K. Senthilkumaravel and B. Rajesh, "Application of Multi-Objective Technique to Incorporate UPFC in Optimal Power Flow using Modified Bacterial Foraging Technique", International Journal of Computer Applications, Vol.13, No.2, pp. 18-24, Jan 2011.
21. K. S. Swarup, "Swarm intelligence approach to the solution of optimal power flow", J. Indian Inst. Sci., Vol.86, pp. 439–455, Oct 2006.
22. Mithun M. Bhaskar and SyduluMaheswarapu, "A Hybrid Genetic Algorithm Approach for Optimal Power Flow", TELKOMNIKA, Vol. 9, No. 1, pp. 209-214, April 2011.
23. KeeratiChayakulkheeree and WeerakornOngsakul, "Multi-Objective Optimal Power Flow Considering System Emissions and Fuzzy Constraints", GMSARN International Journal Vol. 1, pp. 1 - 6, 2008.

AUTHORS PROFILE

Nanda Kumar obtained his Bachelor degree (B.E) in Electrical and Electronics Engineering from the Bharathidasan University, Trichy, India in 1998 and the Master of Engineering (M.E) degree in Power Systems Engineering from the Anna University, Chennai, India in 2007. Currently he has been working toward the Ph.D. degree in the Department of Electrical Engineering, Anna University of Technology, Coimbatore, India. He is currently an Assistant Professor with the department of Electrical & Electronics Engineering at Sri Krishna College of Technology, Coimbatore. His research interests include Power System Optimization Techniques, Power Flow Analysis, Economic Load Dispatch and Power Quality Issues.

Dr. R. Dhanasekaran received his B.E. degree in Electrical & Electronics Engineering from Bharathiyar University, Coimbatore, M.E. degree in Power Electronics & Drives from College of Engineering, Anna University, Guindy, Chennai and Ph.D. in Electrical Engineering from Anna University, Chennai. He is currently working as a Research Director, SyedAmmal Engineering College, Ramanathapuram. His research interest includes EMI/EMC, Power Engineering and Control of Special machines.