ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 6, Issue 12, June 2017

Congestion Management Using Optimal Placement of TCSC Using SOS Algorithm

A.Faustina[1], N.Chidambararaj[2], D.Milantha Minnet[3], Dr.K.Chitra[4]

[1,3] Department of Electrical and Electronics Engineering, St. Joseph's College of Engineering Chennai 600119, India.

[2] Research Scholar, Sathyabama University, Chennai 600119.

[4] Professor, School of Electrical and Electronics Engineering, VIT University-Chennai Campus, Chennai 600127

Abstract*: In this paper, Symbiotic Organism Search (SOS) Algorithm is used for managing the Congestion in power system by optimally placing the Facts device. Here, Thyristor controlled Series Compensator (TCSC) is used as a Facts Device for solving problems such as Minimization of Real Power Loss and Congestion Cost. The Proposed Algorithm is used to find the best position for placing TCSC because of its high cost. In this study, SOS is tested in a standard IEEE 14 bus system with cases such as Minimization of Real Power loss and Congestion Cost.

Keywords: **Congestion management, Thyristor Controlled Series Compensator (TCSC), Transmission Congestion, SOS.**

I. INTRODUCTION

Physical or Operational constraints which become active in the power system, which limits the amount of electric power transmitted between two locations. Various limiting factors related to congestion are: line thermal limits, transformer emergency ratings, bus voltage limits, transient or oscillatory stability, etc. Line flows should not be allowed to increase the thermal limits resulting in the problem of contingency would cause the network to collapse because of voltage instability, etc.

Among the technical solutions, various studies have been done to manage the congestion problems using generation redispatch, security constrained optimal power flow (SCOPF) and load curtailment with redispatch. The two broad prototypes employed for congestion management are the *cost-free* means and the *non-cost-free* means. The former include actions like temporary suspension of operating of congested lines or operation of transformer taps, phase shifters, or FACTS devices. The later procedure involves rescheduling generation and curtailment of loads which results in incremental generator operating costs.

Among the cost-free means FACTS devices can be used to reduce the congestion without touching the economic matters. Controlling the power flows in the transmission network, reduces the power flow in heavily loaded lines, resulting in low system loss, improved stability of the network, reduced cost of production and fulfilled contractual requirement. The possible action of controlling power flow in an electric power system without rescheduling the generation can improve the performance considerably. It is important to determine the location for placement of these Facts devices because of their substantial costs.

There are several methods for finding the optimal locations of the FACTS controllers in vertically integrated systems as well as unbundled power systems [2-6]. In references [7, 8], the optimal locations of FACTS devices are obtained by solving the economic dispatch problem including the cost of FACTS devices making the premises that all lines, initially, have these devices.

Some examples of metaheursistic algorithms used to solve the optimal placement problems are Genetic Algorithm (GA),Particle Swarm Optimization (PSO), Differential Evolution(DE), Ant Colony Optimization (ACO) , Harmony Search(HS) , Artificial Bee Colony (ABC), Bees Algorithm (BA),Firefly Algorithm, Charge System Search (CSS), Big Bang–Big Crunch (BB–BC), Cuckoo Search (CS) Mine Blast Algorithm (MBA), Water Cycle Algorithm, Dolphin Echolocation, and Ray Optimization. The above mentioned methodologies have get over the drawbacks in the Conventional system but it also contains certain limitations like premature convergence.

Min-Yuan Cheng et al proposed the Symbiotic Organism Search Algorithm (SOS) which models the interactive behavior seen among organisms in nature, called Symbiosis. The theory states that, "Organisms rarely live in isolation due to reliance on other species for sustenance and even survival. This relationship is known as symbiosis [7]."

II. MODELLING OF TCSC

A. TCSC representation in Power Flow Analysis

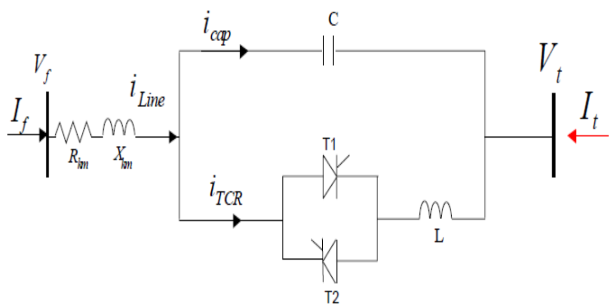

Fig 1.TCSC Model

TCSC is one of the series FACTS controllers which have been in usage for many years to increase line power transfer as well as system stability. The basic model of a TCSC is shown in Fig. 1, consists of three components: capacitor bank C, bypass inductor L and bidirectional thyristors T1 and T2.Additionally one control variable included to the normal power flow equation is firing angle of the thyristor which can adjust the TCSC reactance in conformity with the system control algorithm, normally in response to some system parameter variations.

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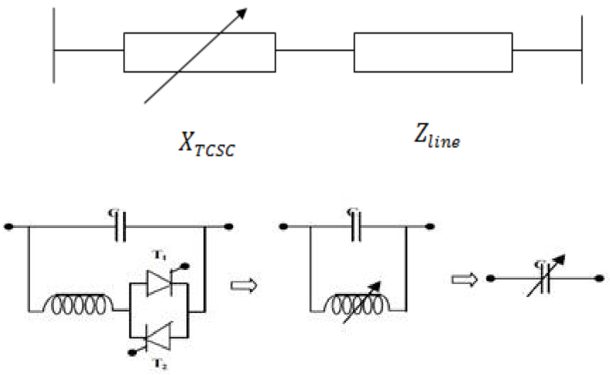

Fig 2.Variable reactance model of TCSC

The TCSC can control the active power flow for the line *l* (between bus- *f* and bus- *t* where the TCSC is installed). The TCSC equivalent reactance as a function of the TCSC firing angle α is;

$$X_{TCSC} = -X_c + K_1(2\sigma + sin2\sigma - K_2 cos^2\sigma(\omega \tan(\omega\sigma) - tan\sigma)$$

Where

$$\sigma = \pi - \alpha$$

$$K_1 = \frac{X_C + X_{LC}}{\pi} \; ; \quad K_2 = \frac{4(X_{LC})^2}{\pi X_L}$$

$$\omega = \frac{1}{2\pi f\sqrt{LC}}$$

Figure 3 shows the relationship between firing Angle (α) and XTCSC

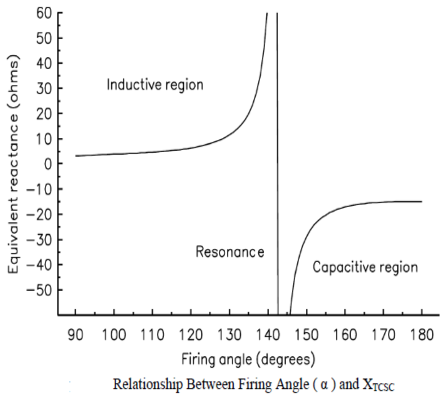

Fig 3.Relationship between firing angle and TCSC reactance

The real and reactive power injection at bus *(-f)* can be expressed as

$$P_{finj}^{TCSC} = G''_{ff}V_f^2 + (G''_{ft}\cos\delta_{ft} + B''_{ft}\sin\delta_{ft})V_f V_t \qquad (1)$$

$$Q_{finj}^{TCSC} = -B''_{ff}V_f^2 + (G''_{ft}\sin\delta_{ft} - B''_{ft}\cos\delta_{ft})V_f V_t \qquad (2)$$

The real and reactive power injection at bus *(-t)* can be expressed as

$$P_{tinj}^{TCSC} = G''_{tt}V_t^2 + (G''_{tf}\cos\delta_{tf} + B''_{tf}\sin\delta_{tf})V_f V_t \qquad (3)$$

$$Q_{tinj}^{TCSC} = -B''_{tt}V_t^2 + (G''_{tf}\sin\delta_{tf} - B''_{tf}\cos\delta_{tf})V_f V_t \qquad (4)$$

Where

$$G''_{ft} = G''_{tf} = -G''_{ff} = -G''_{tt} = \frac{X_c R(2X + X_c)}{(R^2 + X^2)(R^2 + (X + X_c)^2)}$$

$$B''_{ft} = B''_{tf} = -B''_{ff} = -B''_{tt} = \frac{X_c(R^2 - X(X + X_c))}{(R^2 + X^2)(R^2 + (X + X_c)^2)}$$

and Z=R+jX is the impedance of the transmission line , X_c is the magnitude of X_{tcsc} and $\delta_{ft} = \delta_f - \delta_t$

The real power constraint of the TCSC is given by

$$\Delta P_{ft} = P_{ft} - P_{ft}{}^{spec} = 0 \qquad (5)$$

Where

$P_{ft}{}^{spec}$ is the specified power flow of the line l and P_{ft} is the calculated power flow of the line l

$$P_{ft} = G'_{ff}V_f^2 + (G'_{ft}\cos\delta_{ft} + B'_{ft}\sin\delta_{ft})V_f V_t \quad (6)$$

Where

$$G'_{ff} = -G'_{ft} = \frac{R}{R^2 + (X + X_C)^2}$$

$$B'_{ft} = \frac{(X + X_C)}{R^2 + (X + X_C)^2}$$

$$\delta_{ft} = \delta_f - \delta_t$$

B. *Implementing TCSC in Newton-Raphson Power Flow*

A Newton-Raphson method is represented after the placement of TCSC, to control the power flow between *f-t* is controlled to$P_{ft}{}^{spec}$.

$$\begin{bmatrix} \Delta P_f \\ \Delta P_t \\ \Delta Q_f \\ \Delta Q_t \\ \Delta P_{ft} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_f}{\partial \delta_f} & \frac{\partial P_f}{\partial \delta_t} & \frac{\partial P_f}{\partial V_f} & \frac{\partial P_f}{\partial V_t} & \frac{\partial P_f}{\partial \alpha} \\ \frac{\partial P_t}{\partial \delta_f} & \frac{\partial P_t}{\partial \delta_t} & \frac{\partial P_t}{\partial V_f} & \frac{\partial P_t}{\partial V_t} & \frac{\partial P_t}{\partial \alpha} \\ \frac{\partial Q_f}{\partial \delta_f} & \frac{\partial Q_f}{\partial \delta_t} & \frac{\partial Q_f}{\partial V_f} & \frac{\partial Q_f}{\partial V_t} & \frac{\partial Q_f}{\partial \alpha} \\ \frac{\partial Q_t}{\partial \delta_f} & \frac{\partial Q_t}{\partial \delta_t} & \frac{\partial Q_t}{\partial V_f} & \frac{\partial Q_t}{\partial V_t} & \frac{\partial Q_t}{\partial \alpha} \\ \frac{\partial P_{ft}}{\partial \delta_f} & \frac{\partial P_{ft}}{\partial \delta_t} & \frac{\partial P_{ft}}{\partial V_f} & \frac{\partial P_{ft}}{\partial V_t} & \frac{\partial P_{ft}}{\partial \alpha} \end{bmatrix} \begin{bmatrix} \Delta \delta_f \\ \Delta \delta_t \\ \Delta V_f \\ \Delta V_t \\ \Delta \alpha \end{bmatrix}$$

Where $\Delta P_f, \Delta P_t$, ΔQ_f and ΔQ_t, are the active and reactive power mismatches at buses f and t respectively.

ΔP_{ft} is the real power flow mismatch for the line l in which the TCSC is installed between bus –f and bus-t.

$\Delta\alpha = \alpha^{i+1} - \alpha^i =$ Incremental change in the TCSC's firing angle . Superscript represents iteration.

III. PROBLEM FORMULATION

A. *Objective function*

$$Min\ f(x) = Congestion\ Cost$$

where,
CC= congestion cost = Cpg +Cqg
Cpg = real power congestion cost
Cqg= reactive power congestion cost

Power generation limit: $P_{Gi(min)} \le P_{Gi} \le P_{Gi(max)}$
$Q_{Gi(min)} \le Q_{Gi} \le Q_{Gi(max)}$

Bus voltage and power angle limits: $V_{i(min)} \le V_i \le V_{i(max)}$
$\theta_{i(min)} \le \theta_i \le \theta_{i(max)}$

ISSN: 2277-3754
ISO 9001:2008 Certified
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TCSC reactance limit: $X_{tcsc(min)} \leq X_{tcsc} \leq X_{tcsc(max)}$

Firing angle limit: $\alpha_{(min)} \leq \alpha \leq \alpha_{(max)}$

B. Calculation of Congestion Cost:

The real power congestion cost can be calculated by multiplying the locational marginal price difference between two buses with the actual power flow.

Congestion cost = $\Delta\rho * P$ (7)

Where

P =power flow in the line connected between buses $\Delta\rho$= LMP difference between buses

LMP(ρ) = ((2*a) +b)*(1+NRPL-RPL))/Ng (8)

Where a and b are generator cost parameters

NRPL= new real power loss

RPL= real power loss

Ng=number of generators

IV. SYMBIOTIC ORGANISM SEARCH ALGORITHM

Symbiotic Organism Search Algorithm (SOS) is a recently developed algorithm from the interaction strategies adopted by organisms to survive and propagate in the ecosystem.SOS Algorithm was introduced by Min-Yuan Cheng et al in 2013 and is proposed to solve optimization problems. The population-based metaheursistic algorithm is based on the interaction of species in the ecosystem by seeking the organisms randomly to obtain the best survival/global optimal solution [7].

The algorithm gets initialized with random population called the ecosystem, where a group of organisms is generated randomly to the search space. Each organism represents one candidate solution to the corresponding problem. Each organism is associated with a certain fitness value, which reflects degree of adaptation to the desired objective.

The SOS algorithm is defined by introducing three phases of interactions between the organisms in the ecosystem. They are mutualism phase, commensalism phase, and parasitism phase. The character of the interaction defines the main principle of each phase.

- **MUTUALISM PHASE**: Interactions benefit both sides;
- **COMMENSALISM PHASE**: Interactions that benefit one side and do not impact the other;
- **PARASITISM PHASE**: Interactions that benefit one side and actively harm the other.

Each organism interacts randomly with the other organisms through all the three phases. The process will get repeated until termination criteria are met.

A. Mutualism phase

In SOS, Xi is an organism matched to the ith member of the ecosystem. Another organism Xj is then selected randomly from the ecosystem to interact with Xi. Both organisms engage in a mutualistic relationship with the goal of increasing mutual survival advantage in the ecosystem. New candidate solutions for Xi and Xj are calculated based on the mutualistic symbiosis between organism Xi and Xj, which is modeled in Eqs. (9) and (10).

$$X_{inew} = X_i + rand(0,1) * X_{best} - MV * BF_1 \quad (9)$$

$$X_{jnew} = X_j + rand(0,1) * X_{best} - MV * BF_2 \quad (10)$$

Where rand(0, 1) in Eqs (9) and (10) is a vector of random numbers.

$$Mutual\_Vector(MV) = \frac{(X_i + X_j)}{2} \quad (11)$$

The variables BF1 and BF2 are explained as in nature, some mutualism relationships might give a greater beneficial advantage for just one organism than another organism. Organisms are updated only if their new fitness is better than their pre-interaction fitness.

B. Commensalism phase

Similar to the mutualism phase, an organism, Xj, is selected randomly from the ecosystem to interact with Xi. In this circumstance, organism Xi attempts to benefit from the interaction. However, organism Xj itself neither benefits nor suffers from the relationship. The new candidate solution of Xi is calculated according to the commensal symbiosis between organism Xi and Xj, which is modeled in Eq. (12). Following the rules, organism Xi is updated only if its new fitness is better than its pre-interaction fitness.

$$X_{i\,new} = X_i + rand(-1,1) * (X_{best} - X_j) \quad (12)$$

The part of equation,$(X_{best} - X_j)$, is reflecting as the beneficial advantage provided by Xj to help Xi increasing its survival advantage in ecosystem to the highest degree in current organism.

C. Parasitism phase

Parasite Vector is created by duplicating an organism X_i and it interacts randomly with other organism (host say Xj). If Parasite Vector has a better fitness value, it will kill organism Xj and assume its position. If the fitness value of Xj is better, Xj will have immunity from the parasite and the Parasite Vector will no longer be able to live.

The algorithmic steps for solving the problem using SOS algorithm follows the certain steps which is being illustrated in the flow chart.The process of SOS algorithm can be illustrated as follows.

Step 1: Ecosystem initialization.

***Step 2: Identify the initial best solution,* Xbest.**

Step 3: Mutualism phase.

Fitter organisms are selected as solutions for the next iteration. New fitness is better than the old Therefore, fitness value modified to new value.

Step 4: Commensalism phase.

If (New fitness value X1 > old fitness value X1). Therefore, X1 is modified to new value.

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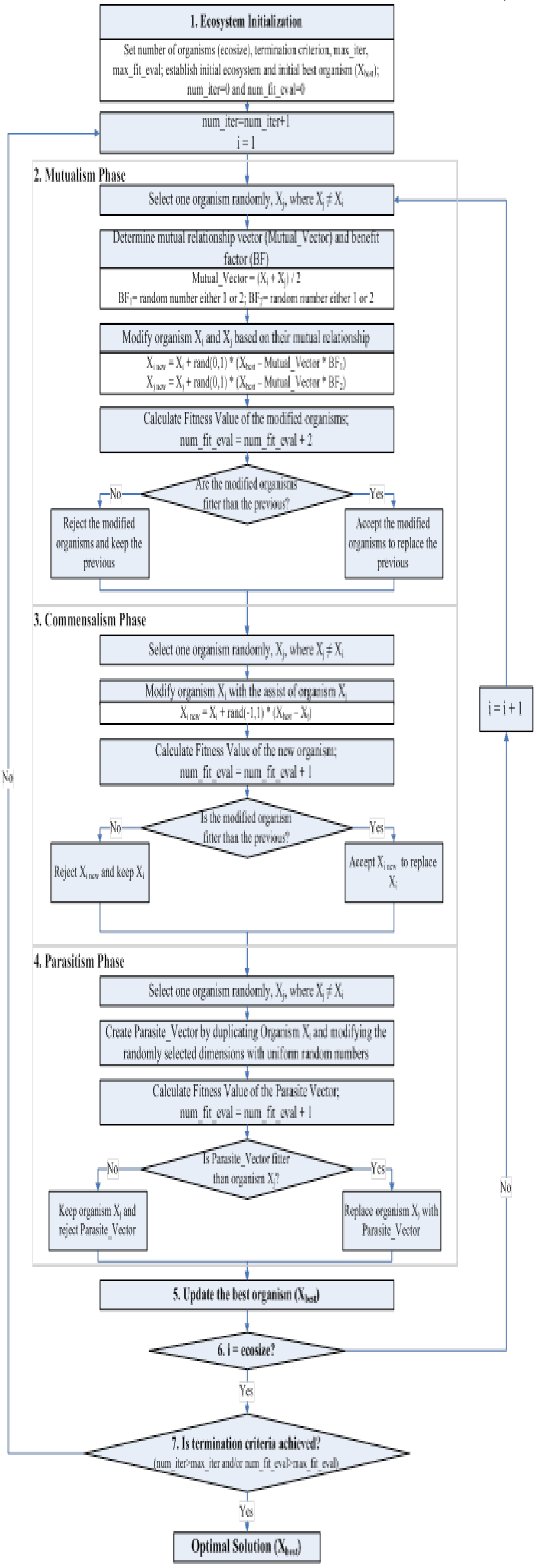

Fig 4. Flow chart for SOS

***Step 5: Parasitism phase*.**

Another organism is selected randomly from the ecosystem. Parasite_Vector is created with the corresponding fitness value. The Parasite_Vector is compared to that organism. The fitter organism will survive to the next iteration.

***Step 6*:** Go to *step 2* if the current Xi is not the last member of the ecosystem; otherwise continue to next step.

Step 7: Stop if one of the termination criteria is reached; otherwise return to *step 2* and start the next iteration is better than organism. Therefore, organism(X) is eliminated from the ecosystem and replaced by parasite vector.

V. NUMERICAL RESULTS

A) IEEE 14-Bus system

SOS approach is tested on the standard IEEE 14-bus system as shown in fig . The line data, bus data, generator data and the minimum and maximum limits for the control variables are referred from [1]. Maximum iteration number is taken to be as 50.

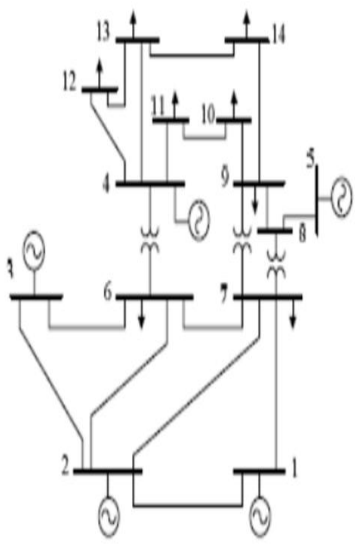

Fig 5.Single line diagram of an IEEE 14- bus test system

B) Results

The proposed approach is applied for minimization of real power loss by placing the TCSC and to determine the congestion cost as one of the objective function. The obtained optimal placement of TCSC and the control variable is given by

The power loss before TCSC installation is **13.393361 MW**
The power loss after TCSC installation is **12.580228 MW**
Optimal TCSC location is **13-14**
The optimal firing angle is **118.693516**
The value of Xtcsc in p.u is **-0.770420**
The congestion cost is **301.942602$**
The congested bus is **1**

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C) Figures

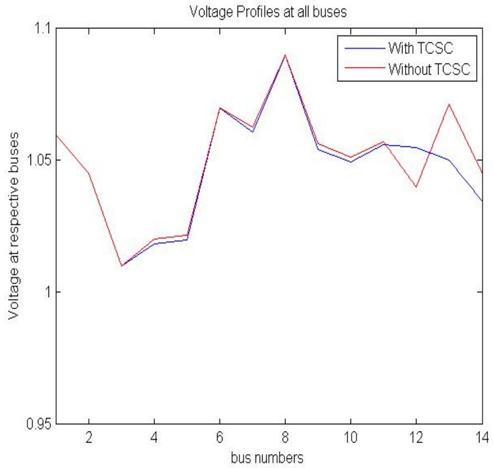

Fig 6 .Voltage Profile

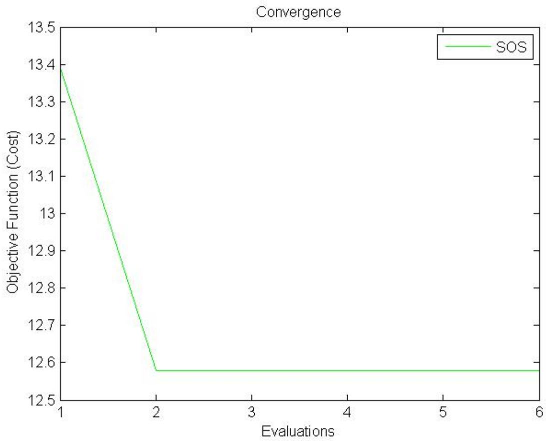

Fig 7 .Convergence graph of the SOS algorithm

VI. CONCLUSIONS

This paper report about optimal placement of TCSC in a power system using SOS algorithm. The three phases of the algorithm are simple to operate and requires simple mathematical operations for coding. SOS algorithm does not use tuning parameters, which enhances performance stability, able to solve various numerical optimizations.

By adjusting the firing angle of thyristor, the value of TCSC reactance is varied which minimizes the real power loss in the system. The proposed method directly identifies a line, having highest impact on the flow in congested line, for the TCSC placement.

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AUTHORS BIOGRAPHY

A.Faustina received her B.E degree in Electrical and Electronics engineering in the year 2014 in Jeppiaar Engineering College, Chennai and done her Masters in Power Systems Engineering in St. Joseph's College Of Engineering, Chennai. She has interest in Power System Analysis, Transmission and Distribution and her area of doing project in Congestion management in transmission network using Facts controllers and in carrying out various algorithms

N. Chidambararaj was born in the year 1981. He completed his Diploma in Electrical and Electronics Engineering in the year 2000. He received his B.E degree in Electrical and Electronics engineering in the year 2003 and proceeded with pursuing Masters in Power Systems Engineering and graduated in the year 2005. He has been working as an Associate professor at St. Joseph's College of Engineering in the department of Electrical and Electronics engineering since 2005 and he has almost 8 years of experience in the respective field. He is currently pursuing Ph.D. in Satyabhama University. His subject of interest includes Power systems, Engineering Electromagnetics, Digital signal processing and Machine design and his core research is on deregulated power system.

D.Milantha minnet received her B.E degree in Electrical and Electronics engineering in the year 2014 in Jeppiaar Engineering College, Chennai Now finished her Masters in Power Systems Engineering in the Department of Electrical Engineering in St.Joseph's College Of Engineering, Chennai. She has interest in Restructured Power System, Congestion management in deregulated electricity markets and in implementation of various algorithms

Dr. K. Chitra is working as a Professor, in the department of Electronics and communication engineering at VIT- Chennai Campus. Dr. K. Chitra received her B.E. Degree in Electronics and communication engineering from Bharathiar University, Coimbatore in 1990, and M.E. Degree in Applied Electronics from Bharathiar University in 1992. She has spent her 23 years of experience in teaching and guiding projects for undergraduate and postgraduate students. Dr. K. Chitra has added 15 international publications to her credit. She has few funded projects from Government of India. She's areas of interests include optical communication, optical networks, wireless sensor and computer networks, Biomedical Engineering and microwave Engineering.