

# Optimal Allocation of Unified Power Flow Controller for Power Loss minimization and Voltage Profile Improvement using Harmony Search Algorithm

B.Sravan Kumar<sup>1</sup>, M.Suryakalavathi<sup>2</sup>, G.V.Nagesh Kumar<sup>1</sup>

<sup>1</sup>Department of Electrical and Electronics, GITAM University, Visakhapatnam, Andhra Pradesh, INDIA

<sup>2</sup>Department of Electrical and Electronics, JNT University, Hyderabad, Telangana, INDIA

sravanbali@gmail.com, drgvnk14@gmail.com

**Abstract.** This paper presents a population based metaheuristic algorithm, namely Harmony Search (HS) is proposed for solving optimal power flow (OPF) problem solution. Harmony Search (HS) is a stochastic algorithm which imitates the music improvisation process. In this process, the musicians improvise their instrument pitches searching for the perfect state of harmony. The HS algorithm does not require initial values and uses a random search instead of a gradient search, so derivative information is unnecessary. The Harmony Search (HS) algorithm is coded in MATLAB and the performance is tested on IEEE 14 bus test system with real power losses minimization and voltage deviation minimization as objective function. Unified Power Flow Controller (UPFC) is a multilateral device in the Flexible Alternating Current Transmission System (FACTS) family. It has capable of controlling the power system parameters like voltage magnitude, line reactance and phase angle either individually or collectively. In this paper UPFC is incorporated in Harmony Search algorithm (HS) based Optimal Power Flow (OPF). UPFC is used to reduce transmission line losses and improve the voltage stability of the system. Harmony Search algorithm gives better results as compared to genetic algorithm in both without and with UPFC.

## Keywords

FACTS device, Harmony Search algorithm, Optimal Power Flow, UPFC.

## 1. Introduction

Restructuring in electric power industry has resulted in exhaustive usage of transmission systems. The competition in electricity market has also led to an increased volume of electricity trade. This situation causes an unexpected need of power transfer through some transmission lines. As the power system becomes more complex and more heavily loaded, it will be operated in unstable or insecure situations. The basic challenge in the evolving deregulated power system is to provide a transmission network capable of delivering contracted power from suppliers to consumers over a large geographic area under market forces-controlled, and continuously varying patterns of demand and supply. FACTS devices can control power transmission parameters such as

series impedance, voltage, and phase angle by their fast control characteristics and continuous compensating capability. They can reduce flow of heavily loaded lines, resulting in low system losses, improved both transient and small signal stability of network, reduced cost of production, and fulfillment of contractual requirement by controlling the power flow in the network. For a meshed network, an optimal allocation of FACTS devices allows to control its power flows and thus, to improve the system loadability and security.

Present day commercial OPF programs can solve very large and complex power systems optimization problems in a relatively less time. Many different solution methods have been suggested to solve OPF problems. In a conventional power flow, the values of the control variables are predetermined. OPF continues to be significant due to the growth in power system size and complex interconnections [3 – 4].

The UPFC is advanced FACTS device capable of providing simultaneous control of voltage magnitude, active and reactive power flows. Owing to its fast response and unrivalled functionality, it is able to solve problems related to power flow control. The UPFC, constructed by the combination of the static synchronous compensator (STATCOM) and the static synchronous series compensator (SSSC) [3] that can control power flow in transmission lines, using a series connected power converter. It was introduced by Gyugiy in 1991 [4] and is believed to have the ability in improving power system performance by means of controlling its parameters, like the voltage magnitude and the phase angle. UPFC is connected in both series and shunt (parallel) on a transmission line of a power system [5, 6]. A mathematical model is required for investigating the effects of UPFC on the power system operation that can be used for further analysis [7].

In this paper, a population based metaheuristic algorithm, namely Harmony Search (HS) is proposed for solving optimization tasks. The harmony search is considered as musician's behavior which is inspired by soft computing algorithm. As the musicians in improvisation process try to find the best harmony in terms of aesthetics, the decision variables in optimization process try to be the best vector in terms of objective function. The HS algorithm does not require initial values and uses a random search instead of a gradient search, so derivative information is unnecessary.

## 2. Unified Power Flow Controller

Gyugyi proposed the UPFC concept is used for real time control and dynamic compensation of the ac transmission system [12, 13]. UPFC provides multifunctional flexibility required to solve many of the problems in the power system. The UPFC is able to control simultaneously or selectively all the parameters affecting power flow in the transmission line (i.e. voltage magnitude, line impedance and phase angle). This capability signifies the term ‘unified’ in the UPFC [14]. The Unified Power Flow Controller (UPFC) viewed as a combination of Static Synchronous Compensator (STATCOM) and a Static Synchronous Series Compensator (SSSC). Both the compensators are coupled via a common DC-link, which allows bi-directional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM.

The UPFC consists of two voltage-source converters, one connected in shunt and one connected in a series. The series converter of the UPFC injects an AC voltage with the controllable magnitude and phase angle in a series with the transmission line via a series connected coupling transformer. The basic function of shunt converter is to supply or absorb the real power demanded by the series converter at the common DC link. It can also generate or absorb controllable reactive power and provide independent shunt reactive compensation for the line. Thereby, the UPFC can fulfil the functions of reactive shunt compensation, a series compensation and phase shifting. Thus the UPFC functions as an ideal ac to ac power converter in which the real power can freely flow in either direction between the ac terminals of two converters and each converter can independently generate or absorb reactive power at its own ac output terminals.

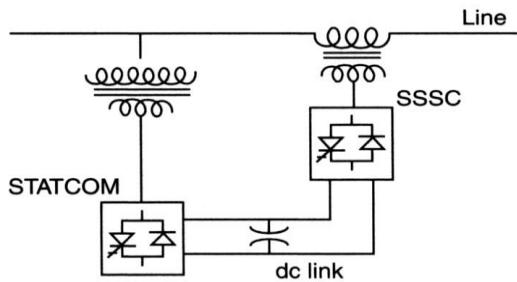


Fig.1.:A simple model of UPFC

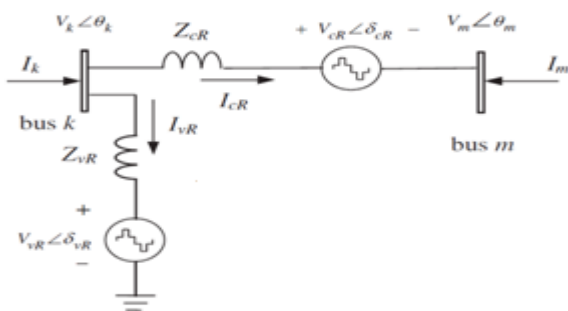


Fig.2: Equivalent circuit of the Unified Power Flow Controller

UPFC voltage sources are written as

$$V_{vR} (\cos \delta_{vR} + j \sin \delta_{vR}) \quad (1)$$

$$V_{cR} (\cos \delta_{cR} + j \sin \delta_{cR}) \quad (2)$$

Where  $V_{vR}$  and  $\delta_{vR}$  are the controllable voltage magnitude and phase angle of the voltage source representing the shunt converter. Similarly,  $V_{cR}$  and  $\delta_{cR}$  are the controllable voltage magnitude and phase angle of the voltage source representing the series converter. The source impedance is considered to be resistance less. (i.e  $R_{vR}=0$ ,  $R_{cR}=0$ ). The active and reactive power equations are

At bus k

$$P_k = [V_k V_m B_{km} \sin(\theta_k - \theta_m)] + [V_k V_{cR} B_{km} \sin(\theta_k - \delta_{cR})] + [V_k V_{vR} B_{vR} \sin(\theta_k - \delta_{vR})] \quad (3)$$

$$Q_k = -V_k^2 B_{kk} - [V_k V_m B_{km} \cos(\theta_k - \theta_m)] - [V_k V_{cR} B_{km} \cos(\theta_k - \delta_{cR})] - [V_k V_{vR} B_{vR} \cos(\theta_k - \delta_{vR})] \quad (4)$$

At bus m

$$P_m = [V_m V_k B_{mk} \sin(\theta_m - \theta_k)] + [V_m V_{cR} B_{mm} \sin(\theta_m - \delta_{cR})] \quad (5)$$

$$Q_m = -V_m^2 B_{mm} - [V_m V_k B_{mk} \cos(\theta_m - \theta_k)] - [V_m V_{cR} B_{mm} \cos(\theta_m - \delta_{cR})] \quad (6)$$

At Series converter:

$$P_{cR} = [V_{cR} V_k B_{km} \sin(\delta_{cR} - \theta_k)] + [V_m V_{cR} B_{mm} \sin(\delta_{cR} - \theta_m)] \quad (7)$$

$$Q_{cR} = -V_{cR}^2 B_{mm} - [V_k V_{cR} B_{km} \cos(\theta_k - \delta_{cR})] - [V_m V_{cR} B_{mm} \cos(\theta_m - \delta_{cR})] \quad (8)$$

At Shunt converter:

$$P_{vR} = [V_{vR} V_k B_{vR} \sin(\delta_{vR} - \theta_k)] \quad (9)$$

$$Q_{vR} = V_{vR}^2 B_{vR} - [V_{vR} V_k B_{vR} \cos(\delta_{vR} - \theta_k)] \quad (10)$$

The UPFC using solid state controllers provides functional flexibility to handle practically all the power flow control and transmission line compensation problems which are generally not obtained by variable impedance type thyristor-controlled controllers. The starting values of the UPFC voltage sources are taken to be  $V_{cR}=0.04$  p.u,  $\delta_{cR}=87.130$ ,  $V_{vR}=1$  p.u. and  $\delta_{vR}=00$ . The source impedances are taken as  $Z_{cR}=Z_{vR}=0.1$  p.u.

## 3. Harmony Search Algorithm

Harmony Search (HS) is a population based metaheuristic algorithm inspired from the musical process of searching for a perfect state of harmony, proposed by Zong Woo Geem in 2001. In the HS algorithm, each (musician = decision variable;

plays=generates; a note=a value; for finding a best harmony=Global optimum).

The pitch of each musical instrument determines the aesthetic quality, Just as the fitness value determines the quality of the decision variables.

In the process of music, all players sound pitches within the possible range together to make one harmony. If all the pitches make a good harmony, each player stores in his memory and the possibility of making a good harmony is increased next time.

In optimization also the same thing follows, the initial solution is generated randomly from decision variables within the possible range.

If the objective function value of these decision variables is good to make a promising solution, then the possibility of making a good solution is increased next time.

### 3.1. Parameters of HS Algorithm

HMS = the size of the harmonic memory.

HMCR =the rate of choosing a value from the harmony memory.

PAR = Pitch Adjustment Rate

$\delta$  = the amount between two neighboring values in discrete candidate set.

fw (fret width) = the amount of maximum change in pitch adjustment.

**Tab.1:** Parameters of HS Algorithm

S.No	Parameters	Optimal range
1	HMS	1 - 100
2	HMCR	0.7 - 0.99
3	PAR	0.1 - 0.5
4	Fw	0.1

The Harmony search algorithm mainly depends upon three rules:

- 1) Harmony memory consideration rule (HMCR)
- 2) Pitch adjustment rate (PAR)
- 3) Random initialization rule.

$$HM = \begin{bmatrix} x_{11} & x_{12} & x_{13} & \dots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{HMS1} & x_{HMS2} & x_{HMS3} & \dots & x_{HMSn} \end{bmatrix}$$

The HMS vectors filled in H matrix.

### 3.2 Algorithm

Step1: Initialize the parameters HMS, HMCR, PAR, BW and NI.

Step2: initialize the HM. Harmonic memory consisting of HMS vectors is generated randomly as  $x_i = x_{ij}$  where,  $j=1 \dots HMS$  and  $j=1 \dots n$ .

Step3: generate a random number rand1, within the range [0, 1]

If  $rand1 < HMCR$  then the first decision variable in the new vector is chosen randomly from the values of the current HM.

$$x_{ij}^{new} = x_{ij}, x_{ij} \in (x_{1j}, x_{2j}, \dots, x_{HMSj}) \quad (11)$$

Step4: now generate a new random number rand2, within the range [0, 1]

If  $rand2 < PAR$ , then the updated decision variable of PAR is calculated.

$$x_{ij}^{new} = x_{ij} \pm rand(0, 1) BW \quad (12)$$

Where, BW is a bandwidth factor.

Step5: Initialize the random vector.

If  $rand1 < HMCR$  fails, then the first new decision variable in the new

Vector is generated with upper and lower bounds.

$$x_{ij} = l_{ij} + (u_{ij} - l_{ij}) \quad (13)$$

Step6: By replacing the worst harmony vector in the harmony memory and updating the harmony memory as

$$x^{worst} = x^{new} \quad (14)$$

Step7: If not, Repeat step3 to step6. Until termination criteria is met.

Step8: If a termination criterion is met, then find the best memory.

## 4. Problem Formulation

### 4.1. Objective function

For a given system load, we look for the best configuration of UPFC device minimizing the following objective function

$$Min F = Min(W_1 * VD + W_2 * FP_{loss}) \quad (15)$$

Where  $w_1, w_2$  are the weighting factors.

$$W_1 + W_2 = 1 \quad (16)$$

$$W_1 = W_2 = 0.5$$

### 1) Voltage Deviation:

To have a good voltage performance, the voltage deviation at each bus must be made as small as possible. The Voltage Deviation (VD) can be expressed as:

$$F_{VD} = \min(VD) = \min\left(\sum_{k=1}^N \left|V_k - V_k^{ref}\right|^2\right) \quad (17)$$

$V_k$  is the voltage magnitude at bus  $k$

$V_k^{ref}$  is the reference voltage magnitude at bus  $k$

### 2) Real Power Loss:

This objective consists of minimizing the real power losses in the transmission lines. It can be expressed as

$$F_{P_{Loss}} = \min(P_{Loss}) = \min\left(\sum_{k=1}^{ntl} \text{real}(S_{ij}^k + S_{ji}^k)\right) \quad (18)$$

Where  $ntl = \text{no. of transmission lines}$

$S_{ij}$  is the total complex power flow from bus  $i$  to bus  $j$  in line  $k$ .

Subject to power balance constraints

$$\sum_{i=1}^N P_{Gi} = \sum_{i=1}^N P_{Di} + P_L \quad (19)$$

Where  $i=1, 2, 3, \dots, N$  and  $N = \text{no. of Buses}$

Voltage constraint:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max} \quad (20)$$

Where  $G_i=1, 2, 3, \dots, ng$  and  $ng = \text{no. of. Generator buses}$

Real power generation limit:

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad (21)$$

Where  $G_i=1, 2, 3, \dots, ng$  and  $ng = \text{no. of. Generator buses}$

Where  $P_L$  is the active power loss in the system,  $P_{Gi}$  is the active power generation at bus  $i$ ,  $P_{Di}$  is the power demand at

bus  $i$ ,  $N$  and  $ng$  are the number of buses and no of generators in the system respectively. The limits of Voltage Magnitudes of the generator buses are taken between 0.9pu and 1.1pu.

## 5. Results and Discussions

In order to demonstrate the performance of the Harmony Search Algorithm in Optimal Power Flow with UPFC, IEEE14 bus system is considered. An OPF program using Harmony Search algorithm approach is written using MATLAB without the UPFC, which was further extended with the UPFC. A MATLAB program is coded for the test system and the results are presented and analyzed. The input parameters of Harmony Search Algorithm, Genetic algorithm for the test systems are given in the Table 1 and Table 2 respectively.

**Tab.2:** Input Parameters of Harmony Search Algorithm

S.No	Parameters	Quantity
1	HMS	20
2	HMCR	0.5
3	PAR	0.2
4	Fw	0.1

**Tab.3:** Input Parameters of Genetic Algorithm

S.No	Parameters	Quantity
1	Population size	20
2	Maximum number of Generations	50
3	Crossover Fraction	0.8
4	Migration Fraction	0.2
5	Migration Interval	20

### For the 14 bus system

In IEEE 14 bus system bus no 1 is considered as a slack bus and bus numbers 2,3,6,8 are considered as a PV buses all other buses are considered as load buses. This system has 20 interconnected lines. A MATLAB program is coded for the test system and the results are presented and analyzed.

**Tab.4:** Power flows for 14 bus system without UPFC and with UPFC placed between bus no 13 and 14

	Power Flow Solution	Total real power generation (MW)	Voltage Deviation in p.u	Total 'P' loss(MW)	Objective Function Value
GA-OPF	Without UPFC	269.5137	0.962753	10.1137	5.508227
	With UPFC	268.167	0.76334	8.767	
HS-OPF	Without UPFC	268.8709	0.9525	9.4709	5.2117
	With UPFC	266.2915	0.6028	6.8916	

P=REAL POWER

**Tab.5:** UPFC Parameters using HS

UPFC placed between bus number 13 and 14	
Series converter voltage in p.u	0.1186
Series converter angle	-136.4655
Shunt converter voltage in p.u	1.0408
Shunt converter angle	-12.4235

**Tab.6:** Comparison of the Real power generation of generator buses in various methods

PV bus NO	Generation limits		NR Method With UPFC	GA-OPF With UPFC	HS-OPF Without UPFC	HS-OPF with UPFC
	Min	Max				
1	10	200	191.90801	188.30	156.4867	164.7142
2	10	50	20.0000	20.00	20.00	20.00
3	10	50	20.00	20.00	19.7376	16.8971
6	10	50	20.000	17.543	29.4365	24.0436
8	10	100	20.0000	22.324	43.2101	40.6366

**Tab.7:** Comparison of the bus voltages for 14 bus system using HS-OPF without and with UPFC

Bus No.	HS-OPF without UPFC		HS-OPF with UPFC(UPFC placed between bus 13 and bus 14)	
	Voltage magnitude (volts)	Phase Angle	Voltage magnitude (volts)	Phase Angle
1	1.06	0	1.0600	0
2	1.0276	-3.1898	1.0450	-3.5851

3	0.9609	-8.4364	1.0100	-9.1378
4	0.977	-5.8347	1.0312	-6.8667
5	0.9888	-4.8906	1.0391	-5.7967
6	0.9393	-7.5001	1.0700	-7.7306
7	0.9433	-5.2053	1.0447	-6.9466
8	0.9831	-0.4977	1.0900	-3.3426
9	0.9039	-8.0426	1.0259	-9.3794
10	0.9015	-8.3194	1.0258	-9.3664
11	0.9161	-8.0665	1.0437	-8.6658
12	0.9116	-8.4886	1.0585	-8.3085
13	0.8968	-8.1906	1.0589	-8.1879
14	0.8125	-7.6001	1.0000	-12.409
UPFC node voltage			1.07	-7.3943

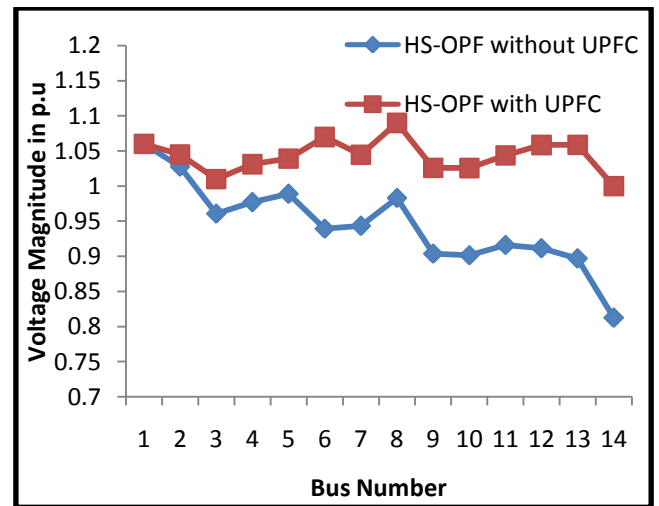


Fig.3: Comparison of the Voltage Magnitudes with and without UPFC

The active power generation and power loss for the IEEE 14 bus system without and with UPFC are shown in Tab.3. From Tab.3, it can be seen that the total active power generation required is reduced to 266.2915 MW from 268.8709MW and power loss are reduced to 6.8916MW from 9.4709MW due to UPFC in Harmony Search Algorithm based OPF. Tab.4 indicates the UPFC parameters using Harmony search algorithm. Tab.5 represents the active power generation of generator buses for different conditions those are GA method, GA method with UPFC and Harmony Search algorithm based Optimal Power Flow without and with UPFC. By using Harmony Search Algorithm Generation reallocation has been done properly resulting in less power loss. Table 6 indicates the voltage profile of 14 bus system using Harmony Search Algorithm based Optimal Power Flow without and with UPFC. It indicates that by incorporating the UPFC in line no 20 (connected between bus no 13 and bus no 14) in HS based OPF voltage profile has been improved. Fig.3 shows the comparison of the voltage magnitudes with and without UPFC

using HS algorithm. Fig.4 shows the objective function value by varying HS algorithm parameters from this it can be observed that by increasing the HMS value objective function value is minimized but the time of computation increases so in this HMS is taken as 20.

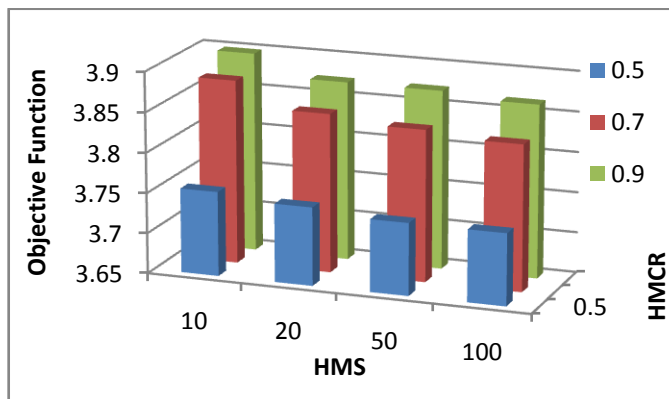


Fig.4: Comparison of the objective function value by varying HMS and HMCR

## 6. Conclusion

In this paper, Harmony Search has been implemented to solve the Optimal Power Flow problem in the presence of the UPFC. The results demonstrate the effectiveness and robustness of the proposed method without and with UPFC. The results obtained for the IEEE 14 bus system, using the implemented method without and with UPFC are compared and observations reveal that the real power losses and voltage deviation has been reduced with UPFC. The obtained results are supportive, and show that UPFC is the most effective devices that can significantly increase the performance of the power system and also improve the voltage profile of the power system. GA is also presented to solve the Optimal Power Flow problem of the power system with UPFC and the results are compared. From the results it can conclude that the UPFC placed in the power system along with Harmony Search algorithm enhances the voltage profile and reduce the real power losses.

## References

- [1] P. Kundur, *Power System Stability and Control*. New York: McGraw-Hill, Inc., 1993.
- [2] N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of Flexible AC Transmission System", IEEE Press, 2000.
- [3] *FACTS Modelling and Simulation in Power Networks* (Book) by Enrique Acha, Claudio R. Fuerte-Esquivel, Hugo Ambriz-Perez, Cesar Angeles-Camacho, Yuryevich Janson, Wong Po kit. Evolutionary programming based optimal power flow algorithm. *IEEE Trans Power System* 1999;14(4): 1245–50.
- [4] Hsmms TJ., Lim S.K. "Flexible AC Tmmision System(FACT.S)". *Ektnc Machines & Power System* VD1.25, w. 73-85.1997,
- [5] Gerbex R Cherkaoui and Germond A J (2001), "Optimal Location of Multi-Type FACTS Devices in a Power System by Means of Genetic Algorithms", *IEEE Transaction Power Systems*, Vol. 16, August, pp. 537-544.

- [6] Bakirtzis AG, Biskas PN, Zournas CE, Petridis V. Optimal power flow by enhanced genetic algorithm. *IEEE Trans Power Syst* 2002;17(2):229–36.
- [7] Ying Xiao, Y.H. Song and Y.Z. Sun, "Power flow control approach to power systems with embedded FCATS devices", *IEEE transaction on power systems*, vol.17, No.4 ,Nov. 2002, pp. 943 – 950.
- [8] Chug T.S., Qifeng D., Bomina Z "Optimal Active OPF with FACTS Devices by Innovative Load-Equivalent Approach", *IEEE Power Engineering Review*, vol. 20.no.5, pp. 63-66, May 2000.
- [9] Sanbao Zheng and yoke Lin Tan "Dynamic Character Study of UPFC Based on Detailed Simulation Model" *IEEE Power Conference* 2000.
- [10] D. Povh, "Modeling of FACTS in power system studies," in *Power Engineering Society Winter Meeting*, 2000. IEEE, 2000, pp. 1435-1439 vol.2.
- [11] Vo Ngoc Dieu, Khai Phuc Nguyen, Nguyen Thanh Hop, "Evolutionary harmony search algorithm for non-convex economic dispatch" *IEEE* 978-1-4799-3254-2/13.
- [12] R.arul,S.Velusamy&G.Ravi "Solving combined economic emission dispatch problems using self adaptive differential harmony search algorithm" *2014 international conference on circuit, power and computing technologies[ICCPCT]*.
- [13] X. S. Yang, *Nature-Inspired Meta-Heuristic Algorithms*, Luniver Press, Beckington, UK, 2008.
- [14] K.S. Verma, S.N. Singh, H.O. Gupta, "Location of unified power flow controller for congestion management", *Electric Power Systems Research* 58, Pages 89–96, 2001.
- [15] Abdel-Moamen M.A and Narayana Prasad Padhy, "Optimal power flow incorporating FACTS devices-bibliography and survey," in *Proc. 2003 IEEE PES Transmission and Distribution Conference and Exposition*, pp. 669-676.