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Optimal Allocation of Interline Power Flow Controller (IPFC) for Improving Power System Performance Using Evolutionary Algorithm

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Dedication

What more than being able to share the best moments of your life with the people you love.

At the end of my studies, I have the great pleasure of dedicating this modest work:

To my dear mother, who always gives me hope to live and who has never stopped praying for me.

To my dear father, for his encouragement and support, especially for his love and sacrifice, so that nothing hinders my studies.

To my brothers and sisters

To my best friends each in his own name.

KAFI Alaeddine

DADA Riad

Appreciation

First of all, we would like to thank Allah, the merciful and merciful, for giving us the strength and patience to carry out this modest work.

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We also extend our sincere thanks to all the teachers of the Department of Electrical Engineering and the University who contributed to our training.

In short, we thank everyone who has contributed directly or indirectly, directly or indirectly, to the success of this work, for which we have devoted so much and put so much heart into it.

Sommary

Chapter I Interline Power Flow Controller

Chapter II Harmony search Alghorithm

Chapter III Results and discussion

Figure list

List of Table

List of Abbreviations

IPFC : Interline Power Flow Controller.

UPFC : Unifiend Power Flow Controller.

TCSC : Thyristor Controlled Series Compensation .

TCPS : Thyristor Controlled Phase Shifter.

OPF : Optimal Power Flow.

VSC : Voltage Source Converts.

AC : Alternative Current.

DC : Direct Current.

VSI: Voltage Sensitivity Index .

SSSC : Static Synchronous Series Compensator.

HSA : Harmony Search Alghorithm.

HMS : Harmony Memory Seize.

PAR : Pitch adjusting rate.

HMCR: Harmony memory considering rate.

BW : Bandwidth.

General Introduction

The main purpose of transmission network is to supply the load at the required reliability, lower cost and with maximum efficiency. The complexity of the power system is increasing due to the increase in load demand, line loss and loop flows. Increasing the power generation and constructing new transmission lines are essential for meeting this load demand. The cost of transmission lines, social and geographical factors, financial factors and ambient factors restrict the construction of new lines to improve the transmission capability. The best solutions available for sorting out this problem are HVDC and FACTS. HVDC is economical only for long distance transmission. The available transmission capability can be increased to a certain level using FACTS by utilizing the existing transmission lines. FACTS devices can control the various parameters of the power system such as voltage, phase angle and line impedance in a rapid and effective manner. FACTS devices can be categorized as Switch based controllers and converter based Controller, which can be further classified as shunt, series and combination of shunt and series controllers. FACTS devices include Static Var Compensator (SVC), Thyristor Controlled Series Compensator (TCSC), Static Series Synchronous Compensator (SSSC), Static Compensator (STATCOM), Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC) [1, 2]. These devices can be used depending on requirements and applications. UPFC is used to control three variables namely real power, reactive power and voltage control simultaneously or as required. IPFC is used to control the real and reactive power flow in multiple transmission lines simultaneously. But taking advantages of these FACTS devices depends greatly on how these devices are placed in the network (*i.e*) the location of the device [3]. Improperly placed FACTS devices fail to provide the optimum performance and can be counterproductive in certain situations. So, proper placement of these FACTS devices is an important task. However, the best choice of location for the installation of these equipments is not a simple task due to the complexity of the electric system.

Chapter I

Interline Power Flow Controller

I.1. Introduction

Optimal placement of FACTS devices with due consideration to line loss. The optimal power flow that used Harmony search algorithm [4] was improved in [5]. The solutions of OPF incorporating IPFC in the network are proposed in [6] and [7]. Basu [8] obtained a solution for optimal power flow problem incorporating TCSC, TCPS. Rami Reddy [9] proposed technique for solving the optimization problems using techniques inspired by evolutionary algorithm. Optimal location based on trial and error method was proposed by S. Jangjit and P. Kumkratug that is very time consuming for a large power system. Differential evaluation algorithm, was proposed by Stron and Price [10, 11]. In this work, purpose is optimization by using the Harmony search algorithm, means that we follow the overall active power loss reduction. The simulation obtained from MATLAB software shows that total active power losses in power systems was reduced by using the IPFC.

I.2. Proposed work

The focus of this work is to find the optimum function for IPFC in a given test system using evolutionary algorithm even as gratifying all of the working and IPFC constraints. The minimization of line loss, monetary dispatch of generators, enhance strength go with the drift and discount with inside the typical gadget fee which incorporates the fee of energetic strength technology and the set up fee of IPFC also are taken into consideration for acquiring the optimum vicinity. Since the chosen line is compensated, this could cause the discount in overall technology fee of electrical strength and funding at the compensating devices. Limited works has been done in optimizing the strength go with the drift in a strength gadget community with IPFC and optimum location of IPFC.

I.3. Interline power flow controller IPFC

I.3.1. Operating principle and mathematical modeling

The basic schematic of IPFC is shown in **FigureI.1** It consists of at least two back-to-back DC-AC converters connected through a common DC link and the DC link between each VSC can be represented by bidirectional link, for exchanging active power between them [12, 13]. The bus i,j and k has the complex voltages V_i, V_j, and V_k and the series compensation of series converter voltage, $V_{\mathbf{sein}}$ is the controllable series injected voltage source which can be defined as $V_{sein} = V_{sein} \measuredangle \theta_{sein}$(n=j, k). **FigureI.1** consists of three buses i, jand k and two transmission lines are connected with ith bus in common. The equivalent circuit of two converters IPFC is shown in **FigureI.2** It has two series injected voltages (V_{se}) and series with the transfer impedance Z_{sein}. P_i and Q_i are the sum of real and reactive power flow from ith bus

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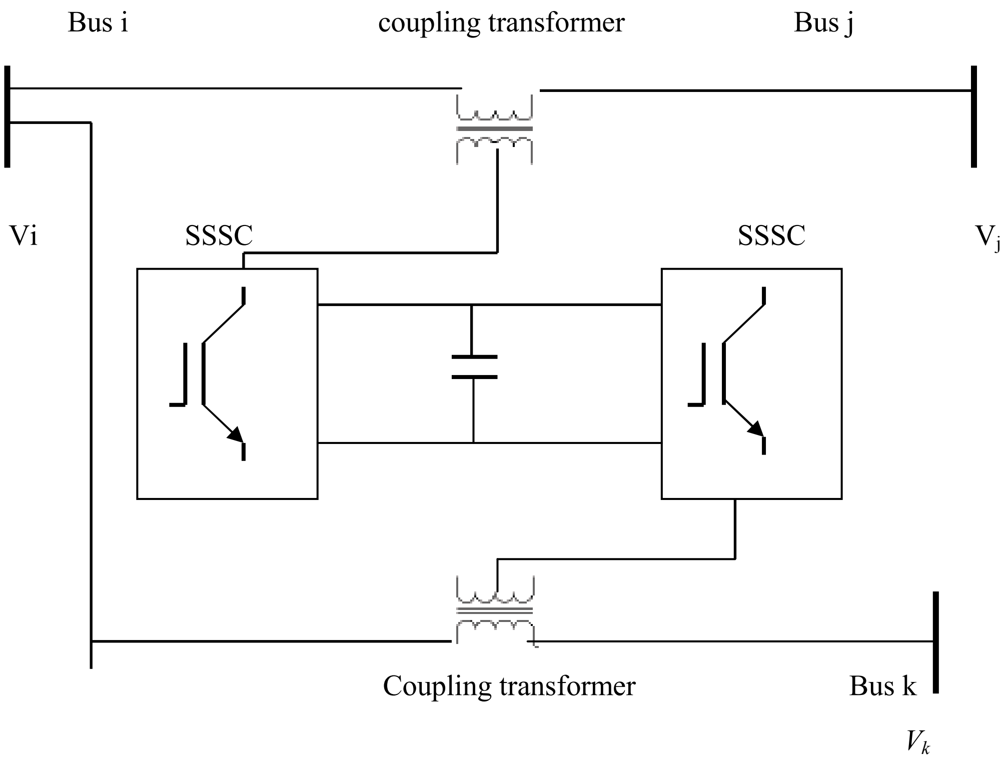


FigureI.1: Schematic diagram of IPFC.

I.3.2Formulation of static load flow equations

In the general case, the power injection relation of any bar i of a network electric of N knots is written by:

$$S_i^* = P_i - jQ_i = V_i^* I_i \tag{I.1}$$

$$I_i = \frac{S_i^*}{V_i^*} = \frac{P_i - jQ_i}{V_i^*} \tag{I.2}$$

In which Ii is positive when entering the system. In the formulation of system equations, if shunt elements with respect to ground are included in the matrix parametric, equation **(I.2**) is the total bus bar current. Otherwise, if the shunt elements have not been included, the total current of the bar i is obtained by:

$$I_i = \frac{P_i - jQ_i}{V_i^*} - y_i V_i \tag{I.3}$$

Where y_i is the total of the shunt admittances connected to bar i and $y_i V_i$ is the current flowing from this node to earth.

$$\frac{P_i - jQ_i}{V_i^*} = V_1 Y_{i1} + V_2 Y_{i2} + \cdots V_N Y_{iN} \tag{I.4}$$

The relation (**I.4**) can be written as a compact mathematical summation to get

$$P_i - jQ_i = V_i^*[V_1 Y_{i1} + V_2 Y_{i2} + \cdots V_N Y_{iN}] \quad \textbf{(I.5)}$$

Mathematical model for IPFC, which will be referred to as power injection model, i helpful in understanding the impact of the IPFC on the power system in the steady state Furthermore, this IPFC model can easily be incorporated in power flow analysis. Usually, in the steady state analysis of power system, the Voltage Source Converters (VSC) maybe represented as a synchronous voltage source injecting an almost sinusoidal voltage with controllable magnitude and angle [14].

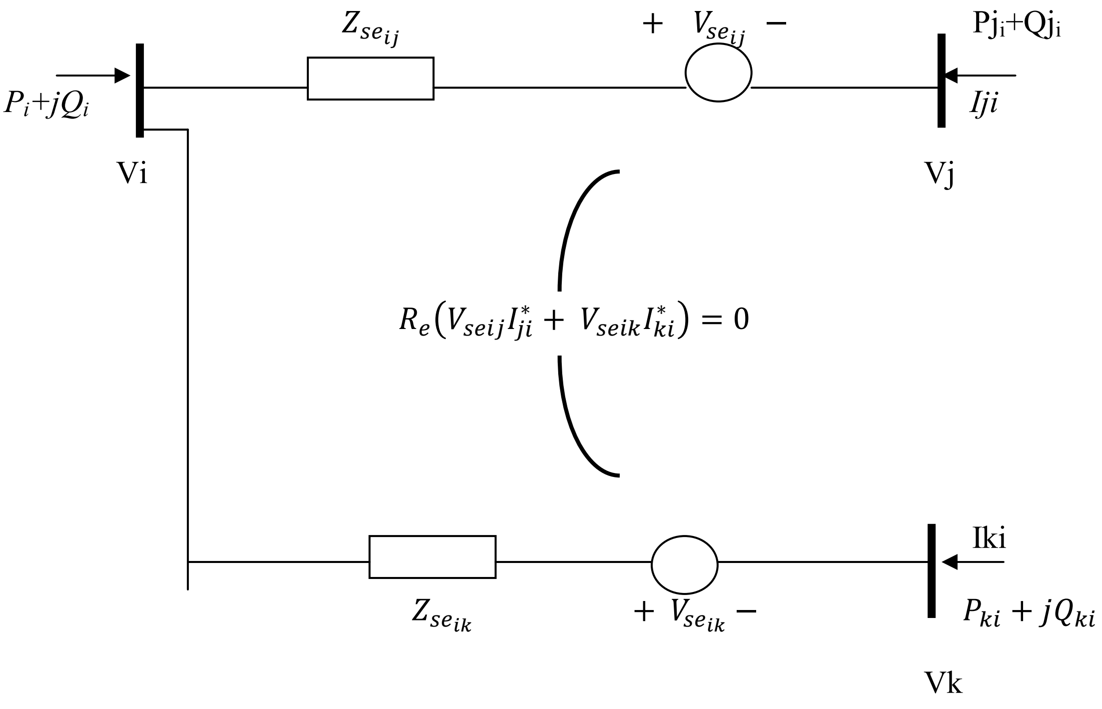


Figure I.2: Equivalent circuit of IPFC.

Based on **FigureI.1** the equivalent circuit of IPFC is shown in **FigureI.2**, V_i, V_j and V_k are the complex bus voltages at the buses *i, j* and k respectively, $V_{sein}$is the complex controllable series injected voltage source, and $Z_{sein}(n = j, k)$ is the series coupling transformer impedance. The complex power injected by series converter connected in between bus i and bus j as shown in **FigureI.2** can be written as:

$$P_i = V_i^2 gn - \sum_{j=1\; j\neq 1}^{n} V_i V_j (g_{ij}\cos\theta_{ij} - b_{ij}\sin\theta_{ij}) + \sum_{j=1\; j\neq i}^{n} V_i V_{seij}(g_{ij}\cos\theta_{ij} - \theta_{seij}) - b_{ij}\sin(\theta_{ij} - \theta_{seij})), \quad \textbf{(I.6)}$$

$$Q_i = V_i^2 b_{ii} - \sum_{j=1 j\neq i}^{n} V_i V_j \left(g_{ij} \sin\theta_{ij} - b_{ij}\cos\theta_{ij}\right) - \sum_{j=1 j\neq i}^{n} V_i V_{se_{ij}} \left(g_{ij} \sin\left(\theta_{ij} - \theta_{se_{ij}}\right) - \right.$$

$$bij\cos\theta ij-\theta seij, \qquad \textbf{(I.7)}$$

$$P_{ji} V_j^2 g_{ii} - \sum_{j=1 j\neq i}^{n} V_i V_j (g_{ij}\cos(\theta_j - \theta_i)_{ij} - b_{ij}\sin(\theta_j - \theta_i)) - \sum_{j=1 j\neq i}^{n} V_i V_{se_{ij}} (g_{ij}\cos\left(\theta_{ij} - \right.$$

$$\theta seij-bij\sin(\theta ij-\theta seij)), \qquad \textbf{(I.8)}$$

$$Q_{ji} = V_j^2 g_{ii} - \sum_{j=1 j\neq i}^{n} V_i V_j \left(g_{ij}\sin(\theta_j - \theta_i)_{ij} - b_{ij}\cos(\theta_j - \theta_i)\right) \qquad + \sum_{j=1 j\neq i}^{n} V_i V_{se_{ij}} \left(g_{ij} \sin\left(\theta_{ij} - \theta_{se_{ij}}\right) - \right.$$

$$bij\cos\theta ij-\theta seij+j=1j\neq inViVseijgij\sin\theta ij-\theta seij-bij\cos\theta ij-\theta seij \qquad \textbf{(I.9)}$$

Where:

$$g_{ii} = g_{ij} = Re\left(\frac{1}{Zse_{ij}}\right) \qquad \textbf{(I.10)}$$

$$b_{ii} = -b_{ij} = Im\left(\frac{1}{Z_{seij}}\right) \qquad \textbf{(I.11)}$$

The active power exchange between series connected inverts via the common *dc* link is

$$P_{mn} = \sum_{j=1\, j\neq 1}^{n} Re(V_{seij} * I_{ij}^{*}) \qquad \textbf{(I.12)}$$

The same equation can be derived for bus *k* also.

I.4. Problem formulation

I.4.1. Minimization of the total cost

The minimization of the total cost is taken as the main objective, which includes the total active power generation cost and the cost of installation of IPFC, which is given by

$$Minimize\ F = W_1 f_1 + W_2 f_2 + W_3 f_3 + W_4 f_4 \qquad \textbf{(I.13)}$$

$$f_1 = \sum_{m}^{NG} C_m(P_{Gm}) \qquad \textbf{(I.14)}$$

$$C_m(P_{Gm}) = \alpha_m + \beta_{Gm} P_{Gm} + \gamma_m P_{Gm}^2$$

Where:

P_{Gm} is the output of the '***m^th^***' generating unit, α_m, $\beta\ m$ *and* $\gamma_m$are the cost coefficients of'***m^th^***' generating unit, *NG* is the number of generators in the test system.

I.4.2. Minimization of active power loss reduction

The second objective function is the active power loss reduction and it can be applied as:

$$\sum_{m=1}^{NG} P_{Gm} - P_D - P_L = 0 \qquad \textbf{(I.15)}$$

I.4.3 Minimization of voltage Sensitivity index (VSI)

Assuming that angle-related problems are not a concern, the voltage sensitivity can he defined as:

$$[\Delta V] = \left[\frac{\partial V}{\partial Q}\right][\Delta Q] + \left[\frac{\partial V}{\partial P}\right][\Delta P] \qquad \textbf{(I.16)}$$

For each system node, there is an associated real power sensitivity ($\frac{\partial V}{\partial P}$) and reactive power sensitivity ($\frac{\partial V}{\partial Q}$).

These values can be used to rank the overall voltage sensitivity of each node to real orreactive power injection. A Voltage Sensitivity Index (VSI) used in ranking is defined as[15]

$$VSI = \omega\left[\frac{\partial V}{\partial P}\right] + (1-\omega)\left[\frac{\partial V}{\partial Q}\right] \qquad \textbf{(I.17)}$$

The diagonal elements of the Jacobien matrix represent the sensitivity of one bus voltage magnitude to the injection of powerat the same bus, whereas the off diagonal elements represent the sensitivity to power injected at other buses. Since the purpose of adding dispersed generation is to bring about an improvement in network performance, the effect of power injection single bus on the voltage sensitivities of the whole network must be considered. This is achieved by expressing the VSI for each node as a Euclidean norm normalized across all load buses. The value of the weighting factor will depend on the XIR ratio of the network under consideration The nodes are ranked according to the VSI value and the ranked set is used to define the optimum sites to accept injection of P and/or Q.

I.5 System constraints

I.5.1 Equality constraints

For optimal power flow with IPFC Equality constraints or optimal power flow with flexible ac transmission (FACTs) problem [24], reflecting the nature of the power system according load flow equation, the power production at bus generator combined with power inject from IPFC equal the demand of load. The equality constraints calculated by using the following equations. [24]

$$\boldsymbol{P_{j,i}} + \sum_{m=i,j,k} P_{inj} - P_{D,i} - \sum_{j=1}^{Nb} \left|Y_{i,j}V_iV_j\right| \cos(\theta_{i,j} - \delta_i + \delta_j) = 0 \qquad \textbf{(I.18)}$$

$$\boldsymbol{Q_{j,i}} + \sum_{m=i,j,k} Q_{inj} - Q_{D,i} - \sum_{j=1}^{Nb} \left|Y_{i,j}V_iV_j\right| \sin(\theta_{i,j} - \delta_i + \delta_j) = 0 \qquad \textbf{(I.19)}$$

Where

$i = 1,2,3,\ldots\ldots N_B$:$\mathrm{N_B}$is the number of the buses

$\boldsymbol{P_{G,i}}$: is the real power generator at the bus $\boldsymbol{i}$

$\boldsymbol{P_{D,i}}$: is the real power demand at the bus$\boldsymbol{i}$

$\boldsymbol{P_{inj,m}}$:is the real power inject from IPFC at bus$\boldsymbol{m = i, j, k}$

$\boldsymbol{Q_{inj,m}}$: is the reactive power inject from IPFC at bus$\boldsymbol{m = i, j, k}$

$\boldsymbol{Q_{i,j}}$: is the angle of bus admittance element $\boldsymbol{i, j}$

$\boldsymbol{Y_{i,j}}$: is themagnetude of bus admittance element $\boldsymbol{i, j}$

I.5.2 Inequality constraints

for optimal power flow with IPFC Inequality constraints for optimal power flow problem, reflecting the limits of the device in power system: system security constraints, i.e. transmission lines loading, generator security constraints, i.e. real and reactive power output. The inequality constraints calculated by using the following equations.[25]

$$P_{G,i}^{min} \leq P_{G,i} \leq P_{G,i}^{max} \quad ; i = 1,2,3, \dots N_G \qquad \textbf{(I.20)}$$

$$Q_{G,i}^{min} \leq Q_{G,i} \leq Q_{G,i}^{max} \quad ; i = 1,2,3, \dots N_G \qquad \textbf{(I.21)}$$

$$V_i^{min} \leq V_i \leq V_i^{max} \quad ; i = 1,2,3, \dots N_B \qquad \textbf{(I.22)}$$

$$Q_{comp,i}^{min} \leq Q_{comp,i} \leq Q_{comp,i}^{max} \quad ; i = 1,2,3, \dots N_C \qquad \textbf{(I.23)}$$

$$T_i^{min} \leq T_i \leq T_i^{max} \quad ; i = 1,2,3, \dots N_T \qquad \textbf{(I.24)}$$

Where

$\boldsymbol{V_i^{min}, V_i^{max}}$: Upper and lower voltage magnitude at bus $\boldsymbol{i}$

$\boldsymbol{P_{G,i}^{min}, P_{G,i}^{max}}$: Upper and lower of real power by generator at bus $\boldsymbol{i}$

$\boldsymbol{Q_{G,i}^{min}, Q_{G,i}^{max}}$: Upper and lower of reactive power by generator at bus $\boldsymbol{i}$

$\boldsymbol{Q_{comp,i}^{min}, Q_{comp,i}^{max}}$: Upper and lower of reactive power source $\boldsymbol{i}$

$\boldsymbol{T_i^{min}, T_i^{max}}$: Upper and lower of tap position of transformer $\boldsymbol{i}$

I.5.3 Penalty Function

The determination optimal power flow function is a nonlinear optimization problem. It consists of a nonlinear objective function defined with nonlinear constraints. The optimal power flow problem requires the solution of nonlinear equation, describing optimal and secure operation of power system. The general optimal power flow problem can be expressed as a constrained optimization problem as follows.

Minimum $f(x)$

Subject $g(x) = 0$, equality contraints

$h(x) \geq 0$, inequality contraint

By converting both equality and inequality constraints into penalty terms and therefore added to from the penalty function as described in the following equations. [26]

$$P(x) = f(x) + \Omega(x) \tag{I.25}$$

$$\Omega(x) = \rho\{g^2(x) + [max(0, h(x))]^2\} \tag{I.26}$$

Where

$\boldsymbol{P(x)}$: is the penality funcion

$\Omega(\boldsymbol{x})$; is the penality term

$\boldsymbol{\rho}$: is the penality factor

I.6 Conclusion

In this chapter the steady state model of an IPFC is presented. The corresponding power flow equations relating to the integration of the IPFC model into load flow studies has been described. Also we defiend the four objective function studied (Minimization of total cost,Minimization of the power loss ,VSI and Loadability) and the systeme constraint for the optimal power flow (OPF).

Chapter II

Harmony Search Algorithm

II.1Introduction to optimization problems

Although substantial amount of search in optimization is conducted with regards to single objective problems, optimization problems with multi objectives are inevitable in many topics specially engineering applications. Two main methods have proposed by scientist for solving multiobjective optimization problems:

1) Classical methods,

2) Evolutionary algorithms.

Classical methods are able to reach one optimal solution at each run, while evolutionary algorithms are based on a population of solutions, which will hopefully lead to a number of optimal solutions at every generation.

The evolutionary algorithms, which had shown benefits over the classical approaches,can be categorized in several categories. Harmony search algorithm is one of these methods. [16].

II.2 What is Optimization

Optimization is a process of making things better. Life is full of optimization problems which all of us are solving many of them each day in our life. Which route is closer to school? Which bread is better to buy having the lowest price while giving the required energy? Optimization is retuning the inputs of a process,function or device to find the maximum or minimum output(s). The inputs arethe variables, the process or function is called objective function, cost function or Fitness value (function) and the output(s) is fitness or cost [16].

In this minimization of cost is tackled, in functions which maximum of costis required, by slapping a minus in front of objective function, the output will be minimized. Therefor all the problems and functions in the thesis are addressed as minimization problem.

When only one objective function involves in the problem, it is called single objective optimization, however, in most real world problems more than one objective function is required to be optimized, and therefore these problems are namedmulti objective optimization [17].

II.3. Implementation of Harmony Search Algorithm (HSA) for optimal location of IPFC

II.3.1 Brief description of HS algorithm

HSA is a metaheuristic technique that is given great ideas from the process of music players to accomplish better harmony, originally proposed by Geem et al in 2001 [18].

The HS method's key steps can be described as [19]:

Step 1: Initialization. Set parameters of HS, The main parameters of the HSA include [20]:

- Harmony memory size (HMS), where the population is memorized.
- Pitch adjusting rate (PAR) for a new generated harmony, with PAR ∈ [0, 1],
- Harmony memory considering rate (HMCR), with HMCR ∈ [0, 1],
- Bandwidth (BW) for pitch adjustment, number of improvisations (NI) and number of maximum iterations (Nmax).

$$Minimize\ f(x) \tag{II.1}$$

$$S.t$$

$$LB_i \leq x_i \leq UB_i i \in [1, N] \tag{II.2}$$

Where, $f(x)$ is the objective function, xi is the solution vector of the HMS, LB_i and UB_i are the minimum and maximum values of x_i.

Step 2. Initialization of the HM matrix

HM is initialized by randomly produced harmony vectors considering HMS [21] by using Eq. (II.3):

$$x_i^j = LB_i + rand() \times (UB_i - LB_i) \tag{II.3}$$

where$j = 1, 2, \dots\dots,$ HMS and $rand()$is random number, uniformly distributed between 0 and 1. The HM matrix can be expressed as follow:

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdot\ \cdot\ \cdot & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \cdot\ \cdot\ \cdot & x_{N-1}^2 & x_N^2 \\ \cdot & \cdot & \cdot\ \cdot\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot\ \cdot & \cdot & \cdot \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdot\ \cdot\ \cdot & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdot\ \cdot\ \cdot & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} = \begin{bmatrix} f(x^{(1)}) \\ f(x^{(2)}) \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ f(x^{(HMS-1)}) \\ f(x^{(HMS)}) \end{bmatrix} \tag{II.4}$$

Step 3. Improvise of a new harmony.

A novel solution vector $x_i^{new} \in \{x_i^1, x_i^2, \dots.., x_i^{HMS}\}$is generated based on the main HSoperators HMCR, PAR and BW. These operators are introduized in production of a new solution as the following [22]:

HMCR,

$$x_i^{new} \leftarrow \begin{cases} x_i^{new} \in \{x_i^1, x_i^2, \ldots\ldots, x_i^{HMS}\}, with\ probabilityHMCR \\ x_i^{new} \in x_i, otherwise i = 1,2 \ldots\ldots N. \end{cases} \tag{II.5}$$

PAR,

$$x_i^{new} \leftarrow \begin{cases} YES\ with\ probabilty\ PAR \\ NO\ with\ probability\ (1 - PAR) \end{cases} \tag{II.6}$$

A new solution vector xi based on the disturbance principle can be generated as follows [23]:

$$x_i'^{\,new} = x_i^{new} + 2.rand(1) \times BW - BW \tag{II.7}$$

$x_i'^{\,new} = is\ the\ i^{th}\ newsolution\ after\ disturbance$

Step 4. Updating the new harmony. The new harmony will replace the worst if $f(x_{new}) < f(x_{worst})$.

Step 5. (Checking the stopping criterion). Repeat Step**3** and **4** until the Nmax is reached.

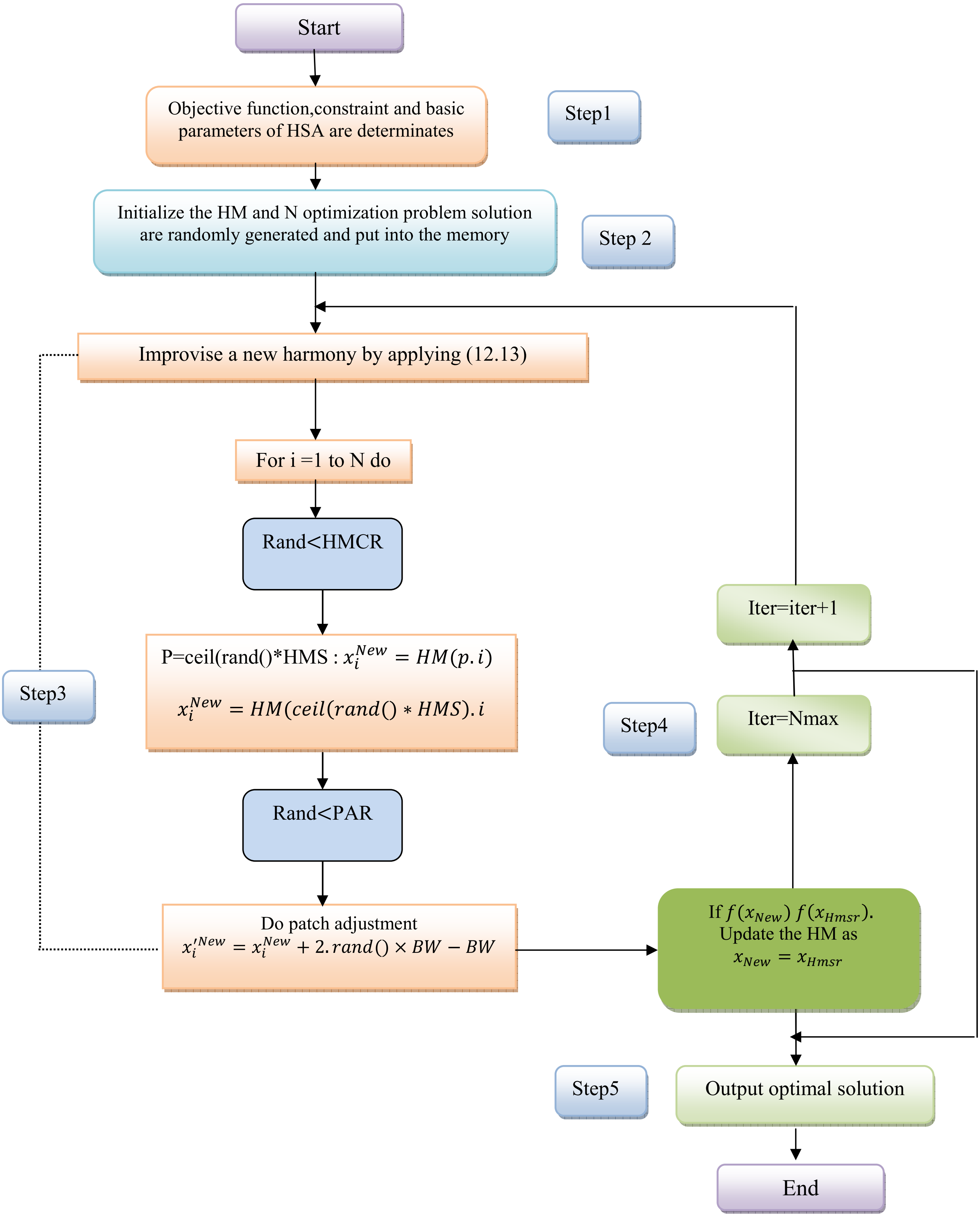
A simplified flowchart of the HS method is demonstrated in Figure II. 2.

If $\sum_i^N \boldsymbol{P_i} < \boldsymbol{P_D}$,Add an amount $\boldsymbol{\varepsilon}$

$\boldsymbol{\epsilon} \leftarrow \left|\sum_i^N \boldsymbol{P_i} - \boldsymbol{P_D}\right|$ to P_i^{new} that doesn't violate P_i^{max} such as $P_i^{new} \leftarrow$ min ($P_i^{new} + \varepsilon . P_i^{max}$)

else if $\sum_i^N P_i < P_D$, subtract an amount $\boldsymbol{\varepsilon}$

$\boldsymbol{\epsilon} \leftarrow \left|\sum_i^N \boldsymbol{P_i} - \boldsymbol{P_D}\right|$ to P_i^{new} that doesn't violate P_i^{min} such as $P_i^{new} \leftarrow$ min ($P_i^{new} + \varepsilon . P_i^{min}$)



FigureII.1: A simplified flowchart of the HS algorithm

Chapter III

Results And Discussion

III.1 Introduction:

Optimal Location of Interline Power Flow Controller (IPFC) for minimizing simultaneously cost of generation, active power losses, loadability, and voltage sensibility index in power system. To demonstrate the accuracy and effectiveness of the proposed HSA technique, the standard IEEE30-bus test systems is considered.The simulation was developed using MATLAB 2017 under windows 8.1 on Intel Core(TM) i3-3110 CPU 2.40 GHz, with 4 GB RAM. The lower voltage limit (V_{min}=0.95 p.u), the upper voltage limit (V_{max}=1.0 p.u), and thethreshold value of power flow analysis is 0.006 has been set. The voltage magnitude and angle of two convertersof IPFC is taken in the range $0 \le V_{se} \le$and $-\pi \le \theta_{se} \le +\pi$ respectively. In IEEE 30-bus system, bus number 1 is a slack bus, bus numbers 2, 5, 8, 11, and 13are considered as PV buses and all other buses are considered asload buses. The single line diagram of IEEE 30-bus system with IPFC between lines 10-20 and 20-19is shownin Figure **III.1**. The network topology and data for simulating above systems are taken from the University ofWashington [25]. The parameters has been used for implementing HSA, to find the optimal values ofIPFC are presented in Table **III.1**.

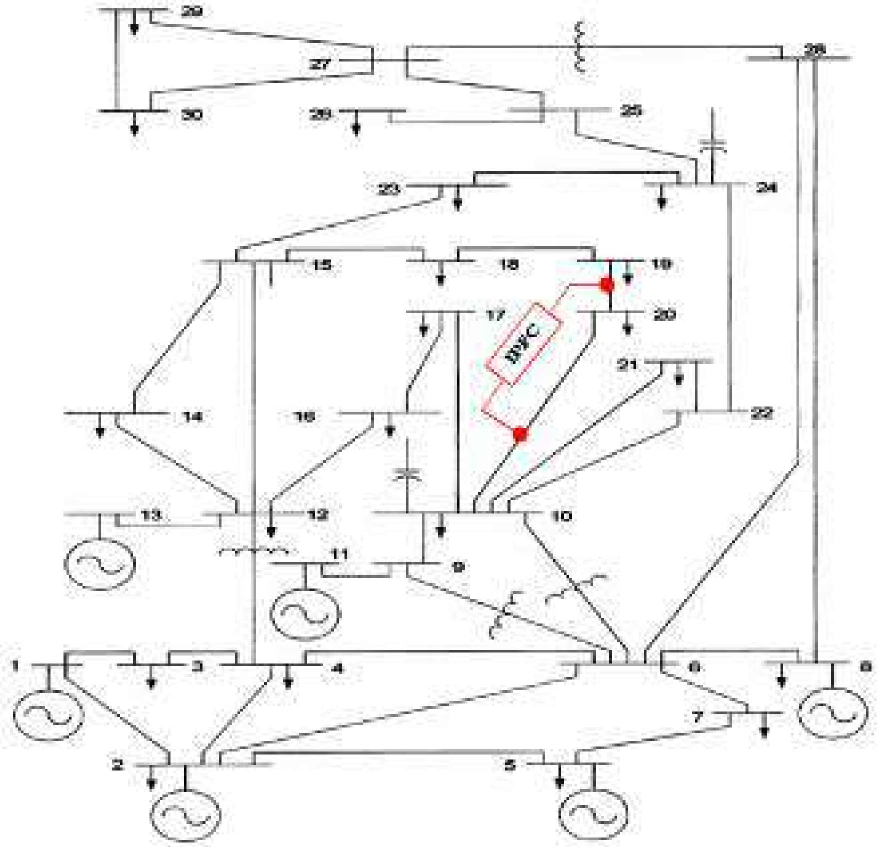


Figure III.1: Single-line diagram of the IEEE 30-bus systemwith IPFC placed between lines 10-20 and 20-19.

TableIII.1 Harmony search algorithm (HSA) settings.

Parameters	HMS	HMCR	N	Nmax	BW	PAR
Values	20	0.5000	20	150	0.9950	0.1000

III. 2 Simulation and results

The OPF problem consists in optimizing four objective functions which are realized for the system for two case (with and without IPFC) studies, cases aim to single-objective functions; and the remaining cases concern multi objective optimizations which are converted into simple objective functions with weighting factors as in many previous studies and reproduced here.

Table III.2 Active and reactive power losses of IEEE30-bus obtained by HSA.

Active power losses (MW)		Reactive power losses (Mvar)		P_L reduction	Q_L reduction
Placement IPFC					
Before	After	Before	After		
2.4438	1.4257	19.9205	18.8069	1.0181	1.1138

Table **III.2** show the active and reactive power losses results for IEEE30-bus obtained by using the harmony search algorithm (HSA), without and with installation of IPFC between buses 10-20 and 20-19. Active and reactive power losses reduction in presented in the same table. The real power generation of the system at individual generators of IEEE 30-bus before and after placement of IPFC, are depicted in Table **III.3**.

Table III.3: Active power generation before and after placement IPFC.

Power generation (MW)	Placement IPFC	
	Before	After
P_{G1}	25.9738	-17.6152
P_{G2}	60.9700	60.9700
P_{G5}	21.5900	21.5900
P_{G8}	36.9100	26.9100
P_{G11}	19.2000	19.2000
P_{G13}	37	37

Figure **III.2** represent the active power flow through the lines before and after tuning the IPFC.

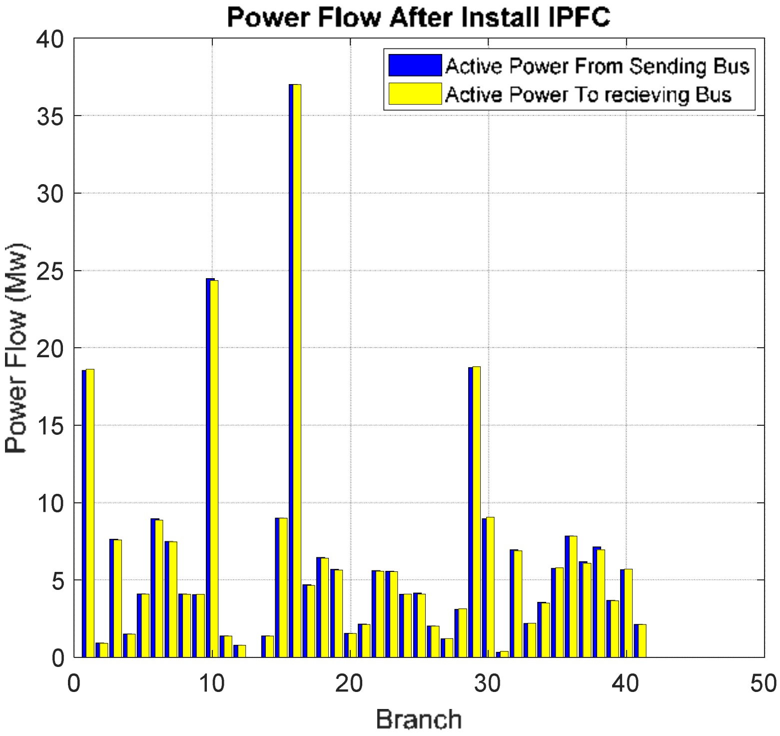


Figure III.2: Active power flow before and after the installation of IPFC.

Figures **III.3** and **III.4**,shows the active and reactive power loss before and after connecting IPFC between lines 10-20 and 20-19, respectively.

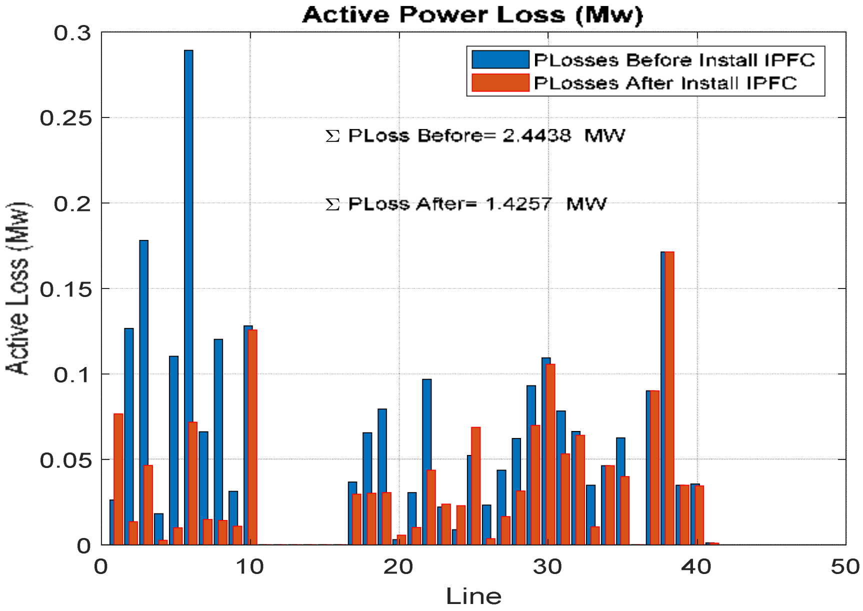


Figure III.3: Active power loss before and after the install IPFC.

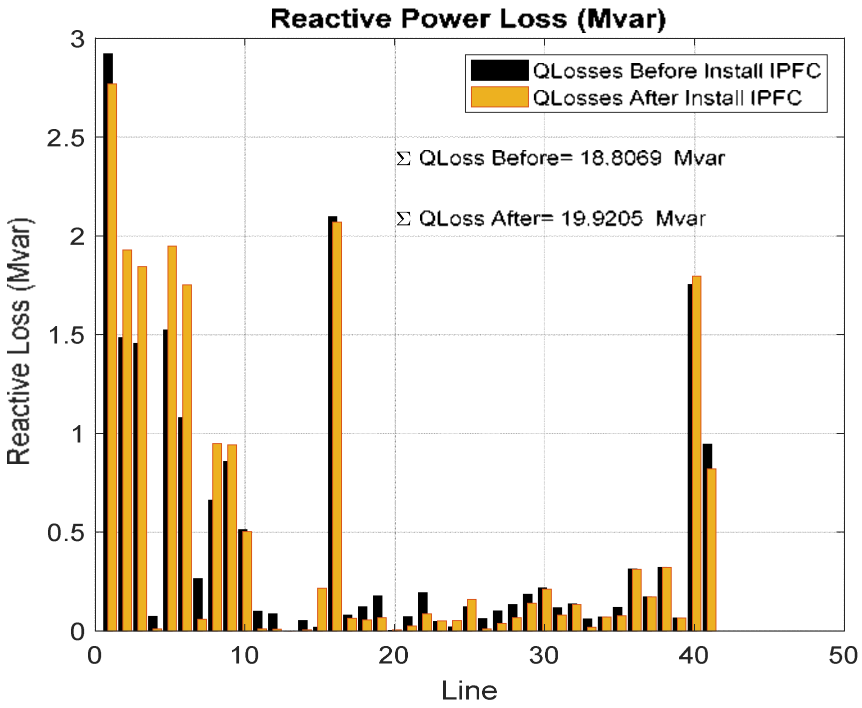


Figure III.4: Reactive power loss before and after the install IPFC.

The voltage profile before and after placement of IPFC for IEEE 30-bus system has been comparedin Figure **III.5**. It isobserved, that after the placement of IPFC the bus voltage of the system has im proved significantly.

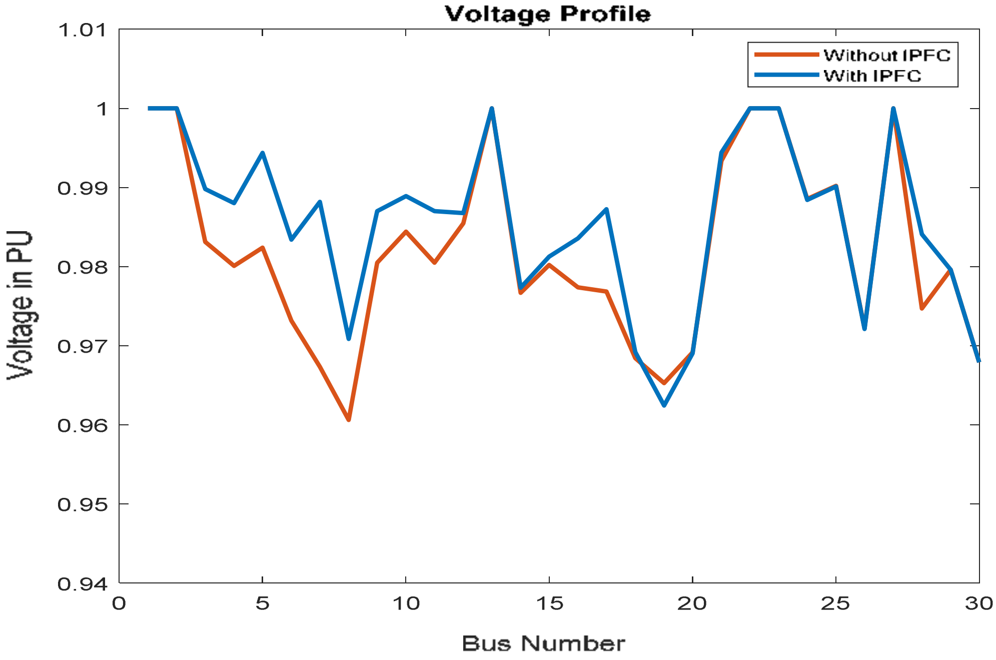


Figure III.5: Voltage profile for IEEE 30-bus power system with and without IPFC.

Figure **III.6**, shows the loadability index before and after connecting IPFC between buses 10-20 and 20-19, respectively. It is observed that the loadability index after installing IPFC is reduced compared than before connection.

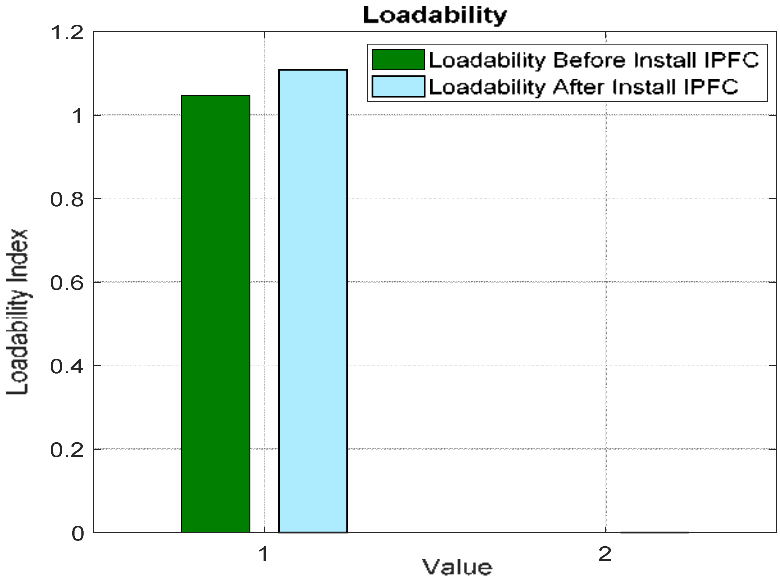


Figure III.6: Loadability index on IEEE 30-bus power system with and without IPFC.

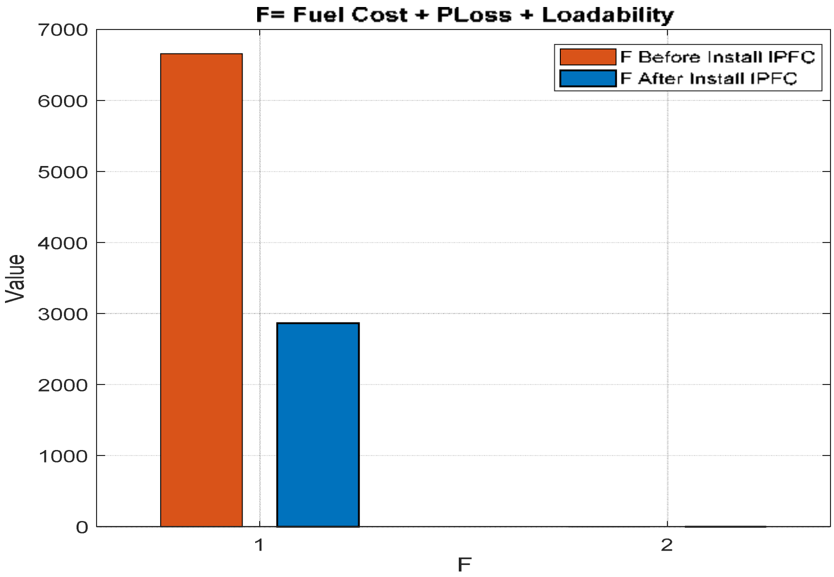


Figure III.7: Total function objective comparison before and after placed IPFC.

Figure **III.7**illustrate the simultaneous simulation of fuel cost, power losses, and loadability index before and after installation of IPFCbetween buses 10-20 and 20-19, respectively.We can be seen, that the total objective function after placement of IPFC is better compared than before installation.

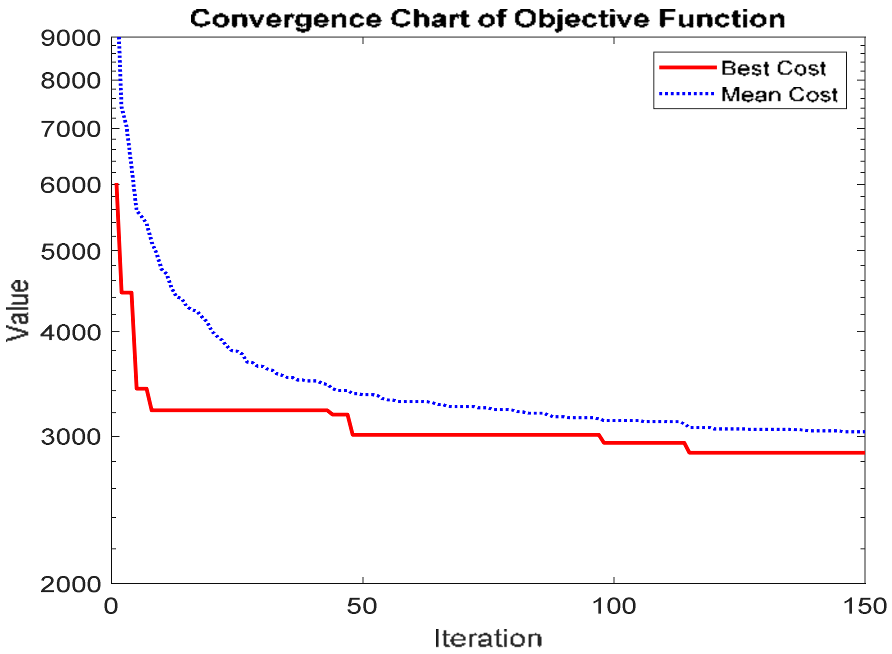


Figure III.8: Convergence characteristic of total function objective after placement ofIPFC.

Figure **III.8**demonstrate the convergence characteristic of the best and mean of total objective function.

Table III.3: Variable control value.

IPFC parameters	Untuned IPFC	Tuning of IPFC using HSA
V_{se1}	0.0050	0.1029
V_{se2}	0.0100	0.0113
θ_{se1}	-159.8295	-11.7257
θ_{se2}	180	47.8998

III.3 Conclusion

It is observed that harmony search technique ismuch more suitable for the multi-objective optimizationproblem chosen. In addition, it isobserved that OPF in the presence of IPFC is much moreeffective in comparison with without IPFC; thedevice proves to be highly effective for the optimization ofthe generators.

Conclusion

In this thesis, an evolutionary algorithm is proposed for proper optimal location of Interline Power Flow Controller (IPFC) based on harmony search algorithm for improving power system performance. Beforeinserting the IPFC in the optimal location, the percentage of overloading of some line is very high which leads to trip the line and continuous failure in the system and nearby system as well. After utilizing IPFC in theoptimal locations, voltage violations are eliminated and loadability index is reduced with considerable amount. Theperformance of HSA is done using IEEE 30-bus test systems and the results show that the effectiveness of HSA for tuning of IPFC. Themulti objective functionis formulated and tuned using HSA and the performance shows that tuning of IPFCreduces the total fuel cost, real power loss, loadability, and voltage violation of transmission lines. In addition, optimal tuning muchreduces the capacity of installed IPFC. It is also noted that the performance of the system improved significantlywith IPFC.

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Optimal Location of Interline Power Flow Controller (IPFC) for Improving Power System Performance Using Evolutionary Algorithms

In this memory, we perceive the solution of optimal power flow dispatch using metaheuristic method which is the harmony search algorithm. The objective is to minimize the active power losses at the various branches of the electrical power system .also minimzation of fuel cost and loadability

The performance of the HSA method has been tested in IEEE 30 bus power. The objective is the optimal powerflow dispatch with optimal adjustment of the variable control without violating of inequality constraints and satisfying the equality constraint.

Keywords : Harmony search Alghorithm , Power flow

في هذه المذكرة ، ندرس الحل الأمثل لإرسال تدفق الطاقة باستخدام خوارزمية عشوائية وهي خوارزمية البحث عن التناغم. الهدف هو تقليل فقد الطاقة النشطة في مختلف فروع نظام الطاقة الكهربائية. وتقليل التكلفة و قابلية التحميل.

تم اختبار أداء طريقة الخوارزمية في نظام IEEE 30. الهدف هو إرسال تدفق الطاقة الأمثل مع التعديل الأمثل للتحكم المتغير دون انتهاك قيود عدم المساواة وتلبية قيود المساواة.

كلمات مفتاحية : خوارزمية بحث الانسجام ,تقليل فقدان الطاقة

Dans cette mémoire, nous percevons la solution de répartition optimale du flux de puissance en utilisant la méthode métaheuristique qui est l'algorithme de recherche d'harmonie. L'objectif est de minimiser les pertes de puissance active dans les différentes branches du système d'alimentation électrique ainsi que la minimisation du coût du carburant et de la capacité de charge

Les performances de la méthode HSA ont été testées avec une alimentation par bus IEEE 30. L'objectif est la répartition optimale du flux de puissance avec un ajustement optimal de la commande variable sans violer les contraintes d'inégalité et en satisfaisant la contrainte d'égalité

Mots-clés : Harmony search Alghorithm , répartition optimale du flux