

Design and Modeling of UPFC Using MPC and Bacterial Forging Algorithm

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ABSTRACT: In this paper, an efficient and practical real-coded genetic algorithm (GAs) has been proposed for solving the economic dispatch problem. The objective is to minimize the total generation fuel cost and keep the power flows within the security limits. For each problem of optimization in genetic algorithms (GAs) there are a large number of possible encodings. Although binary representation is usually applied to power optimization problems, in this letter we use a GAs, which is a modified GAs employing real valued vector for representation of the chromosomes. The use of real valued representation in the Gas has a number of advantages in numerical function optimization over binary encoding. The efficiency of the GAs is increased as there is no need to convert chromosomes to the binary type, less memory is required, there is no loss in precision by discret to binary or other values, and there is greater freedom to use different genetic operators. A non-uniform arithmetic crossover operator was introduced into the Gas. We used a non-uniform arithmetic crossover operator produces a complimentary pair of linear combinations produced from random proportions of the parents. The non-uniform mutation operator is used to inject new genetic material into the population and it is applied to each new structure individually. A given mutation involves randomly altering each gene with a small probability. The proposed technique improves the quality of the solution and speed of convergence of the algorithm. The Coding are written and executed the values are plotted in graph for different values of MW loading.

I. INTRODUCTION

Power system Harmonics & oscillations are an inevitable phenomenon of the system. Though it starts with normal small changes in system loads, it can turn into a disaster following a large disturbance. Faults and weak protective relaying operation can cause the oscillation to collapse the system. In order to damp these power system oscillations, different devices and control methods are used. Power system stabilizer (PSS) has been used for years for this purpose as an economical and effective solution. But, excessive variation in voltage profile as well as the lack of control over three phase large disturbances at generator terminals causes the demand of finding out a better solution to this problem.

FACTS technology is the newest way of improving power system operation controllability and power transfer limits which has been added in the stream with the progress in the field of power electronics devices. FACTS devices can cause a substantial increase in power transfer limits during steady state operation. Among the FACTS devices, UPFC is the one having very attractive and effective features. It is capable of providing simultaneous control of voltage magnitude and active and reactive power flows, in adaptive fashion.

II. MODEL PREDICTIVE CONTROL (MPC)

Model predictive control (MPC) is an advanced method of process control that has been in use in the process industries in chemical plants and oil refineries since the 1980s. In recent years it has also been used in power system balancing models. Model predictive controllers rely on dynamic models of the process, most often linear empirical models obtained by system identification. The main advantage of MPC is the fact that it allows the current timeslot to be optimized, while keeping future timeslots in account. This is achieved by optimizing a finite time-horizon, but only implementing the current timeslot. MPC has the ability to anticipate future events and can take control actions accordingly. PID and LQR controllers do not have the predictive ability. MPC is a digital control.

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III. DAMPING CONTROL

The unique feature of MPC which has made it different from other controllers is the ability to predict the future response of the plant. At each control interval an MPC algorithm attempts to optimize future plant behavior by computing a sequence of future manipulated variable adjustments. Prediction horizon (TP) is the time range which, future system outputs are predicted in it. Control horizon (Tc) is the time steps number that input control sequence calculations for the prediction horizon are done.

IV. PRINCIPLES OF MPC

Model Predictive Control (MPC) is a multivariable control algorithm that uses: an internal dynamic model of the process a history of past control moves and An optimization cost function J over the receding prediction horizon, to calculate the optimum control moves.

The optimization cost function is given by:

$$J = \sum_{i=1}^N w_{x_i} (r_i - x_i)^2 + \sum_{i=1}^N w_{u_i} \Delta u_i^2$$

Without violating constraints (low/high limits)

With:

x_i = i -th controlled variable (e.g. measured temperature)

r_i = i -th reference variable (e.g. required temperature)

u_i = i -th manipulated variable (e.g. control valve)

w_{x_i} = weighting coefficient reflecting the relative importance of x_i

w_{u_i} = weighting coefficient penalizing relative big changes in u_i

V. THEORY OF MPC

MPC is based on iterative, finite horizon optimization of a plant model. At time t the current plant state is sampled and a cost minimizing control strategy is computed (via a numerical minimization algorithm) for a relatively short time horizon in the future t, T + t Specifically, an online or on-the-fly calculation is used to explore state trajectories that emanate from the current state and find (via the solution of Euler-Lagrange equations) a cost-minimizing control strategy until time t + T. Only the first step of the control strategy is implemented, then the plant state is sampled again and the calculations are repeated starting from the now current state, yielding a new control and new predicted state path. The prediction horizon keeps being shifted forward and for this reason MPC is also called receding horizon control. Although this approach is not optimal, in practice it has given very good results. Much academic research has been done to find fast methods of solution of Euler-Lagrange type equations, to understand the global stability properties of MPC's local optimization, and in general to improve the MPC method

VI. BASIC BLOCK DIAGRAM OF MPC CONTROLLER

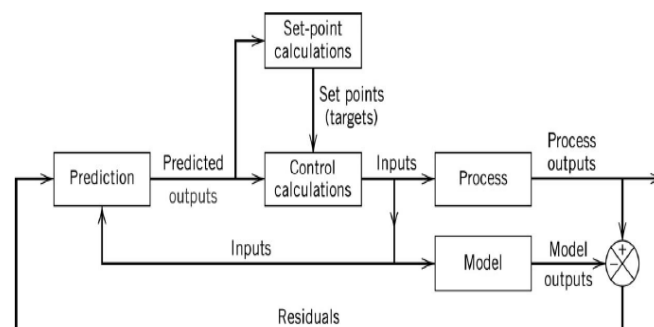


Figure 1

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Basic Elements of MPC

The Following are the basic Elements of MPC

- Reference Trajectory Specification
- Process Output Prediction (using Model)
- Control Action Sequence Computation (programming problem)
- Error Prediction Update (feedback)

VII. MPC MATHEMATICAL FORMULATION

At the k -th sampling instant, the values of the manipulated variables, \mathbf{u} , at the next M sampling instants, $\{\mathbf{u}(k), \mathbf{u}(k+1), \dots, \mathbf{u}(k+M-1)\}$ are calculated.

- This set of M “control moves” is calculated so as to minimize the predicted deviations from the reference trajectory over the next P sampling instants while satisfying the constraints.
- Typically, an LP or QP problem is solved at each sampling instant.
- Terminology: \mathbf{M} = control horizon, \mathbf{P} = prediction horizon
- Then the first “control move”, $\mathbf{u}(k)$, is implemented.
- At the next sampling instant, $k+1$, the M -step control policy is re-calculated for the next M sampling instants, $k+1$ to $k+M$, and implement the first control move, $\mathbf{u}(k+1)$.
- Then Steps 1 and 2 are repeated for subsequent sampling instants.
- Note: This approach is an example of a receding horizon approach

VIII. UPFC – UNIFIED POWER FLOW CONTROLLER

A Unified Power Flow Controller is an electrical device for providing fast-acting reactive power compensation. It uses a pair of three-phase controllable bridges to produce current that is injected into a transmission line using a series transformer. The controller can control active and reactive power flows in a transmission line. The UPFC uses solid state devices, which provide functional flexibility, generally not attainable by conventional thyristor controlled systems. The UPFC is a combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled via a common DC voltage link. The UPFC concept was described in 1995 by L. Gyugyi of Westinghouse.^[1] The UPFC allows a secondary but important function such as stability control to suppress power system oscillations improving the transient stability of power system.

FLEXIBLE AC transmission system is an evolving technology based solution to help electric utilities fully utilize their transmission assets. In order to investigate the impact of UPFC on power systems effectively, it is essential to formulate their correct and appropriate model. In the area of power flow analysis models of the UPFC have been which treat the UPFC either as one series voltage source and one shunt current source model or both the series and the shunt are represented by voltage sources.

UPFC is represented by two voltage sources called the voltage source model (VSM) discusses the distinguishing features of the voltage source model at length. The sequential method and the simultaneous method: In sequential method the equations of UPFC are separated from the system power balance equations. Both the set of equations are solved separately and sequentially. In simultaneous method all the equations are combined in to one set of non-linear algebraic equations. A Jacobean matrix is then formed which is non symmetric in nature.

IX. OPERATING PRINCIPAL OF UPFC

The two voltage source converters of the UPFC, connected through a D.C link can be modeled as two ideal voltage sources, one connected in series and the other in shunt between the two buses. The output of the series voltage source V_{se} and θ_{se} are controllable magnitude and angle between the limits $V_{semax} \leq V_{se} \leq V_{semin}$ and $0 \leq \theta_{se} \leq 2\pi$ respectively

The converter output voltage (magnitude and angle) is used to control the mode of power flow and voltage at the nodes as follows:

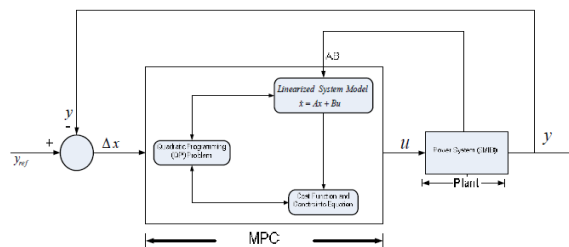
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The bus voltage magnitude can be controlled by injecting a voltage V_{se} in phase or anti phase Power flow can be controlled (Series reactive compensation) by injecting a voltage V_{se}' in quadrature (lead or lag) to the line current Power flow can be controlled (as phase shifter) by injecting a voltage of magnitude(V_{se}'') in quadrature (lead or lag) to node voltage.

X. (a) BASIC BLOCK DIAGRAM OF MPC CONNECTED WITH UPFC



Block diagram of MPC with UPFC connected plant.

Figure No:03

(b) GENERAL BLOCK DIAGRAM

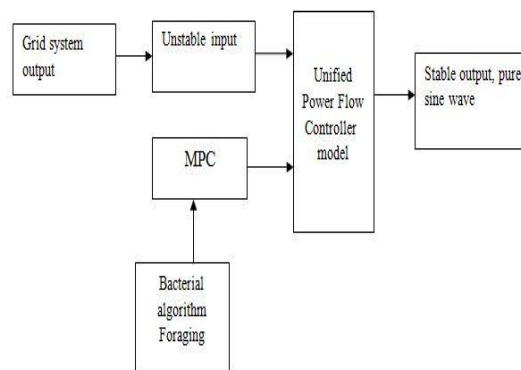


Figure No:04

XI. MATHEMATICAL REPRESENTATION OF UPFC

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} y_{se} + y_{sh} & -y_{se} & -y_{se} & -y_{sh} \\ -y_{se} & y_{se} & y_{se} & 0 \end{bmatrix} \begin{bmatrix} V_k \\ V_m \\ V_{se} \\ V_{sh} \end{bmatrix}$$

the series converter at its output is supplied from the AC Power system by the shunt converters via the common D.C link. The DC link capacitor voltage V_{dc} remains constant. Hence the active power supplied to the shunt converter P_{sh} must be equal to the active power demanded by the series converter P_{se} at the DC link. Then the following equality constraint has to be guaranteed.

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The element of transfer admittance matrix can be put as

$$\left. \begin{aligned} Y_{kk} &= G_{kk} + jB_{kk} = y_{se} + y_{sh} \\ Y_{mm} &= G_{mm} + jB_{mm} = y_{se} \\ Y_{km} &= Y_{mk} = G_{km} + jB_{km} = -y_{se} \\ Y_{sh} &= G_{sh} + jB_{sh} = -y_{sh} \end{aligned} \right\}$$

XII. BACTERIAL FORAGING METHOD

In 2000, Kevin.M.Passino proposed the idea of Bacterial Foraging Methodology or Algorithm to solve the optimization problems. The base work of BFA was based on behavior of bacteria and very clearly states the foraging behavior of E-Coli Bacteria. In the BFA, the optimization process consists of Chemotaxis, swarming (cell to cell signaling and foraging) reproduction and elimination-dispersal activities. The optimization problem can be solved by in BFA, the way of search nutrients, evade noxious environments, the moving circumstance and the way of imitating the existence of the bacteria.

The Bacterial Foraging Optimization (BFA) algorithm is biologically inspired computation technique which is inspired on foraging behavior of E-coli bacteria and its improved version of basic Bacterial Foraging Algorithm (BFA). This paper illustrated how a proposed algorithm different from other social behavior algorithm for solving optimization problems especially in multi-objective case and this proposed algorithm is applied to solve the problem with incorporating Unified Power Flow Controller (UPFC) and optimal location of UPFC based on stability and Harmonics Elimination with reliability analysis. This RBFA algorithm provides an enhanced optimal solution of all control variables and results are shown to be robust and improvement in convergence speed, simulations are performed with help of standard IEEE systems.

The Bacterial Foraging Algorithms has been developed and applied to solve various kinds of real valued problems; such has optimal non-linear dynamic system, PID controller design, optimal power flow, transmission network expansion planning, constrained optimization, Power System Stabilizer and RFID network planning. In this work, the improved version of bacterial foraging algorithm is presented and the proposed algorithm is called as Bacterial Foraging Algorithm (BFA). The solution set of BFA is based optimal sets of own. The position of each bacterium in the population is represented by

$$P(j,k,l) = \theta^i(j,k,l) (i = 1, 2, \dots, S)$$

Equations describe the position of each bacterium, for ith bacteria, jth chemotactic step, kth reproduction step and lth elimination-dispersal event in θ co-ordinate axis in the solution surface.

The aim of BFA algorithm is to fit the best or minimum fitness function and the evaluating the fitness value of each bacterium is consist of following process cell-to-cell communication, its happens via attractant and repellent effect factor. This is given by the following equation

$$\begin{aligned} j_{\alpha}(\theta^i(j,k,l), \theta(j,k,l)) &= \sum_{i=1}^S j_{cc}^i(\theta, \theta^i(j,k,l)) \\ &= \sum_{i=1}^S \left[-d_{attract} \exp\left(-w_{attract} \sum_{m=1}^P (\theta_m - \theta_m^i)^2\right) \right] \\ &+ \sum_{i=1}^S \left[h_{repellant} \exp\left(-w_{repellant} \sum_{m=1}^P (\theta_m - \theta_m^i)^2\right) \right] \end{aligned}$$

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The finding of nutrient position and movement of each bacterium is based on the tumble-run process, the every bacterium in the population will tumble once and the bacteria identify and have better fitness value after the tumble, the bacteria takes place run process with swim or swarm. The run length and step size important parameters in the BFA algorithm. The bacteria movement after the tumble run process is given by in the equation

$$\theta^i(j+1, k, l) = \theta^i(j, k, l) + C(i) \cdot \Phi(j)$$

The evaluation of fitness and search process takes turns to execute until the life time of bacteria. After the cell to cell communication process, there production schemes in follows and in this process the healthy bacteria identified. Finally, in this reproduction schemes the whole population will only keep half of the bacteria. Finally the elimination-dispersal process is takes place to eliminate the worst bacteria and by replacing the best bacteria.

XIII. THE BACTERIA FORAGING OPTIMIZATION ALGORITHM

During foraging of the real bacteria, locomotion is achieved by a set of tensile flagella. Flagella help an E.coli bacterium to tumble or swim, which are two basic operations performed by a bacterium at the time of foraging. When they rotate the flagella in the clockwise direction, each flagellum pulls on the cell. That results in the moving of flagella independently and finally the bacterium tumbles with lesser number of tumbling whereas in a harmful place it tumbles frequently to find a nutrient gradient. Moving the flagella in the counterclockwise direction helps the bacterium to swim at a very fast rate. In the above-mentioned algorithm the bacteria undergoes chemotaxis, where they like to move towards a nutrient gradient and avoid noxious environment. Generally the bacteria move for a longer distance in a friendly environment. Figure 1 depicts how clockwise and counter clockwise movement of a bacterium take place in a nutrient solution.

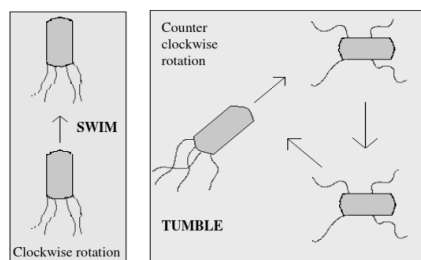


Fig.1. Swim and tumble of a bacterium

Figure No:05

Suitable temperature they break in the middle to form an exact replica of itself. This phenomenon inspired Passion to introduce an event of reproduction in BFOA. Due to the occurrence of sudden environmental changes or attack, the chemo tactic progress may be destroyed and a group of bacteria may move to some other places or some other may be introduced in the swarm of concern. This constitutes the event of elimination-dispersal in the real bacterial opulation, where all the bacteria in a region are killed or a group is dispersed into a new part of the environment. Now suppose that we want to find the minimum of $J(\theta)$ where $\theta \in \mathbb{R}^p$ (i.e. θ is a p-dimensional vector of real numbers), and we do not have measurements or an analytical description of the gradient $J'(\theta)$. BFOA mimics the four principal mechanisms observed in a real bacterial system: chemo taxis, swarming, reproduction, and elimination-dispersal to solve this non-gradient optimization problem. A virtual bacterium is actually one trial solution (may be called a search-agent) that moves on the functional surface (see Figure 2) to locate the global optimum.

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CIRCUIT REPRESENTATION OF MPC

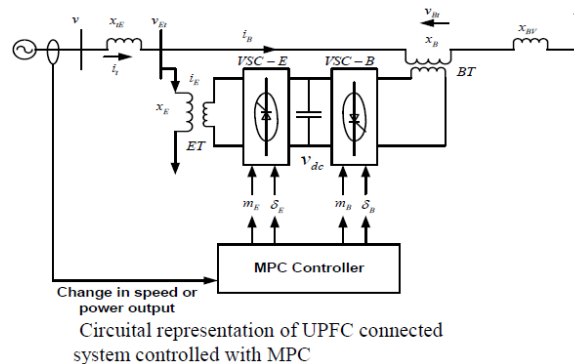


Figure No:06

XIV. REACTIVE POWER

Reactive power is the form of magnetic energy flowing per unit time in an electric circuit. Its unit is VAR (Volt Ampere Reactive). This power can never be used in an AC circuit. Our power system operates on AC system and most of the loads used in our daily life are inductive or capacitive, therefore reactive power is a very important concept from electrical perspective. These power can be defined as:

$$\text{Apparent Power (S)} = V(\text{Voltage}) * I(\text{Current})$$

$$\text{Reactive Power (Q)} = V(\text{Voltage}) * I(\text{Current}) * \sin\theta$$

$$\text{Real Power (P)} = V(\text{Voltage}) * I(\text{Current}) * \cos\theta$$

Where θ is the phase difference between voltage and current and $\cos\theta$ is power factor of the load.

XV. REACTIVE POWER COMPENSATION

Excess of reactive power as well as its scarcity should be monitored. For this purpose, compensation is done by using various devices. Here the reactor absorbs excess reactive power whereas the capacitor supplies for makeup of reactive power in cases of high demand.

For low power factor loads, the reactive power demand is very high. Therefore, we need to increase the power factor using capacitor bank. This reduces the VAR demand by supplying the appropriate amount of reactive power to the load. Other methods include use of shunt capacitor, synchronous phase modifiers, on-load tap changing transformer and shunt reactor.

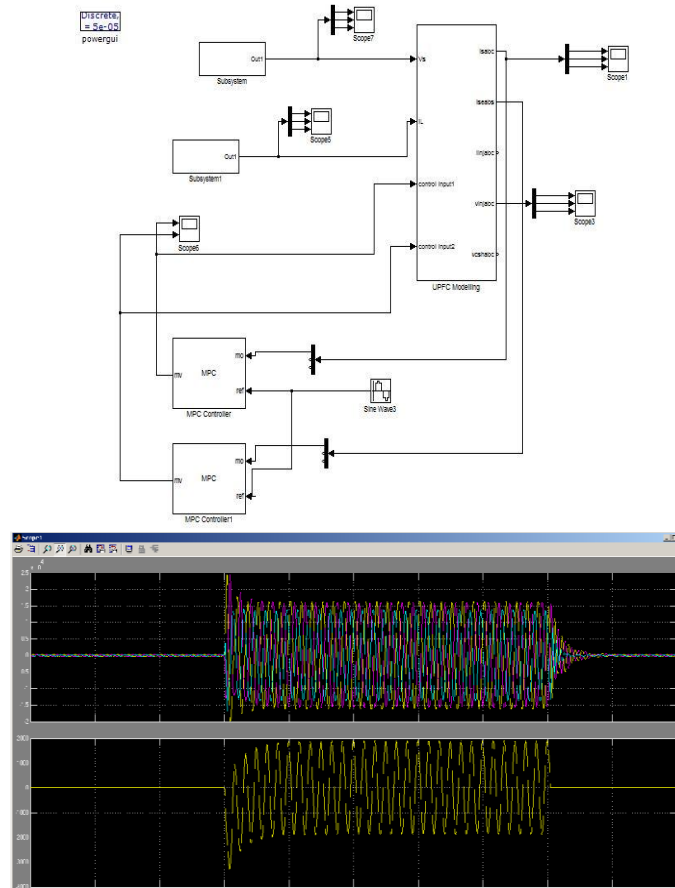
shunt with the load. It serves as a capacitor and is also called synchronous condenser. A shunt reactor is used for the reduction of power factor. In the on-load tap changing

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OUTPUT WAVEFORM OF 3 ϕ GRID CONNECTED SYSTEM



XVI. CONCLUSION

This paper presents bacterial foraging algorithm (BFA) to solve multi objective comprehensive model of optimal power Harmonics Elimination problems with addressing the various objectives of optimal power dispatch problem, like real power loss, voltage stability, profile improvement and in addition to that optimize a various controls. The versatile optimal power dispatch has been developed into modified environment in modern power systems with optimal operating and planning of resources. In feature include: optimal location of UPFC devices and voltage stability and reliability analysis for better voltage profile, reactive power planning, allocation of resources and reduction in line losses. The overall multi-objective solution effectively treated with proposed BFA algorithm and this proposed method tested with various IEEE standard systems. The comparison of results using the pro-posed method is great improvements in

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