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ARTIFICIAL BEE COLONY (ABC) AND NEURAL NETWORK BASED OPF TECHNIQUE WITH FACTS CONTROLLER

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ABSTRACT

In the paper, hybrid technique for solving optimal power flow problems that occur in power systems. The proposed hybrid technique is the combination of artificial bee colony (ABC) algorithm and artificial intelligence (AI) technique. The purpose of the ABC algorithm is used to optimize the optimal operating range of generation limits. So, the fuel cost and the emission of the power generation system is maintained economically. Because, the ABC is an optimization algorithm based on the intelligent foraging behaviour of honey bee swarm. Here, the artificial neural network (ANN) is used as an AI technique. ANN is one of the AI techniques which used for determining the optimal injected voltage magnitude and voltage angle of UPFC. The optimal placement of UPFC is depends on the power flow deviation and the combination of the power system buses. Using the propose hybrid OPF technique, the optimal power flow of the power system is maintained. The proposed hybrid technique is implemented in MATLAB working platform and the power flow parameters are evaluated. The performance of the hybrid technique is compared with ABC algorithm.

Keywords: *OPF, Hybrid Technique, FACTS Controller, UPFC, ABC Algorithm, AI Technique, ANN, Power Loss.*

1. INTRODUCTION

A power system is a set of connections through which energy is transmitted from generators to load. It signifies the association between current and voltage at nodes [2]. In current power system, which is a composite network comprising of several generators, transmission lines, variety of loads and transformers [1]. Providing a dependable power supply with cheapest cost is the main intention of power system [9]. The change of power between different energy carriers launches a coupling of the related power flows resulting in system interactions [8]. Precise and detailed constancy study is a significant matter for power system planning and operating tasks [11]. Normally, Power systems contain OPF problem, hence constancy may happen. Constancy depends upon both the original operating conditions of the system and the sternness of the disturbance [1].

The OPF is a main problem for power generation in the current generation, and it is in common non-convex [6]. The OPF is a fixed nonlinear programming problem which optimizes a definite objective function while gratifying a set of physical and operational controls [20] [6]. The constraints for OPF contain: (i) the AC power flow constraints, (ii) bounds on power generation, (iii) bounds on bus voltage magnitudes, (iv) bounds on line voltage drops, and (v) limits on power transfer on lines [13]. The objective of a power flow problem is to attain the entire voltage angle and magnitude information for every bus in a power system for precise load and generator actual power and voltage condition [3]. Optimal power flow (OPF) problem contracts with finding an optimal operating point of a power system that minimizes an apt cost function such as generation cost or transmission loss on power and voltage variables [14][15].

The power flow difficulty may be sub-divided into the well-conditioned case and the ill-conditioned case. The power flow solution is present with a flat voltage initialization in NR technique in the case of well-conditioned systems [7]. Apply of the optimal power flow is turning into more significant in the deregulated power industry to install the resources optimizations [19]. Usually, multi-objective OPF problem has been worked out

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by weighted sum, constraint strategy and goal attainment technique [18]. Several optimization methods have been implemented and applied to work out the OPF problem through, fuzzy emissions constraints, particle swarm optimization, evolutionary algorithm, iterative approach, genetic algorithm and computational intelligence methods [4]. In the OPF problem, which finds out approximately all of changeable variables, such as; power outputs of generators, transformers tap positions, phase shifter angle positions, shunt capacitor /reactor, etc. [5].

At the instant, to discover and classify different types of OPF events or commotions, a number of OPF maintaining techniques have been suggested. For OPF problem, diverse techniques are applied by the researchers [16]. Interior point methods, modified Primal–Dual Logarithmic-Barrier Method, Successive Quadratic Programming Method are moreover utilized for enhancing OPF [10]. Asymptotic numerical method (ANM) is extremely competent. Currently, ANM has been used with great achievement in an extensive range of problems chiefly in the regions of Continuation Power Flow (CPF), which is a great impact on the voltage constancy study [12]. A competent heuristic algorithm is to work out the optimal capacitor placement problem in radial distribution systems [17].

This document, a hybrid optimal power flow method with FACTS controller is suggested. The suggested hybrid method is the mixture of ABC algorithm and artificial neural network. ABC is one of the swarm intelligence based algorithm which applied to choose the optimal generation limits of the system. The optimal generation limits are found out based on the minimum value of the fuel cost and the emission. For reducing the actual power deviation of system by inserting the voltage magnitude and voltage angle, the UPFC is employed as a FACTS controller. The fitting cost of the UPFC is depends on the actual power deviation of the system. The detailed explanation of the suggested hybrid method and the UPFC power flow model are explained in section 3. Earlier to that, the current research works are offered in section 2. The consequences and the conversation are offered in section 4. In section 5 the paper is finishes.

2. RECENT RESEARCH WORKS: BRIEF REVIEW

A number of research works associated to OPF problem working out based on Goal Attainment method, PSO techniques are previously obtainable in the literature. In this segment, some of the most current literature works on this topic are assessed. A multi-objective harmony search (MOHS) algorithm for optimal power flow (OPF) problem has been improved by S. Sivasubramani *et al*. [21]. OPF problem was created as a nonlinear constrained multi-objective optimization problem where diverse objectives and different constraints have been regarded in the formulation. To find and administer the Pareto optimal front, fast elitist non-dominated sorting and crowding distance have been employed. The fuzzy based mechanism has been applied to choose a compromise result from the Pareto set. Their Simulation results are moreover compared with fast non-dominated sorting genetic algorithm (NSGA-II) technique. Their suggested method created true and well allocated Pareto optimal solutions for OPF problem.

By means of an algorithm of implanting sensitivity theory in ordinal optimization, Shieh-Shing Lin *et al*. [22] have suggested to work out a class of NP-hard problem. The decentralized optimal power flow with nonstop and distinct control variables problem was initially created as a NP-hard optimization problem - Block Additive constrained with Continuous and Discrete variables (BACD) problem. Secondly, an algorithm of implanting sensitivity theory (ST) in ordinal optimization (OO), abbreviated as STOO, was suggested for working out this NP-hard optimization problem. Their suggested technique contains three stages and three models of presentation assessment. The STOO algorithm attained a good adequate result with smaller objective value and devoured less CPU time than four heuristic methods.

Based on multi-agent system for working out large-scale multi-objective OPF problem, a new allocated multi-step learning algorithm has been progressed by T. Yu *et al.* [23]. They have suggested the answer for the complex power OPF problem. In the allocation reinforcement learning, it was based on the individual reinforcement learning (IRL) rule. They did not state any exploitation of the conventional mathematical Optimal Power Flow (OPF) model. The hurdles in the OPF model can be evaded by implementing the idea of power

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grid partitioning and adding incentive to electrical variables of boundary nodes.

To work out power flow problems under both load and line data uncertainty, interval arithmetic in current injection power flow analysis has been suggested by L.E.S. Pereira *et al.* [24]. Using Krawczyk technique, the resulting interval nonlinear system of equations was worked out. The control proposals were executed in Matlab environment by means of the Intlab toolbox. They have verified that their Methodology was very effortless and dependable, and meets with a small number of iterations.

A semi definite programming (SDP) technique to work out the optimal power flow problem has been suggested by Xiaoqing Bai *et al*. [25]. At first, the non-convex OPF problem was altered into its convex SDP model and the matrix variable of SDP was re-arranged by means of the chordal extension of its combined sparsity pattern of the graph partitioning method. Their suggested technique has to be diminished the consumption of computer memory and develop the computing presentation considerably but less CPU time and remembrance.

Lashkar Ara, A. *et al*. [26] have progressed a suitable models of flexible ac transmission systems (FACTS) shunt-series controllers for multiobjective optimization and furthermore offers a multiobjective optimization methodology to locate the optimal location of FACTS shunt-series controllers. The objective purposes were the total fuel cost, power losses, and system load ability with and without minimum cost of FACTS fitting. For the multiobjective mathematical programming (MMP) formulation, the ε-constraint strategy was executed together with the FACTS shunt-series controllers, hybrid flow controller (HFC), and unified power-flow controller (UPFC)). The simulation consequences were offered for the IEEE 14-bus system.

To reduce the generator fuel cost in optimal power flow (OPF) control with multi-line stretchy alternating current transmission systems (FACTS) tool which was interline power flow controller (IPFC), an intelligent search evolution algorithm (ISEA) has been suggested by A. V. Naresh Babu *et al*. [27]. In the suggested algorithm, a two step initialization process have been implemented which removes the mutation operation and moreover it gives optimal solution with less number of generations nothing like the OPF solution techniques presented in the literature. The suggested algorithm has been inspected and checked on a standard IEEE-30 bus system without and with IPFC. The test results were representing that the suggested algorithm with IPFC could find better result than without IPFC.

The latest research works illustrates that, more than a few methods are applied to work out the optimal power flow problems. In the earlier period, researchers spotlighted on how to create some practical constraints, such as bus voltage range, generation limits, line transfer capability, possibility constraints, fuel cost environment concerns etc. For working out the optimal power flow problem, Genetic Algorithm is applied. The main drawback of GAs is the high CPU time implementation and the qualities of the solution decline with practical large scale optimal power flow (OPF) problems. The multi objective OPF problem is worked out by Goal Attainment technique, weighted sum method and ϵ-constraint method. The aforementioned techniques need multiple steps to attain an optimal solution and require much computational time. Due to this reason the optimal power flow problem is not able to uphold successively. Sensitivity Theory in Ordinal Optimization (STOO) is moreover applied for working out OPF problem. This technique is only appropriate for smaller objective value of OPF problem; it is not appropriate for the larger objective value of OPF. In the document, a hybrid method with FACTS controller based OPF technique is suggested. The detailed explanation of the suggested method is explained in the subsequent section.

3. EQUIVALENT CIRCUIT AND POWER FLOW MODEL OF UPFC

UPFC equivalent circuit

The UPFC is one of the FCTS devices which can be able to control the active and the reactive load flow between the terminals. Also, the UPFC may provide the reactive power compensation between the two nodes. In generally, the UPFC consists of two voltage source converters by a DC link [28]. The coupling transformer is providing the connections for these converters to the power system. The shunt side is connected to the sending end node of the system and the series side is connected to the receiving end node of the system. The UPFC not able to generate the active power since, the converters active power is balanced while the active power is neglected by the DC link. The UPFC initialization in power system and the

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equivalent circuit model [29] are illustrated in Figure 1 and Figure 2 respectively.

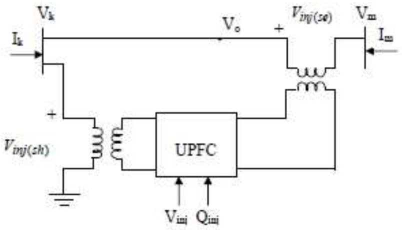

Figure 1: UPFC installed power system.

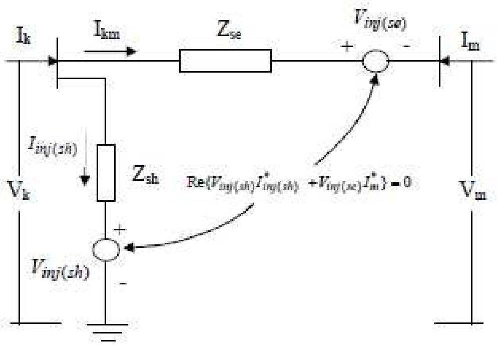

Figure 2: Equivalent circuit of UPFC.

The injected voltage and voltage angle of UPFC are represented as V_{inj} and θ_{inj} respectively. The injected voltage of the UPFC is depends on the shunt injected voltage $\left(V_{inj(sh)}\right)$ and series injected voltage $\left(V_{inj(se)}\right)$. The injected voltage of UPFC is determined by follow [30]:

$$V_{inj} = V_{inj(sh)} + V_{inj(se)} \quad (1)$$

$$V_{inj} = \left\{\left|V_{inj(sh)}\right|\left(\cos\theta_{inj(sh)} + j\sin\theta_{inj(sh)}\right)\right\} + \left\{\left|V_{inj(se)}\right|\left(\cos\theta_{inj(se)} + j\sin\theta_{inj(se)}\right)\right\} \quad (2)$$

Where, $V_{inj} \in V_{inj}^{\min} \le V_{inj} \le V_{inj}^{\max}$ and $\theta_{inj} \in \theta_{inj}^{\min} \le \theta_{inj} \le \theta_{inj}^{\max}$ are the control able injected voltage and voltage angle of the converter. The control voltage is depends on the shunt and series injected voltage of the system.

UPFC power flow equation

From the above equivalent circuit model, the power injection equations are derived from the power flow studies. By using load flow analysis in Figure 2, the real and reactive power of bus k and m are determined. Similarly, the real and reactive powers injected by the coupling transformer are calculated. The important of the power injection representation is that the symmetric characteristics of admittance matrix will not be destroyed [31]. The equations are described as following them,

Real and reactive power at bus k

$$\begin{aligned} P_k = {} & V_k^2 G_{kk} + V_k V_m \left(G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)\right) \\ & + V_k V_{inj(se)}\left(G_{km}\cos\left(\theta_k - \theta_{inj(se)}\right) + B_{km}\sin\left(\theta_k - \theta_{inj(se)}\right)\right) \\ & + V_k V_{inj(sh)}\left(G_{km}\cos\left(\theta_k - \theta_{inj(sh)}\right) + B_{km}\sin\left(\theta_k - \theta_{inj(sh)}\right)\right) \end{aligned} \quad (3)$$

$$\begin{aligned} Q_k = {} & -V_k^2 B_{kk} + V_k V_m \left(G_{km}\sin(\theta_k - \theta_m) - B_{km}\sin(\theta_k - \theta_m)\right) \\ & + V_k V_{inj(se)}\left(G_{km}\sin\left(\theta_k - \theta_{inj(se)}\right) - B_{km}\cos\left(\theta_k - \theta_{inj(se)}\right)\right) \\ & + V_k V_{inj(sh)}\left(G_{inj(sh)}\sin\left(\theta_k - \theta_{inj(sh)}\right) + B_{inj(sh)}\sin\left(\theta_k - \theta_{inj(sh)}\right)\right) \end{aligned} \quad (4)$$

Real and reactive power at bus m:

$$\begin{aligned} P_m = {} & V_m^2 G_{mm} + V_m V_k \left(G_{mk}\cos(\theta_m - \theta_k) + B_{mk}\sin(\theta_m - \theta_k)\right) \\ & + V_m V_{inj(se)}\left(G_{mm}\cos\left(\theta_m - \theta_{inj(se)}\right) - B_{mm}\sin\left(\theta_m - \theta_{inj(se)}\right)\right) \end{aligned} \quad (5)$$

$$\begin{aligned} Q_m = {} & -V_m^2 B_{mm} + V_m V_k \left(G_{mk}\sin(\theta_m - \theta_k) - B_{km}\cos(\theta_m - \theta_k)\right) \\ & + V_m V_{inj(se)}\left(G_{mm}\sin\left(\theta_m - \theta_{inj(se)}\right) - B_{km}\cos\left(\theta_m - \theta_{inj(se)}\right)\right) \end{aligned}$$

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(6)

Series converter injected real and reactive power:

$$P_{inj(se)} = V_{inj(se)}^2 G_{mm} + V_{inj(se)} V_k \left(G_{mk} \cos\left(\theta_{inj(se)} - \theta_k\right) + B_{km} \cos\left(\theta_{inj(se)} - \theta_k\right)\right) + V_{inj(se)} V_m \left(G_{mm} \cos\left(\theta_{inj(se)} - \theta_m\right) - B_{mm} \sin\left(\theta_{inj(se)} - \theta_m\right)\right)$$

(7)

(8)

$$Q_{inj(se)} = -V_{inj(se)}^2 G_{mm} + V_{inj(se)} V_k \left(G_{km} \sin\left(\theta_{inj(se)} - \theta_k\right) + B_{km} \cos\left(\theta_{inj(se)} - \theta_k\right)\right) + V_{inj(se)} V_m \left(G_{mm} \sin\left(\theta_{inj(se)} - \theta_m\right) - B_{mm} \cos\left(\theta_{inj(se)} - \theta_m\right)\right)$$

Shunt converter injected real and reactive power:

$$P_{inj(sh)} = -V_{inj(sh)}^2 G_{inj(sh)} + V_{inj(se)} V_k \left(G_{inj(sh)} \cos\left(\theta_{inj(sh)} - \theta_k\right) + B_{inj(sh)} \sin\left(\theta_{inj(sh)} - \theta_k\right)\right)$$

(9)

$$Q_{inj(se)} = -V_{inj(sh)}^2 G_{inj(sh)} + V_{inj(sh)} V_k \left(G_{inj(sh)} \sin\left(\theta_{inj(sh)} - \theta_k\right) + B_{inj(sh)} \cos\left(\theta_{inj(sh)} - \theta_k\right)\right) \quad (10)$$

Where,

$$\left.\begin{aligned} Y_{kk} &= G_{kk} + jB_{kk} \\ Y_{mm} &= G_{mm} + jB_{mm} \\ Y_{km} = Y_{mk} &= G_{mk} + jB_{mk} \\ Y_{inj(sh)} &= G_{inj(sh)} + jB_{inj(sh)} \\ Y_{inj(se)} &= G_{inj(se)} + jB_{inj(se)} \end{aligned}\right\} \quad (11)$$

The above described equation (11) is the admittance values of the bus, between the buses and power converters. The real power loss of the converter is assumed as loss less then; the converter equation is changed as follow:

$$P_{inj(sh)} + P_{inj(se)} = 0 \quad (12)$$

The above real power mismatch equations are used as the guiding principle for conducting limit revisions. The control parameters of the UPFC are determined accurately from the real power mismatch equation. The real power adjustment of the UPFC is based on the real power converter mismatch equation.

3.1. Problem formulation of optimal power flow

The OPF problem is solved with the variable parameters of the UPFC devices. The objective function is minimization of total fuel cost, the total emission and the UPFC installation cost. Here, the multi-objective problem is mathematically formulated as a constrained nonlinear multi-objective optimization problem as follows:

Minimize, $\left[f(t,x),\ e(t,x), c_{UPFC}(t,x)\right]$

Subject to:

$$g(t,x) = 0$$
$$h(t,x) \le 0$$

where, $f(t,x)$, $e(t,x)$ and $c_{UPFC}(t,x)$ are the objective function of fuel cost, emission and UPFC installation cost of the system. Then, $g(t,x)$ are the equality constraints and $h(t,x)$ is the inequality constraint. The objective function of fuel cost, emission and UPFC installation cost are described as follow:

Fuel cost $f(t,x)$

The total fuel cost ($/hr) of the system can be represented in quadratic function which is described as follows,

$$\text{Fuel cost, } f(t,x) = \sum_{i=1}^{NG} (a_i + b_i P_{G_i} + c_i P_{G_i}^2) \quad (13)$$

Where, a_i, b_i and c_i are the fuel cost coefficient of i^{th} generator. Then, P_{G_i} is the real power of the i^{th} generator.

Emission $e(t,x)$ ***:***

The total environmental emission $e(t,x)$ is expressed as following them,

$$\text{Emission } e(t,x) = \sum_{i=1}^{NG} (\alpha_i P_{G_i}^2 + \beta_i P_{G_i} + \gamma_i) \quad (14)$$

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Where, α_i , β_i and γ_i are the emission coefficient of i^{th} generator.

UPFC installation cost $c_{UPFC}(t,x)$ **:**

The installation cost of UPFC $(\$/KVar)$ is described as follow:

UPFC installation cost

$$c_{UPFC}(t,x) = 0.0003S^2 - 0.2691S + 188.2 \quad (15)$$

Where, S is the real power operating range of UPFC.

3.2. Optimizing Generator Real Power Limits By ABC

Artificial Bee Colony (ABC) algorithm is one of the swarm intelligence optimization algorithms [32] which is based on the foraging behavior of honey bees for numerical optimization problems [33]. In the paper, ABC is used for optimizing the real power of the generator to minimize the fuel cost and emission. Based on the power balance condition, the optimal power is selected. The behavior of real bees on finding nectar and sharing the information of food sources to the bees in the hive. The ABC algorithm has three agents which are classified as follow:

- ☆ Employed bee,
- ☆ Onlooker bee, and
- ☆ Scout bee.

Employed bee: It stays on a food source and provides the neighborhood of the source in its memory.

Onlooker bee: It gets the information of food sources from the employed bees in the hive and select one of the food source to gathers the nectar.

Scout bee: It is responsible for finding new food, the new nectar, and sources. This problem is converted in to the real power optimization concept.

Initially, the real power of the generator is selected randomly and the probability formula for selecting the nectar source is expressed as follow,

$$P_{G_i} = \frac{P(\theta_i)}{\sum_{k=1}^{NG} P(\theta_k)} \quad (16)$$

Where, P_{G_i} is the probability of real power selecting the generator, NG is the number of generator, $P(\theta_i)$ is the real power of i^{th} generator and $P(\theta_k)$ is the real power of k^{th} generator. Then, the formula for updating the new real power values is expressed as following them,

$$h_{ij}(t+1) = \theta_{ij}(t) + \phi(\theta_{ij}(t) - \theta_{kj}(t)) \quad (17)$$

Where, h_{ij} is the position of the first value, t is the iteration number, θ_{ij} and θ_{kj} is the real power of two i^{th} and k^{th} generator, and j is the dimension of the solution.

Steps bee's algorithm for proposed approach

1) In the first step, the scout bees 'N' random initial population are selected. In the paper, the generator limits are selected as the initial population. The initialized generator limits possible candidate solution which satisfies the power balance condition.
2) Apply load flow solution and then, evaluate the fitness values of the random initial populations.
3) In neighborhood search, .the best solutions from the generator limits are selected.
4) The best solutions are separated into two groups, the first groups have the minimum best solutions and another group has maximum best solutions.
5) For each best solution groups, the size of neighborhood search determined. Generate solutions around the selected within solutions neighborhood size.
6) Run load flow analysis and evaluate generated solutions. Then, select the best solution from each patch.
7) Calculated the fuel cost, emission and the power loss values.
8) Check the stopping criterion. If satisfied, terminate the search, else go to step 9.
9) Assign the new population to generate new solutions. Go to Step 2.

The output of ABC is the optimal operating rating of generation limits with minimum fuel and emission. These, optimal operating range is selected based on the power balance condition as well as the real power loss of the system. Once set the optimal generation limits, and the OPF condition is maintained by the UPFC. The control parameters injected voltage and voltage angle of UPFC is determined by neural network. The detailed description of neural network is described in the following section.

3.3. Calculation Of UPFC Injected Voltage And Angle By Neural Network

The neural network is one of the artificial intelligence (AI) techniques [34] which are used to calculate the injected voltage and angle of UPFC. In the paper, the feed forward neural network is

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used for determining the injected voltage and voltage angle of UPFC. The UPFC injected voltage and voltage angle are determined based on the optimal generation limits of the generators. The feed forward network consists of three layers: input layer, hidden layer and output layer. The input of the network is optimal generation limits of the generators and the output of the network is the injected voltage and voltage angle of each buses. The structure of feed forward network is illustrated in Figure 3.

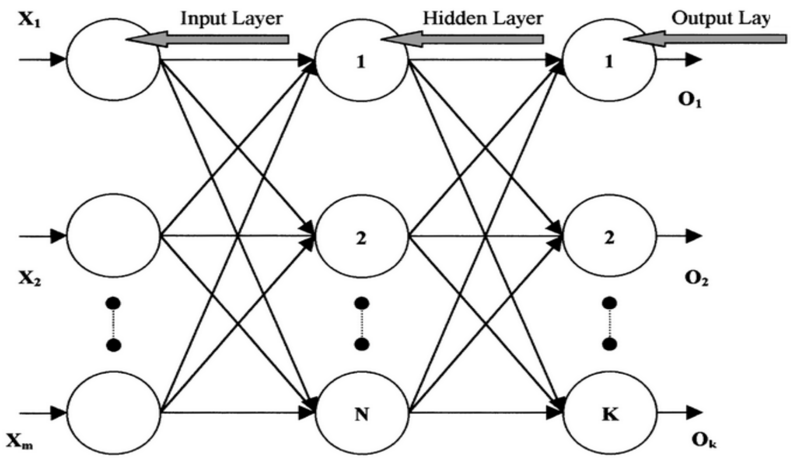

Figure 3: Structure Of Feed Forward Neural Network

The inputs of the network are denoted as x_1, x_2 *and* x_m, the outputs of the network are denoted as o_1, o_2 *and* o_k. The weights of the network from input layer to hidden layer is denoted as $V_{11}, V_{22}, \ldots \ldots V_{1n}$ *and* V_{pn} respectively. Then, the weights between hidden and output layer is denoted as $W_{11}, W_{22}, \ldots \ldots W_{1n}$ *and* W_{mp} respectively. The network is trained by back propagation training algorithm. The back-propagation algorithm is one of the most famous algorithm to train a feed forward network [35]. The back propagation training algorithm is divided into two phases that are named as propagation and weight update. The network training steps are described as following them,

Back propagation learning algorithm steps

(1) The input and hidden layer, hidden and output layer weights of the neural network are initialized randomly.
(2) Learning the network according to the input and the corresponding target.
(3) Calculate the back propagation error of the target o_1, o_2 *and* o_k.

$$\left.\begin{aligned} BP^{1}_{error} &= o_1^{NN(tar)} - o_1^{NN(out)} \\ BP^{2}_{error} &= o_2^{NN(tar)} - o_2^{NN(out)} \\ BP^{k}_{error} &= o_k^{NN(tar)} - o_k^{NN(out)} \end{aligned}\right\} \tag{18}$$

Where, $o_k^{NN(tar)}$ is the network target of the k^{th} node and $o_k^{NN(out)}$ is the current output of the network.

(4) The current output of the network is determined by following them,

$$\left.\begin{aligned} o_1^{NN(out)} &= \alpha_1 + \sum_{n=1}^{N} w_{1n}\, o_1^{NN}(n) \\ o_2^{NN(out)} &= \alpha_2 + \sum_{n=1}^{N} w_{2n}\, o_2^{NN}(n) \\ o_k^{NN(out)} &= \alpha_k + \sum_{n=1}^{N} w_{kn}\, o_k^{NN}(n) \end{aligned}\right\} \tag{19}$$

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Where, α_1, α_2 and α_k are the bias function of the node $1, 2\ and\ k$ respectively.

$$\left.\begin{aligned} o_1^{NN}(n) &= \frac{1}{1+\exp(-w_{1n}o_1 - w_{2n}o_2)} \\ o_2^{NN}(n) &= \frac{1}{1+\exp(-w_{2n}o_2 - w_{kn}o_k)} \\ o_k^{NN}(n) &= \frac{1}{1+\exp(-w_{kn}o_k - w_{1n}o_1)} \end{aligned}\right\} \tag{20}$$

(5) The new weights of the each neurons of the network are update by $w_{new} = w_{old} + \Delta w$. Here, w_{new} is the new weight, w_{old} is the previous weight and Δw is the change of weight of each output. The change of weight is determined by follow,

$$\left.\begin{aligned} \Delta w_1 &= \delta . o_1 . BP_{error}^1 \\ \Delta w_2 &= \delta . o_2 . BP_{error}^2 \\ \Delta w_k &= \delta . o_k . BP_{error}^k \end{aligned}\right\} \tag{21}$$

Where, δ is the learning rate (0.2 to 0.5).

(6) Repeat the above steps till the BP_{error} gets minimized $BP_{error} < 0.1$.

Once the neural network training process is completed, the network is trained well for identifying the injected voltage and voltage angle of the input. Based on the output of the network, the UPFC voltage and voltage angle is injected. After connecting the UPFC, the load flow analysis applied. Here, the Newton Raphson load flow algorithm used for analyzing the power flow solution [36]. Then, the fuel cost, emission, UPFC installation cost and power loss are determined.

4. RESULTS AND DISCUSSION

The proposed hybrid OPF technique with FACTS controller was implemented in MATLB working platform. In the paper, the UPFC was used as FACTS controller for maintaining the optimal power flow condition. For evaluating the performance of the proposed technique, the hybrid technique was tested with IEEE 30 bus bench mark system. The line diagram of IEEE 30 bus system is described in Figure 4. The bus data and line of the tested system are given in Table 1 and Table 2 respectively.

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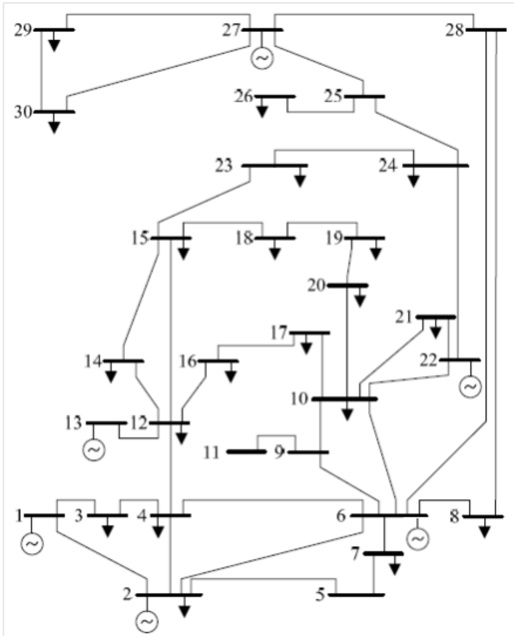

Figure 4: Line Diagram Of IEEE 30 Bus System.

Table 1: Bus Data For IEE 30 Bus System.

Bus No	Voltage in p.u.	Voltage angle in degree	Generation		Load	
			MW	Mvar	MW	MVar
1	1.0600	0.0000	0.000	16.894	0.000	0.000
2	1.0330	-3.6081	40.000	6.903	21.700	12.700
3	1.0228	-4.9889	0.000	0.000	2.400	1.200
4	1.0136	-6.1169	0.000	0.000	7.600	1.600
5	1.0044	-11.5389	0.000	37.000	94.200	19.000
6	1.0100	-7.3632	20.000	-19.525	0.000	0.000
7	0.9999	-9.6045	0.000	0.000	22.800	10.900
8	1.0103	-8.0582	0.000	37.300	30.000	30.000
9	1.0458	-9.2535	0.000	0.000	0.000	0.000
10	1.0367	-10.2492	0.000	19.000	5.800	2.000
11	1.0771	-9.2535	0.000	16.200	0.000	0.000
12	1.0572	-9.0214	0.000	0.000	11.200	7.500
13	1.0710	-7.1792	26.000	10.969	0.000	0.000
14	1.0414	-9.9688	0.000	-0.000	6.200	1.600
15	1.0355	-10.0942	0.000	0.000	8.200	2.500
16	1.0411	-9.8065	0.000	-0.000	3.500	1.800
17	1.0326	-10.3234	0.000	-0.000	9.000	5.800
18	1.0236	-10.8482	0.000	-0.000	3.200	0.900
19	1.0198	-11.1050	0.000	0.000	9.500	3.400
20	1.0232	-10.9488	0.000	-0.000	2.200	0.700
21	1.0228	-10.5951	0.000	0.000	17.500	11.200
22	1.0300	-9.6655	12.000	-3.389	0.000	0.000
23	1.0229	-10.5463	0.000	0.000	3.200	1.600
24	1.0158	-10.2432	0.000	4.300	8.700	6.700
25	1.0069	-9.5967	0.000	0.000	0.000	0.000
26	0.9890	-10.0252	0.000	-0.000	3.500	2.300
27	1.0100	-8.9337	12.500	-6.058	0.000	0.000

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28	1.0094	-7.6744	0.000	0.000	0.000	0.000
29	0.9899	-10.1968	0.000	0.000	2.400	0.900
30	0.9782	-11.1042	0.000	0.000	10.600	1.900

Table 2: Line Data For IEEE 30 Bus System.

From Bus	To Bus	P (MW)	Q (MVar)	From Bus	To Bus	P (MW)	Q (MVar)
1	2	123.907	12.175	2	1	-121.258	-4.242
1	3	59.803	9.978	3	1	-58.324	-4.574
2	4	27.411	3.121	4	2	-27.004	-1.882
3	4	55.924	5.947	4	3	-55.525	-4.801
2	5	72.803	2.549	5	2	-70.456	7.313
2	6	39.344	1.781	6	2	-38.500	0.782
4	6	52.171	-5.601	6	4	-51.852	6.710
5	7	-23.744	13.825	7	5	24.089	-12.957
6	7	47.480	-2.111	7	6	-46.889	3.927
6	8	27.123	-8.214	8	6	-27.029	8.545
6	9	17.128	-17.509	9	6	-17.128	18.705
6	10	9.785	-4.755	10	6	-9.785	5.380
9	11	-0.000	-15.729	11	9	0.000	16.200
9	10	17.128	8.854	10	9	-17.128	-8.480
4	12	22.758	-17.949	12	4	-22.758	19.900
12	13	-26.000	-9.997	13	12	26.000	10.969
12	14	8.354	2.578	14	12	-8.270	-2.403
12	15	19.675	7.796	15	12	-19.409	-7.274
12	16	9.529	4.078	16	12	-9.438	-3.887
14	15	2.070	0.803	15	14	-2.060	-0.794
16	17	5.938	2.087	17	16	-5.908	-2.017
15	18	7.376	2.021	18	15	-7.318	-1.902
18	19	4.118	1.002	19	18	-4.107	-0.980
19	20	-5.393	-2.420	20	19	5.405	2.443
10	20	7.665	3.278	20	10	-7.605	-3.143
10	17	3.099	3.802	17	10	-3.092	-3.783
10	21	14.395	12.586	21	10	-14.276	-12.331
10	22	-4.047	6.617	22	10	4.087	-6.533
21	23	-3.224	1.131	23	21	3.225	-1.128
15	23	5.893	3.546	23	15	-5.849	-3.457
22	24	7.913	3.145	24	22	-7.834	-3.022
23	24	-0.576	2.986	24	23	0.588	-2.962
24	25	-1.453	3.584	25	24	1.481	-3.536
25	26	3.546	2.368	26	25	-3.500	-2.300
25	27	-5.026	1.168	27	25	5.055	-1.113
28	27	5.845	-0.096	27	28	-5.845	0.224
27	29	6.194	1.676	29	27	-6.105	-1.508
27	30	7.097	1.671	30	27	-6.930	-1.357
29	30	3.705	0.608	30	29	-3.670	-0.543
8	28	-2.971	1.399	28	8	2.978	-1.377
6	28	8.836	-1.443	28	6	-8.823	1.490

The power loss of IEEE 30 bus system is 10.809 MW which determined by applying the power flow solution. Then, based on the above described data set, the optimal power flow concept of proposed hybrid technique is discussed. In the tested system, the bus numbers 1, 2, 6, 13, 22 and 27 are the generator buses. The optimal generation limits of the generator bus are selected by the ABC

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algorithm. The optimal generation limits are determined by based on the objective function of fuel cost, emission and power losses. The fuel cost and the emission coefficient of the generator bus are tabulated in Table 3. Then, the total generation real power limit is applied to the input of neural network. The output of the network is the injected voltage, voltage angle of all the buses of the system.

Table 3: Fuel Cost And Emission Coefficient.

Generator bus number	Fuel cost coefficient			Emission coefficient		
	a_i	b_i	c_i	α_i	β_i	γ_i
1	0	2	0.0038	0.0126	-1.1	22.983
2	0	1.75	0.0175	0.02	-0.1	25.313
6	0	1	0.0625	0.027	-0.01	25.505
13	0	3.25	0.0083	0.0291	-0.005	24.9
22	0	3	0.025	0.029	-0.004	24.7
27	0	3	0.025	0.0271	-0.00055	25.3

From the output of neural network, the UPFC injected voltage magnitude and voltage angle are obtained. The obtained voltage magnitude and voltage angle are compared with ABC algorithm. The compared values are tabulated in Table 4. Then, the UPFC is connected at different buses and the power loss, UPFC installation cost, fuel cost and emission are determined. The UPFC connected buses and the corresponding power loss, cost base parameters and emission of the tested system are tabulated in Table 5. The loss comparison charts of proposed hybrid technique and ABC algorithm are described in Figure 6. The cost comparison performance of hybrid technique and ABC algorithm is illustrated in Figure 7.

Table 4: UPFC Injected Voltage Magnitude And Voltage Angle.

Bus Number	UPFC injected voltage magnitude and voltage angle			
	Proposed hybrid technique		NR-method	
	Voltage in p.u.	Angle in degree	Voltage in p.u.	Angle in degree
1	1.0600	0.0000	1.0600	0.0000
2	1.0430	-2.8044	1.0330	-3.6081
3	1.0244	-3.8362	1.0228	-4.9889
4	1.0155	-4.6817	1.0136	-6.1169
5	1.0094	-10.1653	1.0044	-11.5389
6	1.0100	-5.4785	1.0100	-7.3632
7	1.0020	-7.9272	0.9999	-9.6045
8	1.0103	-6.1647	1.0103	-8.0582
9	1.0457	-7.3657	1.0458	-9.2535
10	1.0364	-8.3601	1.0367	-10.2492
11	1.0770	-7.3657	1.0771	-9.2535
12	1.0565	-7.6343	1.0572	-9.0214
13	1.0710	-6.1454	1.0710	-7.1792
14	1.0405	-8.4905	1.0414	-9.9688
15	1.0351	-8.5203	1.0355	-10.0942
16	1.0408	-8.2105	1.0411	-9.8065
17	1.0324	-8.5232	1.0326	-10.3234
18	1.0233	-9.1644	1.0236	-10.8482
19	1.0195	-9.3551	1.0198	-11.1050
20	1.0230	-9.1638	1.0232	-10.9488
21	1.0225	-8.7378	1.0228	-10.5951
22	1.0300	-7.4656	1.0300	-9.6655
23	1.0226	-8.6992	1.0229	-10.5463

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24	1.0155	-8.1414	1.0158	-10.2432
25	1.0068	-7.3492	1.0069	-9.5967
26	0.9889	-7.7779	0.9890	-10.0252
27	1.0100	-6.5952	1.0100	-8.9337
28	1.0096	-5.7390	1.0094	-7.6744
29	0.9899	-7.8583	0.9899	-10.1968
30	0.9782	-8.7657	0.9782	-11.1042

Table 5: The Power Loss, UPFC Installation Cost, Fuel Cost And Emission

UPFC connected bus	Power loss of proposed method	UPFC installation cost ($/KVar)	Fuel cost ($/hr)	Emission (Kg/hr)
2-3	8.4197	185.6821	723.4103	309.2178
5-6	9.1681	184.4326	497.4753	207.7048
6-8	9.6427	189.8293	709.3847	305.2213
9-10	8.9303	185.6462	622.8654	243.4336
12-13	8.6038	185.3133	597.209	250.5799
18-19	9.0287	185.9104	670.7175	284.8097
10-21	9.2015	185.9531	702.2233	291.0308
22-23	8.5548	187.0827	743.3521	329.4189
27-30	9.5826	187.9167	509.228	208.6349
8-28	8.375	190.2497	676.3555	282.9007

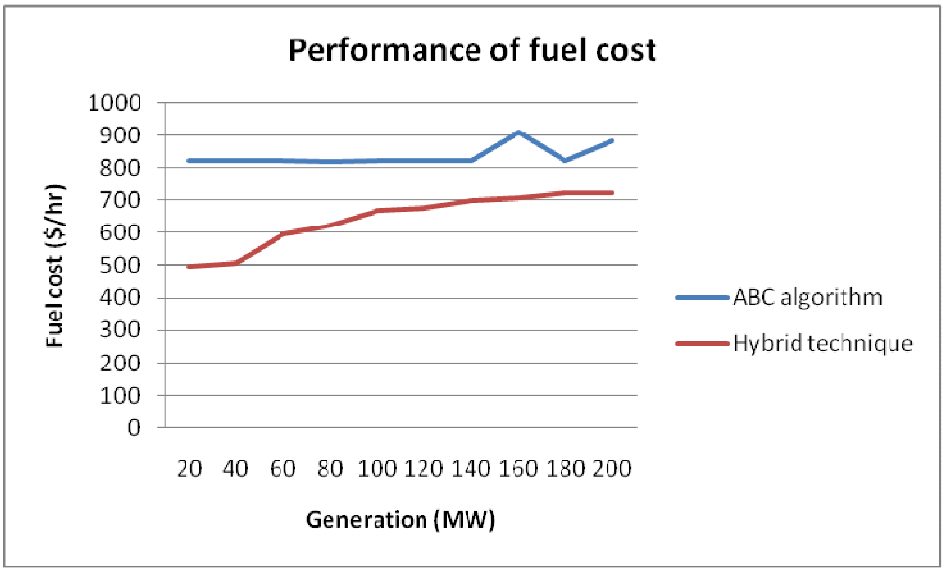

Figure 6: Performance Of Fuel Cost

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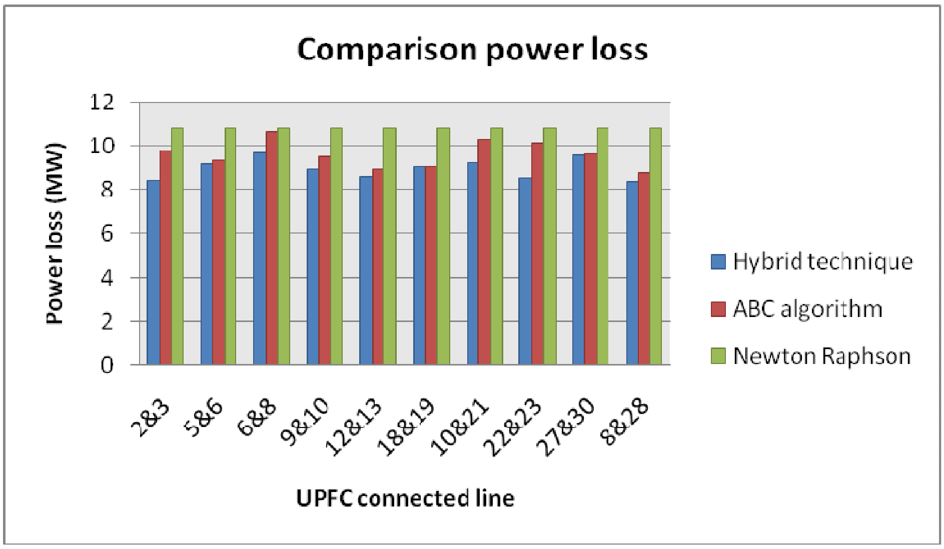

Figure 7: Power Loss Comparison

The Table 4 and 5 shows that, the performance of proposed hybrid technique. For evaluating the performance of proposed technique, it compared with the ABC algorithm and Newton-Raphson method. In table 4, the UPFC injected voltage magnitude and voltage angle of proposed hybrid technique are compared with ABC algorithm. From the comparative analysis, the proposed hybrid technique is selected the injected angle optimally when compared to ABC algorithm. So, the power loss of the proposed method is reduced as well as the fuel cost and emissions are reduced. As, the proposed hybrid technique is achieved a remarkable level for maintaining optimal power flow in power system. Then, the average fuel cost of proposed method is compared with existed work in literature which is presented in table 6. In table 6, the fuel cost of proposed method (with UPFC) is compared with GSA, PSO, BBO, MDE, ABC, and DE without using UPFC device. From the comparative analysis, the proposed method give the fuel cost averagely 645.22 $/hr. But the fuel costs of the existed works are higher as considerable level to the proposed method.

Table 6: Comparison Of Fuel Cost

Methods	Fuel cost ($/hr)
Proposed method with UPFC	645.22
GSA without UPFC [37]	646.84806
PSO without UPFC [38]	647.69
BBO without UPFC [39]	647.7437
MDE without UPFC [40]	647.846
ABC without UPFC [41]	649.0855
DE without UPFC [42]	650.8224

5. CONCLUSION

In the paper, the hybrid OPF technique with FACTS controller was proposed. Then, the proposed hybrid technique was implemented and the OPF performance was tested with IEEE 30 bus system. The optimal generation limits were determined by ABC algorithm and the fuel cost, emission and power loss were analyzed. Then, the analyzed hybrid technique results were compared with ABC algorithm. From the comparative analysis, the proposed hybrid technique has less fuel cost, emission and power loss. Also, the UPFC injected voltage magnitude and the voltage angle are calculated best possible values when compared to ABC algorithm. Since, the voltage deviation is reduced, the real power loss of the system is also reduced. Thus, the power variations of the buses are controlled and the UPFC installation cost is maintained economically. Since, the proposed hybrid technique maintained the OPF concept optimally when compared to ABC algorithm.

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