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Original Article

Optimum Power Flow Model and LMP for Unified Power Flow Controller

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Abstract *- The approach described in this work uses Genetic Algorithm (GA) to install Unified Power Flow Controller (UPFC) in electrical transmission systems to find the best possible location and lower the cost of the transmission network by utilizing MATLAB & MATPOWER. The proposed method is based on Optimal Power Flow (OPF) and optimizes the operating parameters of power generation. OPF was employed to create a multi-objective variable of the optimization issue to choose the best location for the installation of UPFC while taking into account the power injection model of this controller. In this aspect, the activation function consists of the costs associated with UPFC implementation, transfer, and production. The performance and scalability of the proposed method were assessed using the adapted IEEE 14-bus system, and the findings are described.*

Keywords *- Power system, Marketing management Genetic algorithm, IEEE 14 Bus.*

1. Introduction

According to the experience of the past 20 years, electrical businesses could be split into natural monopolies and support competition and the development of an electricity market [1-2]. Through competition between power generation and businesses engaged in the purchase and resale of power, the world leverages this knowledge to generate cheaper power. Generally, pool and secretly negotiated bilateral and international agreements make up this new market environment [3]. However, the current transmission infrastructures might be able to support such trades, and it is challenging to maintain the system effectively given these market activities [4]. Flexible AC transfer processes are thought to be one technology that could assist the developing power grid by improving system reliability, offering better voltage control, and increasing the capacity of the existing transmission grid by enabling lines to be loaded much nearer to their thermal limits [5]. Methods for managing traffic jams depended on the SO, allowing multiple groups to renegotiate their contracts, redistribute producers, utilize different control systems, or drop loads under the worst circumstances [6–8]. Other methods rely on creating new agreements that reroute flows along clogged pathways. To decrease the issue of transmission congestion in a privatized electrical market, phase shifters, tap change converters, and FACTS regulators could be essential [9]. The approaches to managing congestion could be divided into susceptibility factor-based approaches, re-dispatch approaches, willingness-to-pay methods, auction-based approaches, and pricing-based techniques [10]. Dynamic response management and steady-state electricity flow regulation, FACTS devices offer new control capabilities [11–12]. Performance can be greatly enhanced if power flow in an electricity system can be managed with topological or generational variations. Line flows can be adjusted using controlled equipment, programmable series capacitors, and phase shifters in a way that does violate stipulated energy dispatch while also minimizing losses, increasing stability margin, fulfilling contractual requirements, etc. [13–14].

There are primarily two causes of the rising interest in gadgets. Two factors motivate the use of power flow control: first, the recent advancement in large power electronics has made gadgets affordable, and second, the enhanced loading of energy systems in combination with the deregulation of the electricity sector encourages its use as a highly affordable method of dispatching specific power transfers [15]. Because these devices are expensive, it is crucial to decide. It would be placed. LMP site is described as the expense of providing an additional load [16]. Network restrictions, which determine LMP, may be efficiently determined using OPF. The interior point technique has recently been quite popular for solving OPF.

The summation of power network expenses, comprising electricity cost and transmission costs, by considering LMP and UPFC installation costs, is the objective function considered in this work. Since the effect of the UPFC's ideal position on bus LMPs and how it affects transmission costs is not considered, a proposed objective function includes minimizing transport costs and, consequently, reducing the network's overall price.

2. Related Works

However, presuming the predetermined sizes of UPFC devices, the majority of publications reduce the optimization problem. Additionally, UPFC's impact on congestion management and its cost-benefit analysis were adequately addressed [17]. Additionally, the effects of load fluctuations throughout the year have not been taken into account. Slow-response corrective measures could inadvertently fail to respond quickly to emergencies in the real world, which could cause voltage collapse or cascade line outages [18]. Two procedures are separated into 3 stages, the basic case, long-term post-contingency and post-contingency short-term intervals, to assure the safety of the electricity system during this short-term state. The base scenario is followed in the short term. Because of their poor reaction times to change the electrical program's starting operating point during this time, standard preventative control operation would be ineffective [19–20]. Voltage magnitude and Power flow would be limited to short-term incident values during the post-emergency timeframe. Following the long-term is the short-term interval of roughly 10 minutes. During this time, remedial steps are in place to reduce the voltage magnitude and energy flow of long-term urgency levels.

As a result, SCOPF, with preventive and corrective action, uses slow-reaction remedial action in the long-term phase and preventative action in the short-term stage. Preventive measures were proven to increase the protection of the electricity system in the circumstances [21]. But pricey preventive measures also limit the system's adaptability because It cannot be changed in response to various circumstances, which drives up operating costs. Fast-reaction corrective actions are far more adaptable than preventive ones because It can be changed to reduce short-term infractions in response to various conditions [22]. To reduce short-term violations and retain the same system safety level at minimal operational costs, fast-reaction remedial actions to precautionary ones could be taken. However, there is very little research on using fast-reaction remedial actions of SCOPF. Power flow management was the possibility of quick corrective steps to reduce short-term infractions [23]. Promising flexible AC transmission network elements would be the UPFC, which, in the base scenario, may reroute energy flows, offer voltage adjustments, and reduce violations during post-contingency intervals.

Classical methods include linear programming (NLP), quadratic programming, and the Newton-Raphson methodology, whereas AI was promoted as an important method in the second category. Evolutionary programming techniques are thought to be useful in power system management [24]. Different algorithms have been presented in studies of PF and OPF in current years in an attempt to enhance OPF methods to assess power systems featuring FACTS devices. This approach could be used for shifters and sequence compensators, but it ignores PF limitations. In [25], the FACTS parameters for the PF of particular lines are determined using LP of the security-restricted optimal power flow problem. Additionally, OPF is carried out using the Newton-Raphson approach when FACTS are present in the electricity network. To find the characteristics of the FACTS devices, Chung and Li used GA. [26] describes a combinatorial GA-Fuzzy method of locating FACTS devices in power networks in the best possible way.

3. Proposed System

A complete gadget to date result from the FACTS program is the UPFC, depicted in Figure 1. The UPFC can provide adaptive voltage amplitude management and active to reactive power regulation. The UPFC can function operationally as a phase-shifter regulator, a thyristor-controlled levels compensation, and a shunt VAR compensator. UPFC would be a strong competitor in performing several of the control systems needed to address various steady-state and dynamic issues that arise in electric power systems because of their adaptability. The converter's output power was added to the power at the AC connector by transmits that were series linked. The injected power altered an actual sending end voltage, which functions as an AC parallel voltage source. The sum of the transmission line present and the parallel voltage source was used to calculate the exchange of reactive and active power between the series converter and the AC system.

The shunt inverters endpoint Ac power magnitude could be kept at a specific value using the independently controlled circuit reactive compensation. Electricity usage at bus-k (reactive and active):

$$Q_h = U_h^2 L_{hh} + U_h U_m (L_{hm}\cos(\theta_h - \theta_m) + A_{hm}\sin(\theta_h - \theta_m)) + U_h U_{re}(L_{hm}\cos(\theta_h - \theta_{re}) + A_{hm}\sin(\theta_h - \theta_{re})) + U_h U_{rk}(L_{hm}\cos(\theta_h - \theta_{rk}) + A_{rk}\sin(\theta_h - \theta_{rk})) \quad (1)$$

$$P_h = -U_h^2 A_{hh} + U_h U_m (L_{hm}\sin(\theta_h - \theta_m) - A_{hm}\cos(\theta_h - \theta_m)) + U_h U_{re}(L_{hm}\sin(\theta_h - \theta_{re}) - A_{hm}\sin(\theta_h - \theta_{re})) + U_h U_{rk}(L_{hm}\cos(\theta_h - \theta_{rk}) - A_{rk}\cos(\theta_h - \theta_{rk})) \quad (2)$$

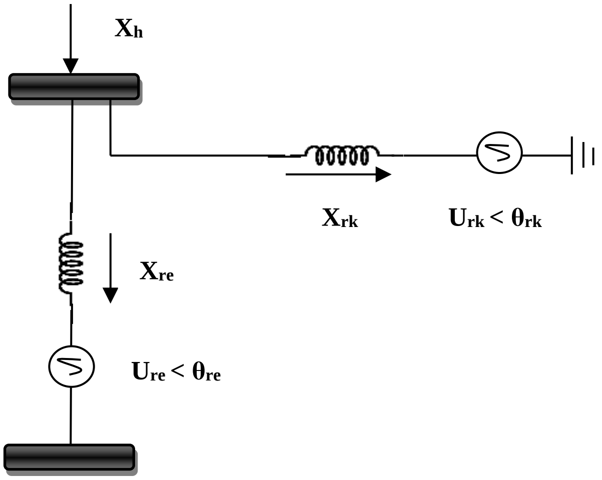

Fig. 1 UPFC equivalent resistance

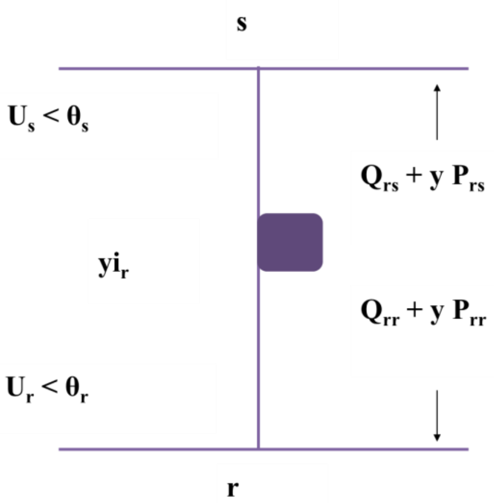

Fig. 2 Injection method of UPFC

Energy usage at bus-m (active and responsive):

$$Q_m = U_m^2 L_{mm} + U_h U_m \left(L_{mh}\cos(\theta_m - \theta_h) + A_{mh}\sin(\theta_m - \theta_h)\right) + U_h U_{re}\left(L_{mm}\cos(\theta_m - \theta_{re}) + A_{mm}\sin(\theta_m - \theta_{re})\right) \quad (3)$$

$$P_m = -U_m^2 A_{mm} + U_h U_m \left(L_{mh}\sin(\theta_m - \theta_h) - A_{mh}\cos(\theta_m - \theta_h)\right) + U_h U_{re}\left(L_{mm}\sin(\theta_m - \theta_{re}) - A_{mm}\cos(\theta_m - \theta_{re})\right) \quad (4)$$

Where,

U_h, θ_h - voltage magnitude and bus-h sending end aspect slopes

U_m, θ_m - Receiving end bus-m voltage magnitude and phase angles

U_{re}, θ_{re} - Phase angles and magnitude of the series voltage converter

U_{rk}, θ_{rk} - phase angles & Voltage magnitude of circuit converter

3.1. Optimal Power Flow Formulation

The goal is to establish the best generating levels by lowering the production expense while considering functional limitations. A quadratic component of a unit's electricity production is typically used to estimate its generation cost. For example:

$$C(Q_{Lx}) = aQ_{lx}^2 + bQ_{lx} + c \quad (5)$$

Where Q_{lx} is generation at bus-x

Therefore, the current issue could be represented as

$$\min_{Qx} \sum_{x=1}^{nl} C(Q_{lx})$$

Subjected to:

a) Power Balance Constraint:

$$\sum(Q_{lx}) = \sum Q_d + Q_G \quad (6)$$

Where Q_G the overall system is active energy less, and $\sum Q_d$ is total demand on the system.

b) Unit Operation Constraints:

$$Q_{Lx}^{min} < Q_{Lx} < Q_{LX}^{max} \quad (7)$$

Where Q_{Lx}^{min}, & Q_{LX}^{max} are the effective lower and maximum parameters of generation unit-x.

c) Line Flow Constraints:

$$GF_h < GF_h^{max} \quad (8)$$

Where GF_h is the MW line flow, GF_h^{max} is the allowable maximum flow of line h.

Figure 2 is used to propose the power injection model of voltage-controlled different loads for Equations (9) – (11).

$$Q_{rr} = -b_r h U_r U_s \sin(\delta + \sigma) - b_r s U_r U_s \sin(\delta + \sigma) \quad (9)$$

$$P_{rr} = -b_r U_r^2 (h^2 + s^2) - 2b_r h s U_r^2 cos(\sigma - \rho) - 2b_r k U_r^2 cos(\sigma) - 2b_r s U_r^2 cos(\rho) + b_r k U_r U_s cos(\delta + \sigma) + b_r s U_r U_s cos(\delta + \rho) \quad (10)$$

$$\bar{R}_{ss} = \bar{U}_s \bar{X}_{rs}^* = Q_{rs} + yP_{rs} \quad (11)$$

3.2. Genetic Algorithm

Biological evolution serves as the basis for the meta-heuristic search technique known as GA. It is based on the idea of natural selection and the potential descendants of the most suitable to survive. Issue parameters in GA could be thought of as genes, which encode binary characters. One of the potential answers to the issue would be a chromosome, which would be made up of a collection of genes. The GA has the following fundamental components: An initial population of chromosomes is first created randomly. The fitness function resulting from the objective function defines each chromosome's fitness. The mutation operator chooses from the population the fittest chromosomes. A new population was generated to employ the crossover and mutation procedures. The procedure would be continuously repeated.

The population improves with each repetition, and the search moves closer to the ideal solution. Until the termination requirement was satisfied, the iterative loop would be run. The number of genes on each chromosome, the quantity of UPFC, and the control parameters for each regulator correlates with the efficient placement problem. Figure 3 shows an example chromosome as the proposed solution architecture.

3.3. Proposed Methodology

Installation of UPFC in the electrical system can result in PF management, decreased system losses, and decreased generator fuel costs. In the existence of UPFC, the aforementioned expenses could be viewed as the ultimate purpose of OPF. The target function in this study is the elimination of all price components, generating price, UPFC delivery price, and transmits cost, taking into account LMPs.

OUPFC Location	σ	r	P	$\frac{V_r}{V_s}$	δ

Fig. 3 depicts the proposed issue's solution structure

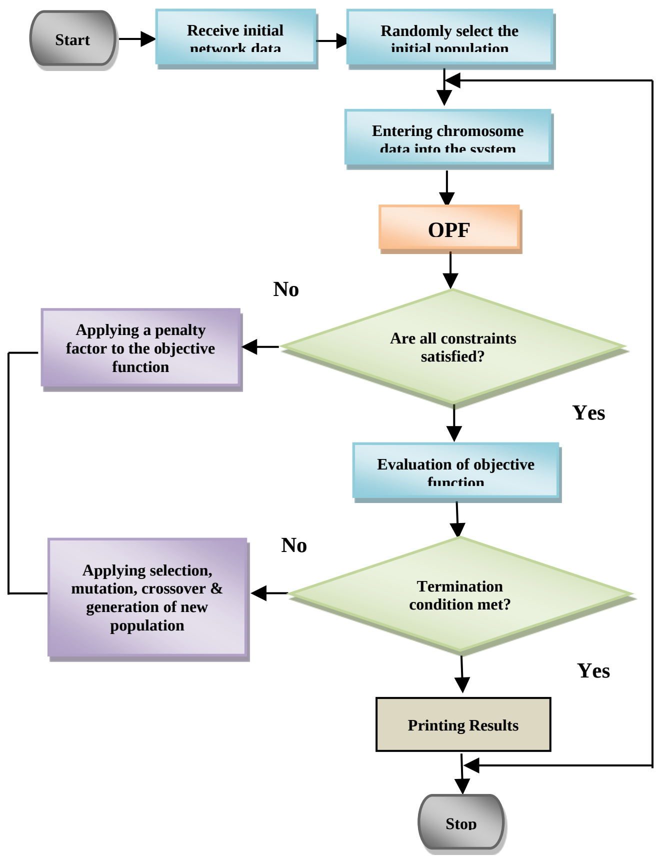

Fig. 4 Proposed Architecture

The following was a description of the production cost function, which describes to created energy while accounting for each unit's fuel price reduction:

$$C_{Gen} = \sum_{x=1}^{n} \alpha_0 + \alpha_1 Q_{Lx} + \alpha_2 Q_{Lx}^2 \quad (12)$$

The variation between the LMPs of the linked buses is commonly referred to as transmission cost. As a result of OPF, the transmission cost function also represents a decrease in transferring energy and is characterized as follows.

The cost function of the UPFC has been just as follows to determine the excellent place:

$$C_{Comp} = \frac{C_{OUPFC}}{8760\times5}(S/k) \quad (13)$$

3.4. Objective Function and Constraints

As long as the impartiality and inequality requirements are met, the objective is to minimize the overall price, which includes the costs of production, transmission, and compensating equipment:

$$min\ C_{Total} = \sum C_{Gen} + \sum C_{Trans} + \sum C_{Comp} \quad (14)$$

Algorithm

i. Select-control parameters for the variables x, y, and s, and give a particular reasonable benefit.
ii. compute ∀x,∀y,∀z
iii. Update x, y, λ, S
iv. Stop the iterative approach to real numbers of the right-side components to the initial optimality requirements' fall to a predetermined modest tuning parameter; however, proceed.
v. The new barrier parameter should be calculated.
vi. k=k+1; step 2 after increasing the index k by 1.

3.5. LMP Formulation

$$LMP = \lambda + \lambda \frac{\partial Q_G}{\partial Q_x} + \sum_{h=1}^{NG} \mu_h \frac{\partial Q_h}{\partial Q_x} \quad (15)$$

$$\lambda \frac{\partial Q_G}{\partial Q_x} = \lambda_{Gx} \quad (16)$$

$$\sum_{h=1}^{NG} \mu_h \frac{\partial Q_h}{\partial Q_x} = \lambda_{Cx} \quad (17)$$

$$\Rightarrow LMP(x) = \lambda + \lambda_{Gx} + \lambda_{Cx} \quad (18)$$

where is the same of vehicles and represents the residual power element at the reference bus, LI represents the residual less element, & CI represents the congested element.

4. Results and Discussion

Table 1. LMPD for a five-bus system

Line	LMPD (S/MWh)
1-2	-3.78
1-4	-0.88
2-3	0.2387
2-5	0.8314
2-5	0.617
4-5	-1.8

Table 2. IEEE 14 bus system LMPD

Line	LMPD (S/MWh)
1-2	-15.147
2-3	3.624
2-4	4.41
1-5	-8.8
2-5	5.4
3-4	0.8
4-5	0.99
5-6	-5.51
4-7	-1.18
7-8	0
4-9	-1.9
7-9	-0.7
9-10	-0.35
6-11	1.16
6-2	0.65
6-13	0.928
9-14	-0.203
10-11	1.3
12-13	0.29
13-14	1.59

The effectiveness of the recommended methodology implemented in MATLAB 7.8 version is tested on 5-bus and IEEE 14-bus devices to show the robustness of the recommended methods. The optimal design approach is used to determine an ideal value for the amount of generating. Separate line flows, and overall system losses are triggered by UPFC deployment in various routes. The price cost of production of a network with UPFC in multiple tracks is affected by constraints on generation units and line flow and produces a better outcome. Line 1-4, a good spot to put the UPFC price of production, was our target function since it has the minimum values, trailed by lines 3-5, 2-5, & lines 4-

5, in that proportion. Congestion rent & locational marginal price difference were computed and presented in Table 1. According to LMPD, lines 2-5 are excellent for the deployment of UPFC because it has the largest LMP differential and congestion rent, followed by lines 3-5, 1-4, and 4-5. The congestion charge is affected by the effective electricity price in the system under consideration since the congestion element of the LMP dominates when compared to the loss element of the LMP. Similar to IEEE 14 bus system, Table 2 shows that line 2-4 is favored for UPFC placement because that line has the maximum LMPD. However, lines 2-5 only save the minimum in congestion rent.

Table 3. Producer One Step Energy Quantity-Price Bids

Generation Number	Bus Number	Price (S/MWh)	Generation (MW)
1	1	5	112
2	2	10	92
3	3	25	32
4	5	15	72
5	7	20	52

Table 4. The Consumers' Demands

Load Number	Bus Number	Demand (MVA)
1	2	22.8+y13.8
2	3	94.3+y20
3	4	47.9-y4.9
4	5	7.7+y1.8
5	6	11.4+y7.6
6	7	0.0+y0.0
7	8	30.1+y16.8
8	9	6.2+y1.8
9	10	13.7+y5.9
10	11	15.2+j6

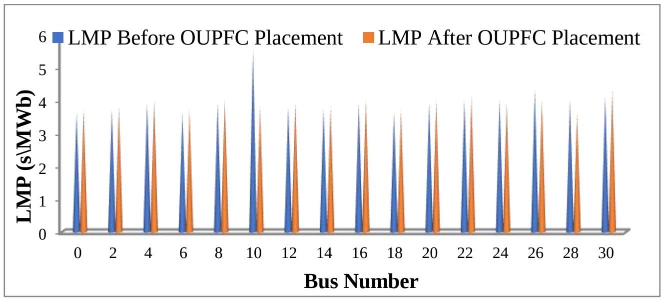

Fig. 5 Contrast between LMPs before and after UPFC implementation

4.1. Analysis

The following was considered of the typical IEEE 14-bus method with five producers, twelve loads, twenty lines, and transistors:

- A pool market system.
- There is only one industry for energy production; customers' needs must be met.
- Some claim that the electricity industry's pricing is used to regulate congestion.
- Producers' power quantity-price proposals are based on a single phase.
- Matpower 1.0, a different form of the electricity simulation model, is used. The mathematical model of UPFC has been added to Matpower to make it more suitable for the proposed study.

Tables 3 and 4, separately, present the power quantity-price bids from producers and the power requests of clients.

The following 3 examples on the IEEE 14-bus architecture had the findings of OPF investigated to demonstrate the effects of UPFC for congestion management:

Case 1: The lines-limits are disregarded, and UPFC is not being used.
Case 2: Lines restrictions have been taken into account by the UPFC.
Case 3: The network's line limitations have been taken into account, and the UPFC has been installed with its specifications modified.

The outcomes of the computerized simulation for the three aforementioned situations have been provided as part of the ongoing procedure.

Table 5 displays the LMP of buses. The overall network production was nearly fixed and identical in the three situations mentioned above since the whole network load has been considered constant. The congestion charge is calculated by the distinction between the revenues generated from network loads and the generation cost paid to generators.

4.2. Simulation Studies

Table 5 presents the data of the IEEE 14-bus test program's buses & lines, accordingly. Given the price of FACTS devices, the quantity of UPFCs evaluated in this study is set at 1. In addition, two N-1 eventualities in the line and generator of a specific system, along with the normal state, are taken into account. Figure 5 also shows a graphic assessment of the LMPs for these three operating circumstances before and after the implementation of the UPFC.

5. Conclusion

This research practiced a technique of locating UPFC for congestion control. The nonlinearities linked to the system could well be missed by the sensitivity-based approach often employed to pinpoint the location of UPFC. The Interior Point Method, which would be best suited for tackling nonlinear combinatorial optimization problems with multiple factors is used to get the lowest useful cost of production. It is clear from the results of the IEEE 14-bus and 5-bus training methods that the proposed technique performed better than the other approach described in the literature. LMPD and congestion rent are also calculated using the network restrictions assessed during improvement.

Table 5. The Voltage of the Buses and their Applicable Lagrange Multiplier

Case	LMP_1	LMP_2	LMP_3	LMP_4	LMP_5	LMP_6	LMP_7	LMP_8	LMP_9	LMP_{10}	LMP_{11}	LMP_{12}	LMP_{13}	LMP_{714}
1	14.52	14.89	16.03	15.54	15.26	15.02	15.69	15.70	15.76	15.75	15.45	15.28	15.44	15.97
2	5.000	21.45	25.01	20.06	18.24	18.35	20.02	20.02	19.98	19.88	19.18	18.73	18.97	19.99
3	14.50	16.03	15.88	15.55	15.24	15.02	15.68	15.68	15.75	15.74	15.44	15.28	15.44	15.96

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