Coordinated Control of FACTS Devices with Evolutionary Optimization Technique

Ragaleela Dalapatirao, Sivanagaraju Sirigiri

Abstract*: Complexity of present day power systems working is persistently expanding is a direct result of bigger power exchange over longer distances, more prominent association among interconnected networks, more confuses coordination and collaboration among different power system controllers and less power holds. To fulfill the expanding power need with existing transmission lines, the presentation of FACTS devices turns into an option. This paper discusses and compares different FACTS controllers such as TCPST, TSSC and Dynaflow Controller - a newly introduced member of FACTS family that includes a TCPST, a multi module TSSC with coordinated control. The purpose of this work is minimization of fuel cost and loss reduction with OPF utilizing PMBCA based hybrid evolutionary optimization method. The adequacy of the proposed methodology with FACTS controllers to meet the objective function was tested on IEEE 30-bus standard test system under MATLAB program.

***Index Terms*: FACTS controllers, TCPST, TSSC, Dynaflow controller, PMBCA .**

I. INTRODUCTION

Rising vitality costs and more awareness to natural effect of new transmission lines required new controllers to limit losses and expand the steady influence transmission limit of existing lines. FACTS technology launches up newly open doors for regulating power and upgrading usable limit of the current lines [1]. FACTS are a choice to relieve the issue of over-burden lines because of expanded transmission by governing power streams and voltages. To stay away from common impacts among a few devices put in a similar network, a coordinated control is essential. This is where the innovation of FACTS gives a huge chance [2-4]. The various surveys in the area of FACTS over the most recent couple of years demonstrate the developing interest and requirement for these devices. The spotlight in this paper lies on the Thyristor Controlled Phase-Shifting Transformer (TCPST) [5], Thyristor Switched Series Capacitor (TSSC) and Dynaflow Controller. Coordination is expected to decide the factors to such an extent that hindering activities are counteracted. Also, measures in different parts of the grid must be considered with the end goal that it is stayed away from that removed lines become over-burden or that voltages at different buses are headed to inadmissible values. Both can be accomplished by an Optima Power Flow (OPF) [6] with multiple objectives which decide the optimal steady-state settings of the FACTS devices. The resulting objective function incorporates a few parts, for example, limiting active power losses & fuel cost, dodging over-burden lines and maintaining bus voltages inside a satisfactory range and near their reference esteems. The objective of this work is to compare the considered FATCS such as TCPST, TSSC and Dynaflow Controller to achieve coordinated control with PMBCA evolutionary optimization method [7] to meet the objective functions using IEEE 30-bus standard test system under MATLAB platform.

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II. ANALYSIS OF FACTS CONTROLLERS

Apart from several FACTS controllers TCPST, TSSC and Dynaflow Controller are considered in this study. The detailed models of these devices are discussed below

A. TCPST

The schematic diagram is presented in Fig. 1. In TCPST the parallel associated transformer carry energy from the system and gives it to the series associated transformer so as to present a voltage V_T at the series branch. The motivation behind the TCPST is to regulate the power stream by changing the transmission angle. Contrasted with regular PST's, the mechanical tap changer is supplanted by a thyristor controlled identical [8].

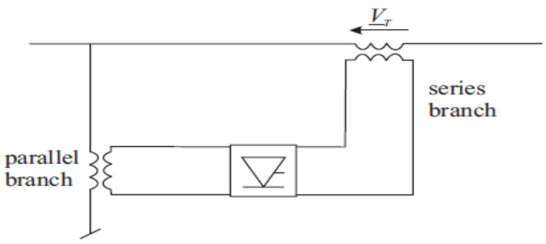

Figure 1 Simplified layout of a TCPST

B. TSSC

The working of TSSC is to control the level of series compensation in a stage like way by expanding or diminishing the quantity of arrangement capacitors embedded [9]. A capacitor is embedded by turning off, and it is avoided by turning on the comparing thyristor valve as shown in Fig. 2. In this work transmission line reactance is adjusted by TSSC directly shown in Equation (1).

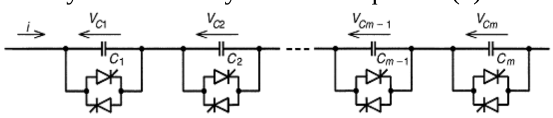

Figure 2 Structure of TSSC

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$$X_{ij} = X_{line} + X_{TSSC} = C_{TSSC} * X_{line} \quad (1)$$

Where

X_{ij}: Transmission line reactance

C_{TSSC}: Represents the compensation level of TSSC.

Series capacitive compensation was acquainted decades prior with drop a bit of the reactive line impedance and accordingly increment the transmittable power. In this manner, inside the FACTS activity, it has been exhibited that variable series compensation is very compelling in both regulating power flow in the line and limiting the losses and fuel cost.

C. Dynaflow Controller

The connection of a TCPST and a TSSC is known as Dynaflow Controller [10]. It comprises of a multi-step TSSC in series with a TCPST with coordinated control. The Dynaflow Controller, drawn in Fig. 3, is a combination of TCPST and a TSSC/TSSR, which arranges a set of thyristor controlled reactance steps associated in series with the line. A Mechanically switched Shunt Capacitor (MSC) is discretionary in Dynaflow Controller setup, contingent upon the framework reactive power necessities. By neglecting MSC, a Dynaflow Controller has been considered in this paper.

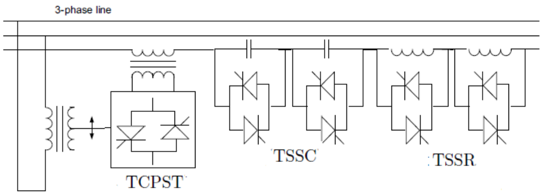

Figure 3. General representation of Dynaflow Controller

By combining the capability of TSSC and TCPST, power flow is controlled in the path in which the Dynaflow Controller is installed or in parallel paths to keep away from overload. This would typically imply that the overload is evenly distributed between the parallel paths [11]. When Dynaflow controller is placed in the transmission line between bus m and n, the load flow Equations (2) – (5) are as follows:

$$P_m = P_{mn} + \sum |V_m||V_x||Y_{mx}|\cos(\delta_m - \delta_x - \theta_{mx}) \quad (2)$$

$$Q_m = Q_{mn} + \sum |V_m||V_x||Y_{mx}|\sin(\delta_m - \delta_x - \theta_{mx}) \quad (3)$$

$$P_n = P_{nm} + \sum |V_n||V_x||Y_{nx}|\cos(\delta_n - \delta_x - \theta_{nx}) \quad (4)$$

$$Q_n = Q_{nm} + \sum |V_n||V_x||Y_{nx}|\sin(\delta_n - \delta_x - \theta_{nx}) \quad (5)$$

Equations (6) to (8) represent P_{mn}, Q_{mn} & P_{nm}, Q_{nm} expressions

$$P_{mn} = (G_{PS} + G_{TS})|V_m|^2 - |V_m| \cdot |E_{PS}| \cdot |Y_{PS}|\cos(\delta_m - \delta_{PS} - \theta_{PS}) + |V_m| \cdot |E_{TS}| \cdot |Y_{TS}|\cos(\delta_m - \delta_{TS} - \theta_{TS}) - |V_m| \cdot |V_n| \cdot |Y_{TS}|\cos(\delta_m - \delta_n - \theta_{TS}) \quad (6)$$

$$Q_{mn} = (B_{PS} + B_{TS})|V_m|^2 - |V_m| \cdot |E_{PS}| \cdot |Y_{PS}|\sin(\delta_m - \delta_{PS} - \theta_{PS}) + |V_m| \cdot |E_{TS}| \cdot |Y_{ST}|\sin(\delta_m - \delta_{TS} - \theta_{TS}) - |V_m| \cdot |V_n| \cdot |Y_{ST}|\sin(\delta_m - \delta_n - \theta_{TS}) \quad (7)$$

$$P_{nm} = (G_{PS} + G_{TS})|V_n|^2 - |V_n||E_{PS}||V_{PS}|\cos(\delta_n - \delta_{PS} - \theta_{PS}) - |V_n||E_{TS}||Y_{TS}|\cos(\delta_n - \delta_{TS} - \theta_{TS}) - |V_n||V_m||Y_{TS}|\cos(\delta_n - \delta_m - \theta_{TS}) \quad (8)$$

$$Q_{nm} = (B_{PS} + B_{TS})|V_n|^2 - |V_n| \cdot |E_{PS}| \cdot |Y_{PS}|\sin(\delta_n - \delta_{PS} - \theta_{PS}) + |V_n| \cdot |E_{TS}| \cdot |Y_{TS}|\sin(\delta_n - \delta_{TS} - \theta_{TS}) - |V_n| \cdot |V_m| \cdot |Y_{TS}|\sin(\delta_n - \delta_m - \theta_{TS}) \quad (9)$$

The two voltage sources E_{PS} and E_{TS} gives four new variables ($|E_{PS}|$, δ_{PS}, $|E_{TS}|$, δ_{TS}) to the load flow problem. The ideal transformers of the TCPST in Dynaflow don't transfer any power with the network. Hence it tends to be composed [12] as shown in Equation (10):

$$P_{TCPST} = \text{real}\ [V_P.I_{mn}^*]\text{-real}\ [V_E.I_E^*] = 0 \quad (10)$$

III. PROPOSED OPF METHODOLOGY

In this work a novel hybrid optimization approach Particle Movement Bee Colony Algorithm (PMBCA) subject to Honey Bee Colony (HBC) [13] and Particle Swarm Optimization (PSO) is considered. The PSO system gives a plebs based investigation procedure in which individuals called particles change their circumstances with time [14]. A Honey bee colony is likewise a populace based Meta heuristic method, spurred by the creative search conduct of honey bee swarms [15-16]. In [17] the colony of honey bees comprises of recruited honey bee, observer honey bee and random honey bee. PSO has poor investigation capacity anyway better abuse limit, though HBC has better investigation and poor misuse [18]. The weaknesses of the two algorithms can be defeated in PMBCA. Fig. 4 shows the simple flowchart of PMBCA method. The 3 plays in PMBCA are introduction, cycles organize and the last play [19].

IV. OBJECTIVE FUNCTION

The principle objective of the OPF is to optimize the specified objective function is identified as below [20-21]:

$$Min \qquad f_1 = F(P_g) = \sum_{i=1}^{ng} (a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad (11)$$

Equation (11) is the total generation fuel cost function

Where,

P_{gi} : Generation of active power of i^{th} bus

ng : number of generator buses

a_i, b_i, c_i: fuel cost coefficients of i^{th} unit

FACTS device constraint:

$V_{CR}^{\min} \le V_{CR} \le V_{CR}^{\max}$ Dynaflow voltage magnitude

$\theta_{CR}^{\min} \le \theta_{CR} \le \theta_{CR}^{\max}$ Dynaflow voltage angle

Where,

$V_{CR}^{\min}, V_{CR}^{\max} and \theta_{CR}^{\min}, \theta_{CR}^{\max}$ are the voltage magnitude and phase angle shift of Dynaflow controller

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$\phi_{\min} < \phi < \phi_{\max}$ TCPST value of phase angle

$X_{TSSC}^{\min} < X_{TSSC} < X_{TSSC}^{\max}$ TSSC reactance

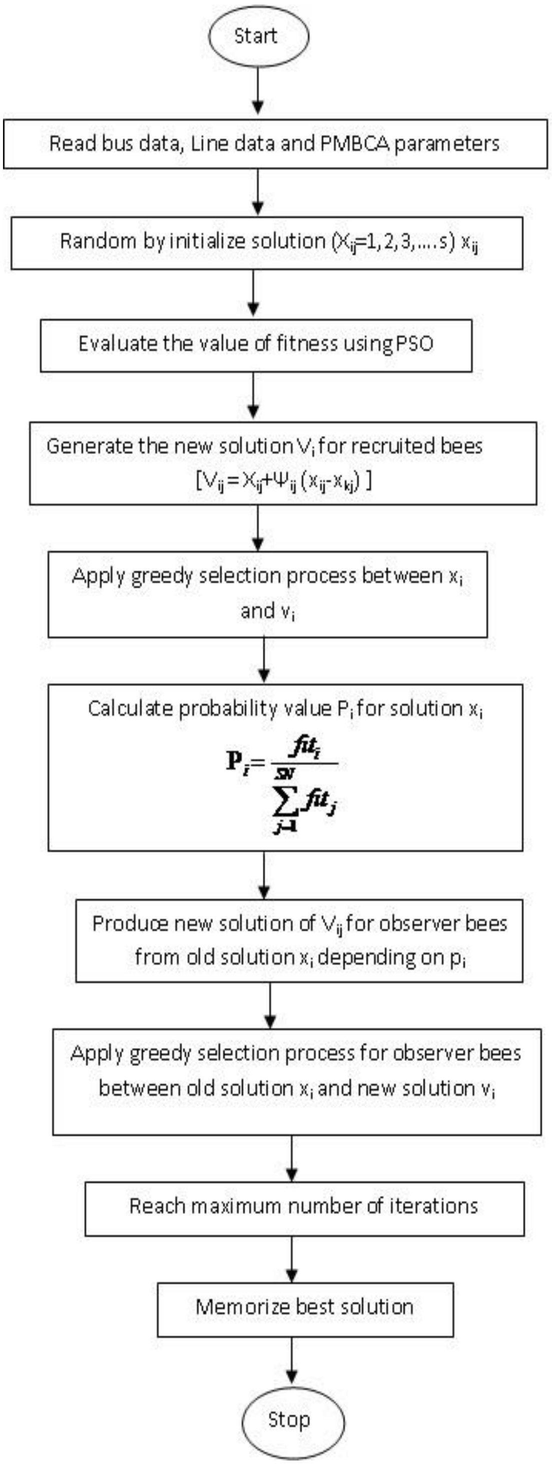

Figure 4. Flowchart of PMBCA approach

V. IMPLIMENTATION OF FACTS WITH OPF

Intake: Line data, Bus data and PMBCA parameters

1. Load the power flow analysis for system data.
2. Select the locale of FACTS Controller in the system
3. Set the PMBCA simulation parameters at the particle P=0; and initialize randomly r particles within respective limits and store them in the annals
4. Run load flow to evaluate load bus voltages, angles, load bus voltage stability indices, generator reactive power outputs and line power flows
5. Compute the penalty functions
6. Compute the value of competence by employing PSO
7. Iteration = 1
8. Construct recent result V_i for employed bees by employing $V_{ij} = X_{ij} + \psi_{ij}(x_{ij} - x_{kj})$
9. Employ the narcissistic determination process among x_i and V_i
10. Estimate the possibility value p_i for solving the x_i utilizing the mathematical statement $X_i^t + \psi * (X_i^t - p^{perfect^t}{}_j)$
11. Produce recent result of V_{ij} for observer honey bees from earlier result x_i relying upon p_i
12. Employ the narcissistic determination process for onlooker bees among earlier result x_i and recent result v_i
13. Recollect the finest result found up until this point
14. Iteration = Iter + 1
15. Repeat the steps from 5 to 15, if one of ending has not met. Else go to next step.
16. Generate results

VI. SIMULATION RESULTS

This section displays the particulars of the investigation of FACTS devices with proposed PMBCA OPF algorithm so as to minimize generator fuel cost and real power loss. Simulation studies are tested on IEEE 30-bus power system [22] using MATLAB. . In appendix Table 2 provides the details of the test systems and the parameters utilized for the simulation of proposed algorithm.

In this work FACTS controllers are placed between bus 9 and 10. Every device is put in optima location acquired from the writing and experimentation technique. Parameter settings of these devices are as follows:

- Active and Reactive power settings of TCPST, P_{mn} = 0.10, Q_{mn} = 0.01 and
- X_{TSSC} value of -0.0007 and 0 ≤ X_{TSSC} ≤ 60% of line reactance.
- Line real and reactive power settings of Dynaflow Controller is P_{mn}= 0.3p.u. and Q_{mn} = 0.01p.u.

The specifications utilized for the simulation of recommended algorithm was utilized from [7]. The optimum settings of control factors and FACTS device specifications during the minimization of objective functions are outlined in Table 1 under base case. From the Table it is noticed that PMBCA algorithm can reduce fuel cost and real power loss while maintaining all control variables within their limits.

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TABLE 1 BASE CASE WITH OPF BASED FACTS DEVICES PLACED IN LINE 9-10

Control Variables (p.u.)		PMBCA with TCPST	PMBCA with TSSC	PMBCA with Dynaflow
Real power generation	P_{G1}	1.7599	1.7460	1.7398
	P_{G2}	0.4880	0.4839	0.4859
	P_{G3}	0.2088	0.2205	0.2249
	P_{G4}	0.1222	0.1265	0.1250
	P_{G5}	0.2136	0.2141	0.2145
	P_{G6}	0.1200	0.1200	0.1200
Generator voltages	V_{G1}	1.0500	1.0500	1.0500
	V_{G2}	1.0408	1.0387	1.0391
	V_{G3}	1.0227	1.0261	1.0249
	V_{G4}	0.9500	0.9515	0.9500
	V_{G5}	1.0164	1.0150	1.0176
	V_{G6}	1.1000	1.1000	1.1000
Transformer tap	Tap-1	1.1000	1.1000	1.1000
	Tap-2	0.9000	0.9002	0.9001
	Tap-3	0.9599	0.9123	0.9662
	Tap-4	0.9522	0.9253	0.9266
Shunt compensation	Q_{Sh1}	0.1000	0.0908	0.1000
	Q_{Sh2}	0.0720	0.0635	0.0501
	Q_{Sh3}	0.0623	0.0904	0.0656
	Q_{Sh4}	0.0837	0.1000	0.1000
	Q_{Sh5}	0.0699	0.0835	0.0915
	Q_{Sh6}	0.1000	0.1000	0.1000
	Q_{Sh7}	0.0645	0.0908	0.0815
	Q_{Sh8}	0.0739	0.0595	0.0853
	Q_{Sh9}	0.0378	0.0583	0.0383
Cost($/h)		796.5711	796.4912	**796.2931**
Ploss(p.u.)		0.0785	0.0770	**0.0760**

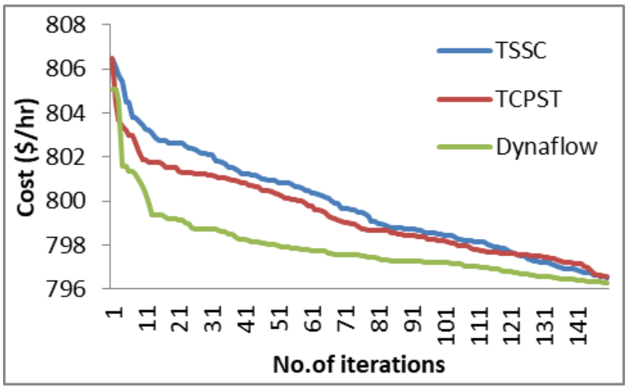

Figure 5. Cost Convergence characteristics

The results revels that the proposed PMBCA methodology incorporating FACTS devices is cable of minimizing fuel cost and loss reduction. From the Table 1 it tends to be seen that **bold values** of various objectives indicate the importance of the PMBCA technique with a Dynaflow controller can lessen the generation cost and real power loss contrasted with alternate FACTS controllers. Also figure 5 presents the generation cost convergence characteristics of the suggested optimization technique with various FACTS controllers.

VII. CONCLUSION

FACTS devices are an amazing asset to diminish power loss and generator fuel cost of the system. Be that as it may, an uncoordinated use of such devices may bring about clashing circumstances which can imperil secure activity of the transmission network. In this manner, an coordinated control based on optima power flow has been developed i.e. Dynaflow with PMBCA in this paper.

In this work various FACTS controller was incorporated into optimal power flow solutions to meet the various objective functions in power systems. The PMBCA based hybrid optimization method is utilized for taking care of the OPF issue for steady-going studies. The usefulness of the suggested methodology was tried on IEEE 30-bus. Outcome determines that the recommended algorithm with dynaflow controller gives improved results for minimizing real power losses and generation fuel cost with coordinated control as contrasted with TSSC and TCPST.

APPENDIX

TABLE 2 ILLUSTRATION OF TEST SYSTEM

Criterion	IEEE 30-bus	Optimal Parameter Setting For PMBCA	IEEE 30-bus
Number of buses	30	Population size	30
Number of gen.	6	Number of iterations	150
Number of transf.	4	Cognitive constant, c1	2
Number of shunts	2	Social constant, c2	2
Number of branches	41	Inertia weight *W*	0.3 - 0.95
		Limit of trials	100

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