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PREDICTIVE CROSS DIFFERENCE PROGRESSION OPTIMIZATION METHOD BASED SAFETY CONSTRAINED OPTIMUM POWER FLOW WITH FACTS CONTROLLERS

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ABSTRACT

The successful implementation of Flexible Alternating Current Transmission System (FACTS) devices has resulted in a new control mechanism for power systems' safe and efficient functioning. A preventative security-constrained power flow optimization approach incorporating Voltage Adjusting Rheostat (VAR) control modes is proposed in this work to make full use and increase the economic efficiency and static security of a power system. A Predictive Cross Difference Progression Optimization (PCDPO) approach with VAR control is first introduced for power flow computation. The contributions of the static VAR compensator (SVC), Thyristor-Controlled Series Compensator (TCSC), and Thyristor-Controlled switching reactor (TCSR) in this coordinate control are compared, and the case the situation where no FACTS devices are inactivity are illustrated**.** The optimization model is then built by selecting a minimum system operation cost and a maximum static security margin as the goal while accounting for the impact of three different VAR management strategies on power flow distribution after an N-1 contingency. The Predictive Cross Difference Progression Optimization (PCDPO) algorithm, which is based on this model, is used to optimize the power system operating parameters and VAR control technique simultaneously. Finally, the proposed method is shown using a standard IEEE 30-bus system, demonstrating that it fully uses the capability of static VAR control and significantly enhances the power system's economic efficiency and static security. The proposed model was designed and implemented in the matalb2017a program to examine power flow optimization.

KEYWORDS: optimal power flow, static VAR compensator, Predictive Cross Difference Progression optimization, power system, matlab2017a.

1. INTRODUCTION

To allow rising electric power demand and exchanges, transmission lines in congested areas are routinely built near or even beyond their points of confinement. As a result of

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the increased risks associated with fault lines, secure operation and reliable supply are exposed. The installation of new electrical wires is frequently hard due to natural, sparse, and other factors. FACTS' invention provides a considerable advantage in this area. The increasing interest and demand for FACTS devices have resulted in a slew of new products in the sector in recent years. All points are the best position, the evaluation of FACTS in the changing power market, the development of a new device, and the control approach.

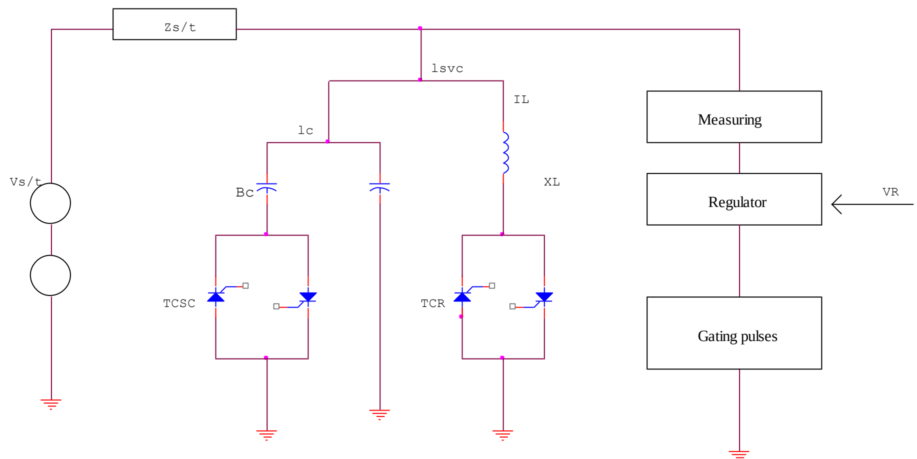

Figure: 1 Hybrid energy compensators

Figure 1 depicts a hybrid energy compensator. FACTS devices can impact power flows and voltages to varying degrees depending on the type of invention. This study focuses on the Static VAR Compensator (SVC), Thyristor-Controlled Series Compensator (TCSC), and Thyristor-Controlled Switched Reactor (TCSR) (TCSR). The devices are often classified into three groups: series, shunt, and both. The SVC is coupled with the shunt-related device and has been used in various locations for a long time. In theory, this variable shunt reactance infuses or absorbs responsive power to control the voltage at a specified conveyance.

To regulate a line's dynamic power, the TCSC modulates the line reactance. This type of element is used in a few places, but it is still in the early stages of development. The fundamental concepts of a TCSR are the same as in a traditional system. A stage move can adjust the transmission point by fusing a voltage in quadrature to the essential transport voltage. Instead of the Predictive Cross Difference Progression Optimization, a Thyristor-controlled version replaces the mechanical tap changer, allowing faster control.

Appropriate models must be employed to capture the impacts of FACTS devices on control streams and voltages to study the effects of FACTS devices in a consistent state. Several models for SVC, TCSC, and TCPST have been proposed and linked in various studies. FACTS devices have far-reaching consequences that aren't restricted

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to a specific form of transportation or line. The power flow in the surrounding lattice changes when the voltage at a certain point or the power stream is modified. Common effects may occur if one FACTS device is placed near another, thereby undermining the benefits of individual devices. To define the components that will be employed to minimize undesired behaviors, coordination is essential.

Moreover, measures in different parts of the network must be considered to such an extent that it is stayed away from that removed lines end up over-burden or that voltages at different transports are headed to unsatisfactory qualities. Both can be accomplished by a Predictive Cross Difference Progression Optimization controller because of Optimal Power Flow (OPF). The coming about target work incorporates a few parts, for example, limiting dynamic power misfortunes, staying away from over-burden lines and keeping transfer voltages inside a satisfactory range and near their reference esteems. A particular kind of FACTS gadget can impact a specific parameter in the matrix, which is identified with a specific piece of the goal work. For example, the SVC infuses or assimilates receptive power, which is firmly coupled to the voltage. TCSC and TCPST then again control dynamic power flow. The following objectives are motivated into this work to enhance the power quality

Objectives:

- The major goal of this study is to devise a new technique for improving voltage profile, increasing voltage stability, and reducing network loss using facts devices.
- To identify precise locations, predict the appropriate FACTS device and determine optimal parameters to ensure enhanced system performance through a suitable optimization technique
- To Increase the loading capacity of transmission lines. To improve generation productivity and controlling the transmission voltage.
- Optimal Location and Sizing of FACTS devices with the aid of Predictive Cross Difference Progression optimization (PCDPO) method

2. LITERATURE SURVEY

This section discusses the literature survey based on power quality improvement using different FACTS and optimization methods.

The work develops a multi-objective optimization methodology for finding the optimal position of flexible ac transmission systems (FACTS) shunt-series controllers and appropriate models of FACTS shunt-series controllers for multi-objective optimization. The objective functions are the total fuel cost, power losses, and system load capabilities with and without the minimum cost of FACTS installation [1]. The advanced gadget is employed in various areas, including the transmission line's sending end,

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middle, and receiving end. The controller circuit's firing pulses are generated using the PWM control technique [2]. Power flow in critical power lines with the lowest feasible losses and transfer capacity. The optimization method can be utilized to control line flows for optimal power transmission, particularly on busy lines and at the point of joining renewable energy resources [3]-[4]. Adding partial decomposed active power demand as a new variable and searching inside the active power generation variables of the new decomposed chromosome is part of the OPF problem strategy [5].

The High-Frequency AC-based Microgrid [6] is a potential first step toward incorporating renewable energy sources into a distributed generation system. Due to a dual correction mechanism, the series converter acts as a sinusoidal current source, while the parallel converter acts as a sinusoidal voltage source. A seamless shift from networked to islanding operation modes, and vice versa, can be achieved without load voltage transients [7]-[10].

The usage of Optimal Power Flow Control, in which the set qualities are resolved to the point where a goal work is limited given the framework model, is a good option. Be that as it may, because of the extensive size of the intensity system, usually troublesome for various motivations to incorporate the whole framework into the optimization procedure [11]. Presents a flexible approach based on practical reasoning rules from fuzzy logic theory for governing a group of Static Compensator (STATCOM) by modifying the reactive power injected or absorbed from the network[12]-[15]. The construction can reduce input current ripple while also balancing the switch's current stress. In addition, the bus voltage was lowered. The CLCL resonant circuit has a gentle switching characteristic, and the main and secondary sides operate in zero voltage and zero current modes [16]-[17].

At the same time, a stable output voltage and a quasi-constant bus voltage can be achieved. Furthermore, by increasing bus voltage ripple and employing the Twin-Bus architecture, short-lifetime electrolytic capacitors can be avoided, and overall LED driver efficiency can be significantly improved [18]-[19]. High-frequency circuiting currents can be reduced in their impact on the fundamental components of split-filter inductor currents. In parallel-operated inverters with unipolar PWM, high-frequency circulating currents are also present, but their effects on the critical elements of split-filter inductor currents cannot be eliminated [20].

The transmission system has some drawbacks from the above analysis, like voltage instability, Reactive power loss, and transmission loss. The proposed technique, Predictive Cross Difference Progression optimization (PCDPO), produces the efficient output that can be determined in the result, the operation and control modules are described below work.

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3. MATERIALS AND METHOD

The optimal power flow (OPF) problem by reducing the actual power cost. The Predictive Cross Difference Progression optimization (PCDPO) is seen as the most efficient way to solve single-transform optimum power flow problems. PCDPO performance has been tested on IEEE 30 bus systems as a function of the test object, thereby reducing the actual cost of electricity. Static VAR compensator (SVC), Thyristor-Controlled Series Compensator (TCSC), and Thyristor-Controlled Phase-Shifting Transformer(TCPST) are the best shunt connected devices in the FACTS family. Bus voltage can be controlled by injecting reactive power into the system. FACTS need equipment that can take on an essential job for side management and, in this way, control the transmission line congestion. The control stability of the bus model is shown in **Figure 2.**

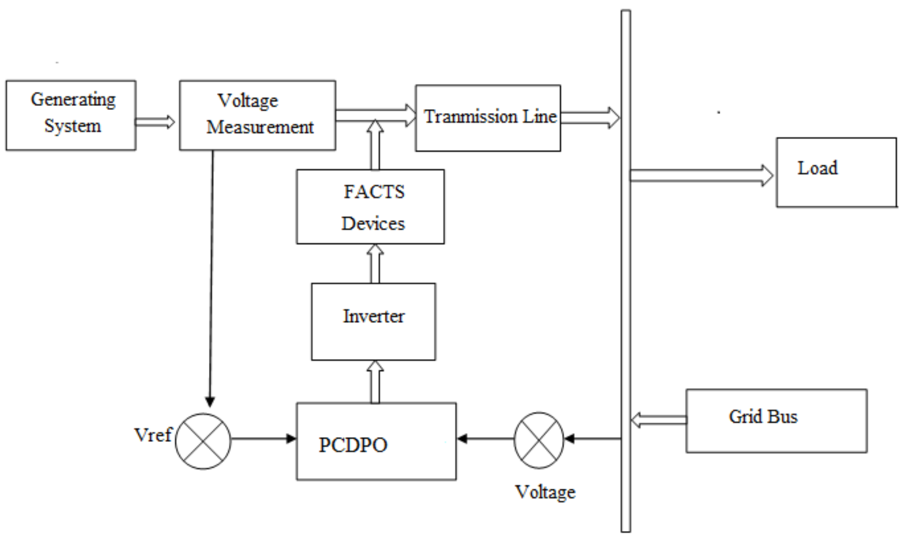

Figure: 2 Block diagram of the co-ordinate inverter control in the transmission line

3.1 Power transmission line:

High power transmission is a long conductor power transmission line with an extraordinary outline (bundles) to transmit mass measurement of output control to another station according to different voltage conditions. The most important factor is by varying the network's parameters and transmitting the reactive power, using high gain controllers to control the transmission path. The operation of the transport structure is controlled by different frequency estimation recurrence FACTS controllers from the lowest to manage, and controls interconnect parameters. It includes placed load current, phase margin, impedance, and shunt resistance where the ability to move is exposed. These imperatives cannot be defeated in general, but at the same time, the

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stability of the required structure, without limiting the transmission limit, can be used by mechanical means.

3.2 Voltage measurement in IEEE 30 BUS system

The Voltage measurement determines the difference in the electrostatic energy between the two points. The voltage unit is referred to as the units in volts (SI) and is defined as both ends between the source and IEEE 30 BUS system.

3.3 Models of FACTS Devices

The primary objective is to respond quickly to the current minor behavioral changes in controlled FACTS equipment replaced by electronically controlled mechanical boundary conditions. These devices can progressively control line impedance, line voltage, dynamic power Flow, and responsive power. When capacity turns out to be monetarily reasonable, they can also supply and retain active power, which should be possible rapidly. The usage of FACTS gadgets requires innovation for improving the optimal power flow in IEEE 30 bus system.

3.3.1 Static VAR Compensator (SVC)

A Static VAR Compensator (SVC) with a variable inductor controlled by a set capacitor and firing angle is used as a shunt compensation device. The SVC's function is changed by changing the firing angle of the Thyristors, which changes the impeller's responsiveness to the voltage control. The SVC shunt behaves similarly to the variable impact during operation. The typical impact model is used for the steady-state function. The current/sensitivity and reactive power characteristics and the control voltage can be modified in the active control SVC characteristics. The SVC connection on any bus is a possible problem with the OPF, and the reactive power provided by the SVC is modeled as:

$$Q_{SVC} = -V_i^2 * U_{SVC}, -U_{SVC}^{min} \leq U_{SVC} \leq U_{SVC}^{max} \ldots (1)$$

Where,

Q_{svc} = The reactive power injected at busi

U_{SVC} = effective susceptance of the SVC

U_{SVC}^{min} = minimum value of the effective susceptance

U_{SVC}^{max} = max value of the effective susceptance of SVC

V_i^2 = bus voltage

This assumption may be valid as long as the SVC operates within their required compensation range, although mistakes can be triggered if the SVC works near its responsive cut points. SVC can have two models: inductive and capacitive to

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individually retain or accept power. The SVC is the shunt connected power flow optimizer in the grid system. The SVC equivalent circuits appear in **Figure 3** based on the calculation of the grid flow system. The SVC produces the reactive power and compensates the voltage fluctuations in bus system. It is infiltrated or retained at the voltage. It takes the correct values which are the function of the power system considered.

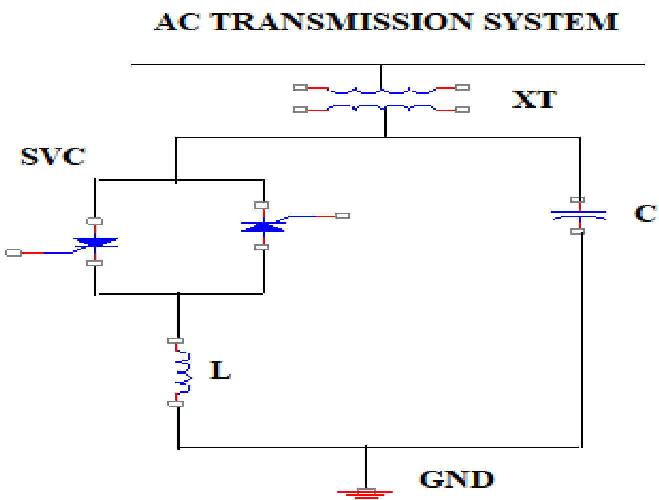

Figure: 3 SVC equivalent circuits.

3.3.2 Thyristor Controlled Series Compensator (TCSC):

A thyristor-controlled series capacitor (TCSC) is a capacitive reactor with a capacitor bank in series that delivers a sequence of capacitive reactions that may be switched on by a thyristor. The Thyristor-Controlled Series Compensator (TCSC) is a device that reduces steady-state in a bus system that is connected in series. The TCSC influence on the network can be seen, allowing it to be introduced into each transmission line that can be adjusted and managed. This TCSC may have several inherent characteristics, the capacitance (XC), induction (XL) are connected in transmission system. A simple transmission line represented between the i and j buses with the distance measurement of π.The iB_{sh} is the before capacitance value and jB_{sh} is the after capacitance added the grid power system. A transmission line model with TCSC connected between Bus-i and Bus-j is shown in Figure 4.

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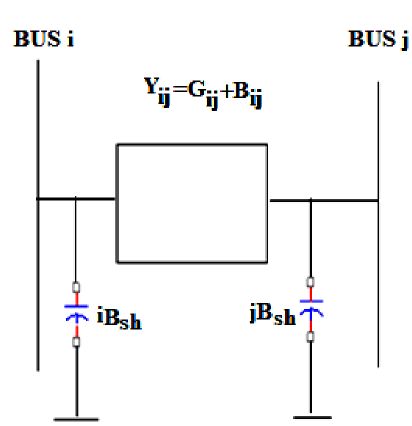

Figure 4(a) Model of Transmission Line

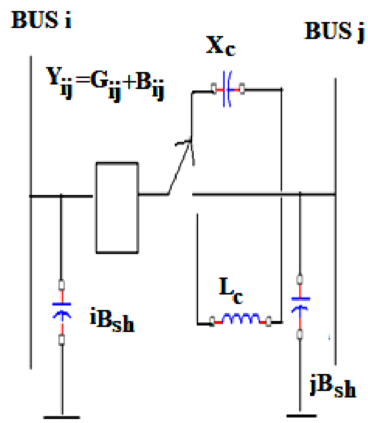

Figure 4(b) Model of TCSC

A Thyristor-controlled reactor (TCR) is a set of co-ordinates used to connect thyristors in series with an inductor. In TCSC, is coupled in parallel to a reference capacitor bypass breaker for high voltage protection. A complete compensation system can be developed by a number of modules.

3.3.3 Thyristor-Controlled Phase-Shifting Transformer (TCPST):

Thyristor-Controlled Phase-Shifting Transformer (TCPST) is a series-linked transformer that is coupled to the bilateral thyristor circuit in Figure 5. A given value of the thyristor valve phase reactive power is controlled, allowing it to be adjusted according to different system conditions. Thyristor controlled transformer can be used to control the voltage rise in optical transmission lines. The current in the TCPST varies almost to zero (determined by the coupling voltage and the induction of the reactor), which differs from the firing delay angle of the closed-loop control sequences in **Figure 5 (b).**

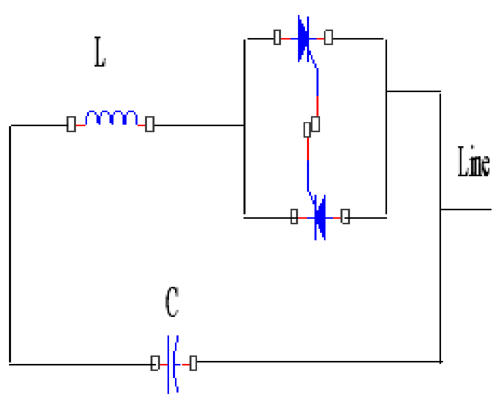

Figure: 5 (a) Single Line of transmission system

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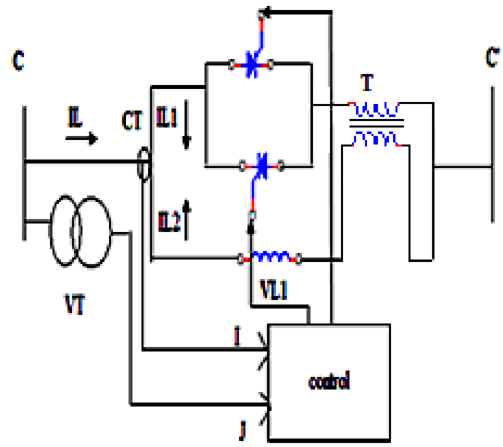

Figure: 5 (b) Closed-Loop Model for TCPST

$$\mathrm{I\ TCPST - max} = \frac{V_{svc}}{2\pi fL}\mathrm{TCPST} \ldots (2)$$

Where,

V_{svc} = RMS value of line to line bus bar voltage.

TCPST = a total voltage variation in bus system.

$2\pi fL$ = firing value of the inductance

TCPST = current flow through the thyristor

3.4 Mathematical Formulation of Multi-Objective Optimal Power Flow Problem

The operation's purpose is to find the optimal FACTS device size by reducing total active power generation while balancing equality and inequality.

Objective function

The objective function is made to reduce by substituting the optimal active power cost.

$$F = \min\left(\sum_{i=1}^{ng} R_i P_{Gi}^2 + Y P_{Gi} + B_i\right) \ldots (3)$$

Where,

F=objective Function

R, Y, B = Cost coefficients of a generator bus

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P_{Gi} = active power generation at bus i

ng = Number of Generator buses

a, b, and c = production cost coefficients of the SVC's based reactive power, which is included as a control variable, and the SVC limitations are given as follows:

$U_{SVC}^{min} \leq U_{SVC} \leq U_{SVC}^{max}$ ... (4)

Where,

U_{SVC} effective susceptance of the SVC

U_{SVC}^{min} the minimum value of the effective susceptance

U_{SVC}^{max} max value of the effective susceptance of SVC

Equality constraints

The following mathematical equations are discuss the function of equivalent with real and reactive power.

$\sum_{i=1}^{N} P_{Gi} = \sum_{i=1}^{N} P_{Di} + P_L$ ... (5)

$\sum_{i=1}^{N} Q_{Gi} = \sum_{i=1}^{N} Q_{Di} + Q_L$ ... (6)

Where i=1, 2, 3..... N and N = no. Of. Buses

P_{Gi} = bus i's active power generation

P_{Di}= bus i's active power demand

Q_{Gi} = bus i's reactive power generation

Q_{Di}= bus i's reactive power demand

P_L = active power losses

Q_L = reactive power losses

N = number of buses

Inequality constraints:

Generator Range Controls: The lower and maximum operational limitations of each generator represent the actual and reactive power of each generator, as shown below.

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Voltage limits:

$$V_i^{min} \leq V_i \leq V_i^{max} \ldots (7)$$

Where i=1, 2, 3... N and N = no.of.buses

V_i = Bus voltage

V_i^{min} = limit of low voltage at bus i

V_i^{min} = limit of high voltage at bus i

The Real Power generation limit:

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \ldots (8)$$

Where;

P_{Gi} = active power generation at bus i

P_{Gi}^{min} = minimum value active power generation at bus i

P_{Gi}^{max}= maximum value active power generation at bus i

Reactive power limits:

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \ldots (9)$$

Where;

Q_{Gi} = Reactive power generation at bus i

Q_{Gi}^{min}= minimum value Reactive power generation at bus i

Q_{Gi}^{max}= maximum value Reactive power generation at bus i

Minimization of power loss

The purpose is to reduce power loss (loss B) in the transmission line, as shown in the equation below.

$$J_1 = P_{loss} = \sum_{K=1}^{N_i} g_k [(t_k V_i)^2 + V_j^2 - 2 t_k V_i V_j \cos \delta_{ij}] \ldots (10)$$

Where,

$P_{loss=}$ power loss

g_k = conductance of branch k between buses i and j;

t_k = tap ration of transformer k;

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V_i = voltage magnitude at bus i;

V ij δ= voltage angle difference between buses i and j.

Security Indices

The power structure that provides energy has the potential to offer clients with the greatest quality power on a continual basis. When driving the power structure, it is vital to maintain the required amount of safety margin. In this work, the safety record margin is classified as follows.

Voltage Security Index (VSI)

The voltage Security Index depicts the level of power grid traffic safety.

$VSI = (\sum_{K-1}^{N} \mid V_K - V_K^{ref} \mid^2)$... (11)

Where,

V_k = voltage magnitude at bus k

V_k^{ref}= reference voltage magnitude at the bus k ref k V

Line Security Index (LSI)

The Line Security Index is the security level of the transmission line's security code. This can be stated in the following manner:

$LSI = \left(\sum_{k=1}^{nts} \left(\frac{S_K}{S_K^{max}}\right)^2\right)$... (12)

Where

S_K = apparent power on the k line

S_K^{max}= maximum potential on the k line.

The safety code contains the line flow-related LSI and bus voltage-related VSI. If the LSI is low, then the number of lines with a higher load is reduced. If VSI is close to zero, we can ensure that the power system is very stable.

Total Cost:

The system's costs are the initial phase of the multi-purpose process. As stated in the equation below, this objective function is made up of three parts:

$OF_{costs} = OF_1 + OF_2 + OF_3$,... (13)

Where each part is calculated as follows:

OF_{costs} = objective function cost

$\mathrm{OF} = \text{objective function } (1,2,3, \dots . n)$

Total Power Losses:

By considering equal and unequal limitations, injecting reactive power is balancing the voltage magnitude two parameters in the electrical system, reducing the loss in DS. To calculate the actual power loss of the network,

$$P_{loss} = \sum_{i=1}^{n} R_i \left| I_i \right|^2 \dots (14)$$

Therefore, the cost of power loss of the different phases can be obtained as follows:

$$OF_1 = P_{loss} \times C_{loss} \times \text{days} \dots (15)$$

Where,

$OF_1 = \text{objective function}$

$P_{loss} = \text{power loss}$

$C_{loss} = \text{cost of the power loss}$

Load ability:

In the power flow problem i^{th} step, all active and reactive loads are increased to obtain the system's maximum load capacity:

$$P_i = \lambda_i \times P_O,\ Q_i = \lambda_i \times Q_o, \dots (16)$$

$$\lambda_i = \lambda_o + (i \times 0.01) i = 1,2, \dots . (17)$$

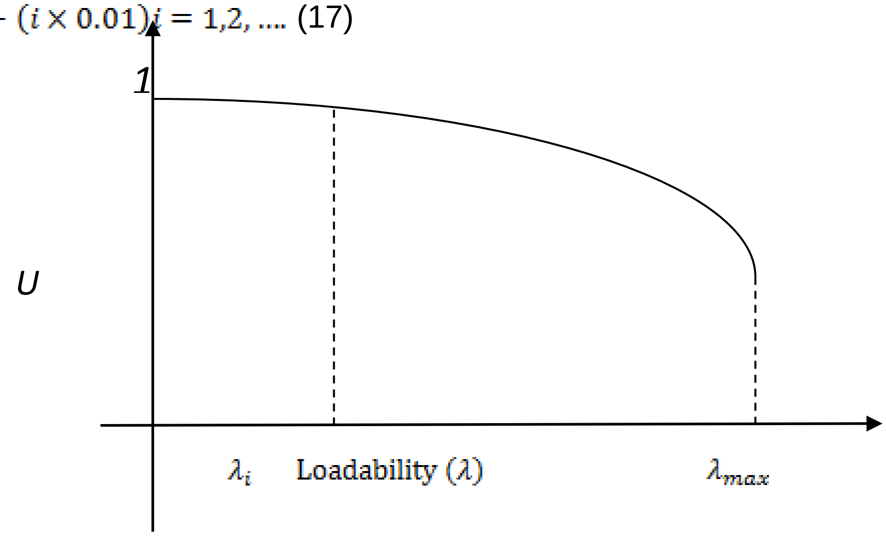

Figure 6: Voltage load ability curve.

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This λ_i will increase until the voltage drops and the load flow calculation variation is discovered. The maximum load capacity (λ_{max}), as indicated in Figure 6, is the most recent permitted value. The following objective function is developed to minimise load efficiency (raise it).

$$OF_{Loadadility} = \frac{1}{\lambda_{max}} \ldots (18)$$

Where,

$OF_{Loadadility}$ = objective function

(λ_{max})=maximum load ability

3.5 SELECTION OF COORDINATING CONTROL SIGNALS

To offer coordinated action, the controller employs all of the feedback signals accessible under the regulatory laws. The goal of this integration is to use a Predictive Cross Difference Progression optimization to assess the system's interactions. PCDPO is an optimization method for signals with significant correlations. Only these signals will be evaluated for deployment of the central coordination controller. As a result, the number of signals that must be measured is reduced. As a result, the complexity of the central controller is greatly decreased.

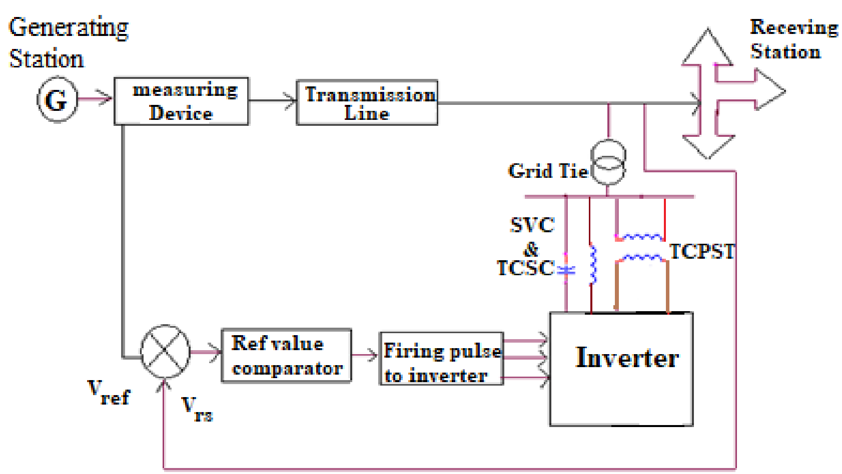

Figure: 7 Control propagation of the Transmission system

Figure 7 illustrates the control distribution of the transmission system, incorporating a Predictive Cross Difference Progression optimization (PCDPO) control-based inverter that can provide artificial power to the FACTS devices to improve the transmission power output of the transmission system.

$$u_{xn} = u_{dc} * d_{xn \ldots}(19)$$

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Where,

u_{xn} = output voltage of the inverter

u_{dc} = input power of the inverter

d_{xn} = the duty cycle of the inverter

3.5.1 PREDICTIVE CROSS DIFFERENCE PROGRESSION OPTIMIZATION STEPS

The PCDPO's general process for tackling the optimization problem is detailed as follows:

Step 1: *Read power system bus and line data for power flow calculations.*

Step 2: *Select all of the generator buses' real and reactive power generation, as well as their size as SVC, as well as the control variables Np, the number of nests, the maximum number of iterations, and the maximum Discovery error rate. Create a population of host nests from scratch.*

Step 3: *To produce the ideal solution, obtain a considerable transformation control method and evaluate its objective function.*

$$F(x) = (p_{gi}, \dots, Q_{gi})T \dots (20)$$

Where,

X is the input variables

p_{gi} *= active power flow*

Q_{gi} *= Reactive power flow*

T=max power generation

Step 4: *In the method described, whether the upper or lower limit of solutions, the best solution to fix the mechanism is PCDPO controller.*

Step 5: *Create new solutions to the various limitations of grid power FACTS devices can control it.*

Step 6: *For the current iteration, get the best Gbest.*

$$X_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1} \dots (21)$$

Where,

X_{id}^{k+1} *=The modified position of the particle i.*

X_{id}^{k} *= The current position of the particle i at iteration K.*

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V_{id}^{k+1} = *The modified velocity of particle i,*

Step 7: *If the current iteration is no better than the prior iteration, get a new value of a ranking rate using Gbest. Otherwise, keep the previous value.*

Step 8: *If Iter < Itermax, Iter= Iter+ 1 and return to Step 3. Otherwise, stop the process.*

$w = w_{max} - [\frac{w_{max} - w_{min}}{iter_{max}}]$ ... *(22)*

$where,$

$W = inertia\ weight\ factor$

$w_{max} = maximum\ value\ of\ the\ weighting\ factor$

$w_{min} = maximum\ value\ of\ the\ weighting\ factor$

Step 9: *If the redundancy rule is satisfied, find the best solution in the search space.*

This method can also be discontinued due to a lack of improvement in the best solution over a certain number of generations. In this work, PCDPO is terminated after certain maximum generations. The Flow chart of the PCDPO controller is shown in **figure 8.**

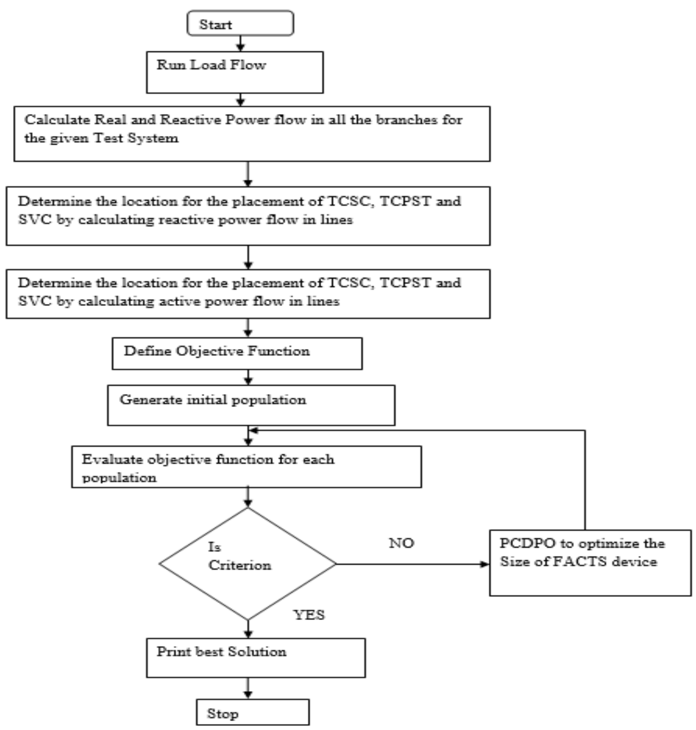

Figure: 8 Flow Chart for the Proposed System

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4. SIMULATION RESULTS AND DISCUSSION

In this section discuss the simulation result and performance analysis of proposed system. Here IEEE30 bus systems are considered to demonstrate the effectiveness of the Predictive Cross Difference Progression optimization (PCDPO) in optimal power flow with SVC, TCSC and TCPST. An OPF program using the PCDPO approach has been written using SVC using MATLAB, which can classify various types of line voltage levels, generation cost and efficiency of data, and line losses.

Case 1: Simulation Result Analysis

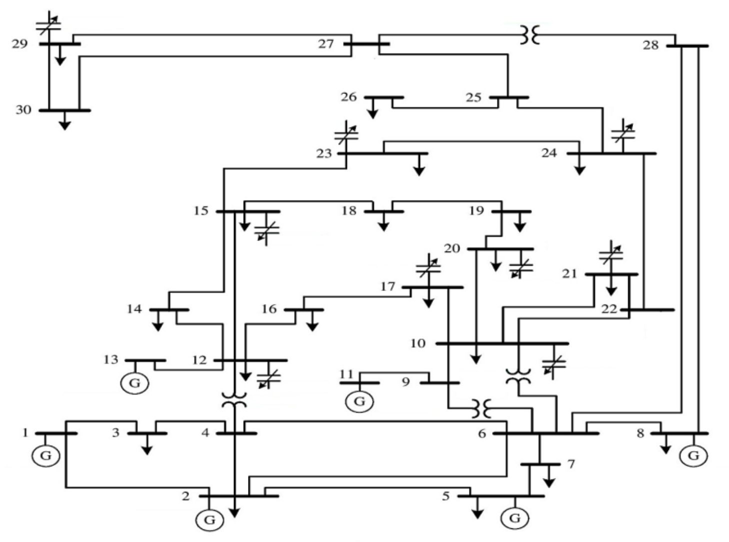

Figure: 9 modeling of IEEE 30 bus systems

Figure 9 shows the operational model of the IEEE 30 bus system, which can be performed on the proposed sophisticated PCDPO. For the power output of the 30 bus system, the power generated by the six generators is propelled by bus with 1, 2, 5, 8, 11, and 13 of those generators produce the active power voltage of the system.

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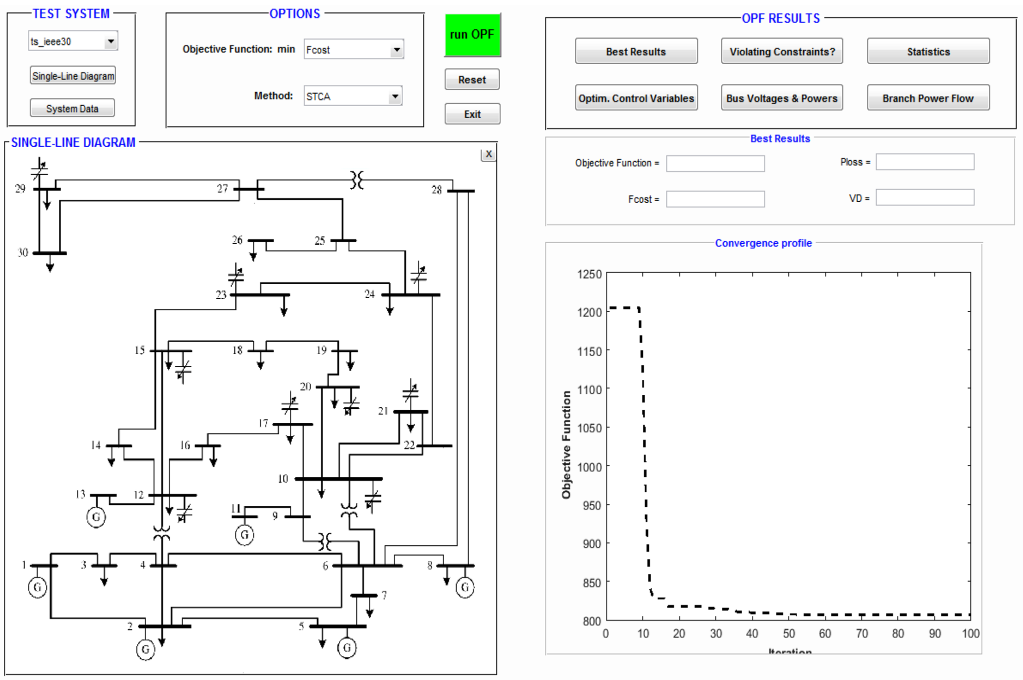

Figure: 10 simulation gain of 30 bus system

The transmission lines in the standard IEEE 30-bus system are shown in Figure 10, with six generators in buses 1, 2, 5, 8, 11, and 13 under the load tap changing transformer branches. Buses 17, 20, and 24 all explore reactive power sources. System line data, bus data, generator data, and control variables all have minimum and maximum limits. Transformer transparent piping system that takes upper and lower buses by various transformers. In this analysis, we performed 72 test runs to solve the OPF different objective function problem.

Table 1: Comparison Result of Iterations Vs. GBSET for PCDPO Controller

S.no	Iterations	G Best
1	10/100	826.792536
2	20/100	826.698996
3	30/100	826.676944
4	40/100	826.669488
5	50/100	826.654144
6	60/100	826.569954
7	70/100	826.364964
8	80/100	826.329474
9	90/100	826.155364
10	100/100	826.135356

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In a 30 bus optimized power flow control system, Table 1 highlights the comparison findings of the proposed system for iterations versus Gbest**.** The optimized power flow with SVC provides the best results by implementing a Predictive Cross Difference Progression optimization (PCDPO).

Table 2: Voltage Magnitudes between Various Buses Using PCDPO Controller

Bus (NO)	**V (PU)**	**Angle (Degree)**
1	1.0600	-0.0000
2	1.0431	-5.3500
3	1.0207	-7.5300
4	1.0118	-9.2800
5	1.0100	-14.1700
6	1.0102	-11.0600
7	1.0024	-12.8600
8	1.0100	-11.8100
9	1.0509	-14.1700
10	1.0451	-15.7000
11	1.0820	-14.1100
12	1.0571	-14.9400
13	1.0710	-14.9400
14	1.0423	-15.8400
15	1.0377	-15.9300
16	1.0444	-15.5300
17	1.0399	-15.8600
18	1.0281	-16.5400
19	1.0256	-16.7200
20	1.0297	-16.5200
21	1.0327	-16.1400
22	1.0333	-16.1300
23	1.0272	-16.3200
24	1.0216	-16.4900
25	1.0173	-16.0600
26	0.9996	-16.4800
27	1.0232	-15.5400
28	1.0068	-11.6900
29	1.0033	-16.7700
30	0.9919	-17.6500

Table 2 demonstrates the relative end of voltage levels with different buses available from the data set with a voltage angle.

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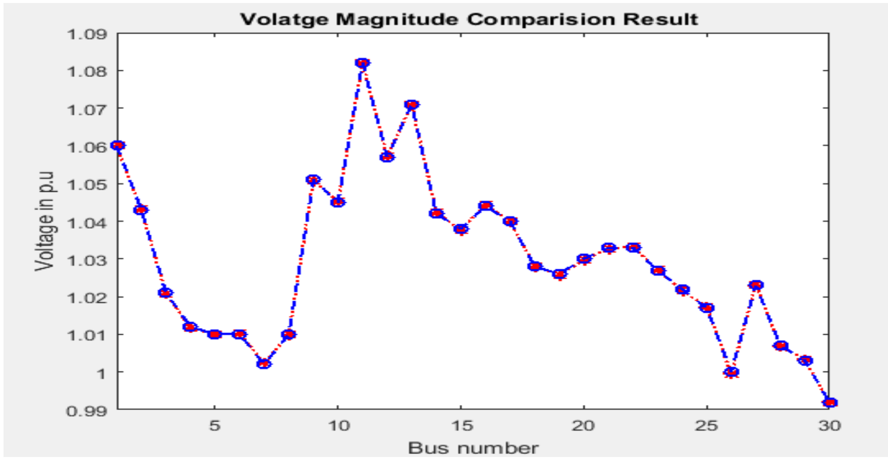

Figure: 11 voltage magnitude of the bus system

Figure 11 shows the voltage measurement on each bus, a Predictive Cross Difference Progression optimization (PCDPO) in the optimal power flow with SVC for low load level and high load condition. Red and violet lines indicate voltage levels with the SVC system. In these situations, the installation voltage level of SVCs is two p.u. Thus, a better voltage profile is achieved.

Table 3: Performance Analysis of the FACTS Devices with PCDPO Control Techniques

Control Variables	PCDPO With SVC	PCDPO With TCSC	PCDPO With TCPST
PG1(MW)	200.58	195.65	183.95
PG2(MW)	37.56	35.61	33.326
PG3(MW)	30.65	29.62	28.43
PG4(MW)	20.36	18.34	16.41
PG5(MW)	15.26	14.32	13.24
VG1(pu)	1.893	1.658	1.583
VG2(pu)	1.562	1.365	1.264
VG3(pu)	1.321	1.125	1.125
VG4(pu)	1.154	1.154	1.109
VG5(pu)	1.156	1.132	1.132
T1(pu)	0.998	0.998	0.995
T2(pu)	0.956	0.948	0.942
T3(pu)	1.32	0.936	0.936

Table 3 shows the various FACTS device control, such as the SVC, TCSC and TCPST with the proposed Predictive Cross Difference Progression optimization (PCDPO) technique.

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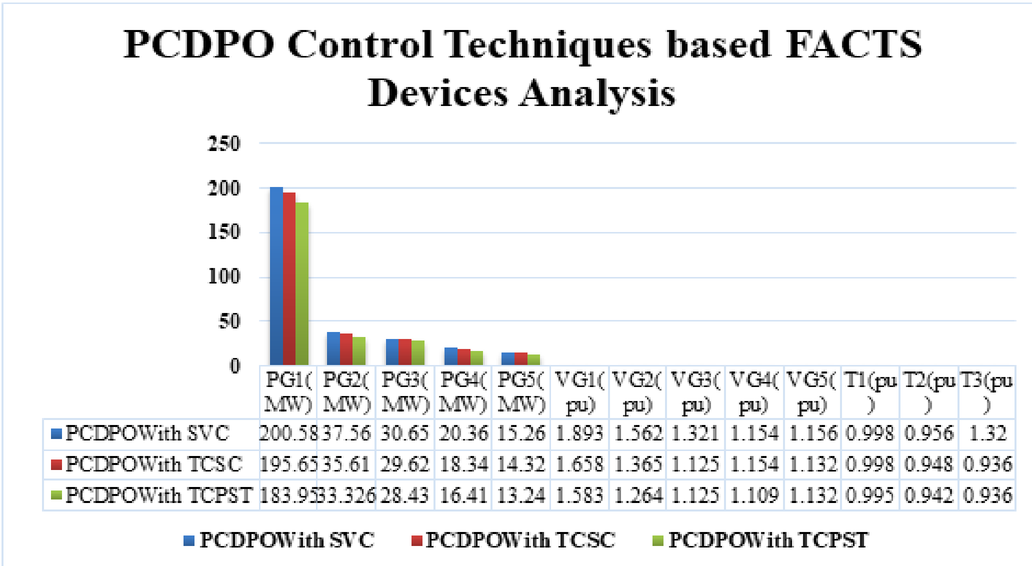

Figure 12: Performances of the PCDPO Control Techniques

Figure 12 shows the Performance analysis of the PCDPO Control Techniques based on the different FACTS devices.

Table.4: Performance Analysis of Generation and Injected Voltage using PCDPO Controller

Bus No	Voltage magnitude	Load(Power)		Generation(Power)		Injected(Power)
		MW	Mvar	Mw	MVar	Mvar
1 - 5	1.028	26.15	6.5	60.20	7.21	1.21
6 - 10	1.025	28.14	8.42	59.32	6.14	2.8
11 - 15	1.04	5.50	2.48	59.05	5.208	2.5
16 - 20	1.031	5.38	2.32	60.30	7.32	0.68
21 - 25	1.016	10.01	1.9	60.12	7.15	1.56
26 – 30	1.012	1.2	1.01	60.01	7.05	1.82

The suggested PCDPO method was used to compare voltage levels, load, generation, and injection in the IEEE 30 bus (see Table 4).

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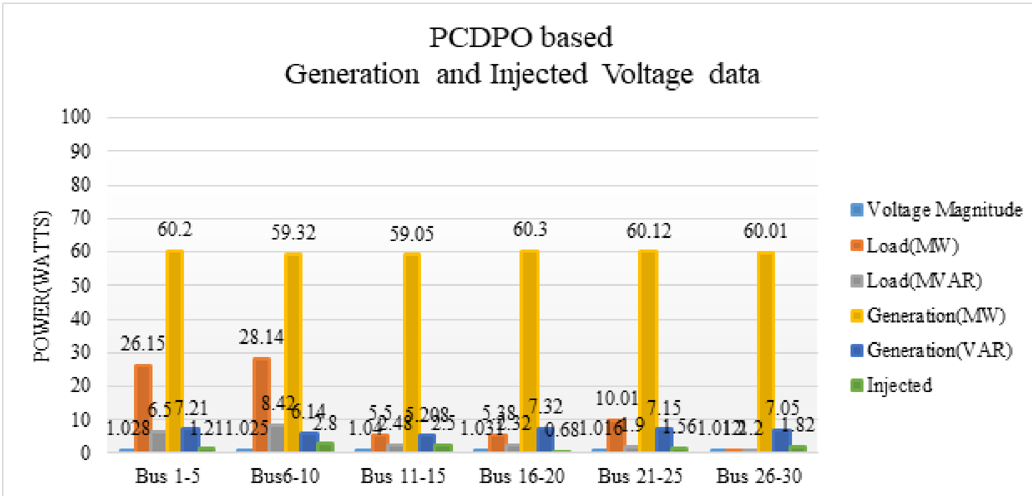

Figure 13: power generation chart for PCDPO controller

The suggested PCDPO method is used to compare voltage levels, load, generation, and injection in the IEEE 30 bus (see Figure 13).

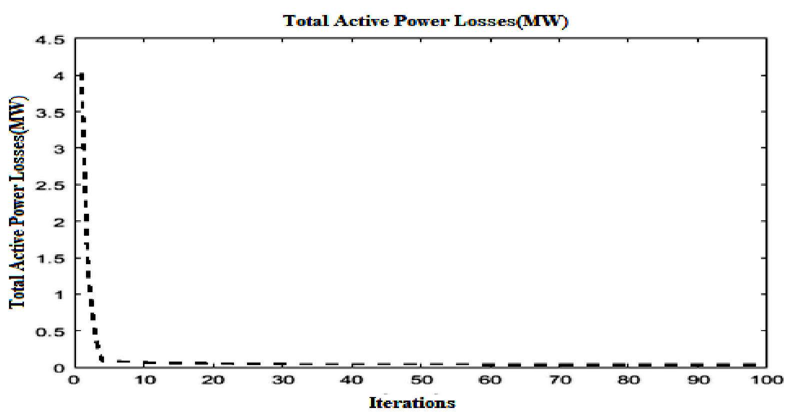

Figure 14: Active Power losses

Figure 14 above depicts the overall active power losses. Power losses against different iterations were measured in this study, which used 100 iterations and the suggested PCDPO algorithm to manage power flow.

Table 5 Line Losses Analysis Using PCDPO algorithm

FACTS Devices	Line Losses (%)
SVC	5.1
TCSC	4.2
TCPST	1.9

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Table 5 describes the Line Losses Analysis of the FACTS devices using the PCDPO algorithm.

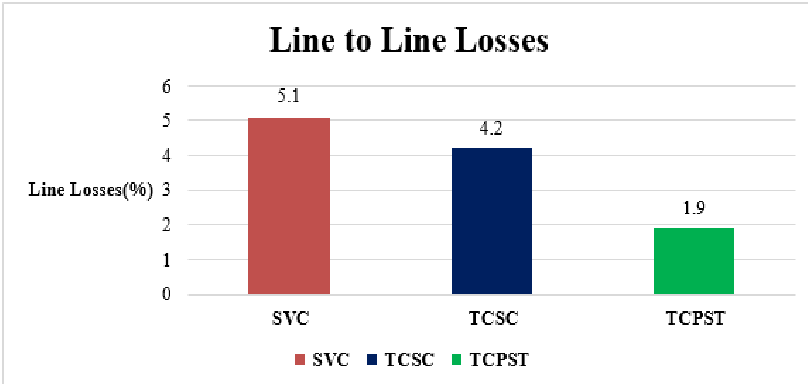

Figure 15: Performance Comparison of SVC, TCSC, TCPST

Figure 15 depicts the comparison by putting FACTS controllers in front of various controllers for study. Losses on the lines have been decreased by 1.9%.

TABLE 6: Performance of OPF BASED ON PCDPO Algorithm

Parameters	PCDPO
Efficiency (%)	91.56
Average Load Voltage (%)	440
Power Losses (%)	4.4

Table 6 demonstrates the Performance analysis of Proposed IEEE 30 bus model-based On PCDPO Algorithm

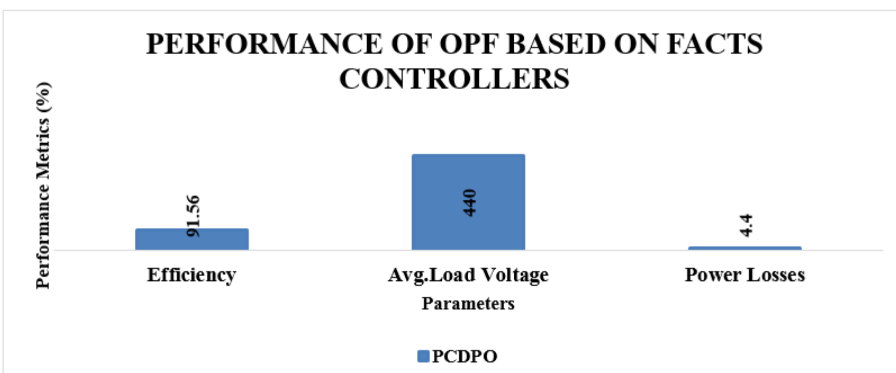

Figure 16: Performance of Reduced OPF (Optimal power flow) Using PCDPO

The findings shown in Figure 16 demonstrate the effectiveness of improving power quality. The analysis clearly demonstrates that the PCDPO method outperforms other conventional methods in terms of enhancing power quality to nominal levels and lowering the ideal power flow system.

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Table 7 Performance analysis of the IEEE 30 Bus with Different parameters

Controller	Execution time (Sec)	Loss minimization (%)	Cost Minimization (%)
PCDPO	0.732	1.0310	0.36

Table 7 Performance analysis of the IEEE 30 Bus with Different parameters Execution (sec), Loss Minimization (%), Fuel Minimization (%).

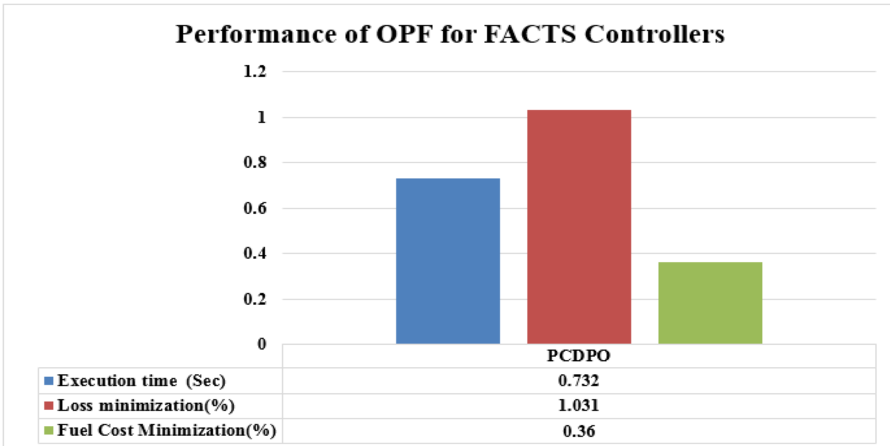

Figure 17: Performance of FACTS Controllers

Figure 17 above shows the FACTS control operation with different parameters such as loss reduction, power loss. From the simulation results, the Proposed PCDPO Controller will provides better output.

Case II: Performance Analysis

Table: 8 Voltage magnitudes between various buses

S.no	Bus Number	GA method (Voltage Pu)	GA method Angle degree	CDP – CEA (Voltage Pu)	CDP – CEA (Angle degree)	PCDPO V (PU)	PCDPO Angle (Degree)
1	2	0.985	-18.146	1.043	-5.43	1.0600	0.0000
2	6	0.989	-18.110	1.012	-11.088	1.0431	-5.3500
3	8	0.991	-17.532	1.010	-11.804	1.0207	-7.5300
4	12	0.994	-16.853	1.058	-14.94	1.0118	-9.2800
5	15	0.998	-15.105	1.038	-15.49	1.0100	-14.1700
6	20	1.053	-14.763	1.029	-16.536	1.0102	-11.0600
7	30	1.016	-9.31	0.995	-17.655	1.0024	-12.8600

Table 8 describes the comparison result of voltage magnitude with various buses that can be with a voltage angle received from the data system.

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Table 9 Comparison of FACTS devices with different control Algorithms

Control Variables	GA With SVC	GA With TCSC	GA With TCPST	CDP – CEA With SVC	CDP – CEA With TCSC	CDP – CEA With TCPST	PCDPO With SVC	PCDPO With TCSC	PCDPO With TCPST
PG1(MW)	176.30	176.03	180.15	185.26	185.91	175.12	186.10	184.64	176.05
PG2(MW)	31.253	32.22	32.105	34.183	33.43	32.623	34.215	33.05	32.569
PG3(MW)	28.105	27.01	27.88	29.763	28.42	26.55	29.856	28.14	26.45
PG4(MW)	10.179	11.03	12.54	11.536	12.71	15.832	11.056	12.56	14.058
PG5(MW)	12.56	13.01	13.96	13.103	13.17	14.745	13.03	13.96	14.056
VG1(pu)	1.04	1.03	1.02	1.01	1.03	1.00	1.01	1.03	1.04
VG2(pu)	1.02	1.01	1.01	1.01	1.01	1.04	1.01	1.01	1.02
VG3(pu)	0.99	1.00	1.01	1.02	0.97	1.023	1.02	1.00	0.99
VG4(pu)	1.02	0.96	0.95	1.02	0.96	0.946	1.02	0.96	1.02
VG5(pu)	0.99	1.01	1.02	1.02	1.01	0.945	1.02	1.01	0.99
T1(pu)	0.98	1.00	0.987	0.987	1.00	0.987	0.987	1.00	0.98
T2(pu)	0.945	0.998	0.965	0.949	0.942	0.943	0.949	0.998	0.945
T3(pu)	1.05	0.98	0.923	1.01	0.982	0.923	1.01	0.98	0.956

The power generation and related grid power load are described in table 9 above. All lines surrounding this line have SVC, TCSC, and TCPST, and losses are estimated using the proposed PCDPO algorithm, which outperforms other prevalent methods.

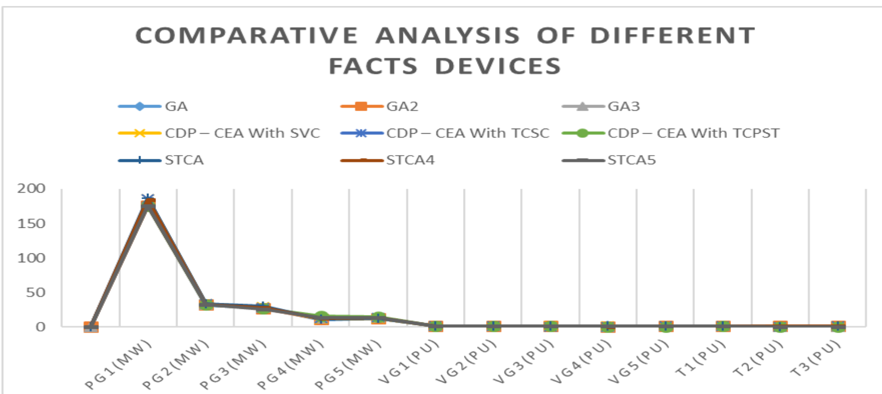

Figure 18: Performances of the FACTS Control devices with other technique

Figure 18 shows the Performances analysis of the differential Control Techniques based on the different FACTS devices

Table 10: Performance Analysis of Generation and Injected Voltage using PCDPO Controller

Bus No	Voltage magnitude	Load(Power)		Generation(Power)		Injected(Power)
		MW	Mvar	Mw	MVar	Mvar
1 - 5	1.028	26.15	6.5	60.20	7.21	1.21
6 - 10	1.025	28.14	8.42	59.32	6.14	2.8
11 - 15	1.04	5.50	2.48	59.05	5.208	2.5

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16 - 20	1.031	5.38	2.32	60.30	7.32	0.68
21 - 25	1.016	10.01	1.9	60.12	7.15	1.56
26 – 30	1.012	1.2	1.01	60.01	7.05	1.82

The suggested PCDPO method was used to compare voltage levels, load, generation, and injection in the IEEE 30 bus (see Table 10).

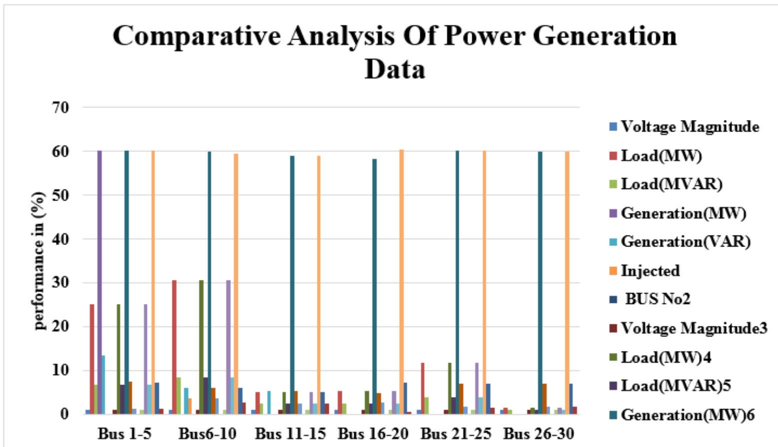

Figure 19. Comparative Analysis Based Generation and Injected Voltage Data

Figure 19 demonstrates a comparison of voltage levels, load, generation, and injection utilizing the proposed PCDPO algorithm in the IEEE 30 bus.

Table 11: Line Losses Analysis Using PCDPO and other algorithms

Control technique	Line Losses CDP-CEA	Line loss GA	Line Losses PCDPO
SVC	5.3	6.5	5.1
TCSC	4.5	5.1	4.2
TCPST	2.5	2.9	1.9

Table 11 describes the Line Losses Analysis of the FACTS devices using PCDPO, CDP - CEA and GA technique.

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Figure 20 Performance Comparison of SVC, TCSC, and TCPST using various strategies

Figure 20 describes the Line Losses Analysis of the FACTS devices using the GA CDP&CE with PCDPO Controller. The loss is reduced by 1.9% with various parameters taken. Figure 19 shows the results of the simulation and the comparison. The results show that the FACTS-based controller outperforms traditional controllers such as the GA and CDP techniques in terms of response overshoot.

Table 12: Performance of OPF Based on various Algorithm

Parameters	GA	CDP&CEA	PCDPO
Efficiency (%)	79	85	91.56
Average Load Voltage(V)	410	440	440
Line Losses (%)	10	7.05	4.4

Table 12 demonstrates the Performance analysis of OPF FACTS devices with a different controller.

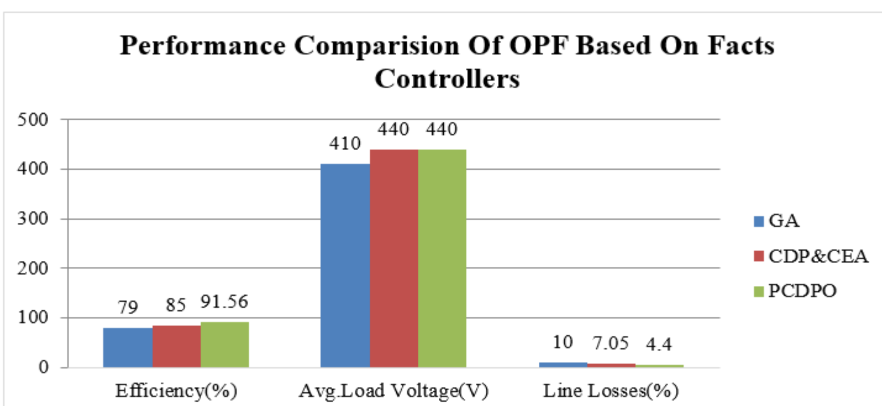

Figure 21: Performance Comparison for OPF based FACTS Devices

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The FACTS Controller action is compared in Figure 21 with various parameters such as Loss minimization, Power loss, Efficiency, Efficiency, and so on. The results show that the PCDPO algorithm-based controller outperforms traditional controllers such as CDP&CEA and GA in terms of response overshoot.

5. CONCLUSION

FACTS devices are an effective means of relieving congestion and enhancing system security. However, if such devices are used in an uncoordinated manner, conflicting scenarios may arise, putting the transmission grid's security at risk. As a result, this work develops the Predictive Cross Difference Progression Optimization (PCDPO) control based on optimal power flow. This technology aims to reduce active power losses by 4.4% while also alleviating traffic congestion. Simulations with various combinations of real devices were used to examine the objective function. Each gadget was shown to have an impact on some aspect of the objective function. The SVCs are in charge of voltage and active power losses, while the TCPST is in charge of the TCSC and line loading. As a result, decoupling occurs, allowing direct usage of multiple reality devices. Finally, simulations were provided that demonstrated improvements in control acquired using Predictive Cross Difference Progression Optimization (PCDPO): congestions were eliminated, voltage profiles were highly uniform, and active power losses were minimized. Furthermore, it was shown that TCSC and TCPST produce similar results when objectives are addressed at 91.56% efficiency.

References

1. Lashkar Ara, A. Kazem, S. A. Nabavi Niaki" Multi-objective optimal location of facts shunt-series controllers for power system operation planning" IEEE transactions on power delivery, vol. 27, no. 2, April 2012.
2. M. Karthikeyan, Dr.P.Ajay-D-Vimalraj" Optimal location of shunt facts devices for power flow control" International conference engineering and technology 978-1-4244-7926-9/11-2011.
3. Dinesh Mehta, Arun Ravindran, Bharat Joshi, Sukumar Kamalasadan" Graph theory-based online optimal power flow control of power grid with distributed flexible ac transmission systems (D-FACTS) devices" IEST, vol. 10, No. 6, November/December. 2015, pp. 339-345.
4. Belkacem Mahdad, Tarek Bouktir, Kamel Srairi" A three-phase power flow modelization: a tool for optimal location and control of facts devices in unbalanced power systems" IEEE transaction on the power system and engineering 1-4244-0136-4/06-2006.
5. Mahdad, K. Srairi, T. Bouktir" Optimal power flow for a large-scale power system with shunt facts using efficient parallel GA" International journal of emerging electric power systems 978-1-4244-1766-7-08-2008.
6. J. M. Corrêa; S. Chakraborty; M. G. Simões, F. A. Farret" A single phase high-frequency ac microgrid with a unified power quality conditioner" IEEE transaction on the power quality conditioner 07803-7883-0/03-2003.

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ISSN：1671-5497
E-Publication Online Open Access
Vol: 41 Issue: 11-2022
DOI 10.17605/OSF.IO/5YBFJ

7. Leonardo Bruno Garcia Campanhol, Sérgio Augusto Oliveira da Silva" Single-stage three-phase grid-tied PV system with universal filtering capability applied to dg systems and ac microgrids" pp; 0885-8993 – 2016.
8. Sachin Devassy, Bhim Singh," Modified p-q theory based control of solar PV Integrated UPQC-S" IEEE Industry applications society annual meeting Pp; 978-1-4799-8397-1/16-2016.
9. Rodrigo Augusto Modesto, Sérgio Augusto Oliveira da Silva" Versatile unified power quality conditioner applied to three-phase four-wire distribution systems using a dual control strategy" IEEE Transactions on Power Electronics pp; 0885-8993 2015.
10. P.Vasudeva Naidu, B.Basavaraja," Design of an SRF based mc UPQC used for load voltage control in parallel distribution systems" pp 978-1-4673-0766-6/12-2012.
11. Gabriela Hug-Glanzmann, G¨oran Andersson " Coordinated control of facts devices in power systems for security enhancement" symposium - bulk power system dynamics, and control August 19-24, 2007.
12. Belkacem Mahdad, Tarek Bouktir, Kamel Srairi" Flexible methodology based in fuzzy logic rules for reactive power planning of multiple shunt facts devices to enhance system load ability" 1-4244-1298-6/07-2007 IEEE.
13. G. Glanzmann, G. Andersson," Coordinated Control of FACTS Devices based on Optimal Power Flow" Power Engineering Journal, 0-7803-9255-8/05-2005.
14. Sahbi Marrouchi, Souad Chebbi" Active and reactive power compensation through a preventive defense strategy based on FACTS devices" International Conference on Electrical Engineering and Software Applications 2013.
15. S. M. Sadeghzadeh, M. Ansarian" transient stability improvement with Neuro-Fuzzy control of facts devices" First international power and energy conference PECON 2006 297, November 28-29, 2006.
16. Yijie Wang, Xihong Hu," A single-stage led driver based on half bridge CLCL resonant converter and buck-boost circuit" IEEE Journal of Emerging and Selected Topics in Power Electronics pp 2168-6777 2018.
17. Yunhui Huang, Xiaoming Yuan" DC-bus voltage control stability affected by ac-bus voltage control in vscs connected to weak AC grids" IEEE Journal of Emerging and Selected Topics in Power Electronics Pp 2168-6777 2015.
18. Hongbo Ma, Yuan Li, Qiang Chen," A Single-Stage Integrated Boost-LLC AC-DC converter with quasi-constant bus voltage for multi-channel led street-lighting applications" IEEE journal of emerging and selected topics in power electronics Pp: 2168-6777 2018.
19. Tsai-Fu Wu, Chia-Ling Kuo," DC-Bus voltage regulation for a dc distribution system with a single-phase bidirectional inverter" IEEE journal of emerging and selected topics in power electronics, vol. 4, no. 1, March 2016.
20. Li Zhang, Yan Xing," Parallel operation of modular single-phase transformerless grid-tied PV inverters with common DC Bus and AC Bus" IEEE journal of emerging and selected topics in power electronics pp:2168-6777 2015.