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FUZZY-PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLER WITH INTERACTIVE DECISION TREE

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Keywords: Biogeography-based optimization; Fuzzy proportional integral derivative (PID) controller; Interactive decision tree; Nonlinear load; Reactive power compensation; Static synchronous compensator (STATCOM).

The STATCOM is extensively used in the power system to address the power quality issues by actively compensating the reactive power requirements of the load. However, the STATCOM performance depends on the underlying controller operation to handle sudden load changes and disturbances optimally with faster response. To solve this issue, this paper presents the intelligent algorithm-optimized fuzzy rule-based Proportional Integral Derivative (PID) controller to enhance the performance of the STATCOM. The proposed controller consists of a fuzzy-PID controller capable of handling non-linear dynamics and sudden changes in the load. The interactive decision tree (IDT) technique detects weaker metrics and improves their influence in control scenarios. The Biogeography-based optimization (BBO) algorithm minimizes the controller's integral absolute error to tune the fuzzy-PID controller parameters. The algorithm terminates once all the metrics are tuned to satisfaction with the operator's consent. The proposed IDT-based fuzzy PID controller is tested on a power system containing a nonlinear load, and its performance is compared with the existing controller and simulated using the MATLAB/Simulink tool. The proposed controller provides fast control action, reduces the reactive power from the source by 42.5%, and improves the power factor by 1.5%.

1. INTRODUCTION

The expansion of renewable energy-based power generation, along with a growth in semiconductor devices, causes distortions in the power quality provided by the grid [1]. Energy conservation methods such as renewable energy generation are excellent options, but decreasing energy use may have an equally significant effect [2–4]. The FACTs devices have also been used in recent technologies such as smart grids, optimal power flow, *etc*., [5, 6]. Maintaining electrical parameters within predetermined limits is referred to as power quality. Its parameters are power factor improvements, maintaining voltage limits without sag and swell, managing reactive power and harmonics, *etc*., [7].

Various reactive compensation devices include reactive static compensators (STATCOMs), shunt capacitors, synchronous condensers, and saturation reactors (SRs). The STATCOM has the advantages of compensating reactive power in two directions and having a wide operating range, fast response speed, small energy storage capacity, and control flexibility over traditional compensators [8,9]. This way, reactive power compensation has become a technologically advanced technology attracting considerable research attention.

Typically, the STATCOM consists of a voltage source shunt converter linked to a load bus via a transformer and filter where the voltage is to be governed. The coupling transformer can be used for impedance matching and isolating converters from the source. The power transmission improves as STATCOM is brought into the system, enhancing the steady-state stability limit. At the same time, the line voltage is regulated at the PCC (point of standard coupling) [10,11].

Performing trial-and-error research on transmission topology changes is not possible for utility engineers, and the issue could be made worse when a scenario causes transmission topology changes. Reactive power support has been proposed in [12] for controlling voltage in hybrid power systems. In this case, STATCOM was not used to decrease voltage fluctuations on the bundle side of the converter. UPFC, STATCOM, and SVC are used alternatively for reactive power control and power factor improvement in microgrids based on wind energy [13].

A nonlinear controller is required to stabilize the intrinsically nonlinear power system while running under dynamic operating circumstances. The primary benefit of using a fuzzy controller is that it is intelligent [14]. A polynomial Petri fuzzy neural network (PPFNN) controller is used to replace the traditional proportional-integral (PI) controller [15], and an unknown system dynamics estimator (USDE)- based control strategy is employed to compensate for the reactive power.

To improve the performance of the PI controller, a variety of artificial techniques are employed, including gain parameters of four PI controllers in the STATCOM control circuit based on genetic algorithms (GA) and bacteria foraging algorithm (BFA) [16]. The STATCOM current controller in [17] uses GA and particle swarm optimization to design PI controllers. Mine blast algorithm (MBA) [18], hybrid ant colony-particle swarm optimization algorithm [19], student-psychology-based optimization (SPBO) [20], and firefly algorithm are proposed to enable reactive power using STATCOM. Despite this, these algorithms use randomization to generate the solution search space and change the position, resulting in an imbalance between exploration and exploitation. The fuzzy logic controller settings are crucial to the control performance they can give, and as a result, various technologies are used to tune fuzzy controllers. Tuning techniques relevant to the domain of computational intelligence (CI) and based on global optimization algorithms have attracted a great deal of attention in this regard due to their simplicity, gradient-free optimization feature, and ability to find an optimum solution even in the most complicated optimization situations [21–23]. This motivated us to propose this study, which presents the BBO approach for optimizing fuzzy PID controller

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parameters by updating weights as needed. This study aims to provide fast control action, reduce the reactive power from the source, and improve the power factor. The significant contribution of the proposed work is as follows.

- Improve the quality of power by improving the STATCOM by compensating reactive power to provide reliable power to the consumers.
- A fuzzy rule-based PID (fuzzy-PID) controller is used to enhance the performance of the STATCOM.
- BBO methods to optimize Fuzzy-PID controller parameters.
- Develop an IDT algorithm to improve the grid system's performance and the transient response.

The paper is structured as follows: section 2 discusses the design of STATCOM and the mathematical concepts underpinning it. Section 3 illustrates the proposed controller's design, the contribution of fuzzy PID controller weights in the cost function, and the suggested tuning technique utilizing the BBO with IDT algorithm as the role of fuzzy Controller parameter weights in the cost function. Section 4 discusses the proposed controller's findings and comparisons with other evolutionary control approaches that have been addressed before. The article provides concluding remarks in section 5.

2. MODELING OF SYSTEM COMPONENTS

2.1 MODULAR STATCOM MODELING

A description of the STATCOM modeling, as well as its configuration to optimize reliability and quality of power, is provided in this section. Figure 1 depicts the fundamental construction of a STATCOM with PWM-based voltage controls. STATCOM is one of the unique devices to compensate reactive power, manage voltage sag & and swell, reduce harmonics, and ensure power quality. The work that is being proposed has several goals, the most important of which are to enhance power factor, diminish harmonics, improve dynamic responses, and manage reactive power. A STATCOM can change its output current independently of the AC system voltage and quickly compensate for capacitive and inductive effects. In many aspects, the STATCOM is like a synchronous compensator; however, it does not have the inertia associated with it. There is no STATCOM without a voltage source converter (VSC). Usually, the input DC voltage gets transformed to three-phase output voltage by VSC under fundamental frequency conditions considering instantly adjustable amplitude and phase angle. The VSC's primary function is to allow power flow in both directions. The VSC controls the voltage's phase angle, amplitude, and frequency on the output. The DC capacitor is used to stabilize the DC voltage, and then storage is done by the DC capacitor. A particular LCL filter can remove harmonics from the VSC's square wave. The system only provides reactive power when V_{out} (converter output voltage amplitude) exceeds V_{AC} (AC system bus voltage amplitude). At that time, I_{AC} flows from the converter to the AC system.

In pure inductive conditions, the angle between AC voltage and current is 90° (current lagging with voltage), assuming that converter losses should be ignored. If V_{out} and V_{ac} are equal, so there is no reactive power generation/consumption because they act as resistive circuits. The magnitude of the AC is computed using the following equation.

$$I_{ac} = \frac{V_{out} - V_{AC}}{X}. \quad (1)$$

Here, X is the coupling transformer leakage reactance. Transferred reactive power for this case may be stated as follows:

$$Q = \frac{V_{out}^2 - V_{out} V_{AC} \cos\alpha}{X}. \quad (2)$$

The relationship between voltages during an actual power exchange is expressed as:

$$P = \frac{V_{ac} V_{out} \sin\alpha}{X}. \quad (3)$$

2.2 LCL PASSIVE FILTER

The inductor-capacitor-inductor (LCL) filter is a good option for attenuation, cost reduction, and size reduction. Using an interface filter like LCL, STATCOM is linked to the load in parallel at PCC. On comparing the L filter with the higher order LCL filter, the latter has a higher capacity for attenuating switching ripple, which can be accomplished by utilization of low levels of overall inductance and capacitance. This can also be discussed as the switching frequency voltage at the leg of the current-controlled VSC is appropriately shaped by the low-pass L filter to inject the necessary filter currents at the PCC. The outcome stays with the injected filter currents, commonly termed rippled switching frequency currents. These ripples are translated into source currents and, in feeder resistance, to PCC voltages. The present ripple's amplitude is inversely related to the L filter's value. As a result, a significant value of L is required to provide effective ripple attenuation, which increases the cost and degrades the compensatory slew rate and, thus, the dynamic performance of the system. An efficient mathematical model is required for constructing the LCL filter as its more substantial harmonic attenuation favors the usage of more minor switching frequencies for achieving the harmonics stipulated by standards IEEE-519-1992 and IEEE-1547.

Here, the inverter side inductor is L1, the grid side inductor is L2, the capacitor with the series Rf damping resistor is Cf, the inductor resistances are R1 and R2, and the input and output voltages are Vi and Vg, respectively (inverter and grid voltages). The mathematical description of LCL filter is described as $\frac{I_g}{V_i} = \frac{1}{S^3 L_1 L_2 + S(L_1 + L_2)}$, while the resonant frequency ω_{res} is represented as $\omega_{res} = \frac{1}{\sqrt{C_f L_p}}$, where $L_p = \frac{L_1 L_2}{L_1 + L_2}$.

The L and C values for the LCL filter were computed based on the requirements specified in its mathematical description. Table 1 contains the parameters that we have chosen for our proposed work.

Table 1

Selected parameters of LCL filter.

Parameter	Value
Switching frequency	10 KHz
resonant frequency	1000 Hz
C	100 μF
L	500 μH
Base Power	100 KVA
Grid Voltage	415 $V\,Ph-Ph$, 50 Hz

3. PROPOSED IDT-BASED FUZZY-PID CONTROLLER DESIGN

The proposed Interactive Decision Tree (IDT) based fuzzy PID controller is shown in Figure 2. To realize the controller, the three-phase grid voltage Vabc, grid current Iabc, and load current ILabc are converted to a d-q framework (Vd, Vq,Id,Iq,ILd,ILq) [22]. Then, the control design contains a voltage & current controller (Id, Iq). The voltage controller provides a setpoint Idref to the Id controller. The outcome from the current controllers generates the reference voltage for the inverter V_{DC}. A switched pulse width modulation inverter uses the reference DC voltage to trigger the IGBT switches, compensating for the grid's reactor power. The fuzzy PID controller design for voltage and the current controllers are explained in what follows.

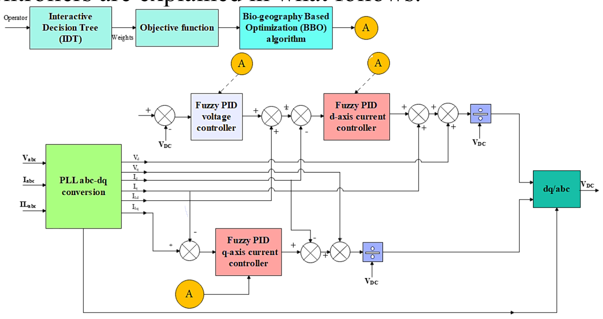

Fig. 1 – Schematic of STATCOM Controller using proposed IDT-based fuzzy PID controller.

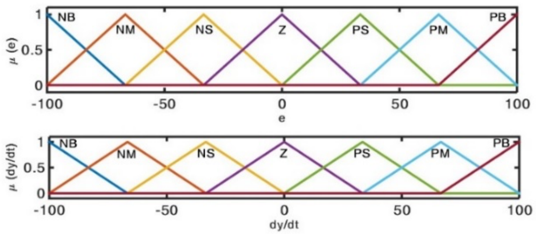

Fig. 2 – Membership functions for error (top) and change in the output (bottom).

3.1 FUZZY PID CONTROLLER

As commonly known, controllers will always be a mix of fuzzy and PID. It combines the fuzzy controller's ability to handle non-linearity and the simplicity of tuning the PID controller. Generally, a fuzzy controller could be constructed either as a PD or PI category based on fuzzy rules. However, this investigation proposes a fuzzy PID controller configuration to suit the fast dynamics of the system, and it is illustrated in the figure. In the controller configuration, input scaling variables are represented by GE and GCE, while output scaling variables are represented by GU and GCU. First, the error (e) and change in output (dy) are defined as follows:

$$ek = rk - yk, \quad (4)$$

$$dyk = yk - yk-1, \quad (5)$$

while r implies the reference signal, y implies system output, and k implies the sampling instant. The fuzzy controller assigns a triangular membership function μ (⊖) to represent the error and change in the output. The input membership functions inputs range from [-100 100] and are labeled as negative big (NB), negative medium (NM), negative small (NS), zero error (Z), positive small (PS), positive medium (PM) and positive big (PB), as shown in Fig. 3. While the output also has a triangular membership function ranging from [-200 200]. Fuzzy is a rule-based system. Consequently, forty-nine fuzzy rules are created using connective, as shown in Table. 2. The rule base renders a non-linear mapping between the error e, change in the output dy, and the control input u, as illustrated in Figure. 3. To compute the control input u from the membership degree, we employ the centroid method-based de-fuzzification step.

The fuzzy-PID controller efficiency could be modified by suitably adjusting both the input and output scaling factors, respectively. Adjustments to the input and output scaling factors can be made by changing the gain values of the fuzzy PID controllers. Though traditional methods to compute the scaling factor exist (see), they are heuristic and lack optimality. Therefore, an evolutionary algorithm named BBO is utilized to find the optimal scaling factors to improve the fuzzy-PID performance.

3.2 TUNING FLC GAIN PARAMETERS USING BBO ALGORITHM

The BBO algorithm works based on the biological distribution of species in a habitat. Unlike other evolutionary algorithms, the BBO preserves the potential optimal candidate solutions from the current iteration to the next iteration, resulting in better convergence towards the global optimal solution. Figure 3 illustrates the BBO algorithm for computing the optimal scaling factors for the fuzzy-PID controller.

3.2.1 BBO DEFINITIONS

Under this section, the basic terminologies in line with the BBO algorithm to obtain optimal scaling factors of the fuzzy-PID controller have been focused on. The parameter Z indicates the set of integers while the set of real numbers by R, then the operator → indicates the mapping between the two sets.

Definition 1. A *Habitat* $H \in Z^m$ is a vector of integers representing a fuzzy-PID controller's feasible scaling factors.

(i.e.) *H* = [*GEvdc, GECvdc, GUvdc, GCUvdc, GEid, GECid, GUid, GCUid, GEiq, GECiq, GUiq, GCUiq*].

Definition 2. *A Suitability Index Variable SIV* ∈ Z is an integer allowed in a habitat *H*. (i.e.) $H = [SIV_1, SIV_2, ...SIV_n]$ where *n* is the number of scaling factors to be evolved for optimal operation of the fuzzy-PID controller.

Definition 3. A *Habitat Suitability Index HIV*: *H* → R is akin to fitness in other population-based optimization algorithms, providing a measurement of the solution's goodness in relation to a particular habitat.

Table 2

Rule base for fuzzy logic controller.

e	*dy/dt* NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

The fuzzy-PID controller has a fitness function that is used to find the best scaling factors [24], where ISE_{Vdc} and IAE_{Vdc} are the integrated squared and absolute error, respectively, which are associated with the DC bus voltage; ISE_{Iq} and ISE_{Iq} are integrated squared error and integrated absolute error of the q-axis current, respectively. Also, w_i is the weight associated with the parameters above.

Definition 4. *Immigration rate* λ (Habitat Suitability Index (*HIS)*): R → R is a monotonically decreasing function of HSI. It indicates the likelihood of SIVs that migrate from habitat H_j to H_i, where $i \neq j$.

Definition 5. *Emigration rate* $\mu(HSI)$: R → R is a monotonically increasing function of HSI. It indicates the likelihood of SIVs that migrate from habitat H_i to H_j, where

$i \neq j$.

Definition 6. *Mutation* $M(\lambda, \mu)$: $H \rightarrow H$ is a process wherein a habitat's SIV is randomly modified through a probabilistic operator based on a habitat's *a priori* probability of existence

min	*w*1.*ISEVdc* + *w*2.*ISEIq* + *w*3.*IAEVdc* + *w*4.*IAEIq*
s.t.	$GEvdc_{min} \leq GEvdc \leq GEvdc_{max}$
	$GEIdmin \leq GEId \leq GEIdmax$
	$GEIqmin \leq GEIq \leq GEIqmax$
	$GCEvdcmin \leq GCEvdc \leq GCEvdcmax$
	$GCEIdmin \leq GCEId \leq GCEIdmax$
	$GCEIqmin \leq GCEIq \leq GCEIqmax$
	$GUvdc_{min} \leq GUvdc \leq GUvdc_{max}$
	$GUIdmin \leq GUId \leq GUIdmax$
	$GUIqmin \leq GUIq \leq GUIqmax$
	$GCUvdcmin \leq GCUvdc \leq GCUvdcmax$
	$GCUIdmin \leq GCUId \leq GCUIdmax$
	$GCUIqmin \leq GCUIq \leq GCUIqmax$
	P4*wi*=1 *i*=1

3.2.2 BBO ALGORITHM

The algorithm starts with initializing the maximum species count S_{max}, maximum emigration and immigration rates E and I, maximum mutation rate m_{max}, and a random set of habitats. For each habitat H_k ($k = 1,2,...n$), calculate the HSI defined in 3.2.1, and assign the number of species.

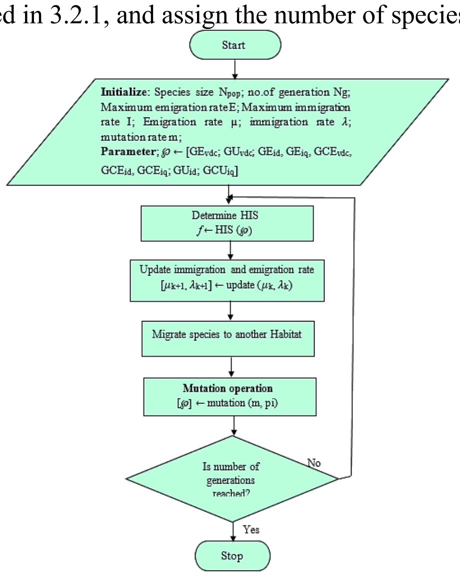

Fig. 3 – Flowchart to tune control parameters in the BBO algorithm.

Then, compute the emigration and immigration rate for a species S in a habitat as:

$\mu k = Ek/Smax$

$\lambda_k = I(1 - k/S_{max})$

Using μ and λ, perform migration operation to modify the SIV of the non-elite habitat with a probability P_{mod}, and recompute the HSI. The probability P_s for holding S species in a habitat H from the time k to $k + \Delta k$ is defined as:

$$Ps(k + \Delta K) = Ps(k)(1 - \lambda s\Delta K - \mu s\Delta k) + P(s-1)\lambda(s-1)\Delta k + P(s+1)\mu(s+1)\Delta k \quad (6)$$

Then, from (6), the following conditions must hold:

C1: If no immigration or emigration occurred between k and $k+\Delta k$, then S species are in a habitat.

C2: If one immigration happened, there are $S - 1$ species in a habitat at time k.

C3: If one emigration happened, there are $S + 1$ species in a habitat at time k.

The mutation process is accomplished by probabilistically altering the SIV's of the non-elite habitats to increase the algorithm's performance, and it is provided by $m(s) = m_{max}((1 - P_s)/P_{max})$.

This step modifies the habitat, and HSI is recomputed. The migration (species moves into other habitats) and mutation operations are sequentially performed for a prescribed number of iterations to yield optimal scaling factors.

3.3 INTERACTIVE DECISION TREE ALGORITHM

An interactive decision tree is a dynamic tool that guides users through a choose-your-own-adventure style procedure to assist them in making decisions. The following steps will be carried out in the proposed system with the assistance of the IDT & BBO algorithm. The weights provided to the objective/fitness function in the BBO algorithm are determined using the interactive decision tree (IDT) algorithm. It combines the operator's expert knowledge with the BBO algorithm to tune the objective function weights in (9a). The human intervention to modify the weights significantly improves the overall efficiency of the controller.

The IDT algorithm starts with initializing weights w_i for the metrics in the objective function, and it is given by

$$wi = \frac{W}{N} \quad \forall\{\, i = 1,2,3, \ldots, N\}.$$

The BBO algorithm is executed with this objective function. Then, the scaling factors are obtained. Then, the improvement in the performance metrics is compared against the conventional type fuzzy-PID controller ($m = 0$). For easy accessing purposes, the percentage improvement in IAE of DC bus voltage is given as

$$\%\, Imp\ I\ AE\ vdc = \frac{I\ AE\ vdc\,|m - I\ AEvdc|m-1}{I\ AEvdc|m} \times 100\% \quad (7)$$

Then, the operator determines the weakly improved metric j, and improves its weight $w_{i=j}$ by a small amount n_i as $w_{i=j} = \frac{n_i}{N} W | i \in \{\, 1,2,, \ldots, N\}$.

Subsequently, without loss of generality, the operator reduces the weights associated with the other metrics $w_{i \neq j}$ as $w_{i \neq j} = \frac{W\,(N - n_i)}{N(N-1)} \mid i \in \{1,2, \ldots, N\}$.

With the modified weights, the BBO algorithm is executed, and its performance is analyzed. If the measures still require improvement, the weights are incremented by Δn. This process is continued until the response is satisfactory.

4. **RESULTS AND DISCUSSION**

This part discusses the effectiveness of the proposed fuzzy-PID controller using the IDT algorithm to provide reactive power consumption. The test system comprises a three-phase source (415 V, 50 Hz, AC) HSI and a nonlinear load comprising diodes and RL loads. RL loads will act as nonlinear loads because they won't follow the linear principle (Their current does not follow the applied voltage waveform). The proposed controller is connected to the grid via an LCL filter. Figure 4 illustrates the nonlinear load, and Table 3 provides the source and the nonlinear load parameters.

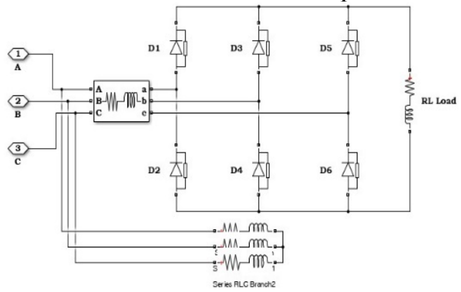

Fig. 4 – Schematic of load used in the simulation

In this study, the simulations were done in MATLAB/Simulink, and the outputs were presented in two ways.

i. Performance of the IDT algorithm in fine-tuning the fuzzy-PID controller.
ii. Comparison of the proposed IDT algorithm-based fuzzy-PID controller with the conventional PI algorithm

Table 3

Source and load parameters used in the simulation.

Item	Parameter	Value
Source	Phase to Phase rms voltage	415 V
	Frequency	50 Hz
	Source Resistance	$1 \times 10^{-6}\,\Omega$
	Source Inductance	1×10^{-6} H
Load	Resistance	10 Ω
	Inductance	300×10^{-3} H
	Diode Resistance R_{on}	0.001 Ω
	Diode Forward Voltage V_f	0.8 V
	Snubber Resistance R_s	500 Ω
	Snubber Capacitance C_s	250×10^{-9} F

4.1 STATCOM PERFORMANCE WITH ITERATIVE DECISION TREE ALGORITHM

The proposed controller starts with initializing the weights in (9a). Initially, the objective function weights are distributed as 0.3 for the IAE of the voltage and the current controller and 0.2 for the ISE of the voltage and the current controller, respectively. Then, the BBO algorithm is executed to obtain the fuzzy PID controller's performance. Subsequently, with the operator's expertise, the objective function weights (9a) are varied to improve the STATCOM performance and compensate for the reactive power. When the objective function (9a) is assigned equal weights, the DC bus voltage reaches 800 at 0.037 s reference voltage with an overshoot of 9.9%. With equal weights assigned to the objective function, the settling time improves up to 30.1%, and the peak overshoot improves up to 25.5%.

Table 5 provides the reactive power compensation for various weights used in the objective function (9a). One can observe that the STATCOM provides a reactive power compensation in all three scenarios. However, close observation reveals that assigning equal weights to the objective functions improves the power factor at the source side by 0.44%. Similarly, the reactive power offered by the source is also reduced by 19.2%. From the STATCOM perspective, one can observe that the active power is reduced by 86.5% with the weight above distribution. This indicates the significance of the IDT algorithm in improving and fine-tuning the STATCOM performance.

4.2 COMPARISON WITH CONVENTIONAL CONTROLLERS

To demonstrate the suggested controller's performance, it is compared to traditional PI controllers that are widely used in STATCOM for reactive power compensation. Though standard tuning procedures are available to tune the PI controller, to ensure optimality, PI controllers are tuned by the proposed BBO algorithm.

The BBO-PI controller exhibits a visible delay in response. At the same time, the proposed controller exhibits faster dynamics. During transients, the BBO-PI controller allows the load to draw more current from the source and distorts the current waveform, affecting the power quality. On the other hand, with the proposed controller, the load draws minimal current from the source during transients, thereby maintaining the power factor close to unity.

Table 4 reports the progressive variation in the weights by the IDT algorithm to tune the controller. As the weights are progressively changed by the operator, a 21.5% improvement in IAEI, 5.3% in IAEV, 5.34% in ISEI, and 0.6% in ISEV are obtained. Similarly, the DC bus voltage transients illustrated in Fig. 5 indicate a significant change in the STATCOM performance.

Table 4.

Active power and reactive power consumption in source, inverter, and grid using IDT method.

Weights	Source			STATCOM		Load		
	Active Power	Reactive Power	Power Factor	Active Power	Reactive Power	Active Power	Reactive Power	Power Factor
w_1=0.3; w_2=0.2; w_3=0.3; w_4=0.2	5.03×10^4	-8084	0.9874	656.7	1.11×10^4	5.05×10^4	8534	0.986
w_1=0.6; w_2=0.1; w_3=0.6; w_4=0.1	5.127×10^4	-6980	0.9909	513.4	1.006×10^4	5.05×10^4	5534	0.986
w_1=0.25; w_2=0.25; w_3=0.25; w_4=0.25	5068×10^4	-6526	0.9918	88.36	1.01×10^4	5.05×10^4	8534	0.986

Table 4 shows various weight changes to reduce integral squared error and integral absolute errors in voltage and current controllers. These reduced errors improved the overall performance of the power system. Table 5 shows active and reactive power usage in several parts of our proposed system, including the source, load, and STATCOM. The data indicated that STATCOM used reactive power rather than the source. Following reactive power consumption, the computed power factor value is kept constant at 0.986, indicating quality power.

The proposed controller beats conventional with improvements up to 66.7% in rise time, 57.9% in settling time, and 73.5% in peak overshoot. Each parameter provides a better value as much as possible when our proposed fuzzy PID IDT is compared with the BBO PI method. The proposed IDT Controller-based fuzzy tuning gives better results than the conventional one. The Fuzzy PID-based IDT controller has a minimum rise time of 0.004, a settling time of 0.037, and a percentage overshoot of 9.98 only.

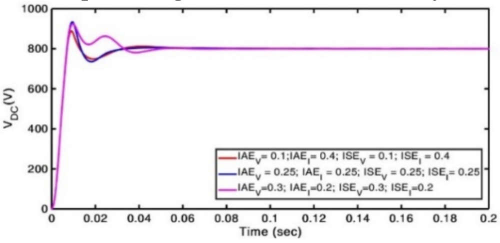

Fig. 5 – Transient response of DC bus voltage for various weights on the current and voltages of IAE and ISE.

The proposed controller reduces the reactive power from the source by 42.7% and improves the power factor by 1.5%. This performance enhancement is due to the fuzzy-PI controller's nonlinear functionality and the fine-tuning of the controller parameters using the IDT algorithm. The main goals of the proposed study are reactive power management and power factor improvement, both of which can be accomplished using the suggested IDT-based fuzzy PID controllers.

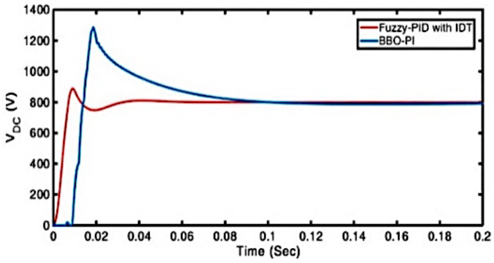

Fig. 6 – Transient response inverter DC voltage of fuzzy PID controller tuning using IDT and PI controller tuned using BBO algorithm.

Figure 6 illustrates the inverter's DC bus voltage transient performance obtained by proposed and conventional controllers. Proposed controller outputs are outperformed.

The above figure shows that a BBO-based PI controller oscillates more than our proposed fuzzy PID IDT algorithms. The BBO algorithm may produce a sudden spike, destroying the system components and/or quality.

5. CONCLUSION

This paper presents the fuzzy-PID controller to compensate for reactive power using a STATCOM for nonlinear loads. A BBO algorithm is proposed to tune the controller parameters. An interactive decision tree algorithm has also been proposed to enhance STATCOM's performance. The simulation results show that the proposed control algorithm provides fast control action, reduces the reactive power from the source by 42.5%, and improves the power factor by 1.5%. The proposed controller enhances the power quality parameters such as power factor, reactive power compensations (Q), and harmonics in power system transmission and distributions. The results further improve weaker weighted metrics to reduce the voltage and current controllers' integral squared and absolute errors. The proposed IDT cont000roller provided a better transient response of DC voltage in the inverter. The proposed IDT-based Fuzzy PID improved the power factor to 0.99 on the source side. Developing a full-fledged controller to handle unbalanced loads effectively will be the future course of investigation. In the future, the proposed technique may apply to various fault systems in the power system to ensure the effectiveness of this controller.

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