



COMPARATIVE ANALYSIS BETWEEN GSA AND CUCKOO SEARCH CONTROL ALGORITHM BASED DSTATCOM

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Abstract

This paper discusses an implementation of DSTATCOM (Static Distribution Compensator) in a distributed power generation system, employing a control technique grounded in compound monitoring. The proposed control technology is designed to isolate key components from the distorted generator load currents. These extracted components are employed to calculate the currents from the reference source, enabling the generation of the DSTATCOM gate signals. This control method is designed to reduce heightened reactive power requirements and harmonic-related distortion, while also improving load balance, whether the loads are linear or nonlinear. DSTATCOM operates effectively under these load conditions, maintaining regulated generator voltage at the point of common coupling (PCC) and ensuring a self-sustaining DC link. Certainly, fine-tuning the parameters of a nature-inspired algorithm is the primary method for enhancing its performance. The deployment, which facilitates the transfer and development of new solutions, is also a key consideration for enhancing its capacity. In this study, the efficiency of the Gravity Search Algorithm (GSA) and Cuckoo Search Algorithm (CSA) was validated using the MATLAB Simulink model. The IGBT serves as an ignition switch, offering minimal switching loss and a straightforward shutdown process. In this study, THD is assessed, and the distortions in current waveforms are reduced using DSTATCOM. The distribution system is modeled and verified using DSTATCOM, with the control system designed to enhance power quality.

Keywords: Static Compensator (STATCOM), Voltage source, Cuckoo search algorithms (CSA), Gravitational search algorithm (GSA), THD (Total Harmonic distortion), Point of common coupling (PCC).

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1. Introduction

A distributed generation (DG) system is a small- to medium-scale electricity source that delivers power close to where it's needed or connects to the existing power grid [1,2]. Hydropower, wind power, solar power, gas, and

other energy sources. may be regarded as Distributed renewable energy sources [3-5]. Hydroelectric potential sites can be found on hills and in remote regions. The machine can be used as a generator with appropriate turbines in a remote location [6-9]. Chu et al. [10] It discusses the transient stability of a distributed induction generator via a proposed parabolic circuit. Calamine et al. [11] proposed a novel method for estimating magnetic induction in an induction generator system. To play a key role in boosting stress and attaining stability, voltage generated under varying loads. The literature [12] has addressed the use of STATCOM to mitigate power quality issues in an autonomous induction generator. For this study, the recommended power conditioner is designed for use with a battery-based power storage system. Joe et al. I referenced [13] a new index designed for Energy Quality Analysis. The key aspects concerning this indicator involve the Euclidean pattern of total harmonic distortions (THD) in the measured quantities voltage and current. Zeng et al. [14] Discuss several reviews on the power circuit topology and control algorithms of the on-grid voltage source converter (VSC) in the power region, focusing on filtration technology. Networked VSC serves as one of the components in distributed power generation and small grid systems. It now offers multiple functions to mitigate power quality issues. Liu et al. [15] It includes compensation for reported harmonics and voltage imbalances, employing a Voltage Source Converter (VSC) strategy tailored for islanded operation within a small network. This compensation was implemented using a simultaneous reference frame control algorithm. The text [16] presents a mathematical analysis of how the generator's supply is affected by the consumer load during induction. The design of the STATCOM's self-excited induction generator (SEIG), relevant to energy quality conditioning, is referenced in the literature [17]. On paper, STATCOM is employed at the common coupling voltage generation point to compensate for the SEIG's inadequate voltage regulation during the dynamic phases of pregnancy. Singh et al. [18] Discuss the implementation of control modeling based on the UNIT and STATCOM models, with STATCOM technical support aimed at enhancing power quality in the SEIG system.

The SEIG Adapter System is also employed in battery charging applications. A logic-based genetic algorithm has been documented in the literature [19]. Bonnert W. Rajakaruna [20] explored advanced control. Power generation technology leveraging SEIG for voltage and frequency control. This system is controlled via additional adjustable resistance on the load side. An advanced STATCOM was proposed based on the relative spin speed theory [21]. It is employed to estimate frequency and assist the STATCOM in synchronizing with the supply system's frequency. Because of this algorithm, variations in stator voltage may occur; these can be eliminated at random during different pregnancies. Other control algorithms employed in an induction generator network include base-adaptive neutral control with steady learning rate [22], vector-based hysteresis control algorithm [23], and similar methods. An observer has reported compound technology in the literature [24]. Designed to enhance strength, this improves the quality of the grid-connected supply system. Moreover, this control proves effective for the distribution generating system owing to specific attributes.

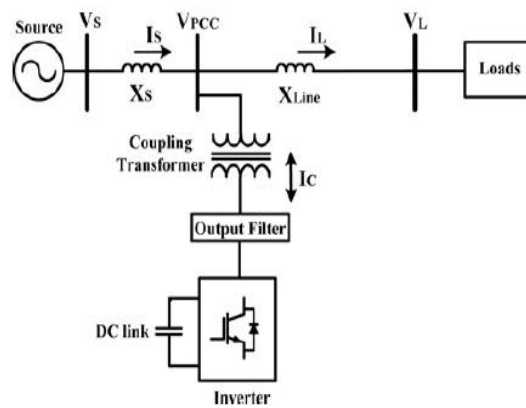


Figure1. DSTATCOM

DSTATCOM is a robust, responsive power controller designed to enhance power quality at the point where it connects to the utility distribution system. It serves as the primary controller for distribution networks. It has been widely employed to accurately control system tension and/or to balance the load. By adjusting the capacitance and phase angle of the VSC voltage relative to the PCC voltage, you can exchange active and reactive power with the distribution system provided an Energy Storage System (ESS) is integrated into the DC bus [11-13]. However, a DSTATCOM-powered capacitor is favored for enhancing power quality by addressing issues such as reactive power compensation to improve module power factor, voltage regulation at the PCC, load balancing, and neutral current compensation.

2. Principle operation of DSTATCOM

The primary goal of DSTATCOM is to monitor current issues related to energy efficiency. DSTATCOMs address reactive power, erratic currents, neutral current, and harmonic distortion issues most commonly tied to power quality. In AC transmission systems, DSTATCOM has evolved into a practical technology capable of offering reactive power control, static current management, and when necessary handling load and resonant current flows. This has expanded alongside advancements in particular systems, control techniques, and solid-state devices over the past twenty-five years. Based on the requirements, control technology, and the structure chosen, these tasks may be carried out either separately or in combination. Typically, DSTATCOM is categorized into three types: two-wire single-phase, three-phase three-wire, and three-phase four-wire to accommodate the requirements of three distinct customer load configurations for processing equipment. Since 1984, a range of methods have been created and studied for use in various applications. Single-phase DSTATCOMs were designed employing current source converters (CSC) paired with inductive energy storage and a power system (VSC).

The primary purpose of DSTATCOMs is to address the power quality issues affecting the manufacturing process. DSTATCOM addresses most current performance challenges including spring power, imbalance, static flow, harmonics (if present), and inherent adjustments by customers or other supply sources and delivers sinusoidal, regulated power with a DC voltage source.

Specifically, DSTATCOM features a VSC linked through a DC cable, and as illustrated in Figure 2, its AC terminals are generally tied to consumer loads or connected via a PCC. VSC incorporates PWM power; consequently, relatively small temporary components are designed to reduce wave turbulence. Typically, VSC is controlled via PWM current control technology to introduce appropriate fluids into the system.

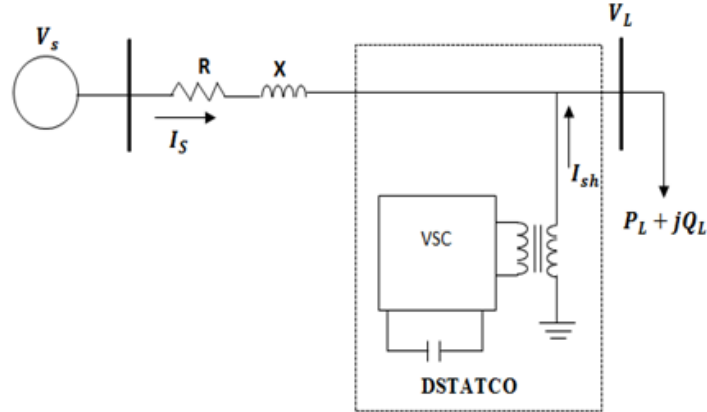


Fig2: Block diagram of compensation by DSTATCOM

3. Instantaneous reactive power theory (IRPT)

Figure 3 illustrates the IRPT-based control algorithm for DSTATCOMs. The three-phase load currents and PCC voltages are measured and then employed to determine the instantaneous active and reactive power values. The three-phase PCC voltages are detected and filtered through bandpass filters to remove their ripple components, then transformed and labeled as (v_{sa} , v_{sb} , v_{sc}). A first-order Butterworth filter serves as the BPF [14].

These three-phase filtered load voltages are converted into two-phase $\alpha\beta$ orthogonal coordinates (v_{α} , v_{β}) as

$$\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix}$$

These three-phase filtered load current are transformed into two-phase $\alpha\beta$ orthogonal coordinates (i_{α} , i_{β}) as

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

The instantaneous active power p_L and the instantaneous reactive power q_L flowing into the load side are calculated from these two sets of expressions.

$$\begin{pmatrix} p_L \\ q_L \end{pmatrix} = \begin{pmatrix} v_{\alpha} & v_{\beta} \\ v_{\beta} & -v_{\alpha} \end{pmatrix} \begin{pmatrix} i_{L\alpha} \\ i_{L\beta} \end{pmatrix}.$$

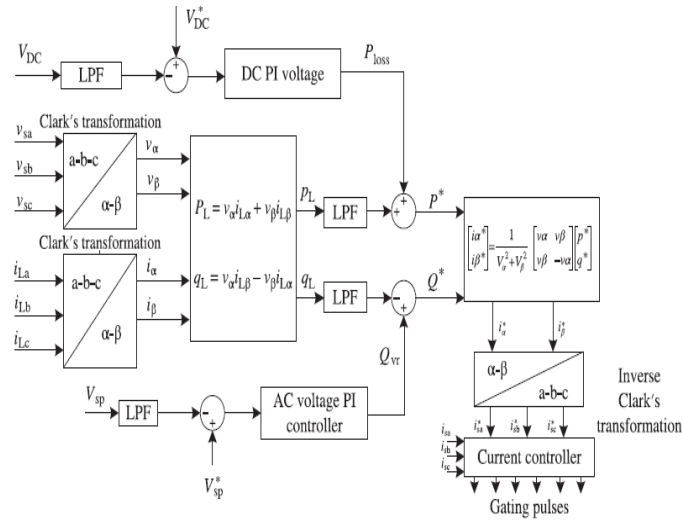


Figure 3: Instantaneous reactive power theory-based control algorithm of DSTATCOMs

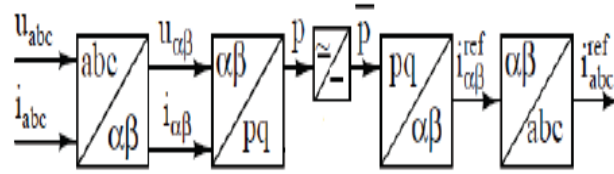


Figure 4: Block diagram of controlled current approach

Let $\widetilde{P}_L$ and $\overline{P}_L$ be the DC component and the P_L AC element, and let $\widetilde{Q}_L$ and $\overline{Q}_L$ be the DC component and the Q_L AC element, alternately.

$$P_L = \overline{P}_L + \widetilde{P}_L, \quad q_L = \overline{q}_L + \widetilde{q}_L$$

Under these conditions, the fundamental load power is broken down into direct-current components p_L and q_L , while distortion or negative-sequence components are represented as alternating-current components $\sim p_L$ and $\sim q_L$. The DC components of effective and passive power are extracted using two LPFs.

The reference current in a two-phase system is given by the equation below. i_{sa} , i_{sb} , and i_{sc}^* represent the reference three-phase storage signals:

$$\begin{pmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix}^{-1} \begin{pmatrix} p^* \\ q^* \end{pmatrix}$$

This IRPT-based control algorithm can be readily adapted for managing supply currents in indirect current control systems. In this scenario, for the power factor correction mode of the DSTATCOM, after transforming from the $\alpha\beta$ to the abc frame, the reference values are $p = P_L + P_{loss}$ and $q = q_L - q_{vr}$. These transformed three-phase currents serve as the reference supply currents, which are then compared with the sensed supply currents in

the PWM current controllers to enable indirect current control of the DSTATCOM. Ploss refers to the instantaneous active power required to regulate the DC capacitor voltage of the VSC, which functions as a DSTATCOM, to match its desired reference value. Additionally, qvr represents the instantaneous reactive power required to bring the PCC voltage to its reference level, while PL and qL denote the fundamental active and reactive power components drawn by the load, respectively. For ZVR at the Point of Common Coupling (PCC) under the voltage regulation mode of the DSTATCOM a PI voltage controller is applied to the PCC voltage, mirroring the aforementioned algorithms. Its output is then utilized to compute p and q as $p = PL + Ploss$ and $q = qL - qvr$. Following the transformation, the three-phase transformed currents serve as reference supply currents, which are then compared with the sensed supply currents illustrated in the figure for implementing indirect current control in the DSTATCOM.

4. PI Controller

In PI control systems, ensuring the controller parameters yield a stable system is crucial. One approach for obtaining these parameters is the SBL method. The SBL method is a graphical technique for identifying controller parameters that ensure system stability. Selecting the right type of controller is essential for meeting the desired design specifications. In most cases, simpler, structured controllers are favored. Industry often favors PID controllers due to their straightforward design and reliable performance traits. The optimization process involves choosing the most suitable option from the existing scenarios. Optimization models using Simulink have been created, guided by integral performance metrics. The optimization process starts by inputting initial values for the controller parameters. Once the smallest error value is achieved, the optimization halts, yielding the optimal controller parameters. For tuning the PI controller parameters, the IAE, ISE, and ITAE performance criteria are employed.

$$\begin{aligned} 1. \quad IAE &= \int |e(t)| dt \\ 2. \quad ISE &= \int e^2(t) dt \\ 3. \quad ITAE &= \int t |e^2(t)| dt \end{aligned}$$

5. Gravitational Search Algorithm and Cuckoo Search Algorithm

This paper introduces a Gravitational Search Algorithm (GSA) to enhance voltage profile and stability by addressing the optimal placement and sizing of StatCom devices. GSA was effectively evaluated on the SVC Allocation problem [15] and demonstrated that it delivers high-quality optimal solutions compared to CSA. The GSA approach was also used to address other power system engineering challenges, such as the reactive power dispatch problem [16-17] optimal power flow, and similar issues. GSA offered effective solutions to the aforementioned problems, outperforming classical optimization methods and also cutting down on computational effort. Specifically, the original GSA algorithm consists of the following steps: initialization, compute the gravitational forces,

determine acceleration and velocity, and update the solution's position. These steps are outlined below, in order. Initially, the masses are created randomly within the solution space. Each mass corresponds to a solution that is:

$$\mathbf{x}_i = (x_{i,1}, x_{i,2}, \dots, x_{i,D}) \quad i = 1, 2, \dots, NP$$

where NP is the number of solutions. Each solution $\mathbf{x}_i$ is a D-dimensional vector.

The gravitational force between the masses is determined by the following formula [10].

$$F_{i,j}^g = G^g \frac{M_i^g \times M_j^g}{R_{i,j}^g + \epsilon} (x_j^g - x_i^g)$$

where M_i^g and M_j^g represent the masses of solutions i and j at generation g , respectively. ϵ is a small constant, and $R_{i,j}^g$ represents the Euclidean distance between two masses i and j .

In operations research, cuckoo search is an optimization algorithm developed by Xin-she Yang and Suash Deb in 2009. It was inspired by the behavior of certain cuckoo species, which are obligate brood parasites and lay their eggs in the nests of other bird species [18]. Certain host birds may confront invading cuckoos directly. For instance, when a host bird realizes the eggs in its nest aren't its own, it may either eject the foreign eggs or leave the nest entirely, constructing a new one elsewhere. Certain cuckoo species, like the New World brood-parasitic *Tapera*, have evolved to the point where female parasitic cuckoos often exhibit highly specialized mimicry of the color and pattern of eggs from a select group of host species. The cuckoo search algorithm was inspired by this breeding behavior and is therefore suitable for a variety of optimization problems.

Cuckoo search (CS) employs the following representations:

Every egg in a nest stands for a solution, while a cuckoo egg symbolizes a fresh one. The goal is to apply the newer, possibly superior solutions referred to as "cuckoos" to replace the less effective ones in the nests. In its simplest form, each nest contains a single egg [19]. The algorithm can be adapted to more complex scenarios where each nest contains multiple eggs, each symbolizing a set of potential solutions.

CS operates under three idealized principles. Each cuckoo lays one egg at a time and places it in a randomly selected nest. Nests with the highest-quality eggs are retained for the next generation. The total number of host nests remains constant, and each cuckoo's egg is detected by the host with probability $p_a \in (0,1)$. If detected, the host may eject the egg or abandon the nest entirely, then construct a fresh one.

6. Block diagram of DSTATCOM and results

The system is simulated under a nonlinear load condition using a PI controller-based DSTATCOM approach. The primary goal is to reduce odd harmonic components by applying the Cuckoo Search Algorithm and the Gravitational Search Algorithm.

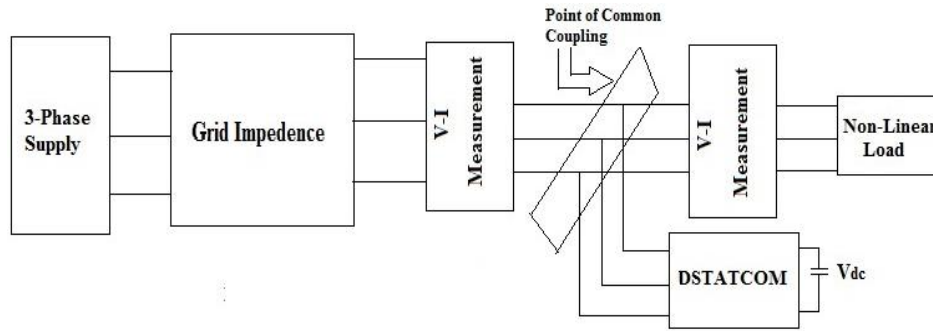


Figure 5: Block diagram of proposed model system

The above simulation can be conducted based on three criteria, namely: IAE, ISE, and ITAE. As shown in Table 2, the ISE criterion yields the lowest THD compared to IAE and ITAE.

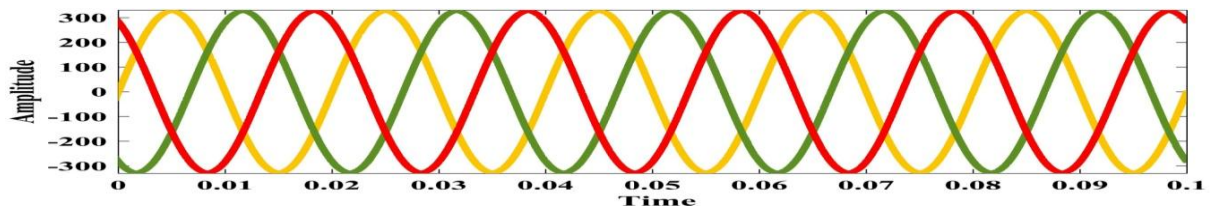


Figure 6: Waveform of source voltage.

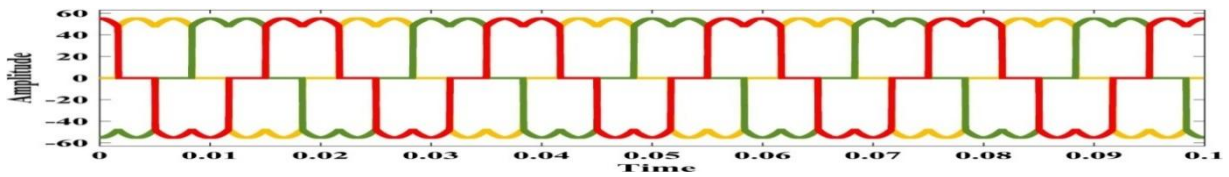


Figure 7: Waveform of source current without filter.

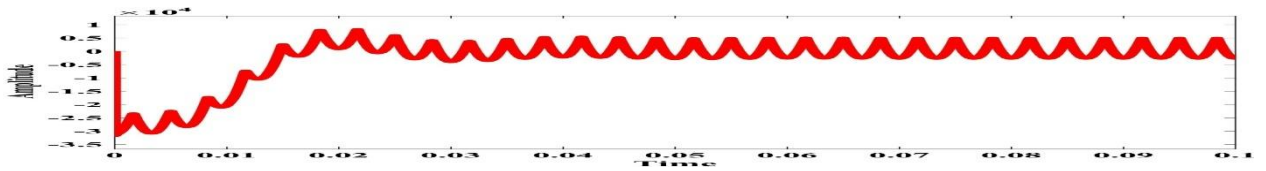


Figure 8: Waveform of P-Loss and Active power loss

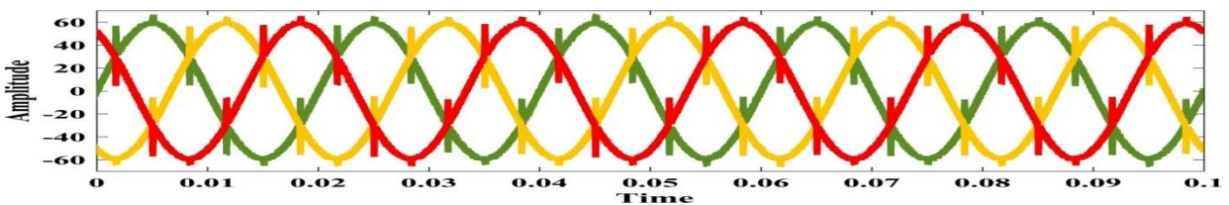


Figure 9: Waveform of source current with DSTATCOM

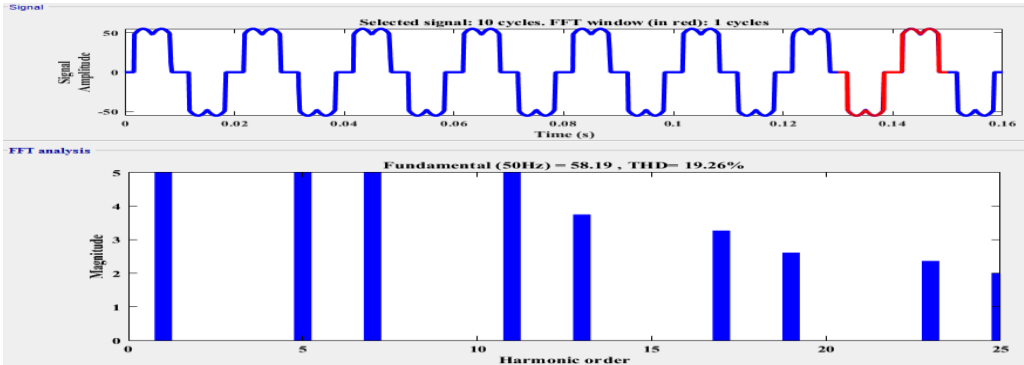


Figure 10: FFT analysis of source current without filter

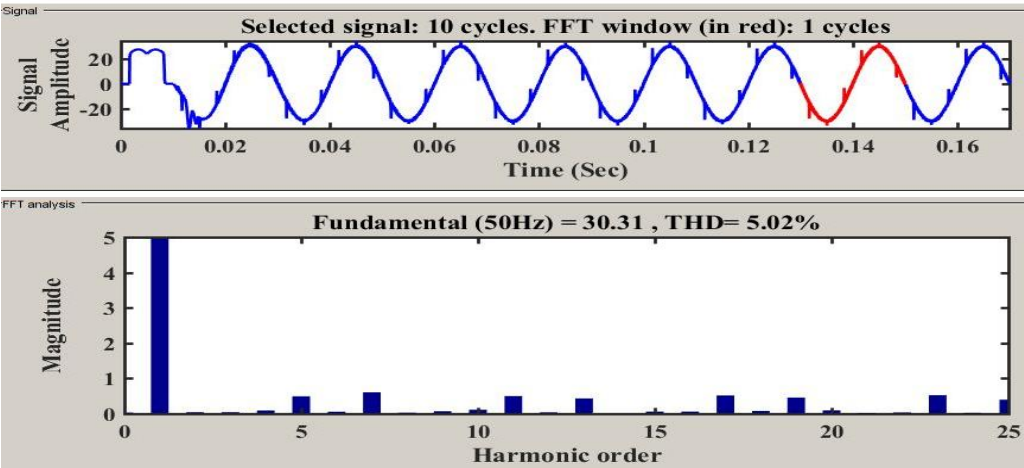


Figure 11: FFT analysis of Source current via Cuckoo Search (ISE Criteria)

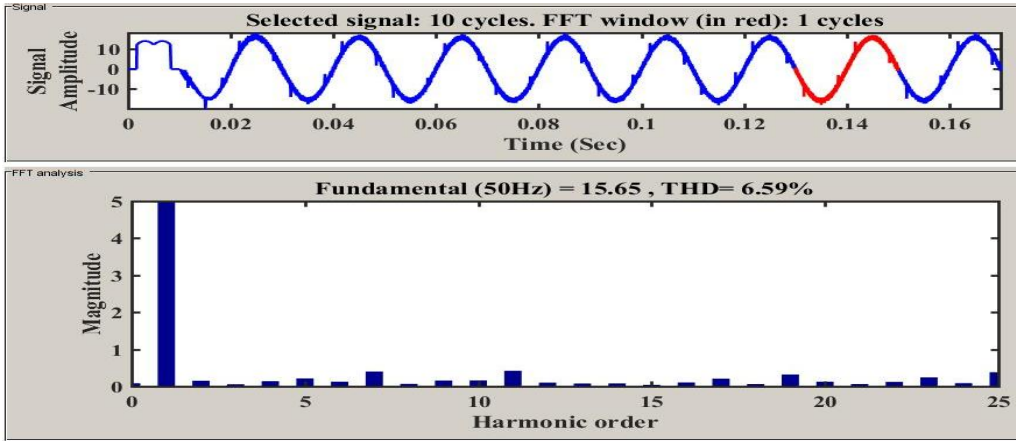


Figure 11: FFT analysis of Source current via Cuckoo Search (ITAE Criteria)

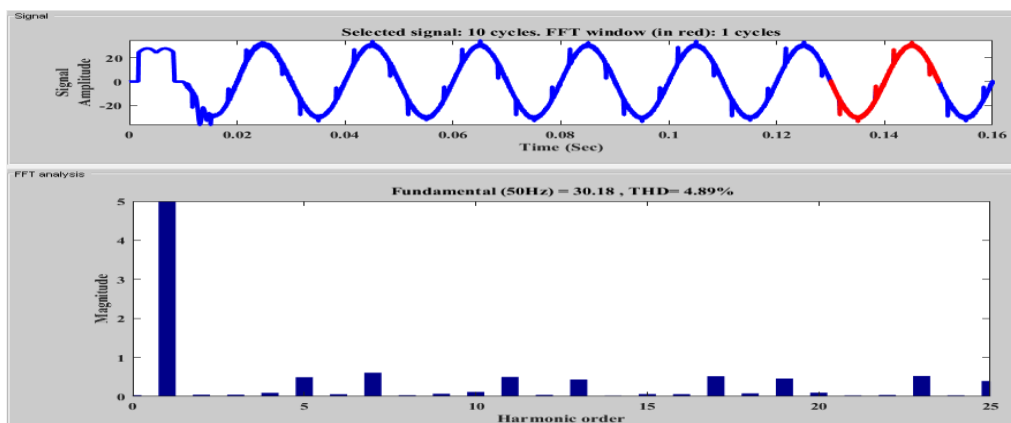


Figure 13: FFT analysis of Source current via Gravitational Search (ISE Criteria)

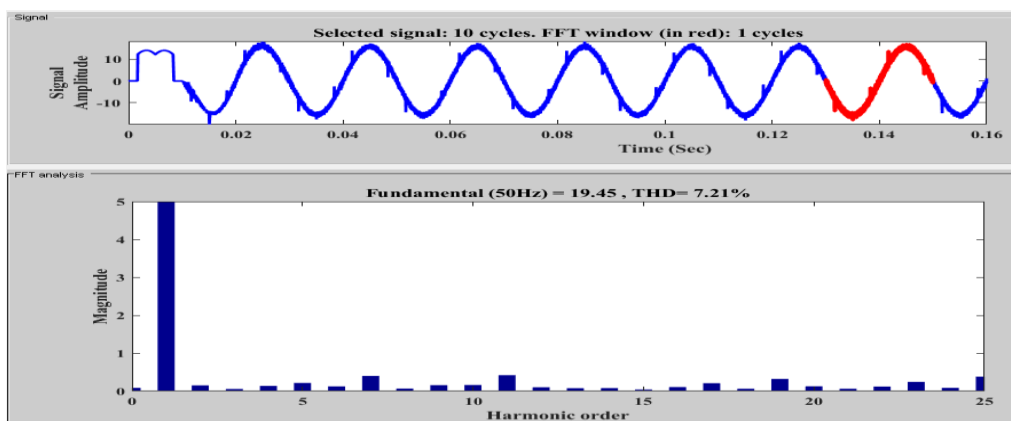


Figure 14: FFT analysis of Source current via Gravitational Search (IAE Criteria)

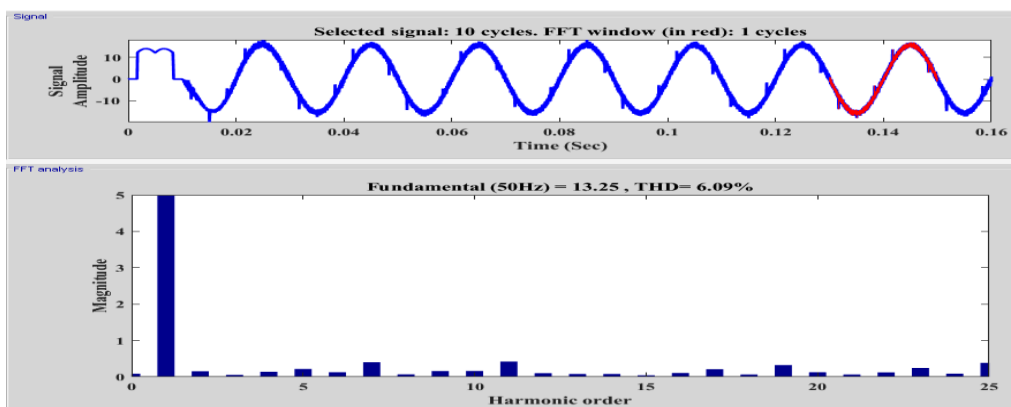


Figure 15: FFT analysis of Source current via Gravitational Search (ITAE Criteria)

Table 1:- Cuckoo Search Algorithm Parameter

GSA Parameter	IAE	ISE	ITAE
P	61.23	39.91	80.15
I	46.31	39.15	50.71
Kp	21.22	70.12	80.12
Ki	22. 51	43.18	81.29

CURRENTTHD (%)	8.05	5.02	6.59
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Table 1 presents the complete parameter values used throughout the entire MATLAB simulation period during which the model was run. As shown in the table. It is evident that the current THD will be simultaneously reduced under the ISE criteria relative to the other criteria, i.e., IAE and ITAE.

Table 2:- Gravitational Search Algorithm Parameter

GSA Parameter	IAE	ISE	ITAE
P	64.92	54.21	80.40
I	26.32	42.22	63.30
Kp	43.21	56.28	69.12
Ki	42.22	48.54	71.35
CURRENTTHD (%)	7.21	4.89	6.09

Table 2 displays the complete parameter values used throughout the entire MATLAB simulation period. As shown in the table. It is evident that, under the ISE criterion, the current THD will be simultaneously reduced compared to the IAE and ITAE criteria. The parameters P, I, Kp, and Ki represent the simulation settings for a PI controller, which can be optimized using the Cuckoo Search Algorithm and the Gravitational Search Algorithm.

7. Conclusion

This paper explores GSA and CSA control algorithms designed for a three-phase , three-wire DSTATCOM to enhance power quality. The primary function of this DSTATCOM is to compensate for reactive power, mitigate harmonic loads, and balance the source currents. Various control algorithms based on instantaneous reactive power (IRP) theory are employed to produce the reference current. DSTATCOM supplies the reactive power needed by the load, ensuring the source current maintains a unity power factor.

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