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COMPARATIVE ANALYSIS OF CONTROLLERS AND THEIR OPTIMIZATION USING META-HEURISTIC TECHNIQUE FOR PHOTO-VOLTAIC FED STATCOM.

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Abstract:

Large-scale PV power generation connected to the grid is causing a number of problems, such as voltage stability, reactive power adjustment, operational dependability, and more. In order to offer reactive power adjustment and boost the controllability of PV systems, new switching devices and improved control techniques of FACTS devices like STATCOM are deployed. Proposed control techniques include Proportional-Integral (PI) and Fuzzy-PI controllers (FL-PI), as well as their optimization using newly created Hybrid Chi-Mo optimization. The benefit of Hybrid Chi-Mo optimization is that it can solve high-dimensional problems while reducing two fundamental issues, such as sluggish convergence speed and local optimal trapping. Comparing the PI controller to the optimized FL-PI controller, the simulation results have been enhanced.

Keywords: Power Quality, PV-STATCOM, Fuzzy-PI controller, Optimization .

1. Introduction

Due to potential to lessen greenhouse impacts, large photovoltaic (PV) systems and wind power facilities are becoming more popular [1]. On the other side, intermittent and unpredictable electricity generation occurs because of PV arrays and wind farms, which is responsible for voltage and stability issues in a power supply because of the high penetration level of a PV system or wind [2]. These incidents have been reduced using a variety of strategies, including energy storage systems [3]. Due to its capacity to provide the necessary dc voltage at a low capital cost, solar photovoltaic (PV) systems are a rapidly growing technology [4].

Power distribution systems are dealing with serious power quality issues such total harmonic distortion (THD), excessive reactive power, unbalanced load, etc. due to various nonlinear loads and unchecked expansion. At the distribution end, a device similar to STATCOM called DSTATCOM is employed to give a solution for these power quality problems. There are several ways to interface STATCOM with the distribution system, which are described [5]. For reliable and effective regulation of different power quality parameters, STATCOM maintains its input DC voltage at the proper level. Traditionally, the STATCOM is provided using a Proportional Integral (PI) controller to do this. Several adaptive controllers are used to show how the Static Var Compensator (SVC) performs better in terms of voltage responsiveness, reactive power compensation, and losses [6]. To maintain the dc voltage, replacing the grid with a PV source is necessary when integrating the PV system with the distribution system. Several studies on PV-STATCOM have been published in the literature due to this issue [7]. Now days, systems are controlled using fuzzy logic controllers (FLCs). To address problems with power quality, FLCs have been implemented in the distribution system. FLC works in conjunction with a pitch angle controller and a STATCOM to balance the power output and manage the voltage output of a wind generator [8]. By regulating the dc-link voltage of converters, the FLC is utilized to improve the low-voltage ride-through capabilities of an adjustable speed synchronous machine (SM) [9]. Operators can evaluate the FLC where voltage sag in line by looking at the kind of issue, the location of the issue, and the computed fault rate in order to predict the fault rates in each power distribution line [10].

Fuzzy logic-based PV-STATCOM is utilized in this work to enhance power quality, ensuring smooth power flow, and decreasing voltage fluctuations brought on by intermittent solar power generation and a nonlinear load linked at the distribution end. A novel metaheuristic approach called Hybrid Chi-Mo is implemented to enhance the PI controller gains and membership functions of FLCs [11]. Hybrid Chi-Mo optimization has several benefits, including low computational costs, simplicity in handling discrete optimization problems, rapid convergence, and convergence to global solutions for high-dimensional problems. The STATCOM's voltage and current regulators are both examined in this paper. Simulink is used in conjunction with MATLAB code (Hybrid Chi-Mo) for both the control actions PI and fuzzy-PI to implement the suggested solution.

2. Methodology

The 66 parallel branches that make up the PV system used in this study are interconnected. There are five PV modules in total on each branch. The system also includes a regulated three-phase inverter, a boost converter, and MPPT control. This system includes the two control stages shown in (Figure 1). (i). DC/DC conversion MPPT controller (ii). The DC/AC controller has two loops to improve system performance during conversion. The direct and quadrature currents are provided by the second loop, while the voltage across the dc connection is regulated in the first loop (I_d, I_q). To obtain the optimal dynamic behavior of solar systems connected with the distribution network, all of these controls rely on fuzzy and PI controllers, whose parameters are adjusted by applying metaheuristic optimization algorithm like Hybrid Chi-Mo.

The d-q domain control, which is straightforward and effective in dynamic settings, is shown in Fig. 1. In the abc to d-q conversions, the phase angle received from the PLL is used to produce the grid voltage Vgrid, abc and grid current Igrid, abc in the d-q reference frame. The voltage and current at PCC in the d-q frame are given by the formulae below [12].

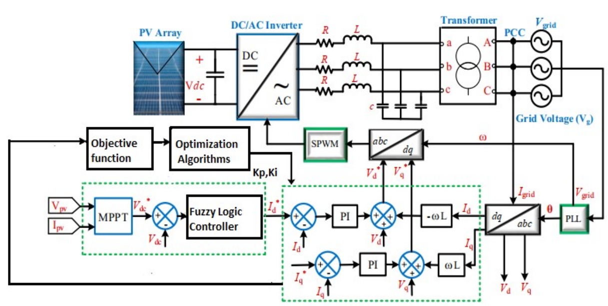

Fig.1 PV-STATCOM Control

$$\begin{bmatrix} V_d \\ V_a \\ V_0 \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{z}\right) & \cos\left(\theta + \frac{2\pi}{z}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{z}\right) & -\sin\left(\theta + \frac{2\pi}{z}\right) \\ \frac{2}{z} & \frac{2}{z} & \frac{2}{z} \end{bmatrix} \begin{bmatrix} V_d \\ V_a \\ V_0 \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_d \\ I_a \\ I_0 \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{z}\right) & \cos\left(\theta + \frac{2\pi}{z}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{z}\right) & -\sin\left(\theta + \frac{2\pi}{z}\right) \\ \frac{2}{z} & \frac{2}{z} & \frac{2}{z} \end{bmatrix} \begin{bmatrix} I_d \\ I_a \\ I_0 \end{bmatrix} \quad (2)$$

Where V_d, I_d and V_q, I_q are the magnitudes of voltages and currents in d-q frames and V_a, V_b, V_c and I_a, I_b, I_c are the 3-ø grid parameters of voltages and currents. The conversion of abc to d-q frame is important in grid-connected converter operations. The PI controller generates the reference values of $V_d{}^*$ and $V_q{}^*$ which is essential for d-q to abc conversion to generate V_{abc}. The values of V_{abc} are then fed to pulse width modulation switching techniques to produce gate pulses for the converter [13]-[14]. The equations of real and reactive power by using Park's transformation are given by,

$$P = \frac{3}{2}\left(V_d{}^*I_d + V_q{}^*I_q\right) \quad (3)$$

$$Q = \frac{3}{2}\left(Vq{}^*I_d + V_d{}^*I_q\right) \quad (4)$$

The reference values of $V_d{}^*$ and $V_q{}^*$ are obtained through current control loop with line frequency shown in Fig 1. with following equations:

$$V_d^* = I_d^* - I_d\left(K_{pd} + \frac{K_{id}}{s}\right) - \omega{}^*L_f{}^*I_q + V_d \quad (5)$$

$$V_q^* = I_q^* - I_d\left(K_{pq} + \frac{K_{iq}}{s}\right) - \omega{}^*L_f{}^*I_d + V_q \quad (6)$$

2.1 Fuzzy logic based PV-STATCOM

Fuzzy logic control is used in this part to describe how PV-STATCOM regulates its DC voltage. The PI controllers are commonly used in exercises for a range of control applications and produce excellent results when the system variables are understood. Nevertheless, as operating conditions change, more modification can be needed for improved outcomes [15]–[16]. The fuzzy-based control system is used in practice to get around this problem. The fuzzy controller system is divided into three parts: input, processing, and output. The processing step uses membership functions and truth values to minimize error. The output values are defuzzified into the precise regulated amounts at this stage. A fuzzy logic system has been built in the PV-STATCOM, as shown in Fig. 1. The DC link serves as an essential component in PV systems connected to the utility network because it connects the boost converter and the AC side converter. The dc capacitor is also used to improve power quality and meet system requirements. As a result, the power flow in PV systems is controlled by a DC regulator. The

DC-link voltage error (e) and rate of change of error (e) are the input side parameters for fuzzy controllers, and they provide an output that is used to establish the reference value of current (i_d^*). The input and output side membership functions are correctly defined in the MATLAB FIS editor to ensure correctness in outcomes.

The fuzzy rules are designed based on actual experience and simulations to get the best system performance. The IF (condition) and THEN statements used in fuzzy rules (action). The fuzzy interfaces fuzzified the inputs to the inference engine. It accepts input that is precise and returns a membership value that is within the supplied range. MATLAB's Toolbox is used to implement the Mamdani type fuzzy. Both input and output use the triangle membership function approach. Defuzzification of linguistic variables yields a crisp quantity as the result. The output signal is defuzzified with the centre of gravity method [17]. This method provides a clear value based on the centre of gravity of the fuzzy set. There are several sub-areas in the region of the membership function distribution that is utilized to represent the combined control action. The area and centroid of each sub-area are identified, and the defuzzified value for a discrete fuzzy set is then obtained by adding the areas of all the sub-areas. Following defuzzification, the value of $\bar{y}$ is given by,

$$\bar{y} = \frac{\sum_{i=1}^{M} \mu_i \bar{y}_i}{\sum_{i=1}^{M} \mu_i} \tag{7}$$

$\bar{y}_i$ - represents the sample elements

μ_i -represents membership function

Table 1 Fuzzy Rules

	Error(e)						
Change in error (Δe)	***NB***	***NM***	***NS***	***ZO***	***PS***	***PM***	***PB***
NB	*NB*	*PB*	*PB*	*PM*	*PM*	*PS*	*PS*
NM	*NM*	*PB*	*PB*	*PM*	*PM*	*PS*	*ZO*
NS	*NS*	*PM*	*PM*	*PM*	*PS*	*ZO*	*NS*
ZO	*ZO*	*PM*	*PS*	*PS*	*ZO*	*NS*	*NM*
PS	*PS*	*PS*	*PS*	*ZO*	*NS*	*NS*	*NM*
PM	*PM*	*PS*	*ZO*	*NS*	*PM*	*NM*	*NM*
PB	*PB*	*ZO*	*NS*	*NM*	*PM*	*NM*	*NM*

The universe of discourse is separated into seven grades based on two variables (e, Δe): "*NB*", "*NM*", "*NS*", "*ZO*", "*PS*", "*PM*" and "*PB*". The system's resolution, sensitivity, and robustness are improved by using closed triangle membership functions shown in Fig. 2.

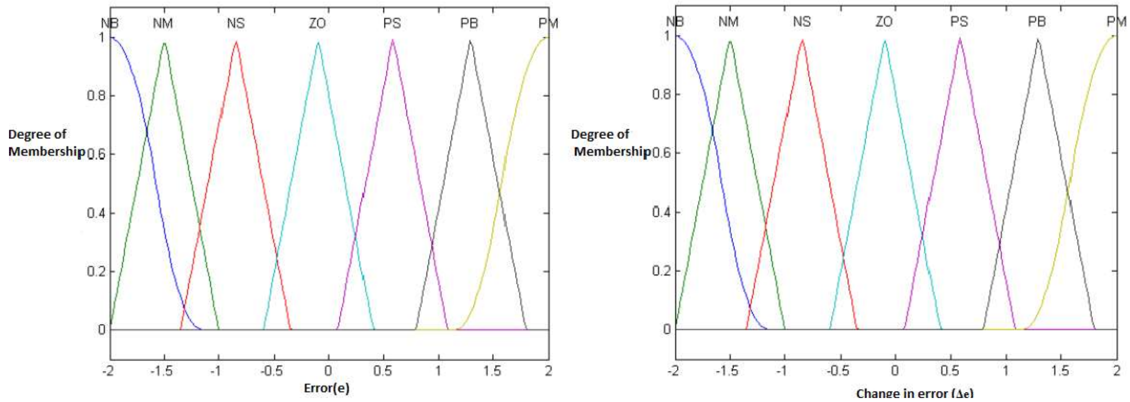

Fig. 2 Membership function

Table 2 System Parameters

Parameters	Values
Voltage across PV	450V
Current across PV	1650A
DC link voltage	500V
Variable load	10kVA to 30kVA

2.2 Optimization Algorithm

The goal of solving an optimization problem is to identify the optimal solutions that take into account the problem's established constraints and the objective function. Population meta-heuristics are the main techniques used to find answers to optimization issues. The suggested Hybrid Chi-Mo metaheuristic approach is used in this study to solve an optimization issue. Genetic algorithms are used to resolve the resource allocation problems. To demonstrate how GA [18]-[19] may be used to solve optimization issues, a numerical example is given. The KNN method is now modified using self-adaptive step firefly algorithm approaches. This study demonstrates that the recommended approach improves results while operating considerably more quickly than the conventional KNN. In turn, this lowers the cost of calculation. The proposed Hybrid Chi-Mo metaheuristic method is designed by combining features, such as prognosticate and Fission-Fusion characteristics, utilized from the Chimp optimization algorithm (COA) [20]–[22] and Spider monkey optimization (SMO) [23]–[24] to address complex optimization issues in engineering applications. The controller settings are enhanced by a mixture of the primates' features, which helps to boost the system's efficiency.

2.2 Fitness Function:

In this research, the fitness function denoted by F(x) used to improve the PI and fuzzy logic controller parameters, namely Kp1, Ki1, Kp2, Ki2. The mean square error of the dc-link voltage to be reduced are taken into consideration as the fitness function to get the best controller settings.

$$\text{Min } F(x) = D_1 \int_0^{T\max} te(t)dt \tag{8}$$

Where e denotes the error and D_1 indicates the weight constant.

A set of controller parameters are given below contains population values chosen randomly,

$0.01 < P_1, P_2, P_3 < 10$; $0.01 < Kp_1, Ki_1, Kp_2, Ki_2 < 100$

2.3 Hybrid Chi-Mo optimization algorithm

The Hybrid Chi-Mo metaheuristic algorithm is used to find the optimal solution; it effectively balances exploitation and exploration circumstances to broaden and intensify the search and produce a global optimum solution. To obtain a clear start on the Chi-Mo optimization, a dimensional form of the position vector with a variety of viable neighbors is provided in this step. As a result, the bonobo's stance (i, j) is adjusted to take into account the position of the prey (i^*, j^*). Initializing the values between 'f', 'b' vectors considers the various places for search space. The location $(i^*–i^*, j^*)$ is determined by considering values ranging from, $f = (1,0), c = (1,1)$ *and* $b = (1,1)$.

$$X_{bon}(t+1) = \frac{X_1 + X_2 + X_3 + X_4}{4} \tag{9}$$

$$X^{t+1}_{howler,ij} = X^{t}_{howler,\min j} + X(0,1)\cdot(X_{howler,\max j} - X_{howler,\min j}) \tag{10}$$

As t signifies the present number of iterations, and f, c *and* b shows the vector coefficients. X_{prey} Indicates vector representation of prey and X_{bon} represents vector location of the bonobo.

Comparing equation (9) and (10) updated position is by equation (11)

$$X^{t+1}_{ij} = 0.5\,X^{t+1}_{ij,howler} + 0.5X^{t+1}_{ij,bonobo} \tag{11}$$

Position update by each search agent is represented by equation (11),

$$X^{t+1}_{ij} = 2\begin{bmatrix} X^{t}_{howler,\min j} + X(0,1)\cdot \\ \left(X_{howler,\max j} - X_{howler,\min j}\right) \end{bmatrix} + 0.125\begin{Bmatrix} [X_u - f_1(h_u)]+ \\ [X_v - f_2(h_v)]+ \\ [X_w - f_3(h_w)]+ \\ X_x - f_4(h_x) \end{Bmatrix} \tag{12}$$

3. Results and discussion

As illustrated in Fig. 3, the system is modelled using varying solar radiations at various time intervals. The irradiance is first set at $1000W/m^2$ and then declines from 0.5s to 0.6s up to $600W/m^2$ before increasing to $1000W/m^2$ from 1.2s to 1.3s later. The actual and reactive power generation of the PV system is displayed in Fig. 4. The control algorithms PI-Hybrid Chi-Mo and Fuzzy-PI-Hybrid Chi-Mo are considered in several simulation iterations. According to Fig. 7, the DC link voltage remains constant regardless of changes in radiation intensity. For the purpose of comparing dc voltage, several configurations including PI-SMO, PI-COA, PI Hybrid Chi-Mo, and fuzzy-PI Hybrid Chi-Mo are taken into consideration. Voltage fluctuations are greatly reduced by the fuzzy-PI Hybrid Chi-Mo, demonstrating its usefulness.

Several scenarios are used to model the system, the first of which is PI-hybrid Chi-MO and the second of which is Fuzzy-PI Hybrid Chi-MO. The integration of a grid-connected PV system utilizing a PV inverter requires a high-performance controller with a dynamic responsiveness that rapidly approaches steady-state while reducing error. The objective of this study is to create an algorithm that improves PI and fuzzy controller performance. The controller settings are set to their optimal values using this method, which is based on a hybrid Chi-Mo optimization algorithm. The output voltage of STATCOM with PI hybrid Chi-Mo and fuzzy-PI hybrid Chi-Mo is shown in Fig. 6 without optimization. With proposed Fuzzy PI hybrid Chi-Mo gives less overshoot compared with other ones. Fig. 5 shows the reactive power output from STATCOM to compensate voltage fluctuations caused by intermittent radiations.

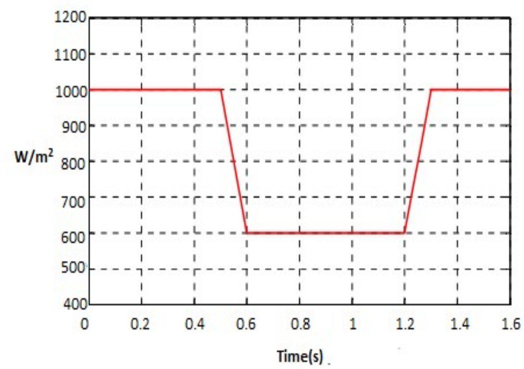

Fig. 3 Variations in irradiance

By offering precise reactive power, the suggested fuzzy-PI hybrid Chi-Mo regulates voltage with accuracy. By comparing the transient behavior of all three configurations, it can be shown that the reaction time of the proposed system is quicker. The settling times of the response without optimization and with optimization for PI and Fuzzy-PI controllers are, respectively, 0.41s, 0.16s, and 0.05s.

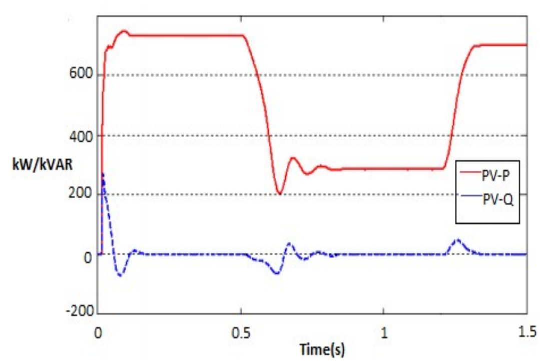

Fig. 4 PV system real and reactive power

Also, the overshoot of the suggested optimization for the PI and fuzzy-PI controllers yields values of 38.58% and 26.4%, respectively, demonstrating that the performance attained with the fuzzy-PI controller is quicker and more stable than the PI controller under various operating situations. Moreover, Fuzzy-PI requires less reactive power to maintain voltage stability than other methods. The transitory behavior in Table 3 demonstrates the efficacy of the fuzzy-PI hybrid Chi-Mo optimization method.

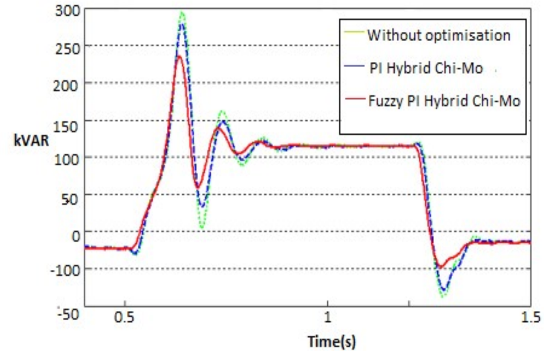

Fig. 5 Reactive power output of PV-STATCOM

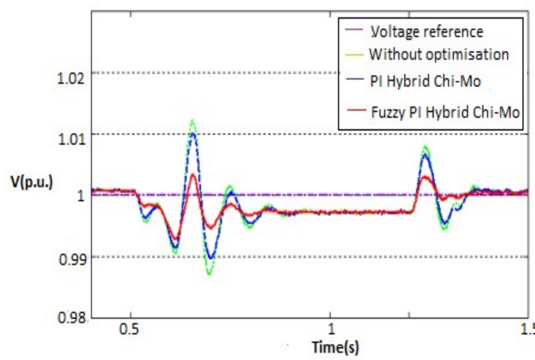

Fig. 6 Voltage response of PV-STATCOM

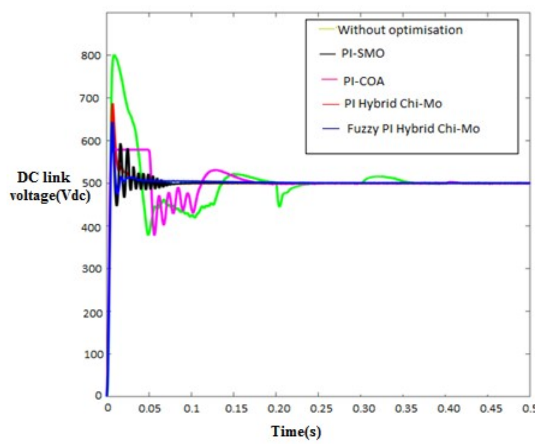

Fig. 7 DC link voltage

Table 3 Transient Response

Response specifications	Without optimization	PI hybrid Chi-Mo	Fuzzy-PI hybrid Chi-Mo
Rise time(s)	0.02	0.015	0.01
Settling time(s)	0.41	0.16	0.005
Overshoot (%)	60.34	38.58	26.4

4. Conclusion

This study compares the performance of PI-based and Fuzzy-PI-based hybrid Chi-Mo optimization algorithms for improving the power quality of distribution systems using PV-STATCOM. These controllers are used to lower dc-link voltage fluctuations, keep voltage constant by regulating reactive power compensation, which is brought on by fluctuating solar radiations and the presence of nonlinear loads. The benefits of hybrid Chi-Mo optimization include low computing costs, ease in handling discrete optimization issues, quicker convergence speeds, and convergence to the global solution of high-dimensional problems. The results demonstrate that for nonlinear loads and changing weather conditions, fuzzy-PI based optimization performs better than PI controller.

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