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Influence of using ACO algorithm in STATCOM performance

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A B S T R A C T

Flexible alternating current transmission systems (FACTS) are technologies that rely on the use of high-power electronic equipment and advanced control methods to increase the ability of electrical transmission lines to transmit the largest amount of electrical power.Static_ synchronous _compensator (STATCOM) is one of FACTS_ family It has a rapid ability to supply or absorb reactive power from the system, traditional controller in STATCOM is (PID) or (PI). The controller is used to control the currents and voltages. In (STATCOM) there are two control loop, the inner loop which is represented by controlling the source current, and the outer loop which is used to control the voltage of the DC-link energy –storage- capacitor (vdc). Many algorithms are used in optimization to predict a specific behavior and to find the best solution for it. Two optimization methods were used Ant Colony Algorithm (ACO) and Genetic Algorithm (GA) to adjust the parameters of the outer PI controller. This unit is responsible for adjusting (vdc). The capacitor voltage is converted by the STATCOM inverter into a three-phase voltage, which is used to supply the load with required reactive power. Through the simulation and control process, the results demonstrated the effectiveness of the compensator in supplying the reactive power to the linear or non-linear loads, The results also showed that using the ACO technique that the integrated time absolute error (ITAE) was reduced which gives more precise in adjusting the PI control parameters Which is achieved best Vd.c response ,compared with the GA and ziklur-nichlos method , by measuring the response of the lowest settling time (TS) and minimal peak overshoot (P-ov) .

Introduction

The use of several non-linear loads has resulted from recent advancements in power electronics technology, which have raised network voltage fluctuations and decreased power quality, impacting equipment functionality. Reactive power compensation lowers power loss, improves long-distance power transfer capability, and helps lessen voltage variations. Reactive power can be effectively controlled to address most power quality issues[1].

A quick-acting tool called a static_ synchronous _compensator (STATCOM) can supply or absorb reactive current, regulating voltage at the point of power grid connection[2] Many researches have been completed in this field. In [3] the static synchronous compensator, its components, and the way it works were studied to prepare the reactive power, and the use of (PWM) technology as a control strategy , and the results were studied with different rates of compensation. This research considered that using the compensator is a better way to compensate without creating new lines. Researchers proposed connecting a static synchronous compensator in distribution networks connected to the photovoltaic network, , to supply changeable reactive_ power from an alternate source in order to lower the demand for (active and reactive)_ power from the network. This reduces dependence on the energy source and enhances the integration of the compensator with renewable energy sources [4]. In [5] researchers studied the use of a conventional controller (PI) in the (STATCOM) to control the voltages of a power system during abnormal conditions such as faults or sudden load changes. The performance of (STATCOM) was compared after adjusting its parameters using the Genetic Algorithm (GA) with the static-synchronous -compensator using the Imperialist competitive algorithm(ICA) for control ,with different operating conditions and many disturbances [6]. Naseer M. Yasin, Haider A. Talib used the genetic algorithm (GA) to determine the optimal size and location of (STATCOM) in the power system (IEEE 5) The results were compared to the results of the classical method [7].

Many researches have applied the trial and error method in determining the parameters of the traditional controller (PI) to obtain the best results in performance and efficiency [8-10]. The compensator controller is usually a PID controllerBut typically, the PID controller is only e xtremely good at one or a few points of operation.T he suggested ANFIS_PSO controller was impleme nted on the power system under consideration with the aim of enhancing the operating efficiency of the STATCOM controller.Time_domain voltage respo nse simulations were run in MATLAB to assess the efficacy of the controllers created for STATCOM in order to show how well the suggested controller functioned.The suggested controllers are more effic ient than the conventional PID controller and can b e utilized to increase system stability and voltage q uality, according to simulation results.Following a t hree_phase ground fault, the best response was obta ined by using the ANFIS-PSO controller [11]. In [12] researchers proposes an Ant_colony genetic_ hybrid _algorithm to adjust PID controller parameters, the algorithm is tested on a hydraulic rotary drilling rig system model .results show the hybrid algorithm find better PID parameters compared to just using Ziegler-Nichols tuning or ant colony optimization alone. Sochima V. Egoigwe and others proposes using ant_colony _optimization (ACO) to control a DC_servo _motor over an Ethernet _network, The ACO algorithm is used to tune the PID-controller to find optimal-parameters that improve stability and performance ,Performance metrics like rise time, settling time, overshoot and undershoot are all improved by using ACO for PID tuning[13].

In this Manuscript , the effect of connecting (STATCOM) to the power system was studied and its efficiency in providing reactive power to the load was demonstrated, ant _colony_ optimization_ algorithm (ACO) and genetic _algorithm (GA) were used to adjust the control parameters (PI) in the outer loop which is used to adjust the inverter capacitor voltage.

1- STATCOM in power-system:

It is one of the members of (FACTS) family, It consists of elements of power electronics with controllers capable of controlling in a very fast manner used to improve voltage stability and the stability of the power system in the cases of continuous and transient work [14].

(STATCOM) consists of a voltage source converter (VSC), which includes isulated gate transistors (IGBT) and is connected to the power system through an electrical power transformer, and at the end of the converter a capacitor with a certain power is connected [15].

One advantage of STATCOM is its quick reaction to power system disruptions in electrical . The STATCOM controller is usually a PI or PID. Obtaining the best fixed values for the parameters of the PID or PI controller is laborious through trial and error and takes a considerable period of time.

Figure(1) represent the system under study and the components of STATCOM.

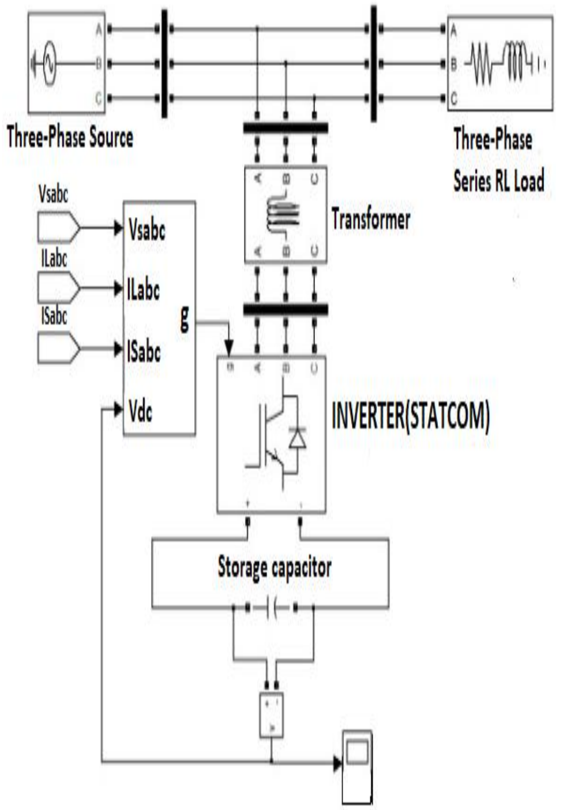


Fig.(1) : Represent the system under study and the components of STATCOM

2-STATCOM control mechanism:

PI controllers are typically used to implement STATCOM control; two PI controllers are involved in the inner current control loop and one PI controller in the outer DC voltage control loop[16]. The value of the direct-axis source current (i_d^*) is generated by the outer DC voltage PI controller as follows[15]:

$$i_d^* = K_{PO}\left(\frac{1+T_\circ s}{T_\circ S}\right)(V_{DC}^* - V_{DC})................(1)$$

Through Equation (1)we conclude that controlling the DC voltage produces the direct reference current ((i_d^*)) that enters the internal control circuit of the (STATCOM).

Figure (2) shows the external control loop connected with the internal control loop to obtain the three-phase reference voltages($V_{abc}ref$), which after comparing them with a repeating signal with a frequency of 10 kHz, we obtain the trigger pulses for the inverter transistors. By controlling the pulses of the inverter, the inverter generates three-phase voltages (VOUT) at the same fundamental frequency of the power system from the dc voltage source represented by the capacitor (vdc), the value of the reactive power exchanged between the STATCOM and the power system dependent on the value of these voltages.

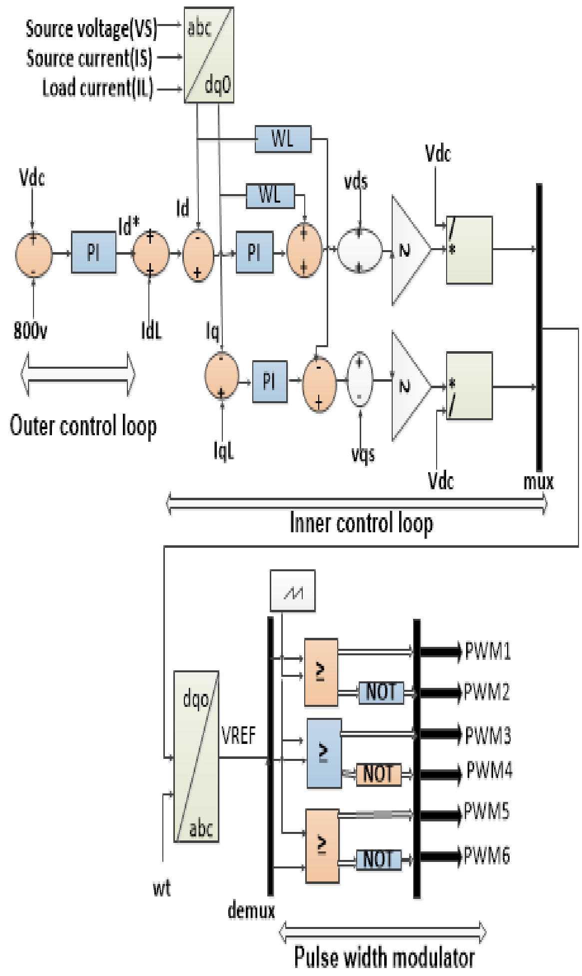


Fig.(2): control loop in STATCOM

3- Ant_ Colony _Algorithm:

The idea of the ant colony algorithm for calculating optimization goes back to the way to reach the food source that the ants use. The ants place a substance called pheromone on the ground To find the optimal route for others to follow. The ants realize the presence of pheromone traces in several directions, so they follow the directions that contain a high concentration of pheromone. Thanks to this technique, ants are able to transport food to their colony in an efficient manner (the shortest path between food and their colony)[17-18].The algorithm performs simultaneous calculations for the ants moving asynchronously across the paths, and the pheromone information is updated at the end of each iteration when all the ants complete their solutions. The pheromone level associated with the components of the solutions increases if the solution is good, or the pheromone level decreases if the solution is bad.This algorithm's primary characteristic is that the N ants, while constructing a solution, adjust the values of the pheromone τ_{ij},The pheromone associated with the path connecting node i and node j is altered in the following manner :

$$\tau_{ij\leftarrow(1-\rho)}.\tau_{ij} + \sum_{k=1}^{N} \Delta\tau_{ij}{}^{k} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$\rho = evaporation\ rate, N = number\ of\ ants$

$\Delta\tau_{ij}{}^{k} = pheromone\ amount\ set\ by\ k^{th}\ anton\ the\ path(i,j)$

$$\Delta\tau_{ij}{}^{k} = \begin{cases} \frac{Q}{L_K} & if\ path\ (i,j) is\ used\ by\ the\ k^{th}\ ant\ during\ move \\ 0 & otherwise \end{cases} \quad \ldots\ldots\ldots(3)$$

$Q = constant\ , L_K = constructed\ move\ length\ by\ k^{th}\ ant$

In this algorithm, the pheromone update occurs after the completion of each construction process (iteration). All the ants carry out this initial pheromone update process, which is applied to the last path traversed by each ant.

$$\tau_{ij=(1-\varphi)}.\tau_{ij} + \varphi\tau_{\circ} \ldots\ldots \ldots\ldots\ldots(4)$$

$\varphi = coefficient\ of$ Decay of pheromones $\in (0,1]$ and $\tau_{\circ}$ = pheromone initial value

The primary objective of this update is to introduce diversity in the search conducted by subsequent ants during iterations. The pheromone concentration on previously traversed paths is reduced, prompting the following ants to explore different paths and thereby update the solution. The updated formula is:

$$\tau_{ij} = \begin{cases} (1-\rho).\tau_{ij} + \rho.\Delta\tau_{ij} & if (i,j) is\ belonging\ to\ thebest\ iteration \\ \tau_{ij} & otherwise \end{cases} \quad \ldots\ldots\ldots\ldots(5)$$

$where\ \tau_{ij} = \frac{1}{L_{best}}$

Within this document, the ACO was use to obtain the optimal parameters for the PI controller in outer loop control in STATCOM, Which is used to adjust the difference between the reference voltages (V_{DC}* =800v) and the voltage of the DC-link energy –storage- capacitor (V_{DC}) which produces the direct reference current (i_d*). A process for calculating the optimal values of the inner control parameters of the STATCOM in the system under study using ACO algorithm are shown Figure (3).

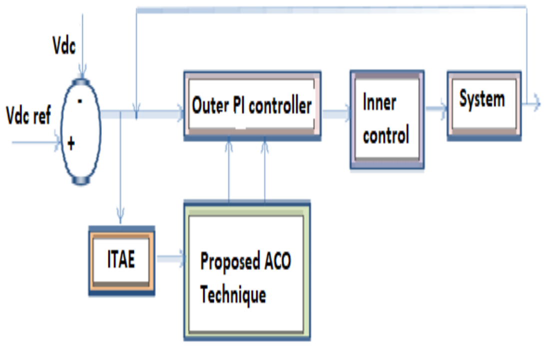


Fig. (3) A process for calculating the optimal values of the PI control parameters in the system under study using ACO algorithm

4-Genetic Algorithm:

Historically, genetic algorithms were introduced at the beginning of the seventies in the Netherlands. They are an algorithm based on searching for the optimal option from a set of available solutions for a specific design and were used in studying machines [19-21] , this technology was inspired by the theory of natural evolution by the scientist Charles Darwin. Genetic algorithms depend mainly on a process known as natural human evolution. This algorithm reflects the process of natural selection of the healthiest individuals and passing the optimal advantages to them through the process of successive breeding.

The process of natural selection begins by selecting the best individuals from the population. These offspring produce offspring that inherit the characteristics of the parents that will be added to the next generation. The healthier the parents are, the better the offspring will be than the parents and have a stronger chance of survival. This theory depends on repetition and in the end we will get the best generation Healthy .

This is done by creating groups of solutions for a specific problem and then choosing the best solutions from these groups,The genetic algorithm relies mainly on five steps:

1-Population , 2- Fitness TEST , 3- Selection , 4- Hybridization, 5- Mutations.

Population: At this stage, the initial population is prepared and initially selected for performing this algorithm. The population consists of a group of individuals, as each individual is a solution to a problem for which we are searching for a solution, which means that the initial preparation consists of a group of potential solutions to the problems for which you are searching. Solution.

Cells are the basic building unit in living organisms. Cells are composed of the same number of chromosomes, which are genes linked together in a chain. Each gene carries a set of characteristics specific to the individual, and thus the chromosome is essentially one of the solutions to the particular problem.

Fitness **:** Determine the fitness of the individual, or in other words, how close the best solution is to the problem. Let us assume that we minimize the error, so therefore the fit individual will have the least probability of error among all. These results are obtained by assigning a fitness record to each individual.

This step is necessary because the probability of an individual being selected and nominated to the next step or to production depends on the fitness record, and the higher the fitness record score, the higher the probability of the individual being selected for reproduction and production, and vice versa.

*Selection***:** At this stage, individuals are selected to produce offspring (children). This is done by selecting individuals and distributing them as pairs to stimulate production, and these individuals, in turn, transfer their genes to the next generation. The main purpose of this stage is to create an area that provides the best opportunities to produce the best solutions in the next generation.

Hybridization: Hybridization is the most important stage of the five stages in genetic algorithms. When mating occurs between each pair, there is a point of hybridization that is randomly chosen within the genes.

For example, let us consider that the point of hybridization is for three as shown in figure (4). The offspring (children) will be produced by exchanging genes between the parents until we reach the point of hybridization as shown in figure (5). After the exchange of genes between the parents, the offspring will be released. The new one and add it to the population as shown in figure (6).

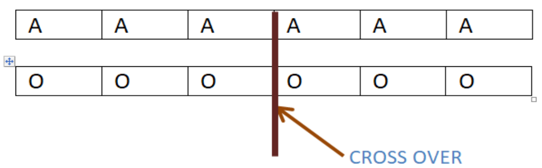


Fig. (4): three point of hybridization between two pair

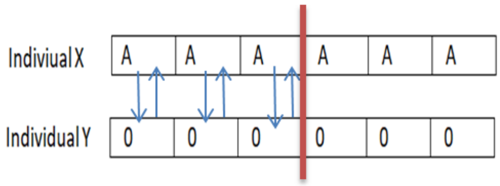


Fig.(5): point of hybridization

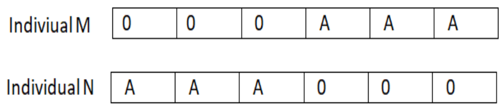


Fig.(6): the new offspring

Mutation: There are changes that occur in the genes of children during the development stage that make them different from their parents, and this process is known as mutation, and it is defined as a random change or development in the chromosomes, which in turn supports the idea of diversity and difference in the population. Figure (7) shows a simplified method for mutations to occur.

The last stage is finalizing or stopping the standard: There are different final states, which are as follows:

1-There is no improvement in the population during repetition, so we have to end the program

2- We pre-determined the number of times the algorithm should be repeated.

3- When the desired goal specified in the fitness record is reached (which is a value with the least error between the design value and the obtained value).

In all the previously mentioned cases, we assume that the genetic algorithm provided us with the best possible solutions to the problems at hand.

6-Methodology:

1-The system described in paragraph 2 has been modeled and run. The system parameters chosen are: Source line-line voltage: 415 V, Vdc : 800 V, linear load with a capacity of (100kw+50kvar), frequency : 50Hz, line resistance R: 2mΩ, line inductance L: 400uH, DC linkage capacitance C 5.6mF.

The right approach in obtaining reactive power from STATCOM is, quadrature reference current (Iq ref) is taken as quadrature load current IqL in the inner loop control. The strategy of STATCOM control briefly explained in [2]

Figure (8a) show the real power of the source ,STATCOM and the linear load while Figure (8b) represents the reactive power of the source ,STATCOM and the linear load.

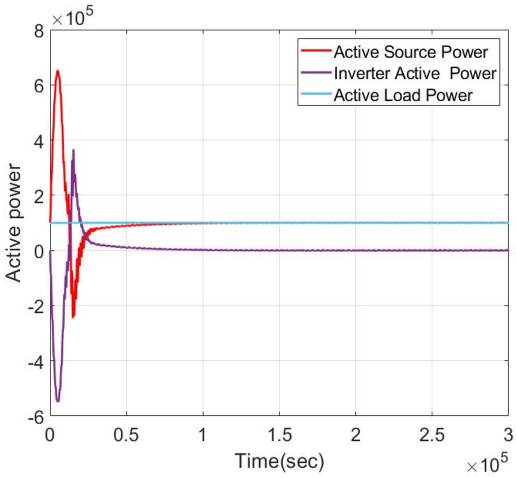


Fig.(8a) Real power in source, load, STATCOM.

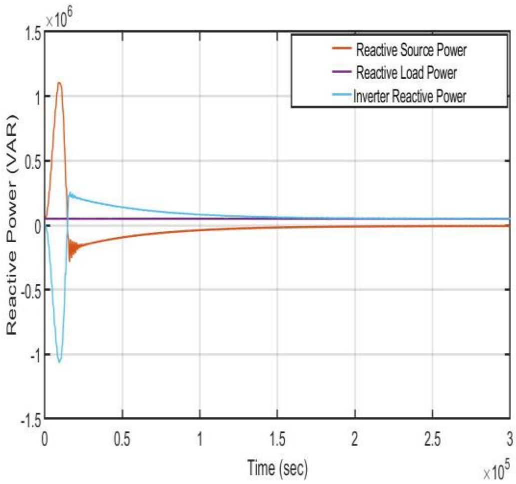


Fig.(8b) Rreactive power in load, STATCOM ,source

It is clear from Figure 8b that the reactive power of the load and STATCOM equal to 50 kvar , while the reactive power of the source is equal to zero. This means that the load receives the reactive power from the STATCOM . from Fig (8a) the active load power 100 kw and active source power also 100kw while the STATCOM active power equal zero ,that’s mean the active load power equipped by the source و Which means that the power factor of the source is equal to one if the STATCOM is present in the system.

2- in addition to the linear load a(1kw+2.5kvar)balanced nonlinear star-connected series load was added to the system, represented by an uncontrolled three-phase rectifier, Figure(9a) shows source current and its total harmonic distortion (THD), while Figure(9b) shows source current and its THD when we connected linear load, Figure (9c) represents the active and reactive power of non linear load.

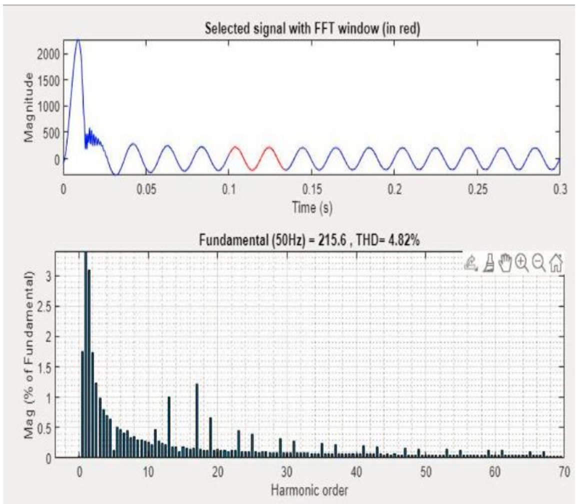


Fig.(9a):source current and its THD in case of nonlinear load

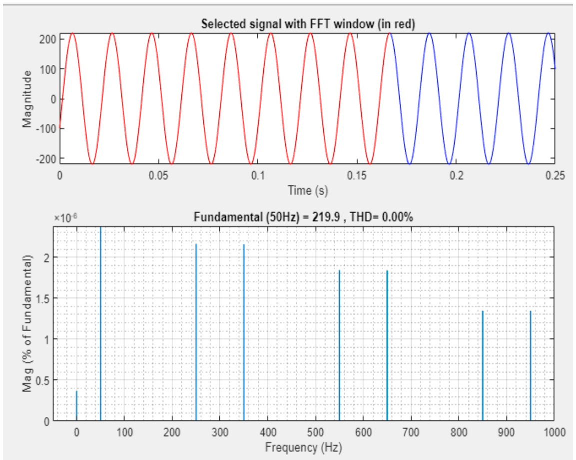
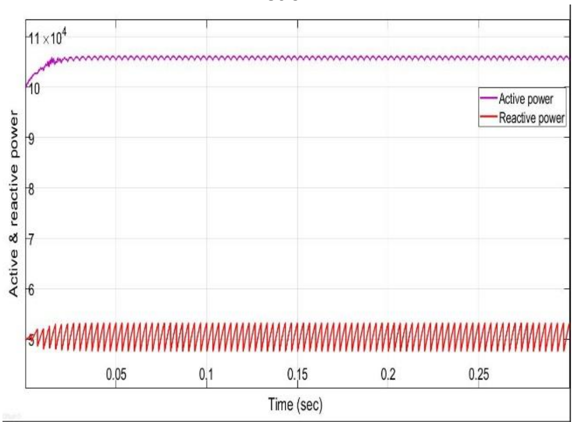
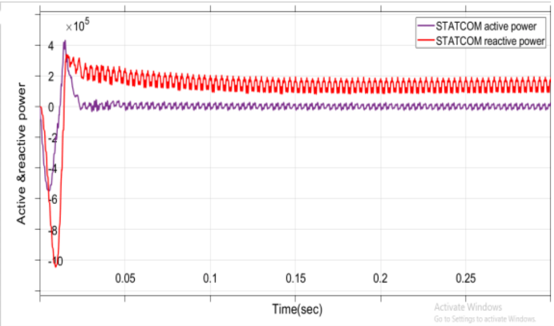


Fig.(9b) source current and its THD in case of linear load



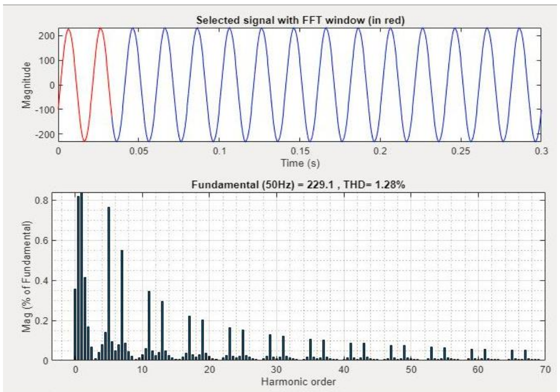
Fig(9c) active and reactive power of non linear load

The effect of connecting a nonlinear load to an electrical power system causes harmonic distortion in current and voltage waveforms .power electronics devices is one of nonlinear loads which is draw current not sinusoidal .this can result in harmonic current flowing back into the system leading to additional losses ,voltage fluctuations. Fig(10) illustrates the active and reactive power of STATCOM when nonlinear load addition to the system.



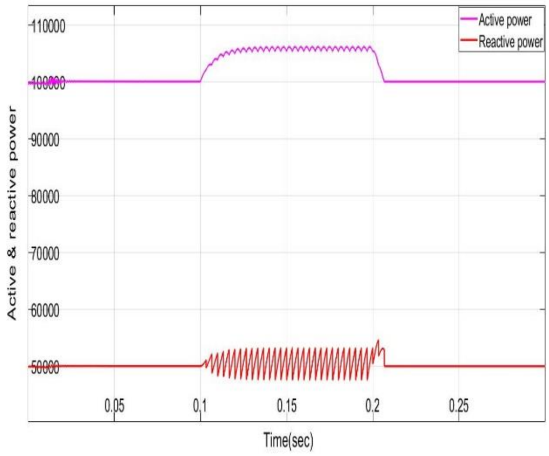
Fig(10) active and reactive power of the STATCOM after adding non linear load to the system

The source current and its harmonics in the case of a nonlinear load with absence of STATCOM shown in Fig(11).



Fig(11): Source current and its THD in the case of a nonlinear load and without a STATCOM.

3- Another case study is simulated which is constituted by three diode-rectifier star connected with loads capacity(50kw+50kvar), (50kw+30kvar), and (50kw+30kvar), the load switching at 0.01 and disconnecting at t=0.2 second, Fig(12) shows the active and reactive power of the load in this case.



Fig(12) active and reactive power of non linear unbalan1ce load added at the time 0.01 to 0.2 second

4- ACO algorithm, whose method is described in paragraph 4, was applied to the system described in paragraph 2, using MATLAB code to find the optimal values for the control parameters in the outer loop of STATCOM control (K_P,K_I) .first defined The objective function (ITAE) , decision variables(K_P,K_I) set the values of N = 50 (numbers of Ants),h-size= 0.5(search space divisions),

U_b =[10 100]upper band ,

L_b=[0 0] lower band

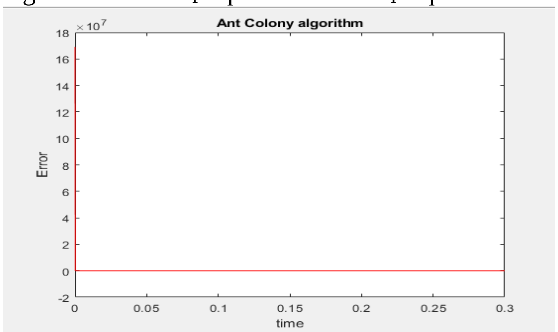
,$\rho = 0.5(evaporate\ rate)$,

$\tau = intial\ pheromone,$

$\zeta = scaling\ parameters,$

itration = 10.

After implementing the algorithm ,values for the (K_P,K_I) are produced, The performance criterion is the dc capacitor voltage signal , reactive power supplied to the load form the STATCOM and real power of the source. Figure (13) shows the (ITAE) value after the tenth iteration of the ACO algorithm, The optimal values that resulted from applying the algorithm were K_P equal 4.25 and K_I equal 85.



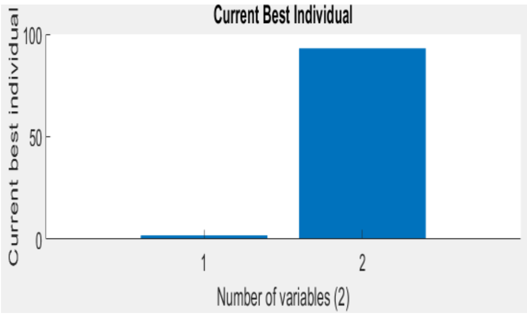
Fig(13): represented the error decrease at the end of the tenth iteration

5- Optimize live editor task /matlab2021 used to initialize values of the genetic algorithm, number of generation is 100 , population size considered is 10 , mutation probability is 0.01,cross over 0.8 and the fitness function is the integrated time absolute error (ITAE) which is calculated from the difference between the DC capacitor voltage (VDC) and the reference voltage (800 volt) over the simulation period of the system.

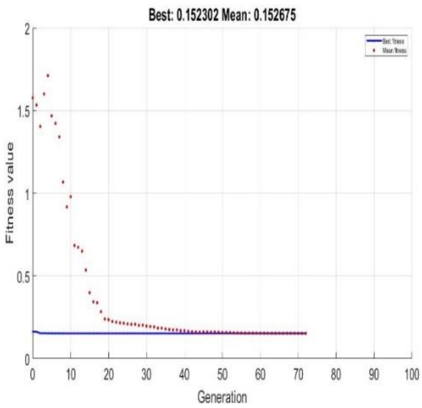
$$ITAE=\int_{t=0}^{t=s.e}|e(t)| \times t \times dt \ldots\ldots\ldots\ldots(6),$$

Where (s.e) represent simulation end.

The algorithm is executed and the error is calculated the number of specified generation times or when the best value of the function is reached.
The output of GA at the end of the 70 generation is the best value , kP equal 5.54 & kI equal 40.926 , Figure (14) illustrated the value of the variables with the best individual ,Fig(15) show the best value of the fitness function with the number of generation , run time of the algorithm took many hours, and the program stopped after 70 generation.



Fig(14) : best value of K_P,K_I when the algorithm stops



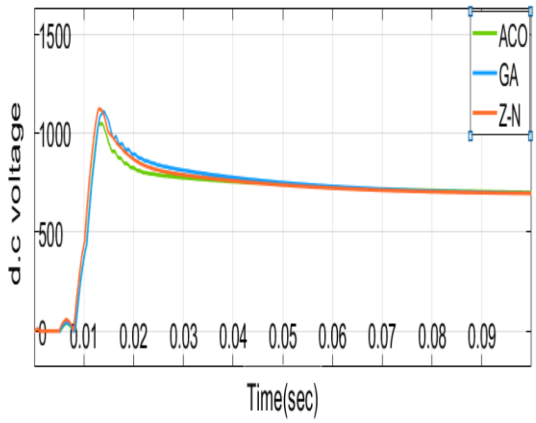
Fig(15): Number of times of generation to get the best fitness function

7-Results Discussion:

Table(1) methods of PI parameters optimization and performance metrics

algorithm	KP	KI	PO.SH (volt)	TS (sec)	TR (sec)
ACO	4.22	85	1119.4	0.0767	0.0030
GA	5.54	40.928	1176.8	0.0957	0.0033
Z-N existing	5	100	1180.1	0.0809	0.034

as can be seen based on the comparative information in table 1, the PI parameters optimized by ACO algorithm outlined in this document are the best As the value of the peak overshoot ($P_{O.SH}$),settling time T_S and rise time T_R For controlled V_{DC} ,are lower .
After applying the new parameter values of the out loop controller of STATCOM to the system in paragraph 2, which resulted from implementing the ACO algorithm first and the genetic GA second, findings demonstrated Effectiveness of STATCOM in equipping the load with reactive power , figure(16) shows the voltage of the DC-link storage capacitor voltage for all methods.



Fig(16) : Voltage signal using the three optimization methods

8-Conclusion:

Maintaining the stability of the Vdc and reducing its ripple is very important. The PI controller can control the dynamic behavior of the STATCOM. The research presents two methods for determining the optimal value of PI parameters, the first is using the ant colony algorithm ACO and the second is using the genetic algorithm GA. The results show that the two methods have strong stability and efficiency and can solve the problem Adjusting parameters easily and conveniently, these methods enable control units to achieve optimal dynamic response in a very short time, settling time (TS) is the amount of time needed for the response to stabilize and remain within the designated tolerance ranges surrounding the final value, with the tolerance range being (2-5)%, T_S of vdc signal in case of using ACO algorithm is equal to 0.0767 second while T_S after using GA and Z-N equal 0.0957 and 0.0809 second respectively. The minimum peak overshoot $P_{O.SH}$ value equals 1119.4 volts when we use the ACO algorithm, while the $P_{O.SH}$ increases to 11176.8 volts when we use GA.same thing for the rise time the shortest time is in the case of using the parameters resulting from applying the ACO algorithm to the system .

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References:

[1] Abd-Elazim, S. M., & Ali, E. S. (2016). Imperialist competitive algorithm for optimal STATCOM design in a multimachine power system. International Journal of Electrical Power & Energy Systems, 76, 136–146.

[2] Al-Flaiyeh, M. A., Aziz, N. H., & Khalel, S. I. (2023). Controlling the effectiveness of STATCOM using ANFIS based on PI controller. Bulletin of Electrical Engineering and Informatics, 12(5), 2595–2604.

[3] Boghdady, T. A., & Mohamed, Y. A. (2023). Reactive power compensation using STATCOM in a PV grid connected system with a modified MPPT method. Ain Shams Engineering Journal, 14(8), 102060.

[4] Chiha, I., Liouane, N., & Borne, P. (2012). Tuning PID controller using multiobjective ant colony optimization. Applied Computational Intelligence and Soft Computing, 2012, 11.

[5] Chowdhury, A. A., Agarwal, S. K., & Koval, D. O. (2002). Reliability modeling of distributed generation in conventional distribution systems planning and analysis. Conference Record of the 2002 IEEE Industry Applications Conference. 37th IAS Annual Meeting (Cat. No. 02CH37344), 2, 1089–1094. IEEE.

[6] Egoigwe, S. V, Akpeghagha, O., & Chukwudozie, C. (n.d.). Optimal Control of DC Motor via Ethernet Using Ant Colony Optimization (ACO).

[7] Eshtehardiha, S., & Kiyoumarsi, A. (2007). Optimized performance of STATCOM with PID controller based on genetic algorithm. 2007 International Conference on Control, Automation and Systems, 1639–1644. IEEE.

[8] GANESH, R. (2017). VOLTAGE STABILITY IMPROVEMENT IN GRID CONNECTED PV SYSTEM USING STATCOM WITH FUZZY CONTROLLER. ANNA UNIVERSITY CHENNAI.

[9] Gupta, N., Kaur, M., & Gupta, R. (2022). Ant colony optimization based optimal tuning of Fractional Order (FO) PID controller for controlling the speed of a DC motor. Journal of Engineering Research.

[10] Kumar, D., & Bhowmik, P. S. (2020). Genetic Algorithm-based Optimal Placement of STATCOM in Pre-islanding and Post-islanding Condition. 2020 IEEE Calcutta Conference (CALCON), 373–377. IEEE.

[11] Li, H., Li, F., Xu, Y., Rizy, D. T., & Kueck, J. D. (2010). Adaptive voltage control with distributed energy resources: Algorithm, theoretical analysis, simulation, and field test verification. IEEE Transactions on Power Systems, 25(3), 1638–1647.

[12] Mayer, M. J., Szilágyi, A., & Gróf, G. (2020). Environmental and economic multi-objective optimization of a household level hybrid renewable energy system by genetic algorithm. Applied Energy, 269, 115058.

[13] Mrs. Manisha patel1, D. S. P. M. J. C. K. K. N. B. K. P. (n.d.). Reactive power compensation using STATCOM. International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056 Volume: 04 Issue: 04 | Apr -2017, 4002, 4001–4002.

[14] Nguyen, H. V., Nguyen, H., Cao, M. T., & Le, K. H. (2019). Performance Comparison between PSO and GA in Improving Dynamic Voltage Stability in ANFIS Controllers for STATCOM. Engineering, Technology & Applied Science Research, 9(6).

[15] Pradhan, P. C., Ray, P. K., Sahu, R. K., & Moharana, J. K. (2013). A STATCOM-control scheme used for power factor improvement of grid connected weak bus system. International Journal of Engineering Research & Technology (IJERT), 2(12), 3527–3534.

[16] Stephen, S. F., & Raglend, I. J. (2016). A review on pi control of statcom for voltage regulation. J. Chem. Pharm. Sci, 9(1), 334–340.

[17] Tembhurnikar, G., Chaudhari, A., Wani, N., Gajare, A., & Gajare, P. (2014). A review on Reactive Power Compensation Techniques using FACTS devices. International Journal of Engineering and Management Research (IJEMR), 4(1), 76–80.

[18] Tripathi, S. M., & Barnawal, P. J. (2018). Design and Control of a STATCOM for Non-Linear Load Compensation: A Simple Approach. Electrical, Control and Communication Engineering, 14(2), 172–184.

[19] Yasin, N. M., & Talib, H. A. (2018). Genetic based optimal location of statcom compensator. International Journal of Applied Engineering Research, 13(10), 7516–7521.

[20] Yousif, S. A., & Mohammed, S. E. (2021). Reactive power control using STATCOM for power system voltage improvement. Al-Rafidain Engineering Journal (AREJ), 26(2), 124–131.

[21] Zhang, G. (2017). Optimization of PID parameters based on ant colony genetic hybrid algorithm. 2017 5th International Conference on Machinery, Materials and Computing Technology (ICMMCT 2017), 1285–1292. Atlantis Press.