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Reactive power mitigation using STATCOM based on DSA/WDO technique

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Abstract

A static synchronous compensator (STACOM) is shunt Flexible AC Transmission Systems (FACTS) device used in distribution system to mitigate the reactive power dynamically as well as to improve the power quality in Transmission network. This paper will show the design of a STATCOM for three phase three wire system to mitigate the reactive power using constant decoupled current control method. It is difficult and time consuming process for conventional method to tune the PI controller parameters of STATCOM. In order to tune the PI controller parameters properly two recent optimization techniques has been developed, one is Differential Search algorithm (DSA) and another one is Wind Driven optimization (WDO) which are used in this paper. The aim is to be minimize the integral square error for both outer voltage controller and inner current controller simultaneously. To calculate the PI gain by DSA and WDO technique will be demonstrate and show the improvement of convergence speed, reduction of error, the overshoot in capacitor voltage and other circuit parameters. The results are compared with hit and trial method, which are shown that the DSA algorithm based PI controller tuning method giving more optimized results.

Keywords: STATCOM, reactive power mitigation, decoupled current control, differential search algorithm & wind driven optimization

1. Introduction

Today's, the major power are consuming by reactive loads only like motors, fans & pumps etc. in a distributed system. These loads give reactive power burden by drawing lagging power factor. The reactive power demand and active power capability are inversely proportional to each other. If reactive power demand is increases then transmission losses will be also increases. For which, there is degradation of active power capability as well as voltage regulation in transmission system. To overcome the reactive power burden as well as the power quality problems, the conventional static VAR compensators (SVC) has been used to mitigate the reactive power. and day by day the device has been developed to a greater extent, known as STATCOM. If Compared with SVC, the STATCOM has more solid & compact structure and ability to respond in quick way [1].

For reactive power mitigation and power factor improvement in distribution network, there are several control schemes have been implemented in STATCOM such as control of phase shift, decoupled current control theory (p-q theory), SRF theory, AC and DC voltage regulation etc.

STATCOM has been designed for reactive power mitigation by decoupled current control technique. This control technique required a number of PI controllers, which are solid and simple design. These PI controllers are used to improve the transient and steady state response. To take the benefit of the PI controllers, it is require to tune the PI parameter in proper way. By using conventional techniques, it is very time consuming work to tune the PI parameters properly because of nonlinear operation of STATCOM [2, 3].

For having proper control scheme there is a need of significant mathematical model system to study. The conventional techniques such as pole-zero cancellation method, Ziegler-Nichols oscillation method, pole assignment method and smith predictor etc. requires exact transfer function for tuning of control parameters. Therefore, it is very difficult in conventional methods to find out the transfer function as well as determine the optimize control scheme of STATCOM. Using optimization techniques the problem can be solved up to large extent. For the objective, two newly developed optimization technique (DSA and WDO) has been applied to get the optimum values of PI controller parameter to STATCOM for its control purpose. The control system parameters has got by an offline evolution of fitness function. The new PI gains are calculated by DSA and WDO technique with minimizing the objective function and that are used in the controller to show the improvement of convergence speed, reduction of error, the over shoot in capacitor voltage and other circuit parameters. The results are compared with hit and trial method [4, 5].

Segment II the paper gives details idea of operation and principle of STATCOM. Segment III drive the control technique which is used in this paper. Segment IV gives significant parameters. Segment V show the basics of DSA followed by implementation of DSA algorithm. Segment VI show the basic of WDO followed by implementation of Wind driven optimization technique. Segment VII gives the model and design parameter for STATCOM. segment VIII show Simulation studies and discussion and the conclusion is given in segment IX.

2. Basic operations of STATCOM

Basically, STATCOM work as a controlled reactive source. It has a voltage source converter (VSC) and a DC link capacitor are connected in shunt with the system. In D- STATACOM the pulse width modulation technique has been used to remove the lower order harmonics from the converter output side. This shunt device which is connected to the power distribution network through a coupling transformer which is shown in Fig.1. It operates in a similar manner as the STATCOM but it has some specific purpose The Active power flow can be controlled by controlling the angle between the AC system and VSC voltage and reactive power flow is controlled by the difference between the magnitudes of the voltages. If output voltage of the VSC is equal to the AC terminal voltage, no reactive flow will occur. If the output voltage is greater than the AC terminal voltage, the STATCOM is in the capacitive mode operation and it will supply lagging reactive power to the system and vice versa.

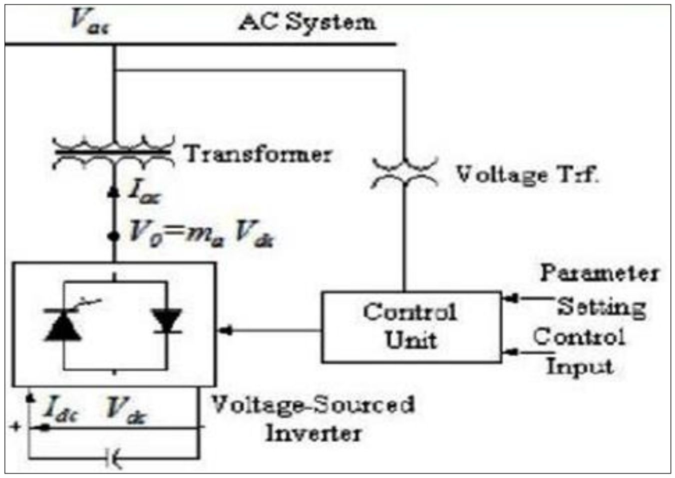

Fig 1: Fundamental diagram of STATCOM

Depending upon the application of STATCOM, it may be operate for different objective which are following below.

a. Voltage regulation in a particular AC line.
b. Power factor improvement for a particular load.
c. Load balancing as well as harmonics elimination for a particular load.

3. Controller structure of STATCOM

The control algorithm studied in this paper is applied to the STATCOM to study the performance of a STATCOM for reactive power compensation and power factor correction.

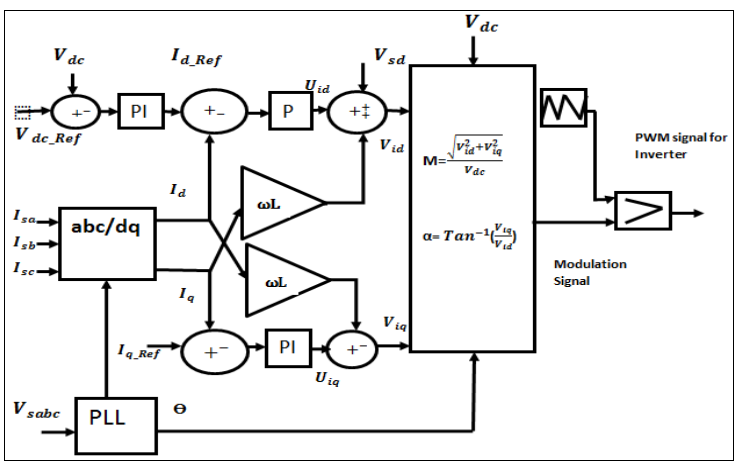

Fig 2: Controller diagram of STATCOM [6].

The measurement of instantaneous value of three phase voltage and current are required for the control scheme, which is shown in Fig. 2. Here i_d and i_q are controlled to achieve compensation. The shunt current from VSC is split into d-axis and q-axis components by the application of park's transformation. The decoupled d-axis and q-axis components i_d and i_q are regulated by two separate PI regulators. A separate dc voltage PI regulator is used to obtain the instantaneous reference d-axis current (i_{d_ref}). The control loop is synchronized to ac supply by using a phase locked loop (PLL) in order to operate in the abc to dq reference frame and again these dq components are converted to abc frame. To produce the required PWM pulse for switching device in VSC of STATCOM, the available sine wave is compared with high frequency triangular wave.

According to the definition of instantaneous reactive power theory for a balanced 3-phase, 3-wire system, the real power (p) and reactive power (q) is injected into the system by STATCOM can be expressed under the d-q reference frame as

$$p=\frac{3}{2}(v_d i_d+v_q i_q) \quad 1$$

$$q=\frac{3}{2}(v_q i_d-v_d i_q) \quad 2$$

When the d-axis is made to lie on the space vector of the voltage, its quadrature component is always zero. ($v_s = v_d$ and $v_q = 0$). therefore equation (i) and (ii) will become

$$p=\frac{3}{2}(v_d i_d) \quad 3$$

$$q=-\frac{3}{2}(v_d i_q) \quad 4$$

Hence the Mitigation has been achieved by controlling of i_d and i_q therefore, i_d and i_q can completely describes the instantaneous value of real power as well as reactive power produced by the STATCOM.

4. Designing of system

The important parameters are required to the design of STACOM are following below

a. Requirement of DC link voltage.
b. Requirement of coupling inductance.
c. Requirement of DC link capacitor.

Here, we are assuming a balanced 3- phase AC supply and the voltage source converter are operating in linear mode.

(a) DC link voltage (V_{dc}) of Device

The minimum dc bus voltage of VSC of STATCOM should be greater than twice the peak of the phase voltage of the system. therefore, the dc bus voltage can be calculated as

$$V_{dc} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}m} \quad 5$$

Where m is the modulation index and its value is taken as 0.8, V_{LL} is the line voltage=$\sqrt{3}$ *110V. So V_{dc} is found to be 388.90V and is selected as 400V.

(b) Coupling Inductance of Device

The selection of the coupling inductance (L_f) depends on the switching frequency (f_s), dc voltage (V_{dc}) and the current ripple $i_{cr(p-p)}$

$$L_f = \frac{\sqrt{3}mV_{dc}}{12af_s i_{cr(p-p)}} \quad 6$$

Where m=0.8, a=1.2 is the over load factor, $i_{cr(p-p)}$=5%, f_s=10KHZ, V_{dc}=400V. So the L_f is found to be 3 mH.

(c) DC link capacitor of Device

The value of DC capacitor (C_{dc}) depends upon the instantaneous energy available to the STATCOM during transient. Using the principle of energy conservation, the equation governing (C_{dc}) is as,

$$\frac{1}{2}C_{dc}[(V_{dc}^2)-(V_{dc1}^2)] = 3\text{V (A I) T} \quad 7$$

Where V_{dc} is the reference dc voltage, V_{dc1} is the minimum voltage level of DC bus, V is the phase voltage, A is the overloading factor, I is the phase current.V_{dc1}=392V, V_{dc}=400V, A=1.2, T=0.02s, V=110V, therefore the value of C_{dc}= 2000 μF.

5. Differential search algorithm

Differential Search algorithm used to simulates the Brownian-like random-walk movement used an organism to migrate [19]. Reason of periodical climate changes, many organisms show seasonal migratioSn behavior where they shift from one habitat to a more efficient one with respect to capacity and efficiency of food areas. In the process of migration, the species undergoing migration forms a super organism consisting of a large number of individuals and the super organism changes its position toward more fruitful areas.

The artificial organisms (i.e., X_i, *i*= 1, 2, 3,....*N)*constituting a super organism contains members equal to the size of the problem (i.e., $X_{i,j}$,*j*= 1, 2, 3, ..., *D*).*D* is the size of the problem and *N* denotes the number of elements in a super organism. In initial position, a member of an artificial organism is given by,

$$X_{i,j} = \text{rand} \times (UP_j - Low_j) + Low_j$$

The super organism migrates toward global minimum and during this process, the members search for some randomly selected position suitable to stop over temporarily and on finding such position, the members of the artificial super organism immediately settle there and continue their migration from this position onward.

In order to discover site, randomly selected individuals move towards the targets of migrates donor [$X_{random-shuffling(i)}$]. The extent to which the change occurs is controlled by a scale value. The stopover site position is given as,

Stopover site = Super organism + scale × (donor-super organism)

The members to participate in search process are selected by random process of specific structure. If any element goes beyond the limits of habitat, the element is randomly deferred to another position.

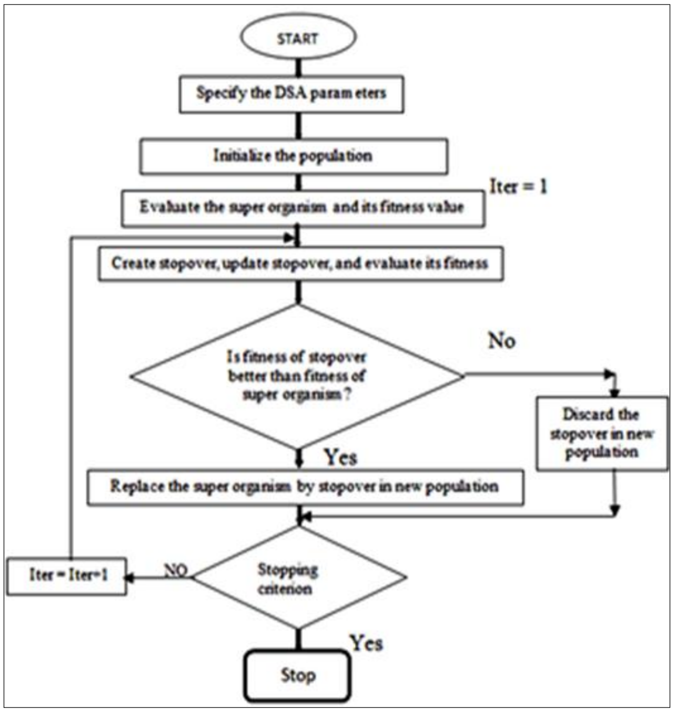

Fig 3: DSA flow chart

Software code of the algorithm of DS algorithm can be found in Civisioglue in 2011.

Algorithm: Differential Search Algorithm
Pseudo code of DS algorithm
Require:
N: The size of the population, where i= {1,2,3,...,N}
D: The dimension of the problem.
G: Number of maximum generation.
1: Super organism = initialize (), where super organism= [$ArtificialOrganism_i$]
2: yi=Evaluate (Artificial Organism)
3: for cycle = 1:G do
4: doner= $Superorganism_{Random\_Shuffling(i)}$
5: Scale= randg [2$\cdot rand_1$].($rand_2 - rand_3$)
6: Stop over Site=Super organism + Scale· (doner-Super organism)
7:P_1=0.3$\cdot P_1$=0.3$\cdot rand_4$and P_2=0.3$\cdot rand_5$
8: if $rand_6$<$rand_1$ then
9: if $rand_8$<P_1 then
10: r = rand(N,D)
11: for Counter1=1:N do
12: r(Counter1,:) = r(Conter1,:)<$rand_9$
13: end for
14: else
15: r =ones(N,D)
16: for Counter2=1:N do
17: r(Counter2,randi(D))=r(Counter2,randi(D))<$rand_{10}$
18: end for
19: end if
20: else
21: r=ones(N,D)
22: for Counter3= 1:N do
23: d=randi(D,1, P_2 ·rand·D)
24: for Counter4=1:size(d) do
25: r(Counter 3,d(Counter4))=0
26: end for
27: end for
28: end if
29: $individuals_{i,j} \leftarrow r_{i,j}$> 0|I∈ i,J∈[1 D]
30: Stopover Site($individuals_{i,j}$) :=Superorganism($individuals_{i,j}$)
31: if $StopoverSite_{i,j}$<$low_{i,j}$ or$StopoverSite_{i,j} > up_{i,j}$ then
32:$StopoverSite_{i,j}$:= rand·(up_j -low_j)+low_j
33: end if
34: $y_{StopoverSite;i}$ = evaluate ($StopoverSite_i$)
35: $y_{Superorganism;i} := \begin{cases} y_{StopoverSite,} & If \; y_{StopoverSite;i} < y_{Superoranism;i} \\ y_{Superoranism,i} & else \end{cases}$
36: $ArtificialOrganism_i := \begin{cases} StopoverSite_i & If \; y_{StopoverSite;i} < y_{Superoranism;i} \\ ArtificialOrganism_i & else \end{cases}$
37: end for

6. Wind driven optimization technique

WDO technique is a nature inspired optimization technique, which can motivated from earth's atmosphere, where wind blows in an attempt to equalize horizontal imbalance in the air pressure. It is based on Newton's second law of motion. The most important thing of WDO is that it is to execute and highly effective in solving multidimensional numerical optimization problem. [18] Basically this technique is population based iterative heuristic global optimization technique specifically applied for multi- dimensional, multimodal problems with the ability to implement constraints in the search domain. As compared to swarm based optimization techniques, WDO exploded additional terms in the velocity update equation such as gravitation and carioles forces. By this technique robustness and extra degree of freedom is achieved for which fine tuning is possible.

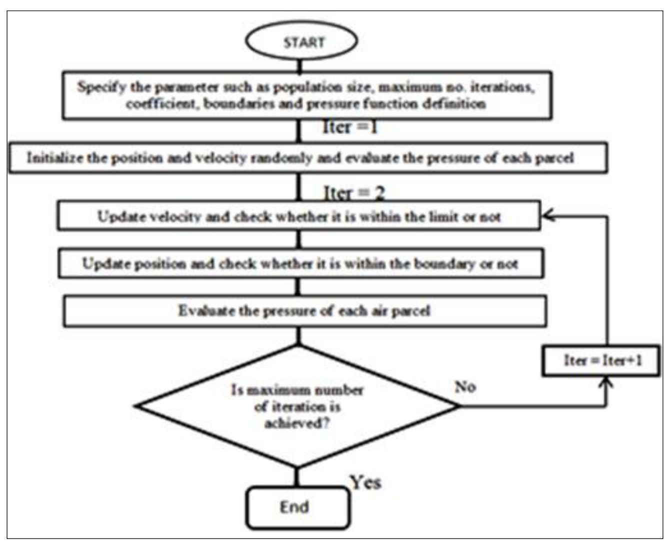

Fig 4: Flow chart of WDO

7. Formulation of objective function

In this paper Integral Square Error (ISE) performance index is used as objective function 'J' for optimization. The index ISE is Expressed as

$$J_{ISE} = \int_0^T (error)^2 dt \qquad 8$$

The upper limit of the integral, T is usually chosen as the settling time or greater than the settling time. So the integral approaches to a steady -state value.
For the STATCOM system, the adopted objective function is

$$OF(X) = w\int_0^T (e_{dc})^2\,dt + \int_0^T (e_{i_d})^2\,d + \int_0^T (e_{i_q})^2\,dt \qquad 9$$

$$OF(X) = 10\int_0^T (V_{ref} - V_{dc})^2\,dt + \int_0^T (i_{dref} - i_d)^2\,dt + \int_0^T (i_{qref} - i_q)^2 \qquad 10$$

Where, X = [$K_{p1} K_{i1} K_{p2} K_{i2} K_{p3} K_{i3}$] and w is the weighting factor.
This equation is used when outer dc voltage controller and inner current controller is regulating.

8. Simulation Results

This paper show that the design of STATCOM with the system parameters which are given below in table I. First the PI controller parameters are tuned by hit and trial methods. Then the parameters are tuned by DSA and WDO technique with ISE (integral square error) as objective function. The results are compared in terms of simulation graph. The optimum value of PI parameters of DSA and WDO are given in table II. The results are obtained by MATLAB (R201aa) on a 2.4 GHz Intel (R) Core (TM) i3 processor personal computer with 6-GB RAM. The comparison of graph characteristics of DSA as well as WDO technique are shown below in fig. 9.

Table 1: System parameters used for simulation

Distinct Parameters	Values
Resistance of Soure	Rs =0.3Ω
Inductance of Source	Ls =0.0013H
Source voltage	Vs = 110(Voltage in phase)
DC capacitor	C= 2000^{e-6}F
Filter resistance	R= 0.03Ω
Filter inductance	L= 3mh
Initial capacitor voltage	C= 410v
Fundamental frequency	f = 50 HZ
Sampling frequency	fs =10 KHZ
Load	P= 2000W, Q= 5000W

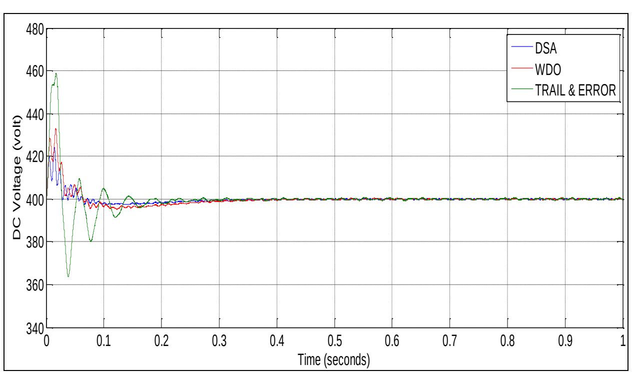

Fig 5: DC capacitor voltage responses of STATCOM.

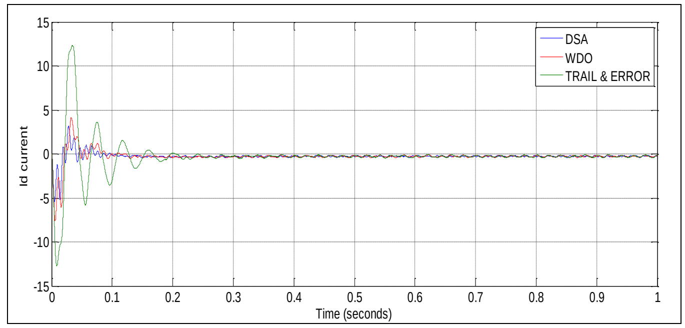

Fig 6: d-axis current responses in STATCOM controller.

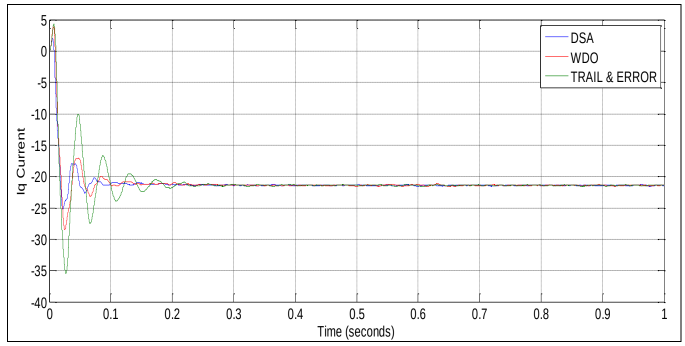

Fig 7: q-axis current responses in STATCOM controller.

The simulation results in Fig. 5, Fig. 6 & Fig. 7 shows that the capacitor voltage responses, d- axis current responses and q-axis current responses respectively for three different sets of PI gains obtained by using three different techniques. In this case the capacitor voltage remains constant at 400V. therefore, the STATCOM will be able to mitigate the reactive power to the system by converting DC voltage into AC.

Without Compensation

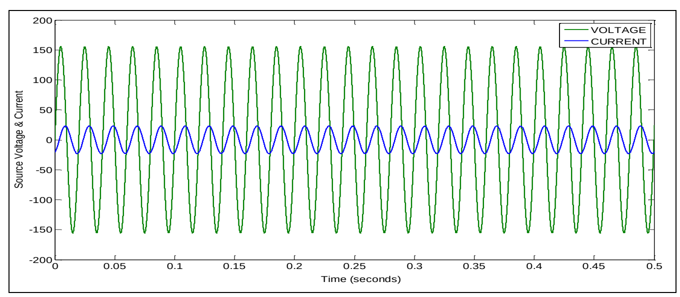

Fig 8: Source voltage and current. (R L load) of phase A

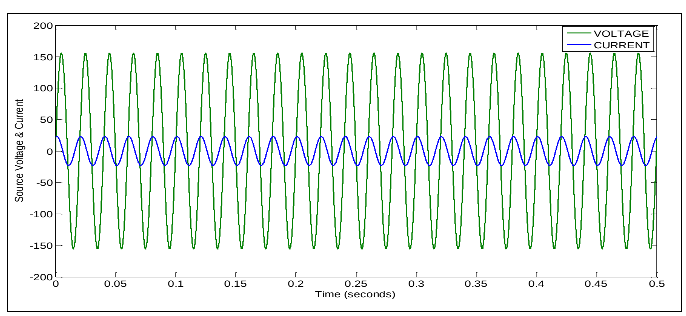

Fig 9: Source voltage and current. (RC load) of phase A

With Compensation

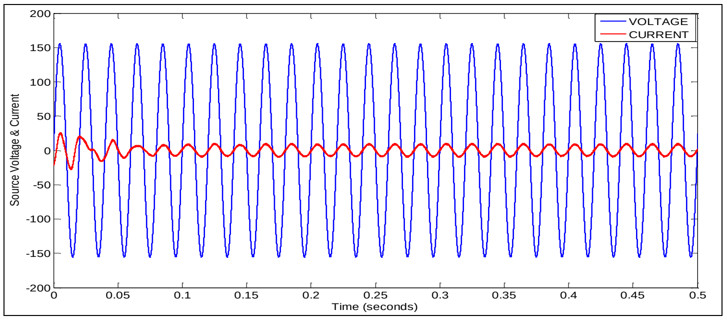

Fig 10: Source voltage and current of phase A.

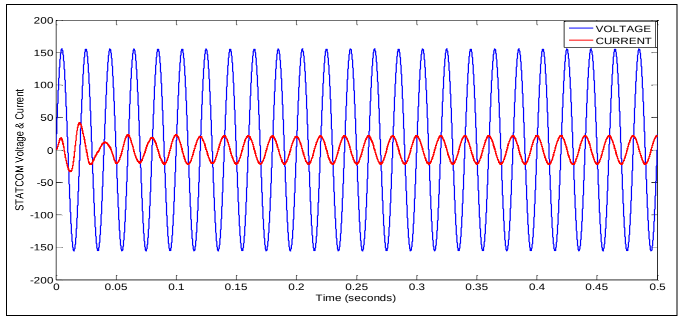

Fig 11: STATCOM output voltage and current. (RL load) of phase A

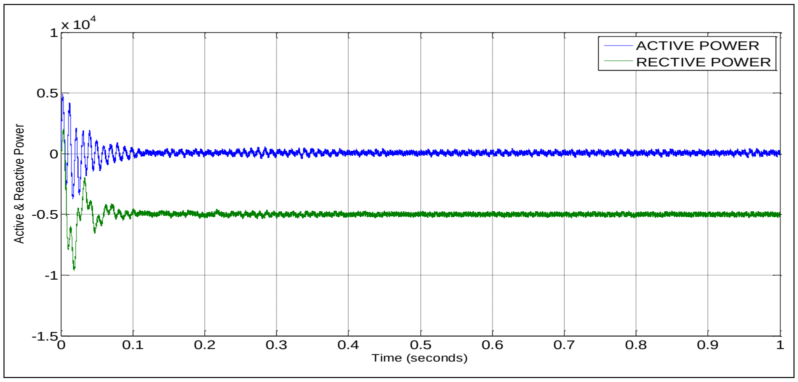

Fig 12: Active and Reactive power supply by STATCOM.

Fig. 11 & 12 shows that STATCOM is absorbing the leading reactive power from the system when the load is RL that means it is supplying the lagging reactive power to the system.

Table 2: Comparison of Pi Parameters

	PI Parameters Value using Hit & Trail error method		Optimized value of PI controller Parameters using WDO		Optimized value of PI controller Parameters using DSA	
	K_p	K_i	K_p	K_i	K_p	K_i
DC Voltage controller	1	30	1.5	40	1.5	40.00
Inner current controller	4	45	3	20	3	30.00

9. Conclusion

The main effort has been done in this paper is to design a proper model of STATCOM to mitigate the reactive power in transmission line as well as in distribution line by using decoupled current control technique. and the PI controller parameters of STATCOM controller are tuned by two recently developed global optimization techniques which know as Differential search algorithm and Wind driven optimization technique with some necessary boundary constraints. In this case ISE is used as an objective function. From this paper we conclude that DSA gives better result in comparison to WDO in terms of minimum oscillation, high convergence speed, robustness and improvement in transient performance.

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