Intelligent Technique Based Reactive Power Compensation of Dish-Stirling Solar Thermal-Diesel Hybrid Power System

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Abstract

This analysis investigates the application of Genetic Algorithm (GA), Particle Swarm Optimization(PSO) and Flower Pollination Algorithm (FPA) to obtain optimized voltage stability of an isolated Dish-stirling Solar Thermal System (DSTS) and diesel system based on reactive power control. The system model is composed of diesel engine based Synchronous Generator (SG), a DSTS based Induction Generator (IG) and Static Compensator (STATCOM). Reactive power requirement of the system components are balanced by synchronous generator and FACTS controller (STATCOM). The optimization algorithms are applied to solve an optimization problem and to achieve PI control parameters of STATCOM. Simulation studies show the control effect and robustness of the proposed optimized controller. A comparison is given with and without optimized PI controller. Simulation results revealed that FPA optimised controllers for STATCOM provides the improved dynamic performance of the hybrid energy system as compared with GA and PSO optimised controllers.

Keywords: *DSTS, Induction Generator, STATCOM, reactive power compensation*

1. Introduction

Any mismatch between reactive power demand and generation results in a deviation of system voltage from its nominal value. The voltage deviations like over-voltage or under voltage may affect the system performance in the form of insulation failure of equipments or system voltage collapse[1] and even may damage the system stability in absence of the proper voltage control [2].Different flexible AC transmission system devices are available to provide continuous reactive power support. In standalone application capacitive VAR controller is used to meet the demand. In the present work, STATCOM is considered for the purpose of reactive power support.

In literature, for wind-diesel hybrid power system to compensate reactive power, SVC and it's types have been reported [4-6]. Recently, automatic tuning of controller parameters using heuristics algorithms has gained much interest. Gain of PI controller in STATCOM were optimised keeping the parameters of automatic voltage regulator (AVR) control constant[7-8]. The controller parameters of the SVC and AVR were optimised simultaneously by genetic algorithm (GA) under random load change with fixed reactive power consumption by the IG, which is not realistic [2]. In addition to optimizing the controller parameters of STATCOM, the system reactive power demand and voltage variation will be reduced if the load interaction with the system is considered [11]. It is found that the system reactive power demand by compensating devices and voltage variation will be reduced if optimized controllers were used [9, 11]. The major contributions of the present work are summarised as follows

(i) Tunable parameters of STATCOM in isolated hybrid power system are optimized with the help of GA, PSO and FPA algorithms.

(ii) Compared the performance of FPA optimised PI controllers with their PSO and GA optimised counterparts in terms of terminal voltage response and the convergence.

2. Mathematical modelling of the system

Block diagram of the proposed isolated DSTS-diesel hybrid power system is shown in Figure 1. Sudden change in reactive load affects system stability and to overcome this problem STATCOM tuned by optimized controller is employed.

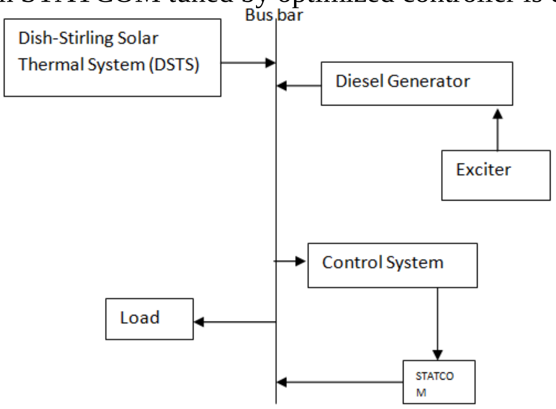


Figure 1. Block Diagram of Isolated Hybrid Power System

The reactive power demand equations for the studied power system model is as follows

$$\Delta Q_{SG}(s) + \Delta Q_{Statcom}(s) - \Delta Q_{Load}(s) - \Delta Q_{IG}(s) = 0 \quad (1)$$

and the transfer function for incremental change in load is written as

$$\Delta V(s) = \left(\frac{K_v}{1+sT_v}\right) [\Delta Q_{SG}(s) + \Delta Q_{Statcom}(s) - \Delta Q_{Load}(s) - \Delta Q_{IG}(s)] \quad (2)$$

The disturbance in the reactive power demanded by the load (ΔQ_{Load}) will lead to system voltage change which results in incremental change in reactive power demand of the other components. The left hand side of (1) represents the net incremental reactive power and this change in reactive power demand will have effect on the change in system voltage (2). But as per the recommendation of the grid, the voltage change should be within its permissible limit and hence terminal voltage profile should be maintained properly [14].

2.1 Modelling of SG block

The incremental change in reactive power of SG is given by [4]

$$\Delta Q_{SG}(s) = K_1 \, \Delta E'_q(s) + K_2 \, \Delta V\,(s) \quad (3)$$

Where

$$K_1 = \frac{V \cos\delta}{X'_d} \quad (4)$$

$$K_2 = \frac{E'_q \cos\delta - 2V}{X'_d} \quad (5)$$

The transfer function equation for state variable $\Delta E'_q(s)$ is obtained from the flux linkage equation of the SG along with the excitation system (IEEE type I), as given in [4, 11]

$$\Delta E'_q(s) = \left(\frac{1}{1+sT_g}\right) \left[K_3 \Delta E_{fd}(s) + K_4 \Delta V(s)\right] \quad (6)$$

$$K_3 = \frac{X'_d}{X_d} \quad (7)$$

$$K_4 = \frac{[(X_d - X'_d)\cos\delta]}{X'_d} \quad (8)$$

$$T_g = T'_{d0} \frac{X'_d}{X_d} \quad (9)$$

2.2 Modelling of IG block (DSTS)

The Dish-Stirling Solar Thermal System comprises parabolic dish, receiver and the tracking device [25].DSTS systems track the sun and concentrates solar energy into a cavity receiver [20]. Parabolic dish have concentration ratio as high as 3000 [24]. The absorbed solar energy is transferred to the working fluid (water, hydrogen or helium gas) in Stirling engine by the receiver. The engine then converts the absorbed thermal energy to a mechanical power by compressing the working fluid when it is cool and expanding it when it is hot[21,26]. Stirling engine is coupled to induction generator (IG) to generate electricity [27].

DSTS systems have demonstrated the highest efficiency than any other solar power technology [20-23]. The output power of DSTS [27] is given by

$$P_{DSTS} = 0.015 P_m V_p f \quad (10)$$

where P_{DSTS}, P_m, V_p and f are thermal power output, mean cycle pressure, displacement of power piston and frequency respectively. Hence, P_{DSTS} is equal to P_{IG}. A constant slip model IG is considered (Power input to DSTS is assumed constant). For small perturbation, reactive power absorbed by the IG is [6, 12]

$$\Delta Q_{IG}(s) = K_5 \, \Delta V(s) \quad (11)$$

where

$$K_5 = \frac{2VX_{eq}}{R_Y^2 + X_{eq}^2} \quad (12)$$

2.3 Modelling of STATCOM

Reactive power supplied by STATCOM is written as [3, 19]

$$\Delta Q_{STATCOM}(s) = K_9 \Delta V(s) + K_8 \Delta \propto (s) \quad (13)$$

where

$$K_8 = kV_{dc} V B_{ST} sin \propto \quad (14)$$

$$K_9 = -kV_{dc} B_{ST} cos \propto \quad (15)$$

3. Problem formulation

The control parameters of proportional and integral controller in STATCOM are optimised

employing search based optimization techniques. The objective is to optimize the controller parameters by minimizing the performance index J which is given as below

$$J = \int_0^T (|\Delta V|) dt \quad (16)$$

Where T and ΔV are the simulation time and voltage deviation respectively.

Subject to

$$K_{p,STATCOM}^{min} \leq K_{p,STATCOM} \leq K_{p,STATCOM}^{max} \quad (17)$$

$$K_{i,STATCOM}^{min} \leq K_{i,STATCOM} \leq K_{i,STATCOM}^{max} \quad (18)$$

Where K_p and K_i are proportional and integral gains respectively. The ranges of K_P and K_I for STATCOM are given in Table 1 and the parameters of GA, PSO and FPA are given in Table 4 respectively.

The simulation block diagram of the hybrid power system for reactive power control at constant input to DSTS using STATCOM and IEEE type-I excitation system is shown in Figure 2. The data used for designing the IHPS is given in the appendix.

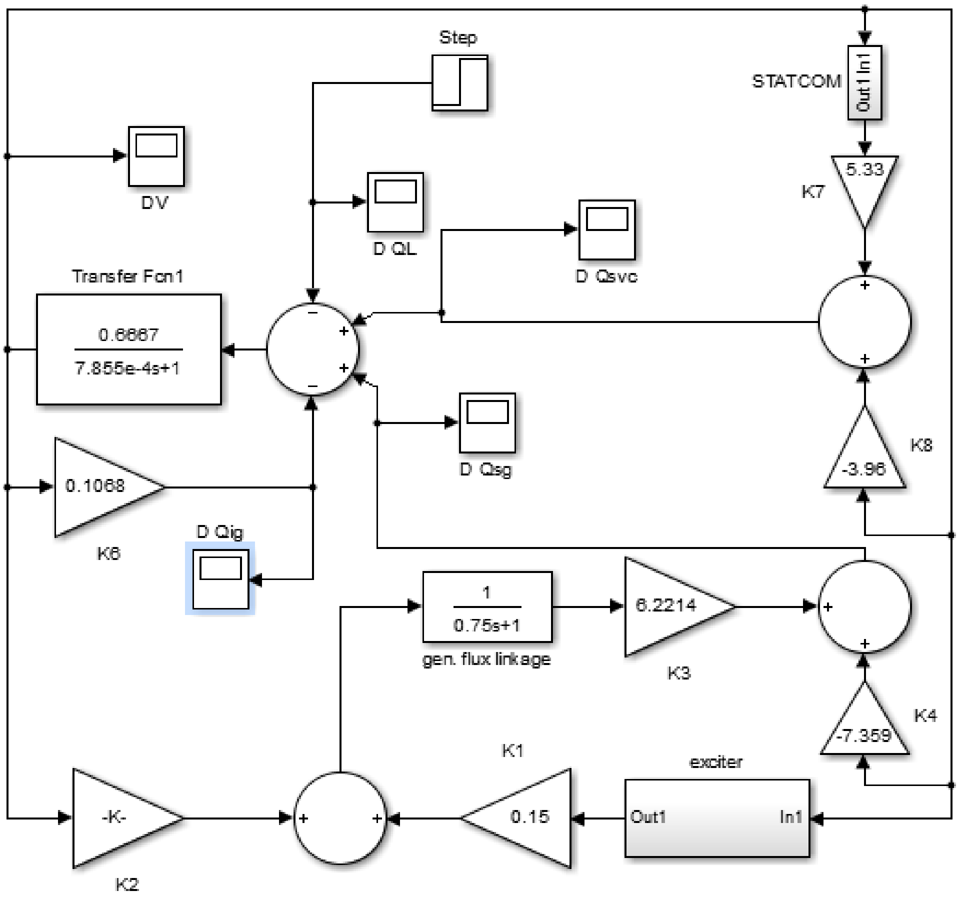


Figure 2. Simulation Block Diagram of Isolated Hybrid Power System

4. Results and discussion

Different response of hybrid system with fixed input for DSTS(constant slip IG) for deviation in voltage, reactive power of synchronous generator, induction generator and STATCOM are discussed with controller parameters optimised using GA, PSO and FPA algorithms.

4.1 Transient performance analysis of hybrid system without STATCOM under step load disturbance

The dynamic performance of the system without STATCOM is analysed by step change in Q_{Load}. In this paper Q_{Load} increases by 10% of its nominal value(0.75p.u.) at t = 0.2s and 1% of nominal value at t = 0.4s. Figure 3 shows the voltage deviation corresponding to step changes in Q_{Load}. It has been found that AVR employed with SG is not able to mitigate mismatch in reactive power and reactive power compensating devices are required to stabilise the response

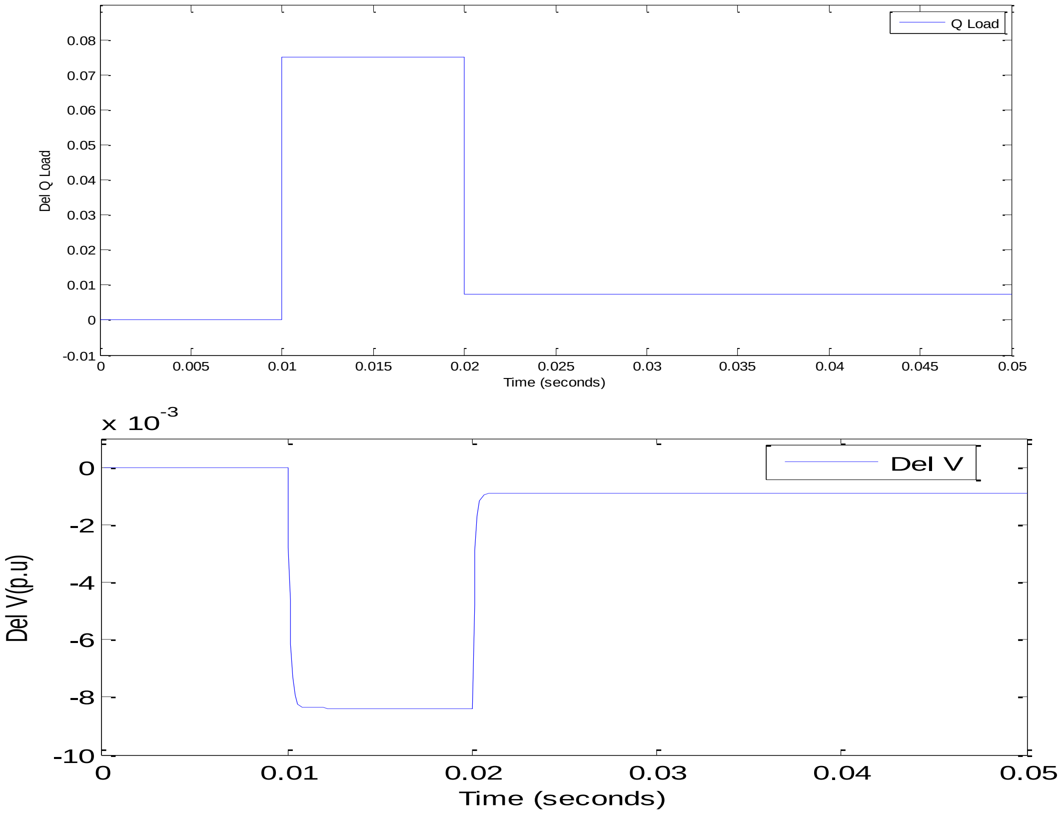


Figure 3. ΔQ_{Load} and ΔV of the System Without STATCOM Under Step Disturbances in Q_{Load}

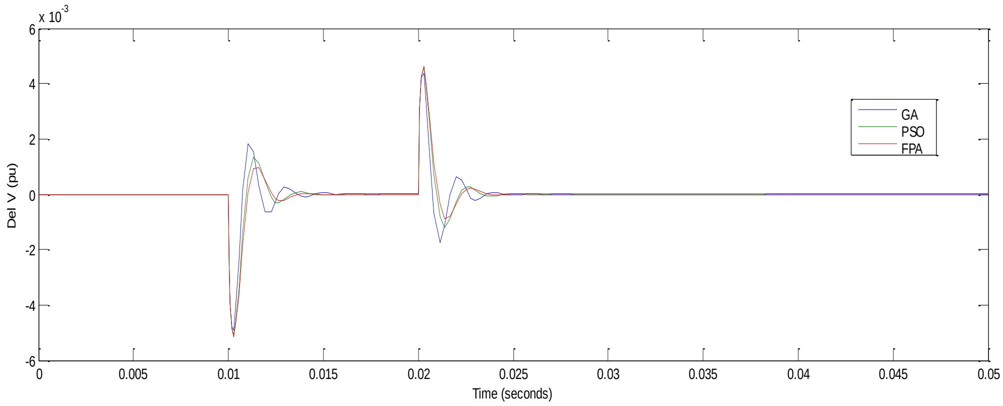
Table 1. Range of Gain Values

Variables	Minimum	Maximum
K_p	1	500
K_i	0	15000

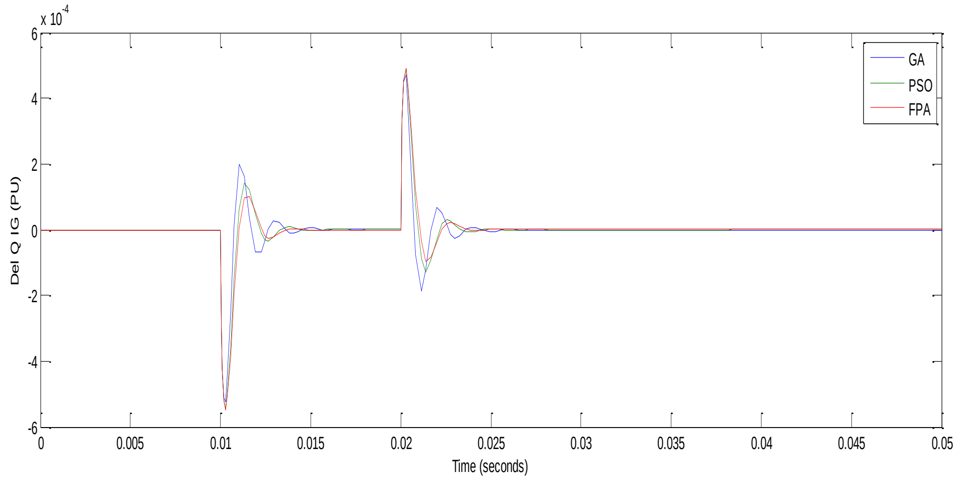
4.2 Transient performance analysis of hybrid system with STATCOM under step load disturbance

The dynamic performance of the system with STATCOM is analysed by step change in Q_{Load} and constant P_{IG} (slip of induction generator is constant). In this paper Q_{Load} increases by 10% of its nominal value (0.75p.u.) at t = 0.2s and 1% of nominal value at t = 0.4s.

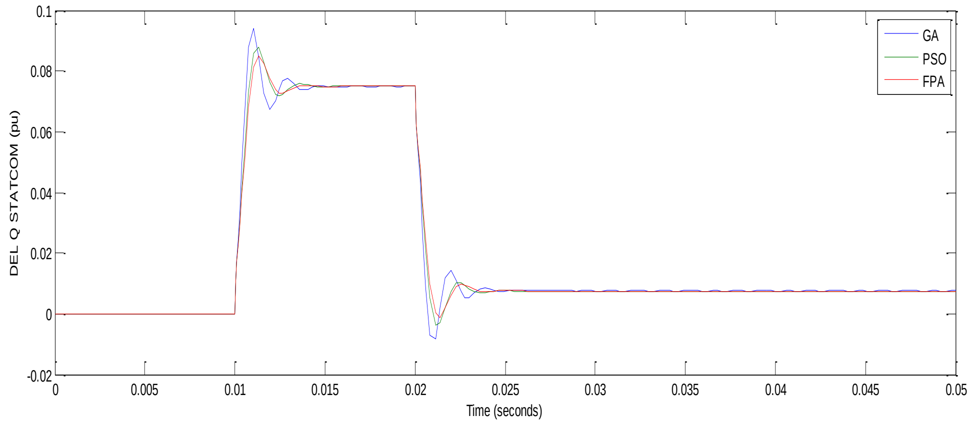
From Figure 4 it is be inferred that terminal voltage decreases due to increase in reactive power demand at t-0.2 s. When reactive power demand decreases at t=0.4 s there is increase in voltage due to deviation. The voltage deviation in both the cases is stabilised quickly by STATCOM. Figure 4 shows the dynamic response of ΔQ_{IG}, $\Delta Q_{STATCOM}$ and ΔQ_{SG} respectively.


x 10^-3
Del V (pu)
Time (seconds)
GA
PSO
FPA
6
4
2
0
-2
-4
-6
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05

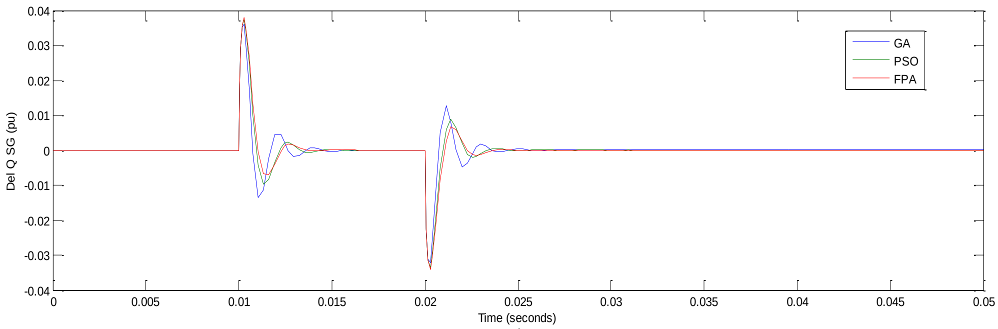
a


x 10^-4
Del Q IG (PU)
Time (seconds)
GA
PSO
FPA
6
4
2
0
-2
-4
-6
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05

b


DEL Q STATCOM (pu)
Time (seconds)
GA
PSO
FPA
0.1
0.08
0.06
0.04
0.02
0
-0.02
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05

c


Del Q SG (pu)
Time (seconds)
GA
PSO
FPA
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05

d

Figure 4. Dynamic Response of Hybrid Energy System with STATCOM, Step Change in Load and Constant Slip (a) Transient Response of ΔV, (b) Transient Response of ΔQ_{IG} (c)Transient Response of $\Delta Q_{STATCOM}$ (d) Transient Response of ΔQ_{SG}

The value of gain constant of PI controller optimized using GA, PSO and FPA for step change in Q_{LOAD} is given in the Table 2. Maximum voltage deviations of transient responses are shown in Table 3. From this it is clear that FPA optimized controllers provide better performance compared to GA and PSO optimized controllers.

Table 2. Value of Optimized Controller Gains

Techniques	$K_{P,STATCOM}$	$KK_{I,STATCOM}$
GA	16	8911
PSO	11	6736
FPA	9.81	5436

Table 3. Maximum Voltage Deviation (∆V) in pu for Controllers Optimized by GA, PSO and FPA.

Techniques	t = 0.2 s	t =0.4 s
GA	0.0018	-0.00174
PSO	0.0013	-0.0012
FPA	**0.0009**	**-0.00895**

Table 4. Parameters of GA, PSO and FPA

GA	Value	PSO	Value	FPA	Value
No. Of Generation	50	No. Of Generation	50	No. Of Generation	50
Population size	30	Population size	30	Population size	30
Crossover probability	0.5	C_1	1	Switch probability	0.5
Mutation probability	0.01	C_2	3		

5. Conclusion

Reactive power control of DSTS based hybrid system with STATCOM is investigated for the first time. From the analysis it is clear that SG alone cannot stabilise the system under varying load condition. Reactive power demand by the system is compensated by both STATCOM and SG. Dynamic response of the system is studied based on reactive power flow balance. The contribution of the work is as follows

i. Dynamic performance analysis of DSTS hybrid system without STATCOM for step change in load has been done. It is clear that voltage deviations are large and AVR employed with SG is not sufficient to stabilize the system. It is concluded that to mitigate the voltage deviation reactive power, compensating devices are needed.
ii. Reactive power generation through STATCOM depends on PI controller. PI controller in STATCOM is tuned by three different techniques namely GA, PSO and FPA. The performance of the system for three different controller gains were compared.

iii. Transient response shows that FPA tuned controllers provide better response for system with voltage deviation than GA ad PSO tuned controllers.

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APPENDIX

System Parameters	
Synchronous Generator	
P_{SG}	0.4 pu kW
Q_{SG}	0.2 pu kVAR
Induction Generator	
P_{IG}	0.6 pu kW
Q_{IG}	0.291 pu kVAR
η	90%
P.f	0.9
$x_1 = x_2'$	0.56
$r_1 = r_1'$	0.19
Load	
P_L	1.0 pu kW
Q_L	0.75 pu kVAR
P.f	0.8
STATCOM	
Q_{COM}	0.841 pu kVAR
$\propto^0$	53.314^0
T_α	0.0003
T_d	0.00167