COMPARATIVE PERFORMANCE OF WIND ENERGY CONVERSION SYSTEM (WECS) WITH PI CONTROLLER USING HEURISTIC OPTIMIZATION ALGORITHMS

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ABSTRACT

Integrating large-scale wind turbine generators (WTGs) may have significant impacts on power system operation such as system frequency, voltage profile, stability and reliability. This paper studies the stability and performance of the wind energy conversion system (WECS) based on Static Var Compensator (SVC). Without reactive power compensation, the integration of wind farm based on induction generators (IGs) in a network may lead to the voltage collapse in the system and hence it becomes unstable. The paper also shows that a dynamic reactive power compensation using Static Var Compensator (SVC) at the point of common coupling (PCC) is successful in maintaining the system voltage at acceptable level and hence increases stability of the system. Moreover, this paper presents, using advanced optimization techniques based on artificial intelligence (AI) such Harmony Search Algorithm (HS), Self-Adaptive Global Harmony Search Algorithm (SGHS), Firefly Algorithm (FA) and Improved Firefly Algorithm (IFA)as to tune the parameters of PI controllers for SVC and pitch angle.

INTRODUCTION

A pressing demand for more electric power and the need to reduce pollutant gas emissions lead to the rapid growth in the amount of renewable energy that connected to distribution grids [1]. Wind is still less costly than other forms of renewable energy. Self excited induction generators (SEIGs) are widely used for wind farm integration because of its low cost, robustness, low maintenance and self-protection against severe overload and short circuit [2].

the unpredictability and continuous fluctuations of wind speed and the varying power demand are more than enough concerns to justify the need for a control system, which will regulate the parameters of the wind energy conversion system that need to be controlled to provide high quality of supply [3].

the power quality issues, such as power fluctuations, voltage fluctuations, and harmonics, cannot be solved satisfactorily by conventional devices because these devices are not fast enough [4]. Therefore, a dynamic shunt reactive power compensator is required to tackle this problem and this can be achieved by using Flexible AC Transmission System (FACTS) devices such as the Static Var Compensator (SVC) [5].

Proportional-Integral (PI) control strategy prefers today in automatic process control applications in industry. The poor tuning of PI parameters has bad effect on the system performance and in the worst case scenario may lead to the collapse of system operation [6].

Harmony search optimization algorithms and firefly optimization algorithms are used for searching the optimum solution in a wide variety of problems [7-10].

The main contribution of this paper is using advanced optimization techniques based on AI (HS, SGHS ,FA and IFA) to enhance the dynamic performance of WECS.

Also, a comparative study of the dynamic performance for the system with SVC based PI controller tuned by HS, SGHS, FA and IFA is evaluated by subjecting this system to different disturbances.

HARMONY SEARCH ALGORITHMS

The basic HS algorithm [6,7] consists of three basic steps, namely, initialization, improvisation of a harmony vector and updating the harmony memory (HM) as shown in the flowchart illustrated in Figure 1.

Recently a (Global Harmony Search) GHS algorithm that modifies the pitch adjustment rule has been proposed [8]. An extension of the GHS algorithm, a self-adaptive GHS (SGHS) algorithm [9], presented in this section employs a new improvisation scheme and an adaptive parameter tuning method. In this algorithm, four control parameters harmony memory size (HMS) (kept as a user defined value), harmony memory consideration rate (HMCR), pitch adjustment rate (PAR) and band width (BW) are closely related to the problem being solved and the phase of the search process that may be either exploration or exploitation.

The computational procedure of the SGHS algorithm is illustrated in the following steps:

Step 1: Set parameters HMS, learning period (LP) and number of improvisations (iterations) (NI).

Step 2: Initialize maximum BW (BWmax), minimum BW (BWmin), mean HMCR (HMCRm) and mean PAR (PARm).

Step 3: Initialize and evaluate HM. Set generation counter lp = 1.

Step 4: Generate HMCR and PAR according to HMCRm and PARm.

Yield BW according to BWmax and BWmin.

Step 5: Improvise a new harmony by using a memory consideration rule, a pitch adjustment rule and a random re-initialization.

Step 6: If new harmony vector is worse than the worst vector in HM, update the HM as worst vector equal new vector and record the values of HCMR and PAR.
Step7: If lp = LP, recalculate HMCRm (PARm) according to the recorded values of HCMR (PAR) and reset lp = 1; otherwise, lp = lp + 1.
Step 8: If NI is completed, return the best harmony vector in the HM; otherwise go back to step 4.

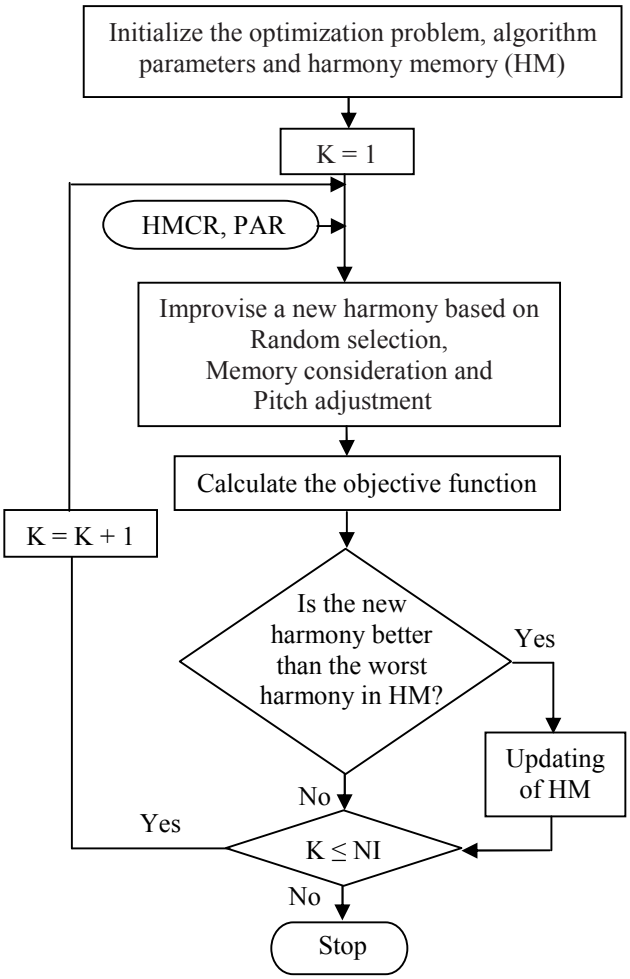


Figure 1. Optimization procedure of the harmony search algorithm

FIREFLY ALGORITHMS

In FA [6,10] each firefly will be attracted to more brighter or more attractive fireflies, and at the same time they will move randomly. The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases. The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem. An IFA was developed to address the shortcomings of the basic FA algorithm which uses fixed value for randomization parameter [6]. Figure 2 shows the flow chart of Improved Firefly Algorithm (IFA).

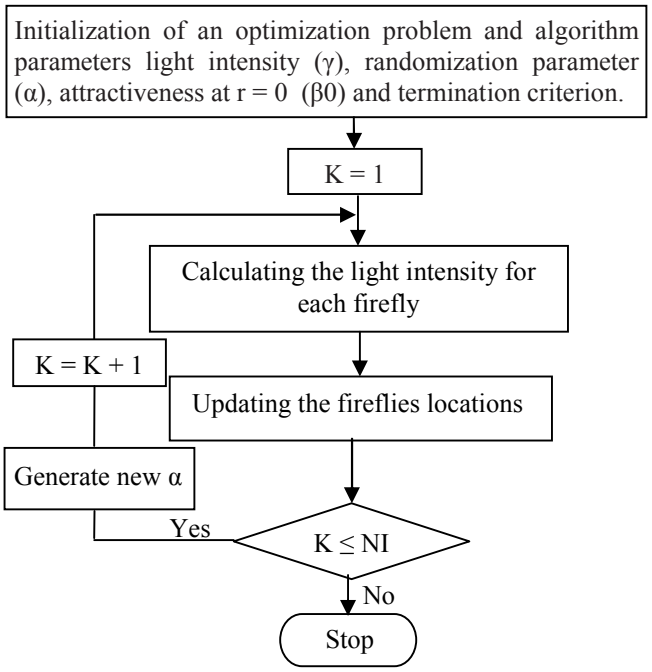


Figure 2. Flowchart of IFA algorithm

STUDY CASES

System description

The single line diagram of the proposed WECS is shown in Figure 3. A 22 kV distribution system is fed by a 220 kV, 50 Hz grid bus through a step down transformer. Three loads; one load of 2 MW at the transformer, 0.98 p.f (lag), one load 1 MW 0.98 p.f (lag) at 30 km and another load is 5 MW with 0.97 p.f (lag) at 50 km from the transformer. A 9 MW wind farm consisting of three 3 MW variable pitch wind turbines coupled with squirrel-cage induction generators is connected through step up transformer to the 22 kV distribution network at the point of common coupling. The SVC rating is determined from load flow studies. It is obtained to be + 2 Mvar capacitive and –1 Mvar inductive. The specifications and data sheets for various components of this system are given in [5].
The WECS can operate in grid-connected mode or in islanding mode when grid is broken down.

Dynamic behavior of the WECS connected to grid

FA, IFA, HS and SGHS algorithms are employed to tune PI controller by minimizing the integral of time absolute error (ITAE). Figures 4 and 5 illustrates that at specific operating point the SGHS reaches to the minimum ITAE value faster than other algorithms and also this value is smaller than that produced by HS, FA and IFA. SGHS has the capability to explore the search space. This shows the robustness of the SGHS algorithm.

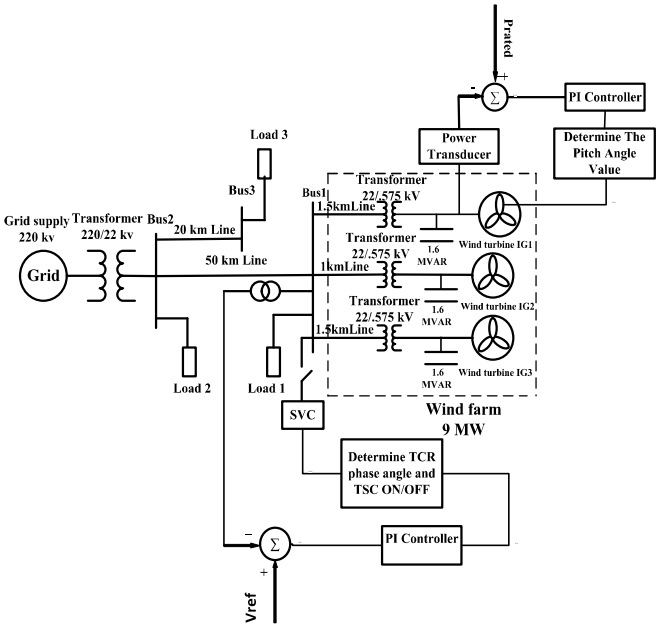


Figure 3. Single line diagram of the proposed system

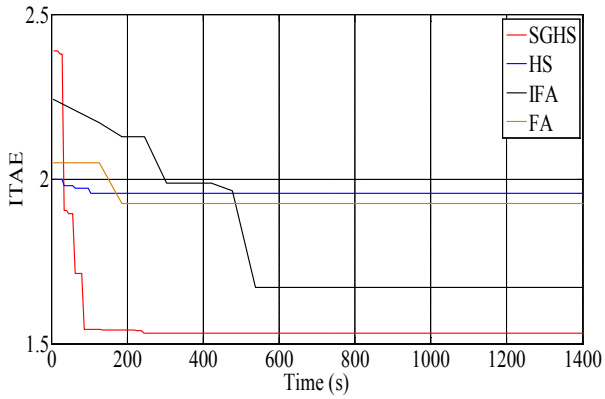


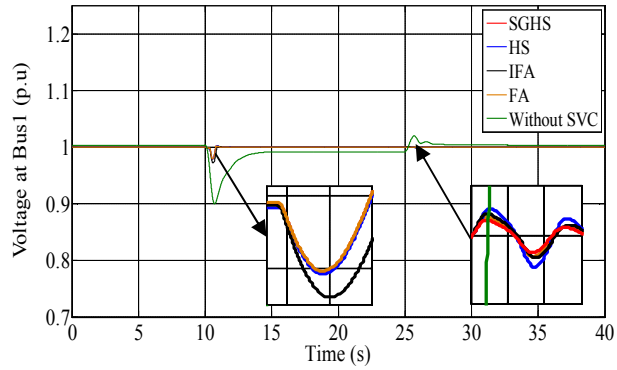
Figure 4. ITAE for pitch angle controller obtained by the best runs of FA, IFA , HS and SGHS algorithms

Changing in wind speed

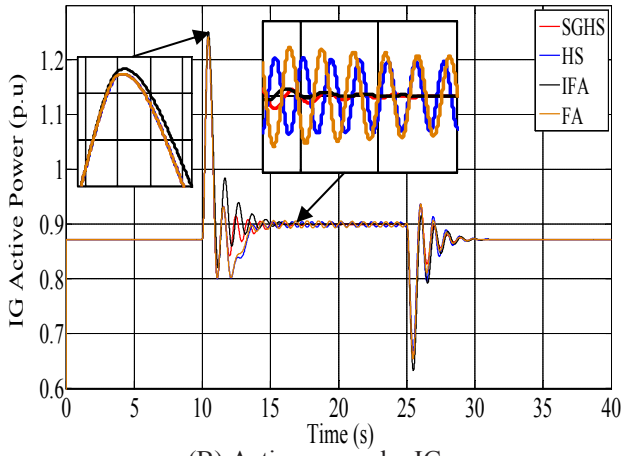
It is assumed that the wind speed starts at 9 m/s, increases to 10 m/s after 10 s and further decreases to 9 m/s at t=25 s. It is obvious from Figure 5 that the power production increases when the wind speed increases and as a result, the reactive power absorbed by T.L and transformer increases. The lack of reactive power supplied to IG leads to decrease the output voltage of IG.

The pitch angle controller turns the blade around its own axis to adjust the rotation speed and the generated power. The SVC provides more reactive power to compensate the reactive power absorbed by T.L and so keep the terminal voltage within acceptable limits. The vice versa effect in case of decreasing the wind speed at 25 s.

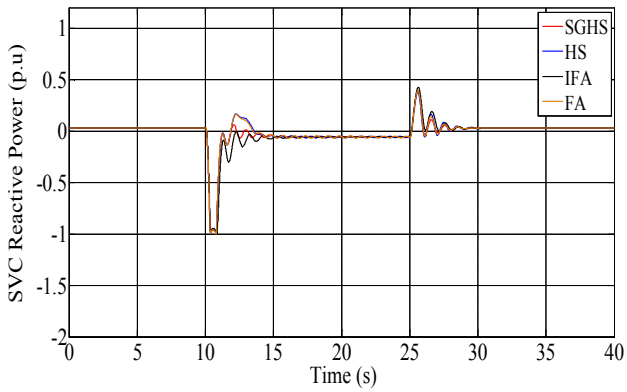
Figure 5 also illustrates that the SVC boosts the performance of the system. The WECS based controllers tuned by SGHS produces slightly better performance than other algorithms in terms of settling time and maximum overshoot.



(A) Voltage response at bus 1



(B) Active power by IG

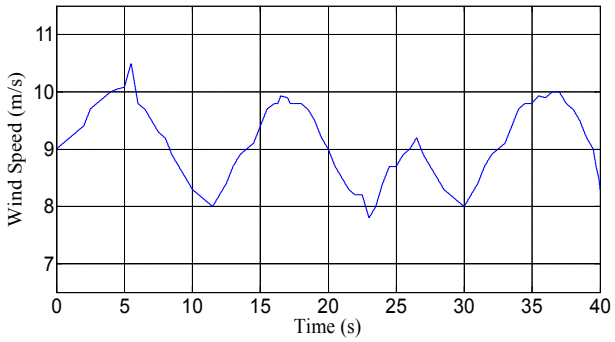


(C) Reactive power supported from SVC

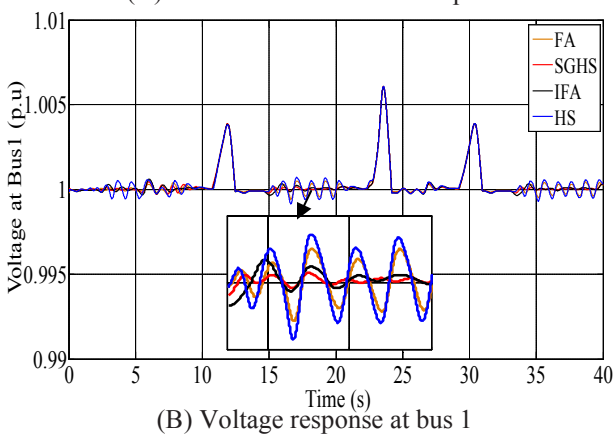
Figure 5. System performance for step change in wind speed

Practically, the system may be subjected to random changes in the wind speed as shown in Figure 6. Due to, the continuous fluctuations of wind speed the mechanical power extracted from wind changes rapidly and so the power generated and reactive power consumed by IG changes continuously. The SVC compensates the reactive power continuously to maintain the terminal within allowable range.

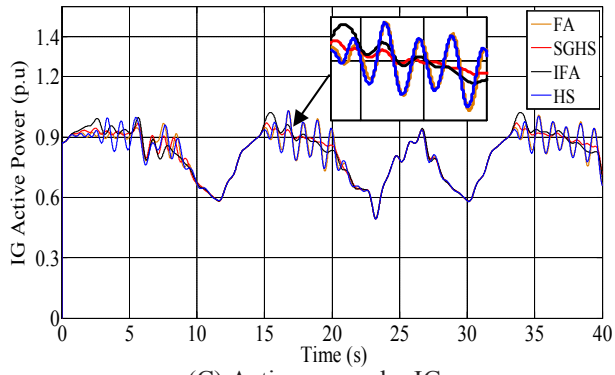
As can be seen from Figure 6, PI controllers tuned by SGHS is more efficient than HS, FA and IFA.



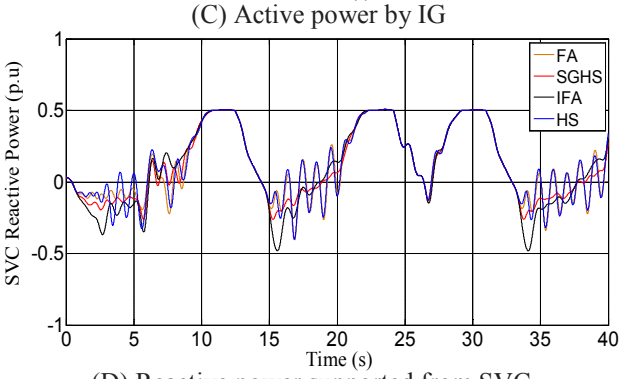
(A) Pattern of variation wind speed



(B) Voltage response at bus 1



(C) Active power by IG



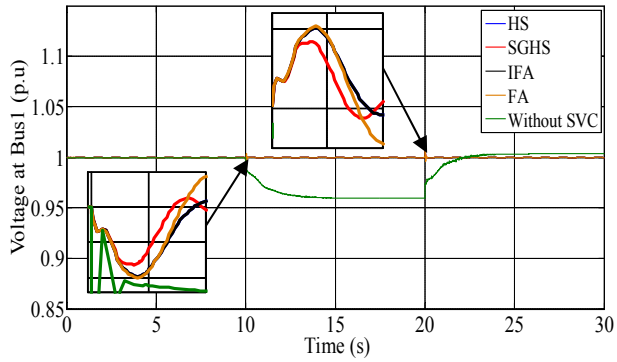
(D) Reactive power supported from SVC

Figure 6. System performance for random change in wind speed

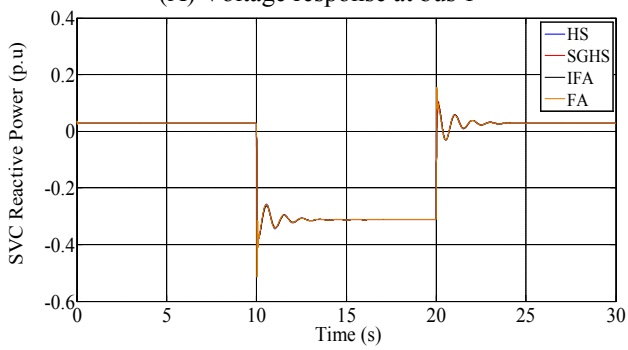
Changing in load

Figure 7 shows the system response when load at bus 1 increases from 5 MW, .97 p.f to 6 MW, .96 p.f at 10 s and then decreases again to 5 MW, .97 p.f at 20 s. As clear, the bus voltage decreases with increasing the inductive load and due to this, the SVC generates more reactive power to compensate the reactive power absorbed by the load and restore the desired value of the terminal voltage. The vice versa effect as the inductive load decreases at 20 s.

it is also clear that SVC improves the voltage profile and SGHS is the best as far as voltage maximum overshoot (POS) is concerned.



(A) Voltage response at bus 1



(B) Reactive power supported from SVC

Figure 7. System performance for sudden change in load

Occurrence of symmetrical fault

Figure 8 describe the behavior of the system under application of symmetrical three phase fault at bus 1 which is considered the most severe on the stability of system and imposes more heavy duty on the circuit breaker.

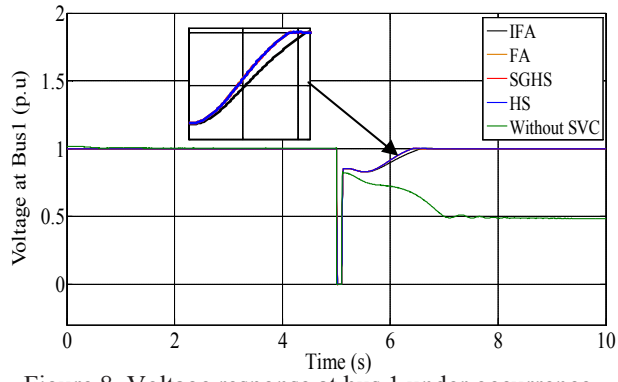


Figure 8. Voltage response at bus 1 under occurrence fault and lasted for 100 ms

It is clear that SVC based PI controller tuned by HS, SGHS, FA and IFA enhances the stability of the system.

Dynamic behavior of the isolated WECS

Changing in wind speed

It is obvious from Figure 9 that when the wind speed increases by 10% from rated value at 5s, the system frequency increases because the input mechanical torque increases (Tm>Te). The blade pitch angle increases to maintain the frequency within the acceptable limits. The vice versa effect when the wind speed decreases at 30s.
The blade pitch angle controller based on SGHS produces better performance than other algorithms.

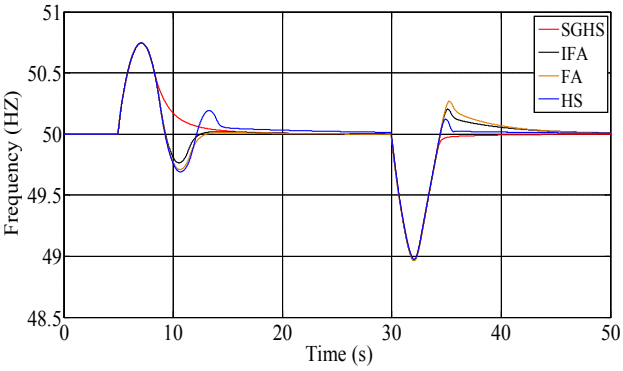


Figure 9. System frequency for sudden change in wind speed

Changing in load

Figure 10 indicates that the terminal voltage increases with decreasing the inductive load at bus 1 by 10% at 5 s. The SVC generates less reactive power to regulate the voltage. The vice versa operation in case of increasing the inductive load at 35 s.
SGHS, HS and FA produce approximately the same performance. They are slightly better than IFA as far as settling time is concerned.

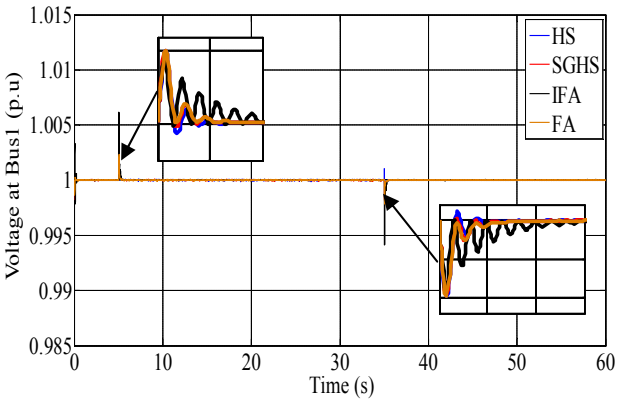


Figure 10. Voltage response at bus1 for sudden change in load

CONCLUSION

In this paper FA, IFA, HS and SGHS algorithms have been presented to tune WECS controllers and this system was tested for some types of disturbances such as changing in wind speed, load and fault occurrence.
The results obtained illustrates that the proposed PI controllers parameters tuned by advanced meta-heuristic algorithms (HS, SGHS, FA and IFA) improves the dynamic performance of the system. However, SGHS provides controller parameters with an optimal performance and takes less execution time which will be considered an important factor for on-line operation as compared to HS, FA and IFA.

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