Performance Enhancement of STATCOM Integrated Wind Farm for Harmonics Mitigation Using Optimization Techniques

Mohamed Hamdy, Mahmoud A. Attia, Almoataz Y. Abdelaziz, Sachin Kumar, Kumari Sarita, and R. K. Saket

Abstract Renewable energy generation is growing every day all over the world. This injects the grids with harmonics and increases the total harmonics distortion of the systems. In the other hand, Flexible AC transmission systems (FACTS) are used in the different power systems for the enhancement of the stability of these systems. In this paper, Flexible AC transmission systems (FACTS) shall be used not for the enhancement of the stability of the system as usual, but to mitigate the harmonics of the system and decrease the Total harmonics distortion (THD). The Static Synchronous Compensator (STATCOM) performance is compared using The Harmony Search Optimization Algorithm (HSA) and the Invasive Weed Optimization (IWO) trying to achieve better results. MATLAB/SIMULINK is used to create a power system model of wind generation system and then is used to compare the two techniques.

Keywords Renewable energy · Wind turbines · Harmonics · Total harmonics distortion · Optimization techniques · Flexible AC transmission systems · Static compensator

1 Introduction

The harmonics generated from the wind turbine are one of the withdraws of the wind generation as it causes lots of problems in the power systems. The harmonics can be defined as a function that has integer frequencies are multiples of the frequency of

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the fundamental power waveform. Some of the electrical components of the power system such as the power panels and transformers can become resonant mechanically to the magnetic fields resulting from the harmonics with higher frequency when these frequencies of harmonics are prevalent. As a result of that, these components might make a buzzing noise and suffer from vibration corresponding to different frequencies of harmonics. In the modern power system, the harmonics from 3rd to the 25th can be considered as the most common range.

The total harmonic distortion (THD) is an important parameter that represents the harmonic distortion level of any voltage or current signals. So, taking voltage as an example, THD is an index to compare the harmonic voltage components with the fundamental element of the voltage signal, as per Eq. 1.

$$\mathrm{THD} = \frac{\sqrt{\sum_{h=2}^{n} V_h^2}}{V_1} = \frac{\sqrt{V_1^2 + V_2^2 + \cdots V_n^2}}{V_1} \tag{1}$$

where, the variable h is the number of harmonics of the signal, and n is the maximum harmonic order of voltage, $_1$ is the nominal system voltage at the fundamental frequency [1]. The (ANSI/IEEE 519-1992) standard lists are one of the most widely used guides for THD limits in any power grid system [2]. Thus, the critical objectives of any harmonic analysis are to assist the system, both design and installation in meeting (IEEE 519-1992) standards regarding limiting THD.

The Flexible AC Transmission Systems (FACTS) involves a group of power electronic devices which are developed for the applications including phase-shifting transformers, tap changers, reactive compensators, synchronous condensers, etc. [3]. The FACTS devices are used to control the parameters of the transmission line, such as line reactance and node voltages [4]. The use of semiconductor switches makes the FACTS devices much faster as compared to the conventional mechanical switches, but the FACTS technology is costly [5].

The dependency of the performance of industrial applications, including information technology and production engineering on the power quality has made this an important factor to achieve [6]. At the generator side, the power quality is defined as the ability of the generator to generate power at 50 Hz without any variations to that power, but in for the transmission and distribution level, it is defined as the ability of the voltage to stay within the limit of 5%. Another definition of the power quality is that it is the analysis, measure, and improvement of the voltage of the bus to maintain this voltage to be sinusoidal in a wave within the rated voltage and frequency [7].

The connectivity of renewable energy resources (RERs) with the transmission or distribution systems are increasing without any issue due to the availability of power electronic converters. These converters affect the system power quality and increase the harmonics at the common coupling point. The mitigation of these power quality issues is very important and challenging too [8, 9]. So, the use of RERs in the traditional electrical system resulted in changing the reliability, management, power quality, protection, and control policies of electrical utilizes. In other words, good power quality can be considered as a critical factor for a reliable power system.

However, the non-sinusoidal waveforms produced from different electronic devices and nonlinear loads will result in poor power quality systems [10, 11].

During the last few years, the FACTS technology has been used in power systems for power quality enhancement, voltage stabilization, power factor correction and harmonic mitigation [12, 13]. So, there is significant research that was trying to get the maximum energy that can be extracted from the RERs, and the results of implementing FACTS devices in the grids with RERs are encouraging [14, 15]. So, the implementation of different FACTS devices in any of the power systems shall have the effect of reducing different problems of power quality. The FACTS's basic concept is the real and reactive power flow control and also the voltage control in the power system by the usage of the high-voltage power electronics devices [16, 17]. The usage of the Static Synchronous Compensator (STATCOM) facilitates the connection of wind power to any power systems [18], helps in the improvement of the power system stability that contains wind energy sources [19], improve voltage ride-through, and regulate the power flow [20]. The Dynamic Distribution System Compensator (DDSC) enhances the stability of main buses of the system and the power quality of the whole system. It increases the capacity of the distribution feeder transmission [21]. As for the Power filter compensator (SFC), it improves the power factor, stabilizes the AC voltage, and enhances the power quality of the system [22]. The Static Synchronous Series Compensator (SSSC) helps in providing voltage ride-through and regulation of power flow [20]. The Static Var Compensator (SVC) improves the stability of the power system with PV energy source [23], the power quality of the system, and the transient stability [24]. For the Distribution-STATCOM, it improves the voltage profile of the power system that has distributed wind generation [25].

2 Optimization Techniques

Harmony Search Optimization Algorithm (HSA) can be considered as one of the meta-heuristic techniques that are used in the optimization of electrical power engineering problems [26]. This optimization algorithm is using random numerical simulations with certain algorithmic steps so that it can find engineering problems optimum solution. The HSA uses the concept of the musical performance that tries to reach a pleasing harmony for the audience to deal with the optimization problem and its objective function. The steps involved in HSA can be found in [27]. Invasive Weed Optimization (IWO) is another Optimization Algorithm that we can consider as an evolutionary meta-heuristic algorithm to solve different engineering optimization problems [28, 29]. To perform this algorithm, we should use the following steps [30]:

Population initializing: The finite number of populations that we can call them (seeds) shall be selected, and they all shall have random positions.

Spatial dispersal: These seeds that are produced newly shall be spread all over the search area randomly and grown to new plants. In this part, the algorithm randomness and adaptation that shall be provided, and this because of the fact the generated seeds shall be randomly distributed over the dimensional search space (d), and this distribution shall be by normally distributed random numbers that have mean equal to zero, but also, they have variable variance. While the simulation is working, an alteration that is nonlinear shall obtain performance that we can call satisfactory, which is shown in Eq. 2. That shows that.σ_{iter} is the present time step standard deviation, while $\text{iter}_{\max}$ is the maximum iterations number, and finally, n is the index of the nonlinear modulation.

$$\sigma_{\text{iter}} = \frac{(\text{iter}_{\max} - \text{iter})^n}{\text{iter}_{\max}^n}(\sigma_{\text{intial}} - \sigma_{\text{final}}) + \sigma_{\text{final}} \tag{2}$$

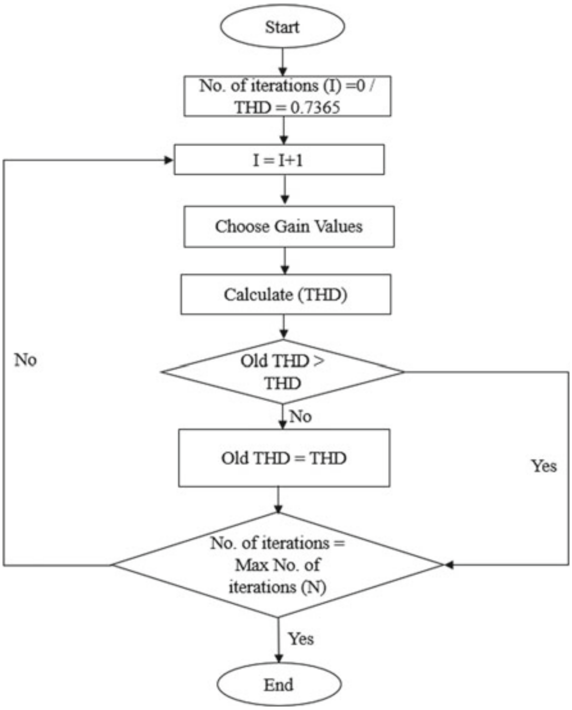
Competitive exclusion: In this process, the maximum plants' number shall be reached. After that, until reaching the maximum iterations number, the procedure shall continue, and this point, the plant that has the best fitness that is the closest to the optimal solution should be achieved hopefully.

Using the optimization technique to get the best (lowest) THD by controlling the control gains of the STATCOM by making them the parameters of the Optimization Technique, and making the objective function of the Optimization Technique, and choosing the algorithm to minimize the objective function (THD). So, the Optimization Technique shall use random values of the gains from the specified range that is inputted in it and gets the corresponding THD, and then changes the gains again and check the corresponding THD and compare it with old one. Finally, use the lower one, Optimization Technique shall change the gain back, and so on until we get the best (lowest) THD. The specified range of the gain shall be selected in the beginning to be from 0 to maximum by trial and error until reaching to the final range of gain, and then apply the Optimization Technique with this range, to get the best gains that can achieve the best (lowest) THD, Fig. 1 represents this process.

3 Results and Discussion

The model that is constructed by MATLAB SIMULINK and it can be divided to a wind farm that uses Induction Generators (IG), and that is 9 MW. The model consists of a wind farm that has six 1.5 MW wind turbines, and this wind farm is connected to the distribution system that is 25 kV, and using a 25 km, 25 kV feeder, this distribution system is connected to a 120 kV grid. Three pairs of 1.5 MW wind turbines simulate this 9 MW wind farm. The stator winding of the induction generators (IG) is directly connected to the 50 Hz grid, and the variable-pitch wind turbine is driving the rotor. To maintain the output power of the generator at the nominal value while winds speed

Fig. 1 The flowchart of THD calculation using optimization algorithm



exceeds the nominal value that is (9 m/s). The speed varies approximately between 1 per unit (PU) at no load and 1.005 per unit (PU) at full capacity.

The model is then modified with adding of 3 MVAr STATCOM to limit the total harmonics distortion (THD) of the system. The STATCOM is phasor type as the wind farm turbine so that it can work in the system. For the wind farm system without any harmonics reduction device, the THD is 73.65% which is very high and can cause lots of instability in the system. Figures 2 and 3 represent the wind farm power wave farm (MW) and the voltage waveform (pu), and we shall consider these waveforms as the standard to compare the other results with.

Fig. 2 Wind farm power (MW)

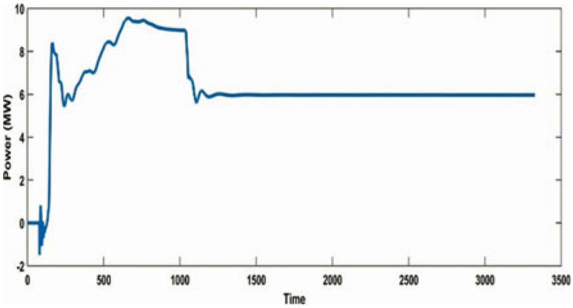
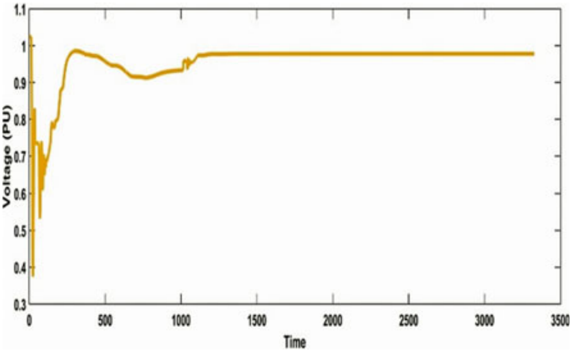
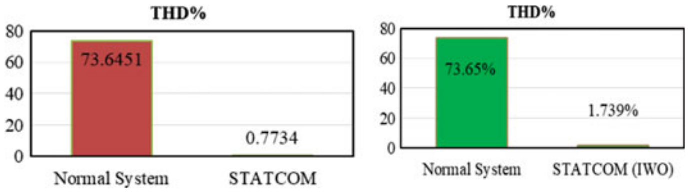


Fig. 3 Wind farm (abc) voltage (PU)



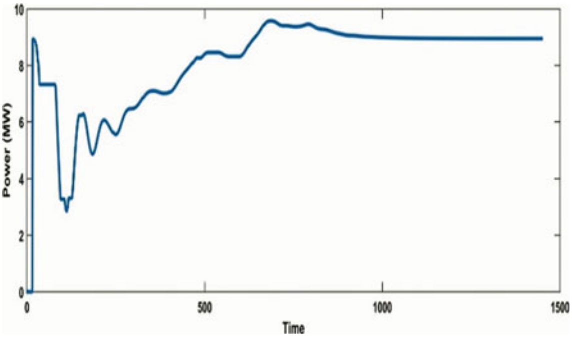
The wind farm system that is equipped with STATCOM that uses the HSA has much better THD as the (THD) is 0.7734% which is a big improvement from the 73.65% (THD) of the normal system, which is 98.95% Improvement from the normal system as shown in Fig. 4a. The power waveform (MW) of the wind farm system that is equipped with STATCOM, it becomes more stable, and Fig. 5 represents the waveform of it. Figure 6 shows the voltage waveform (PU) of the system, which is far more stable than the voltage of the normal system. The same model of the wind farm connected to the STATCOM is used again but with using IWO this time. The



(a) (b)

Fig. 4 Comparison between normal system and STATCOM with **a** HSA system THD, **b** IWO THD

Fig. 5 Wind farm with STATCOM with HSA power (MW)



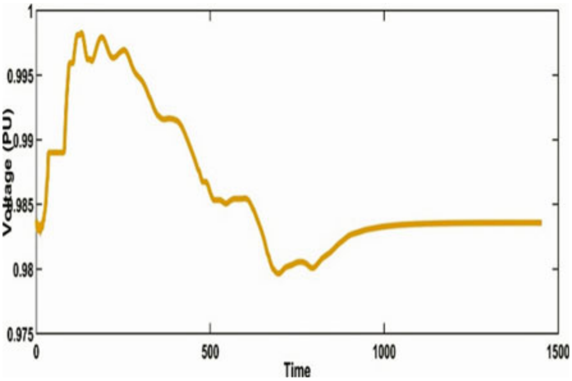


Fig. 6 Wind farm with STATCOM with HSA voltage (PU)

THD of the system became 1.739% by IWO which can also be considered as a big improvement from the 73.65% (THD) of the normal system, as it is 97.25% Improvement from the normal system as shown in Fig. 4b. The power waveform (MW), it becomes slightly more stable, and Fig. 7 represents the waveform of it. Figure 8 shows the voltage waveform (PU) of the system, which is also slight stable than the

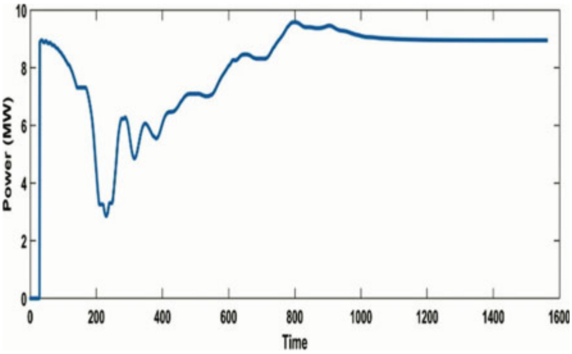


Fig. 7 Wind farm with STATCOM using IWO power (MW)

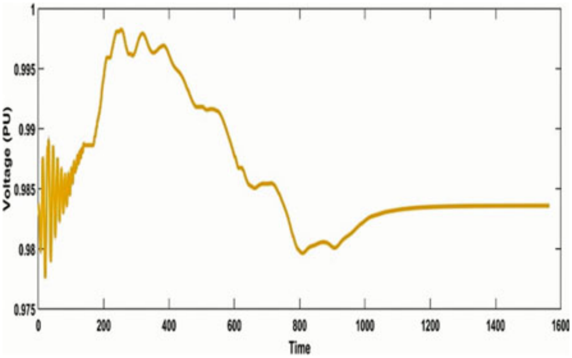
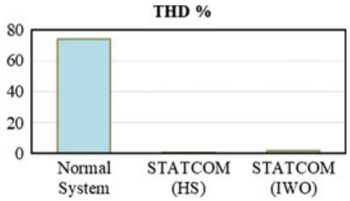


Fig. 8 Wind farm with STATCOM using IWO voltage (PU)

Fig. 9 Comparison between normal system and STATCOM system with IWO and HSA techniques



voltage of the normal system. After testing both Techniques, the Harmony Search Algorithm (HSA) has better results than the IWO in the Total Harmonics Distortion (THD) improvement that is 98.95% for the Harmony Search Algorithm (HSA) while it is 97.25% for the IWO. The comparison regarding the Total Harmonics Distortion (THD) improvement is shown in Fig. 9. Figures 10 and 11 shows the difference between the effect of the STATCOM of both power and voltage waveforms using both Techniques, Harmony Search Algorithm (HSA) and IWO.

Fig. 10 Comparison between the system power using both IWO and HSA techniques

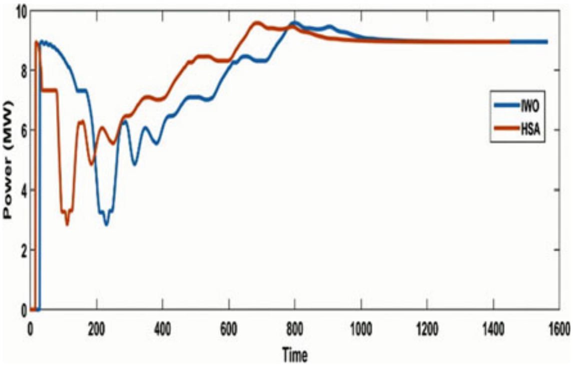
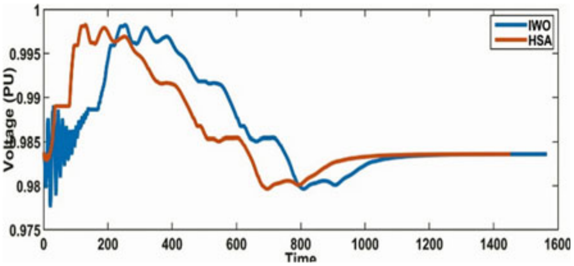


Fig. 11 Comparison between the system voltage using both IWO and HSA techniques



4 Conclusion

The paper has described the effect of STATCOM in the wind integrated power system. The output power, voltage and THD are analyzed in the wind farm model with STATCOM using HSA and IWO techniques. Both the HSA and the IWO are used to optimize the STATCOM performance in mitigation of the THDs in the power system integrated with a wind farm. The HSA has slightly better results than the IWO regarding the THD reduction also in the enhancement of voltage and power performance. The work can further be extended to observe the performance of the power system implementing other FACTS devices. Also, the use of other meta-heuristic optimization techniques can further be applied for better results.

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