Optimization of wind energy conversion systems – an artificial intelligent approach

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Article Info	ABSTRACT
	The environmentally friendly wind energy conversion system has become one of the most studied branches of sustainable energy. Like many other power generator, maximum power point tracking is an easy yet effective way to boost the efficiency of the conversion system. In this research, a modified Electromagnetism-like Mechanism Algorithm (EM) is proposed for the maximum power point tracking (MPPT) scheme of a micro-wind energy conversion system (WECS). In contrast with the random search steps used in a conventional EM, modified EM is enhanced with a Split, Probe, and Compare (SPC-EM) feature which ensures solutions with higher accuracies quicker by not having to scrutinize the search in details at the beginning stages of the iterations. Experiments and simulations are carried to test the SPC-EM in tracking the maximum power point under different wind profiles. Results indicate that the performance of the modified EM showed significant improvement over the conventional EM in the benchmarking. It can thus be concluded that based on the simulations, the SPC-EM performs well as an MPPT scheme in a micro-WECS.

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1. INTRODUCTION

Fossil fuels based power generation has always raised environmental concerns. Researchers around the world are racing in search for alternative sources with less environmental impacts. With it comes a rapid development of renewable energy studies [1-5]. Renewable energy can generally be divided into several major branches. Among others is the wind energy. Wind energy is known to be one of the most environmental friendly and quickly developing source of electricity nowadays [6-8]. In a wind energy conversion system (WECS), the overall efficiency is generally tied to the ability of the system to abstract maximum output power at all instant in a wide range of wind speed [9]. In order to grant the WECS with maximum output power, a maximum power point tracking (MPPT) mechanism is crucial to bring the turbine to the maximum power point (MPP) for all wind speed values.

Many MPPT mechanisms are proposed in the literature. Incremental conductance (IC) algorithm, for instance, does not require sensors and details on the turbine and generator, thus making it more reliable and less expensive [10-13]. Hill climbing (HC) algorithm applies a different strategy which relies heavily on mathematical optimization approach to find the local optima of a given function [14-18]. In this method, if the current solution is on the right of the best optima, the switching moves the operating point to the left,

making it nearer to the optima, and vice versa. The general plan of the HC is based on changing a control variable in a determined step size and analyze the resulting changes in the outcome, until there is no more improvement [19-21]. HC can be widely found in the MPPT studies [22-25]. However, in a rapid wind variation, HC can be sluggish and head in the wrong direction to the MPP [26]. Other MPPT algorithms for WECS, such as the perturb and observe (P&O) algorithm aims to maximize the generated power output while cutting down the reliance on control units and sensors [27, 28].

In this paper, a modified Electromagnetism-Like Mechanism (EM) algorithm is proposed as the DPC MPPT mechanism of a micro WECS. The contribution of this paper is two-fold and can be summarized along the lines as followed. First, a modified EM algorithm with Split, Probe, and Compare (SPC) feature is proposed. With this feature, this global optimization algorithm is enhanced with the ability to find solutions with relatively higher accuracies in shorter time. Secondly, the modified EM is tested in simulation to track for the maximum power point of a WECS. The paper is presented in five chapters. Chapter Two explains the work mechanism of the EM and the details of the proposed modifications. The implementation and design of the proposed MPPT mechanism is discussed in Chapter Three. Chapter Four presents the experimental results and the discussions derived. The final chapter offers the conclusions drawn from the research.

2. ELECTROMAGNETISM-LIKE MECHANISM ALGORITHM

The EM is a population based optimization method proposed by Birbil and Fang [29]. The basic idea of the EM is to imitate the attraction-repulsion mechanism of electromagnetic charges in the effort to find the best global optimal solution in bounded variables. Figure 1 shows an example of the attraction-repulsion search mechanism used in the EM.
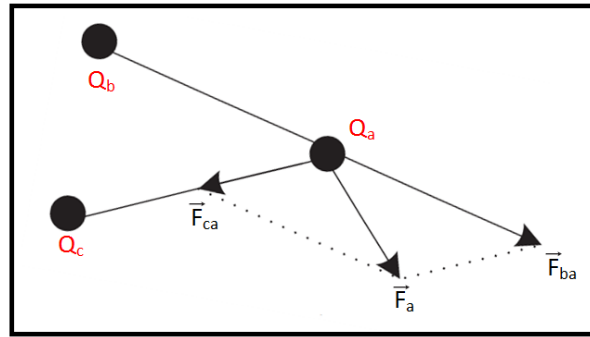

Figure 1. Total force exerted on Q_a by Q_b and Q_c

There are several important operations in the EM, including the initialization, local search, charge calculation, force calculation, and movement of particles, as shown in Figure 2. In this research, the adjustment parameter is the rotor speed allowed in the wind turbine. In the algorithm, *m* sample of initial particles are randomly picked from the feasible PWM value range. Each value of a particle is assumed to be uniformly distributed inside the upper and lower bound. For the purpose of WECS MPPT, the particle with the highest output power is marked as the best particle.

An EM with Split, Probe, and Compare (SPC-EM) feature is proposed in this research. The SPC-EM is an enhanced version of the EM which has the ability to hit accurate solutions without heavily slowing down the entire convergence process. The local search mechanism of a conventional EM is replaced with the SPC search procedure. A tuning equation is designed to dynamically regulate the lengths of the probes based on the outcomes of every iteration, as shown in equation (1).

$$L = \frac{2}{1+\exp\left(\frac{10i}{Max\_LSIte}\right)} \quad (1)$$

In equation (1), *i* indicates the current number of local search iteration while Max_LSIte represents the maximum number of iteration. Figure 3 explains the decision making process of the SPC search mechanism in the form of a flowchart. This enhanced SPC-EM algorithm is then employed as the MPPT scheme of a WECS, which is further explained in the next chapter.
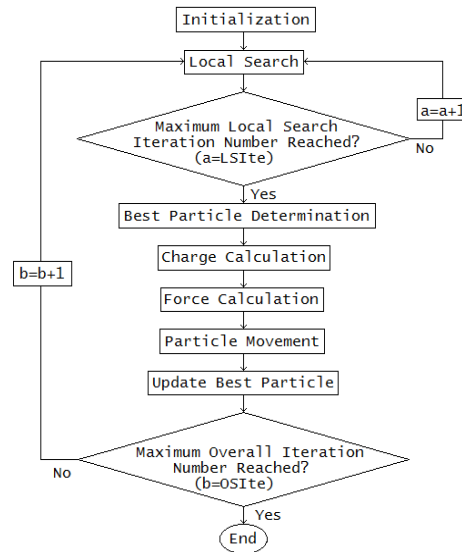
Figure 2. The flow of a conventional EM algorithm, where *a* and *b* denote the iteration number of local and global search respectively, while *LSIte* and *OSIte* refer to the pre-determined maximum iteration number in local and overall search.
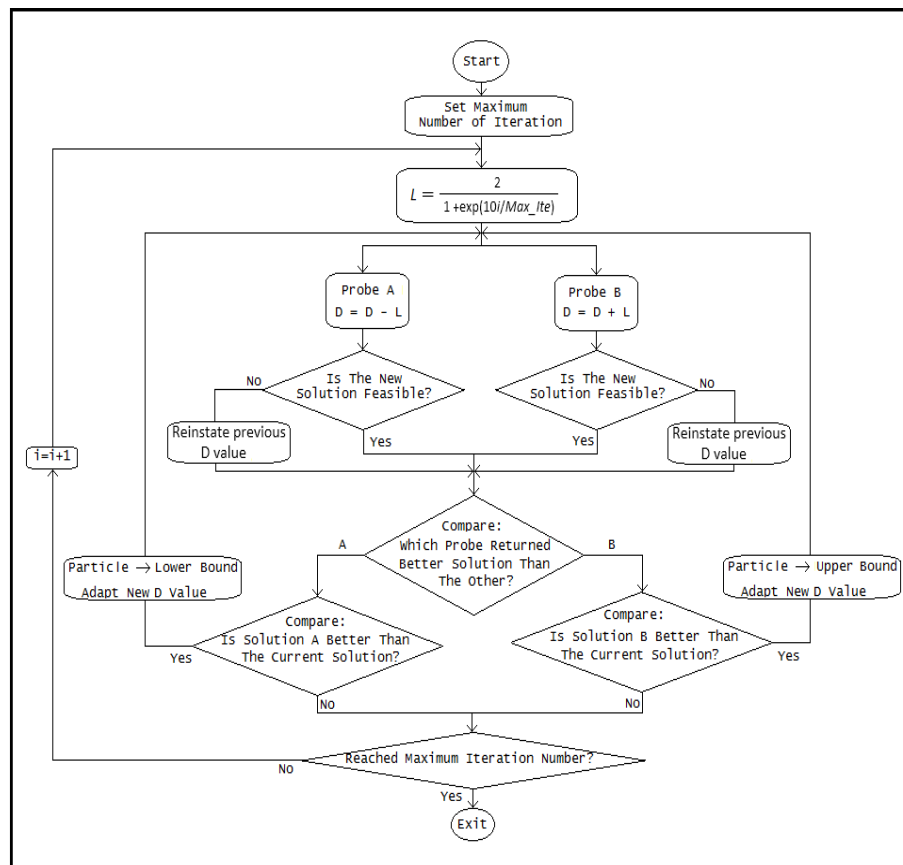

Figure 3. The flow of the proposed SPC-EM, in which *D* represents the parameter of a particular dimension in a particular solution and λ denotes the size of the search step

3.   MAXIMUM POWER POINT TRACKING

The aim of the MPPT scheme is to make sure the turbine operates to push the maximum output power possible. In this research, the enhanced SPC-EM is proposed as the MPPT scheme of a WECS. The proposed implementation is as depicted in Figure 4. An adjustable electrical load is added to control the speed of the turbine when needed. The SPC-EM algorithm monitors the power output and electronically controls the dump load by adjusting the pulse-width-modulator (PWM) signal, which in turn controls the speed of the turbine, ensuring the operation to produce the maximum possible output power.
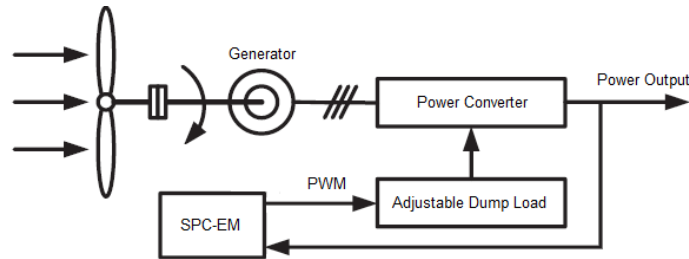

Figure 4. The proposed implementation of SPC-EM as the MPPT scheme of the WECS.

3.1. Algorithm performance tests

Simulations are carried out to investigate the performance of the proposed MPPT scheme under different wind profiles. In the simulations, a WECS with 300W Permanent Magnet Synchronous Generators is employed. The rated wind speed is set at 12m/s. The performance of the proposed SPC-EM is put to test under three different wind profiles simulated individually, as shown in Figure 5. Then, to mimic the ever changing wind speed in the real world application, the simulation of the wind changes from the first profile to the second, and then to the third, to further investigate if the proposed algorithm has the ability to track for the MPP with changing wind speeds.
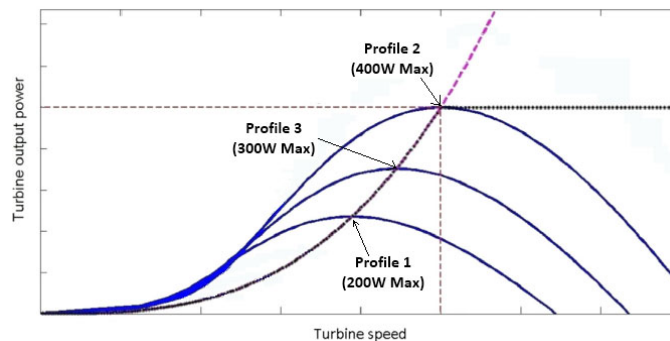

Figure 5. The wind profiles generated to test the proposed SPC-EM.

Simulations are conducted in VB.Net software with Intel 1.6GHz Core i5 processor, 4G RAM and 64-bit Windows 7 operating system. Ten particles are employed in the SPC-EM to track for the MPP. To further study the improvement made by the modified algorithm, the performance of the SPC-EM is benchmarked with that of a conventional EM. 30 individual runs are conducted to avoid stochastic discrepancies. The results are presented in the following chapter.

4.   RESULTS AND ANALYSIS

The experiments are conducted by testing the performance of the algorithms in tracking the maximum power point in the simulated wind profiles. The results of the 30 individual runs are compared in the forms of best solutions, worst solutions, and average solutions. The standard deviations of the gathered

results are also calculated. Table 1 shows the comparison of the results in 3 respective wind profiles. The highest average solutions are highlighted in boldface.

It can be observed from Table 1 that the proposed SPC-EM found higher output powers, which indicates that the SPC-EM managed to hit solutions with relatively higher accuracies. It is also worth noticing the large gap between the best and worst solutions returned by the conventional EM. This inconsistency is caused by the random steps employed in the conventional EM, in which the exploitation of a solution cannot be guaranteed.

Table 1. Comparison of the solutions obtained after 30 individual runs.

		Profile 1	Profile 2	Profile 3
SPC-EM	Best Solution	200	400	300
	Worst Solution	199.94	399.9	299.91
	Average Solution	**199.97**	**399.92**	**299.96**
	SD	8.26E-08	2.74E-07	9.33E-08
EM	Best Solution	199.97	399.96	299.95
	Worst Solution	196.01	396.82	295.01
	Average Solution	198.79	398.09	297.62
	SD	1.25E+00	1.72E+00	1.64E+00

The convergence processes of the simulations are sampled and compared. Figures 6 (a), (b), and (c) show the comparison of the convergence performances of the algorithms under wind profile 1, 2 and 3 respectively. Several things can be observed from the plots. First, the SPC-EM managed to hit relatively higher best output power. Secondly, the SPC-EM also found the final best solutions relatively quicker. Observe the rapid conversion of the SPC-EM at the beginning phase of the convergence processes. The conventional EM, on the other hand, found the best solutions in relatively later iterations.

It can be observed that the proposed SPC-EM performed well in tracking for the maximum output power under different wind profiles. Adopting the advantages of quicker search and higher accuracies, the automatically adjusted search steps enabled the SPC-EM outperform all other benchmarking algorithms.
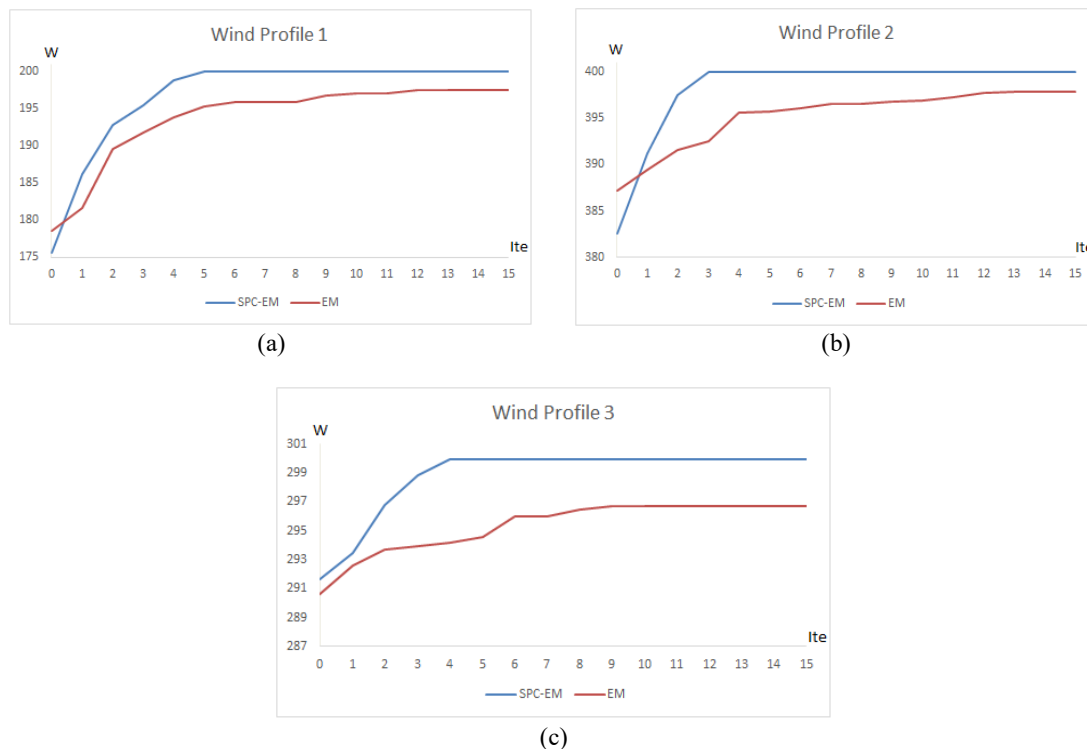

(a)

(b)

(c)

Figure 6 (a), (b), and (c). Convergence analysis of the algorithms under different wind profiles.

5. CONCLUSION

In this research, an SPC-EM global optimization algorithm is proposed as the MPPT scheme of a micro-WECS. The SPC-EM begins the local search with big steps and dynamically tunes the step size as the search moves on. Experiments and simulations are carried out to test the performance of the proposed SPC-EM in tracking the maximum power point under different wind profiles. The results indicate that the SPC-EM showed significant improvement over the conventional EM in the benchmarking. It can thus be concluded that based on the simulations, the SPC-EM performs well as an MPPT scheme in a micro-WECS. In time to come, the research will move on to test the SPC-EM in an actual WECS. Implementation of the SPC-EM in other hybrid renewable energy conversion systems is also worth exploring in the future expansion of this study.

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