



Designing and Optimization of Hybrid Solar and Wind Turbine, With Superconducting Magnetic Energy Storage, By TLBO Algorithm

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Abstract

Considering the outstanding use of renewable energy sources, most of industrial countries secure a main part of their required energy from renewable energy resources. Solar panels and wind turbines are the most important sources for the scattered production based on Renewable energies. In this study the optimized design of a solar panel, wind turbine hybrid system with superconductive magnetic energy storage (SMES), separated from network, to provide for the load demand of a military site is considered. The aim of a system optimization is specifying the number of solar panels, wind turbines, and SMESs with minimizing the cost of system's energy production. In hybrid systems, due to fluctuations in energy production of solar panels and wind turbines, accumulation systems are used in order to provide for a perpetual load. This system is also used to minimize annual costs of energy production for a system of load demand of a military site with the use of TLBO algorithm on a basis of teach-learn is being studied.

Keywords: Wind turbine, Solar panel, Superconducting magnetic energy storage, TLBO algorithm.

1. INTRODUCTION

Nowadays, considering the outstanding population growth and the process of industrialization, the need of mankind for energy is felt more. As all energy sources of Fossil fuel nature are running out and due to worries about environmental effects of these resources, all attention is being detecting the renewable energy sources. But the main drawback to the expansion of these kind of resources is their economic justification that seems to be getting better with the consideration of technological improvements and the soaring prices of Fossil fuels in the near future. Therefore, in future, we would see the spread of renewable energy power plants [1]–[3].

The most important sources of scattered production of renewable energy are based on solar energy and wind turbines. The combination of the use of wind and solar energy under the name of Hybrid Systems is much utilized in power systems. As these systems are feed simultaneously by the Sun and wind, they are more reliable than any other system using only one source of energy for producing power [1], [4], [5].

Recent progress in the technology of energy storage has provided for using different methods of accumulation that minimize the effects of wind fluctuations on the power system.

Energy storage can play a vital role in sorting out power fluctuations due to wind undulations. These storage devices can be used in fleeting moments to strengthen DC bias and by this im-

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provement, the low voltage provides high capacity [5], [6].

In connection with Hybrid System design, including renewable energy sources, many studies have been done. Many of these methods have been considered with the aim of minimizing system cost and improving reliability of providing load. In [7] by using annealing algorithm, based on turbulent search for broken harmony, three methods of improving turbulence, searching for harmony and discrete simulated annealing (DSA) algorithm, are compared in order to consider the extent of improvement in hybrid wind and solar systems. The aim of this article is to minimize the annual cost comprising annual capital cost and annual maintenance cost. The achieved results show that the broken cooling method provides better results compared to other methods. In [8] article for measuring the size of improvement in hybrid solar, wind systems, broken harmony search algorithm has been used, which as it is simple, it is also very fast in its calculations. This algorithm can provide for hopeful results in less than one second.

In [9] article, in order to consider the size of hybrid wind and solar systems, using improvement formula in minimizing hybrid system size has been considered, and by utilizing intelligent methods attempted to select more improved points and showed results in numeric examples and calculations.

In this article by using Teaching-Learning-Based-Optimization (TLBO) algorithm improved size of solar and wind systems besides superconductive accumulators of energy has been calculated. The aim of improvement is to minimize the cost of energy production and providing desirable demand for load. Since the cost reduction for electrical energy production is very important, In order to minimize the number of equipment of energy storage, an improved equation has been presented and their result on the sample networks has been verified through experiments. Superiority of the results earned in this article over other sources has been justified. In this study, improvement the number of solar panels, wind tur-

bines and SMESs for different scenarios has been evaluated and calculated, like changing the capacity of production of energy in the solar panels, wind turbines, and superconductive accumulator of energy.

The paper organization is given in following. In Section 2, the optimization TLBO algorithm is explained. In Section 3, a model for solar panel and wind energy production systems is introduced. Calculation of the required number of SMES is given in Section 4. Target function and simulation results are in Section 5 and 6. Finally, in Section 7, we have conclusion.

2. TLBO OPTIMIZATION ALGORITHM

TLBO algorithm is an intelligent optimization method that is based on the effectiveness of a teacher on students in order to increase the scientific level of the class. This method is based on the axiom that a teacher tries to approach class level to his own and the students not only share the teacher's knowledge but also benefit from other classes to improve their own scientific level or improve their ability. As the teacher is not able to approach the students' level to him one by one, so he tries to increase the median level of the class as a whole, and evaluates the class level by examinations and marks of the students [10].

In this algorithm, a group of students are considered as population and the different courses offered to them are considered as different variants of decision in the question of optimization, and the results that students get in different courses are compared with the goal values. The best answer in the whole population is considered as the teacher. Determining variants are in fact parameters that aim functions of optimization are defined according to them and the best result is the same as the best value for the aim function. This method is divided into Teacher phase and student phase.

The stages of implementing the TLBO algorithm are explained in following:

- Stage1: Assigning the question of optimization and prime values for optimization parameters;

In this stage, the number of population numbers D_n , the number of generations G_n , the number of deciding variables D_n and equal, unequal limits of problem L_l , U_l are defined. Target function is defined as:

$$\text{Minimize } f(X), \quad X_i \in x_i = 1, 2, \dots, D_n \quad (1)$$

where $f(X)$ is target function and X is a vector of decision variables as:

$$L_{L,i} \leq x_i \leq U_{L,i} \quad (2)$$

- Stage 2: Setting prime values for population;

Making random prime values for population members equal to the number of members and number of decision variables are as follows:

$$\text{population} = \begin{bmatrix} X_{1,1} & X_{1,2} & \dots & X_{1,D} \\ X_{2,1} & X_{2,2} & \dots & X_{2,D} \\ \vdots & \vdots & \ddots & \vdots \\ X_{Pn,1} & X_{Pn,2} & \dots & X_{Pn,D} \end{bmatrix} \quad (3)$$

- Stage 3: Teacher phase;

Computing the mean value of student's marks in different courses, a person with the best mark is chosen as new teacher.

$$M_{,D} = [m_1, m_2, \dots, m_D] \quad (4)$$

$$X_{teacher} = X_f(x) - \min \quad (5)$$

The difference between the two medians and new values is updated as in (6):

$$X_{new,i} = X_{old,i} + Diff_Mean_i \quad (6)$$

- Stage 4: Student phase;

As indicated before, students in this phase are interacting and they are learning from each other so they help each other for improvement.

- Stage 5: Standards for finishing optimization;

If the number of generations reaches its maximum, the algorithm process stops, otherwise the algorithm goes to stage 3 and repeats the procedures. As it is evident in the above stages, no limits are defined for limitation of process whereas in control techniques, there are many limitations. In the Optimization algorithm TLBO, Debz constraint technique is used. In this technique a structure of selection of processor is used. Two

answers are chosen and compared with each other. Below are rules for this comparison.

If one answer is practical and the other not practical, the practical one is preferred. If two answers are practical, then the answer that has a better for the target function is chosen. If both answers are impractical, the answer with the least difference between them and constraints are chosen [10].

3. MODELING SOLAR PANEL AND WIND ENERGY PRODUCTION SYSTEMS

Hybrid energy production systems consists of solar panels (PV), wind generators (WG), super-conductive magnetic energy storage (SMES), controller, inverter and load which are shown in Fig. 1. Solar panels and wind generators are used in electrical power generation. SMES is used for generated excessive energy storage. So that at times of need for energy enters the circuit and with the help of solar panels and wind generators, provide the load. At the mean time, controller controls the electrical power between generation and storage units. So when generated energy by these units is more than load, excessive power is accumulated in the SMES, otherwise SMES is used as a generating source. The inverter is used for converting DC power into AC power with the desired frequency and it also conveys power to load [4], [5], [7]–[9].

If P_{pv} be the output power of the solar panel, generated energy by N_{pv} solar panels would be defined as (7) where. Δt is the time span,

$$E_{PV}(t) = N_{PV} \cdot P_{PV}(t) \cdot \Delta t \quad (7)$$

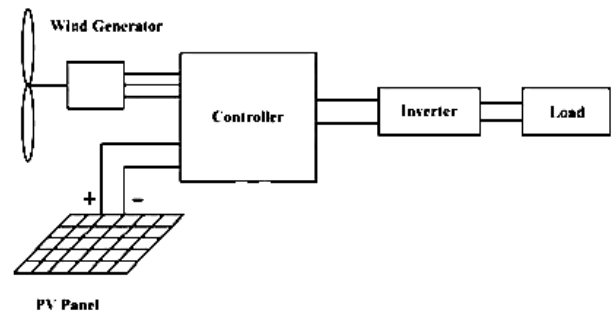


Fig. 1. Solar panel and wind turbine hybrid system with SMES.

If P_{WG} be the output power of the wind turbine in kilowatts, the generated energy by N_{WG} wind turbines in the time span of Δt is as follows:

$$E_{WG}(t) = N_{WG} \cdot P_{WG}(t) \cdot \Delta t \quad (8)$$

The superconductive energy storage used in this study is of the type SMES. The SMES bank is used for accumulation of excess electrical energy, system's voltage regulation and providing for load demand under reduction in the generation of power by solar panels and wind turbines. When the total generated electrical energy by solar panels and wind turbines is more than load demand, the SMES goes to discharge state. The amount of accumulated energy in the superconductive energy bank in the charge and discharge conditions is obtained from equation 9 [6]–[9]:

$$E_{SMES}(t) = E_{SMES}(t-1) + \left[(E_{PV}(t) + E_{WG}(t)) - \frac{E_L(t)}{\eta_{inv}} \right] \quad (9)$$

where $E_{SMES}(t)$ is the total accumulated energy in the superconductor at time t , $E_{SMES}(t-1)$ is the total accumulated energy in the superconductor at time span $t-1$, $E_L(t)$ is the consumed energy load at time t and η_{inv} is the inverter's efficiency. For every time t , the amount of energy in the SMES should satisfy equation 10 [7]–[9]:

$$E_{SMES,\min}(t) \leq E_{SMES}(t) \leq E_{SMES,\max}(t) \quad (10)$$

where $E_{SMES,\min}$ is the minimum capacity of the SMES bank in watt, hour (Wh); and $E_{SMES,\max}$ is the maximum capacity of the SMES bank in Wh, that is defined by the marker. SMES should be oscillating between its maximum and minimum values, so that its serviceable life span is guaranteed. So the number of superconductive accumulators are determined by (11) [7]–[9]:

$$N_{SMES} = \text{Roundup} \left[\frac{E_{SMES}^{Request}}{S_{SMES} \cdot \eta_{SMES}} \right] \quad (11)$$

where *Roundup* is the upper rounded value, S_{SMES} is the nominal capacity of every SMES,

$E_{SMES}^{Request}$ is the total needed capacity or required capacity and η_{SMES} is the percentage of the nominal capacity usage which is determined by (12) as follows:

$$\eta_{SMES} = \frac{E_{SMES,\max} - E_{SMES,\min}}{E_{SMES,\max}} \quad (12)$$

4. CALCULATION OF THE REQUIRED NUMBER OF SMES FOR THE SYSTEM

The aim of optimized system design is to determine the size or the optimized capacity of equipments including: number of solar panels, number of wind turbines and number of SMESs. In this study, the main goal is the capacity optimization in order to provide the constant load demand with minimizing energy production cost. One point which is not considered in other articles is that the criteria for choosing the number of SMESs should be on the basis of the maximum difference between energy generation and load consumption at every moment of time. Accordingly, the proposed algorithm is defined as follows: the minimum number of SMESs should be calculated according to the number of solar panels or wind turbines. The point that should be considered in selecting number of solar panels and wind turbines is that the total sum of 24 hours energy production for solar panels and wind turbines should be more than total sum of 24 hours energy load consumption. In this way the algorithm for selecting the number of SMES is determined as follows:

- First stage: The number of solar panels and wind turbines is chosen so that:

$$\left[(E_{PV}^T + E_{WG}^T) - \frac{E_L^T}{\eta_{inv}} \right] \geq 0$$

where E_{PV}^T is total sum of produced energy by solar panels in 24 hours, E_{WG}^T is total sum of generated energy by wind turbines in 24 hours, and E_L^T is total sum of energy consumption in 24 hours.

- Second Stage: As regards the number of solar panels and the wind turbines, the total of energy shortage in every hour is determined from (13).

$$\Delta E(t) = \frac{E_L(t)}{\eta_{inv}} - \left[E_{PV}(t) + E_{WG}(t) \right] \quad (13)$$

- Third Stage: According to (14), the sum of difference of energy generation and consumption for 24 hours ($Sum\Delta E(j)$) for different times from $j=1$ to $j=24$ is determined,

$$Sum\Delta E(j) = \sum_{t=1}^j \Delta E(t) \quad (14)$$

- Fourth Stage: Required energy for the SMES ($E_{SMES}^{Request}$) is determined from (15), where $Sum\Delta E(j)^{Max}$ and $Sum\Delta E(j)^{Min}$ are respectively the maximum and minimum values of $Sum\Delta E(j)$ among the 24 different states acquired from (13):

$$E_{SMES}^{Request} = Sum\Delta E(j)^{Max} - Sum\Delta E(j)^{Min} + Sum\Delta E(24) \quad (15)$$

- Fifth Stage: The number of required SMES is determined based on (11).

5. TARGET FUNCTION

Supposing the optimization equation, the target function can be considered on the basis of annual cost index of energy generation of a system. In solving the problem of determining the number of solar panels and wind turbines, cost analysis is an important factor. Annual cost of the system includes: capital investment and maintenance costs. So target function of the problem in mathematical form is formulated as [7]–[9]:

$$Cost = C_{Cap} + C_{Main} \quad (16)$$

where $Cost$ is for the annual cost C_{Cap} is capital cost, and C_{Main} is maintenance cost all in Dollars. Maintenance cost is for the project lifetime, but the capital cost is only for the beginning of the project. In order to convert the primal capital

cost into annual capital cost, capital recovery factor (CRF) is defined [7]–[9]:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (17)$$

where i is the interest rate and n is the useable system life span. Capital cost of the system includes investing cost for solar panels and wind turbines and SMES bank, defined in (7) and [7]–[9]:

$$C_{cap} = CRF \cdot \left[N_{PV} \cdot C_{PV} + N_{WG} \cdot C_{WG} + \left(\frac{n}{L_{SMES}} \right) \cdot N_{SMES} \cdot C_{SMES} \right] \quad (18)$$

where N_{PV} is the number of solar panels, N_{WG} is the number of wind turbines, C_{PV} is the cost of investment in solar panels, C_{WG} is the investment cost in wind turbines, N_{SMES} is the number of SMESs, C_{SMES} is the cost of SMES for each unit, and L_{SMES} is the useful life of SMES. Annual maintenance cost is defined as (8) in which C_{main}^{PV} is the cost of maintenance of solar panels for each kWh, C_{main}^{WG} is the cost of maintenance of wind turbines for each kWh:

$$C_{main} = \left(C_{main}^{PV} \cdot \sum_{t=1}^{24} E_{PV}(t) + C_{main}^{WG} \cdot \sum_{t=1}^{24} E_{WG}(t) \right) \cdot 365 \quad (19)$$

Limits considered for optimization problem are $0 \leq N_{PV} \leq N_{PVmax}$ and $0 \leq N_{WG} \leq N_{WGmax}$. In which N_{PVmax} is the maximum number of solar panels and N_{WGmax} is the maximum number of wind turbines. An important point is that the optimized number of solar panels and wind turbines for a network is a onetime process done by the system designer. Intelligent algorithms may sometimes freeze in finding a local optimization and cannot find the optimized answer. So in utilizing intelligent algorithms like TLBO algorithm, the problem should be experimented sev-

eral times in order to find the best optimized answer.

6. SIMULATION RESULTS ON A SAMPLE NETWORK

6.1 Studied System Parameters

The network is begin tested by a military site that is modeled separately from the global network (island mode). The system parameters include the energy produced by each solar panel, the production energy of each wind turbine, and the demand for military site load over a 24-hour period as shown in Table 1 [7]–[9].

Wind turbine, solar panel and energy structure parameters superconductivity are also presented in Table 2 [6]–[9].

6.2. Simulation Results

Fig. 2 shows the convergence of TLBO algorithm for the experimental network.

Table 1. Generated power and consumed power studied for 24 hours.

hour	Power consumption	Power generation 10 solar panels	Power generation of each wind turbine
1	1.37	0	0.58
2	1.23	0	0.49
3	1.17	0	0.48
4	1.2	0	0.53
5	1.32	0	0.47
6	1.78	0	0.51
7	2.63	0.016	0.46
8	2.86	0.034	0.46
9	2.49	0.103	0.61
10	2.18	0.246	0.76
11	2.02	0.317	1.1
12	1.92	0.353	1.53
13	1.8	0.366	1.67
14	1.69	0.374	1.89
15	1.6	0.368	2.43
16	1.63	0.335	2.45
17	1.85	0.242	1.91
18	2.26	0.134	1.76
19	2.55	0.056	1.57
20	2.57	0.015	1.16
21	2.51	0	0.87
22	2.46	0	0.76
23	2.25	0	0.74
24	1.77	0	0.7

Table 2. Parameters of the studied system.

Parameter	amount
Interest rate i	6%
Useful life span (n)	20 Years
Capital investment for each wind turbine C_{WG}	25000 \$
Capital investment for each solar panel C_{PV}	525 \$
Capital investment for each SMES C_{SMES}	170 \$
Maximum number of solar panels N_{pvmax}	500
Maximum number of wind turbine N_{WGmax}	100
Study purview time unit ΔT	1 Year
Efficiency of the inverter η_{inv}	100%
Wind turbine maintenance cost	0.02 \$/kWh
Solar panel maintenance cost	0.005 \$/kWh
Nominal capacity of each SMES	2.1 kWh
Percentage of usage of SMES capacity η_{SMES}	80%
Useful life SMESs	4 Years

High convergence speed and low tolerance of TLBO are good reasons for high capability in finding optimized answer. Table 3 shows the obtained results by this article and other sources [7]–[9]. It is noticed that even though the networks parameters are the same, the optimized results may be different. Although in all articles electricity conveyance to the load is constant, but the cost of the project proposed in this article is lower in comparison with other articles, which shows the superiority of the values obtained in this paper Because of setting the number of corrected energy accumulators and also repetition of TLBO algorithm several times.

Table 3 shows that using only two wind turbine accompanying SMES is the best choice and no needs to use the solar power plant. But if the capacity of energy generation in solar panels, fixed cost condition, is increased then the optimizing point will be different. Tables 4, 5 and 6 show the results for finding hybrid system optimization supposing that generating power of solar panels, wind turbine and also the amount of consumption load is altered from 10% to 200% time's present. It is noticed that in different con-

ditions, number of wind turbine, number of solar panels, and number of energy accumulators are different. So that if wind turbine capacity in fixed cost condition is decreased, the inclination toward using solar power plant is increased, or else at present conditions inclination is toward wind turbine system.

Table 3. Results for finding optimized number of generating equipment for experimental network.

Algorithm used in	N _{WG}	N _{PV}	N _{SMES}	Cost
This paper	2	0	7	5255.97\$
[8]	2	0	11	5652.66\$
[9]	2	0	10	5652.38\$
[7]	2	2	58	9687.11\$

Table 4. Optimized number of network equipment in varied capacity of wind turbine from 10% to 200%.

Percentage changes	N _{WG}	N _{PV}	N _{SMES}	Cost \$
10%	0	160	16	8595.62
20%	0	160	16	8595.62
30%	0	160	16	8595.62
40%	0	160	16	8595.62
50%	0	160	16	8595.62
60%	3	2	8	7564.52
70%	2	37	9	7004.33
80%	2	20	9	6254.82
90%	2	2	8	5384.90
100%	2	0	7	5255.97
110%	2	0	6	5219.66
120%	2	0	5	5183.36
130%	2	0	4	5147.05
140%	1	37	9	4824.71
150%	1	28	9	4426.80
160%	1	20	9	4075.21
170%	1	11	8	3603.19
180%	1	2	8	3205.29
190%	1	0	7	3057.46
200%	1	0	7	3076.36

Table 5. Optimized number of network equipment in varied capacity of solar panel from 10% to 200%.

Percentage changes	N _{WG}	N _{PV}	N _{SMES}	Cost \$
10%	2	0	7	5255.97
20%	2	0	7	5255.97
30%	2	0	7	5255.97
40%	2	0	7	5255.97
50%	2	0	7	5255.97
60%	2	0	7	5255.97
70%	2	0	7	5255.97
80%	2	0	7	5255.97
90%	2	0	7	5255.97
100%	2	0	7	5255.97
110%	2	0	7	5255.97
120%	2	0	7	5255.97
130%	2	0	7	5255.97
140%	2	0	7	5255.97
150%	2	0	7	5255.97
160%	2	0	7	5255.97
170%	1	43	11	5191.45
180%	1	40	11	5053.54
190%	1	38	11	4962.11
200%	1	36	11	4870.46

Table 6. Optimized number of network equipment in varied capacity of consumption 10% to 200%.

Percentage changes	N _{WG}	N _{PV}	N _{SMES}	Cost \$
10%	0	16	2	889.20
20%	0	32	4	1778.41
30%	1	0	1	2442.72
40%	1	0	2	2516.82
50%	1	0	4	2665.04
60%	1	9	5	3155.95
70%	1	24	7	3998.84
80%	1	40	8	4813.94
90%	2	0	5	5107.76
100%	2	0	7	5255.97
110%	2	1	9	5450.50
120%	2	17	10	6265.59
130%	2	32	11	7034.38
140%	3	0	8	7698.69
150%	3	0	10	7846.90
160%	3	0	12	7995.12
170%	3	9	13	8486.03
180%	3	25	15	9375.23
190%	3	41	16	10190.33
200%	4	0	13	10437.83

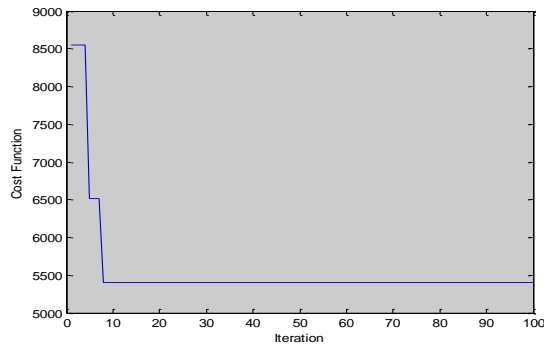


Fig. 2. Convergence curve for TLBO algorithm according to its repetition (optimized state).

7. CONCLUSION

In this study, the capacity optimization is investigated by TLBO algorithm for solar – wind system equipment, including: the number of solar panels, wind turbines and SMES. The aim of optimization is minimizing the system costs, including cost of capital investing and cost of maintenance. System inputs are the power production of each solar panel, power production of each wind turbine, and load demand for 24 hours.

The corrected equation is provided in order to choose the number of electrical energy storages.. Acquired results show that this equation is capable of assigning minimum number of required energy accumulators.

Comparison of optimization results, show that using intelligent algorithm reduces the time of calculations but necessarily does not lead to find the most optimized result. Also for the proposed system, due to higher cost of solar panels, using two wind turbines is more optimized and using solar panels is not recommended, but if the amount of power production of each panel, at fixed price, is increased; inclination toward using solar panels will be intensified.

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