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Research Article

Optimisation of power quality in solar/wind power stations using developed artificial bee/ant hybrid heuristic algorithm

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ABSTRACT

Voltage regulation needs to be optimised to reduce energy losses and improve power quality in renewable solar/wind plants. The Artificial Bee/Ant Hybrid Heuristic Algorithm has been developed in the study, and voltage regulation was optimised using this developed algorithm. A computer program in the C++ programming language was developed to prevent the undesired effects of electrical events occurring during the integration of renewable energy sources and to make the system work more efficiently. The interface of the program was made using the Visual Studio program. It became possible to produce power estimation, power quality estimation and power loss estimation using the intuitive artificial bee/ant hybrid algorithm created on the data set obtained from solar and wind power plants. It was found that there is a ± 4% difference between the values obtained with the developed algorithm and the computer program and the values obtained from the power plants. The developed algorithm and the computer program created successfully optimise power quality in solar/wind power stations. The study makes it possible to estimate the amount of energy produced, the amount of energy lost, and the quality of energy in solar/wind power stations.

1. INTRODUCTION

Power quality protects a sensitive receiver by providing electrical power to that receiver in a way that does not adversely affect its performance. Power quality is a combination of voltage quality and current quality concepts. Tension quality is the variation of the actual tension in moving away from the ideal tension shape [1-3]. On the other hand, current quality is adapting this description to the current. Ideal current and voltage are currents and voltages with a sinusoidal waveform oscillating at a constant amplitude and frequency at their nominal values.

Ideally, the current waveform should be at the same frequency and phase as the voltage. The change of current and voltage in a way that deviates from their ideal shape causes power quality deterioration. Power quality degradation is caused by current or voltage. Voltage disturbances occur centred on the grid, and this affects consumers. Stream distortions are consumer centred. This affects the network.

Some problems need to be solved in smart grids, which aim for an economically efficient and sustainable energy system by reducing losses. These are the integration of the energy produced in Solar/Wind hybrid renewable energy stations into the system, the voltage changes occurring during load shedding and commissioning, and the harmonics created by the inverters [4-6]. Precautions to be taken in order not to reduce the electrical energy quality during integrating the energy produced in solar/wind hybrid renewable energy stations into the system are essential for the system's efficiency and the consumers' safety. Voltage and frequency are two crucial parameters of electrical energy quality, and these are vital to be within the determined standards and constantly checked.

The study aims to prevent voltage changes during switching on and off in intelligent networks from harming consumers [7-9]. The voltage regulation on the smart grids has been optimised using the Developed Artificial Bee/Ant Hybrid Heuristic Algorithm to reduce the losses on the line. A computer program has been developed to prevent the undesirable effects of electrical events while integrating renewable energy sources and making the system work more efficiently.

2. MATERIALS AND METHOD

2.1. Power quality in solar/wind hybrid power stations

The solar/wind power station is given in Figure 1. Long transmission lines connect generation systems in renewable energy sources, where considerable power is produced, to the distribution system. In long transmission lines where the cross-section is not selected appropriately, the voltage rise problem arises at the renewable energy plant side and the point connected to the distribution system [10-12]. The rate of voltage change varies depending on the cross-section of the transmission line, the number of systems connected in parallel, the distribution point to which the connection is made, and the amount of energy produced. Also, losses occur on these long lines.

The generating systems in the renewable power plant change the short circuit limit of the bus bar to which they are connected. The short-circuit contribution of the integrated manufacturer should be well calculated. Otherwise, the problem arises because the limit values in the connected bus bar exceed the limits calculated during design. The integrated renewable energy generation plant causes the power flow to change in the region where it is connected [13-15].

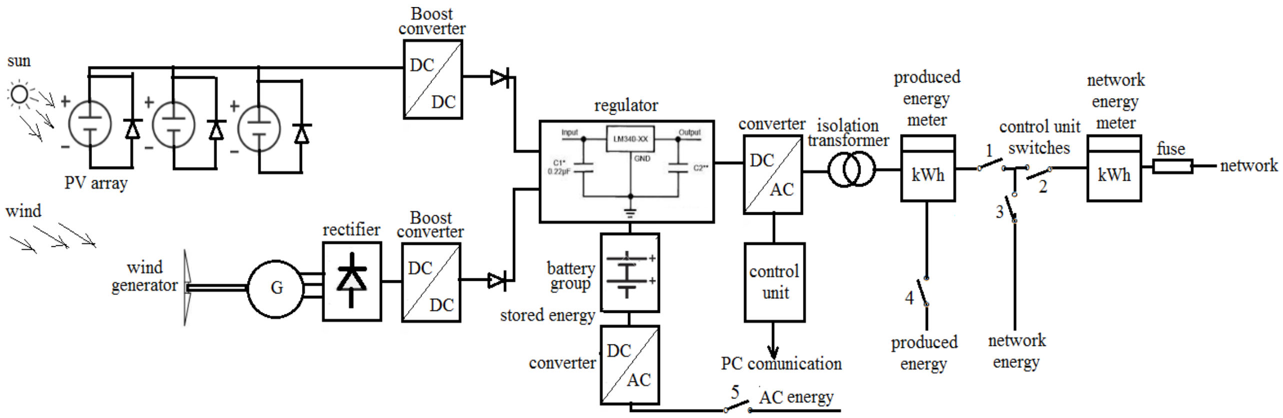

Figure 1. The solar/wind power station.

When the power flow direction changes, there are differences in the reactive power control calculations. Thus, the way the protection relays of the distribution system work also changes. Converter systems used to integrate the generation system into the grid cause the increase of different harmonic currents in the grid system and the formation of flicker [16-18]. Such islanding may also occur because of a short circuit at one point in the distribution system. There is a high probability that the resulting islanding will disable the operating land. In faults between the phase and the earth, voltage spikes occur in non-faulty phases, which can be harmful [19-21].

Voltage fluctuations in the energy produced in renewable power plants and overloads on lines are the most important problems. These problems turn into advantages with the optimum integration of distributed energy generation. Production of renewable resources is discontinuous and uncertain. During the integration of the energy produced in solar power plants, voltage regulation problems, correction of sudden voltage spikes, energy storage costs, and correct connection location. During the integration of the energy produced by wind power plants, there are problems such as high variability and large variation in instantaneous generation.

In the production integrations that will take place from the distribution system, the right analyses should be performed, and the right precautions should be taken. Otherwise, problems will be encountered that may deteriorate energy quality, endanger life and equipment safety, and cause the power produced not to be used efficiently. Many problems are encountered when the power quality is insufficient: harmonics, voltage increase and decrease, transients, inrush currents, interruptions, flicker, frequency changes, and imbalances [22, 23].

The instantaneous changes in load flow caused by this uncertainty and production discontinuity should be determined by how they will affect the system. It has become possible to predetermine these with the optimisation algorithm and the developed computer program. Thus, preventive measures were taken, and healthy and dynamic power distribution was ensured. With the solution to the problems that may occur in the load flow, the voltage amplitude, power coefficient, and active-reactive power drawn from the lines connected to the bus bar are determined in each bus bar serving in the network system. The effect of renewable distributed generation sources added to the bus bar is achieved by reducing the power flowing to the added bus bar from other generation bus bars.

Voltage regulation needs to be optimised to reduce energy losses and improve power quality in renewable solar/wind plants. The Artificial Bee/Ant Hybrid Heuristic Algorithm was developed in this study, and voltage regulation was optimised using this algorithm.

2.2. Optimisation algorithm and computer program of power quality in solar/wind hybrid power stations

The Artificial Bee Colony algorithm is a heuristic algorithm based on swarm intelligence inspired by the joint movements of bee swarms. A bee colony is a dynamic system that gathers information from an environment and adjusts its behaviour accordingly. The intelligent decision-making behaviour of the territory is due to the high level of communication between individuals [24-26].

The value of the source depends on many factors, such as its richness, proximity to the nest, the density of nectar, and ease of obtaining nectar. However, for the model's simplicity, the food source's profitability is sufficient as a single quantity. When these bees are associated with the food sources they are exploiting; they carry information about the distance, profitability, and direction of the source from the nest. They share this information with certain possibilities. The richer the resource, the more likely bees are to tail-dance and share information with the colony. The entire roof of the honeybee colony depends on communication. Bees communicate about the quality of food sources in the dance area. These bees share their knowledge with a probability proportional to the profitability of the food source. The ant algorithm is inspired by the behaviour of real ant architecture [27-29].

An ant determines the shortest path between its home and food source by way of smell, according to environmental conditions. When ants go to and from the food source, they deposit a substance called pheromone on the ground. Other ants sense the presence of the pheromone. These ants try to determine the shortest path to the food source by following the paths where the pheromone density is higher. As ants tend to choose the path with higher pheromone levels with a higher probability, the path begins to be used by other ants over time. Thus, the level of pheromones on the road becomes more pronounced. In this way, the success of the ant swarm increases in finding the shortest path and the most intense food source. The ants have found the most efficient method in terms of road and food sources to reach their goals and start using it. This system in ants has been used to optimise power quality by integrating energy produced in renewable solar/wind power plants. This algorithm is highly flexible and can easily adapt to changes, such as adding or removing new channels to the solution. A hybrid algorithm has been developed for power quality optimisation in integrating multidimensional and multimodal renewable solar/wind hybrid energy by simulating the foraging behaviour of honeybees and ants.

The artificial Bee/Ant Hybrid Heuristic Algorithm developed for optimisation of power quality optimisation in the integration of multidimensional and multimodal renewable solar/wind hybrid energy is shown in Figure 2. The algorithm randomly generates areas of food sources that initially correspond to solutions in the search space. These sources are randomly generated, as shown in Equation 1, considering the lower and upper limits of the parameters. Also, the trial limits counter of the solutions is reset at this stage.

$$\gamma_{fp} = \gamma_{p\min} + random(0,1)(\gamma_{p\max} - \gamma_{p\min}) \qquad (1)$$

f: The index of the food source (f=1,2,3,…,f)

p: Index of parameters to be optimised (p=1,2,3,…,p)

γ_{pmax}: The top value of the parameter

γ_{pmin}: The lowest value of the parameter.

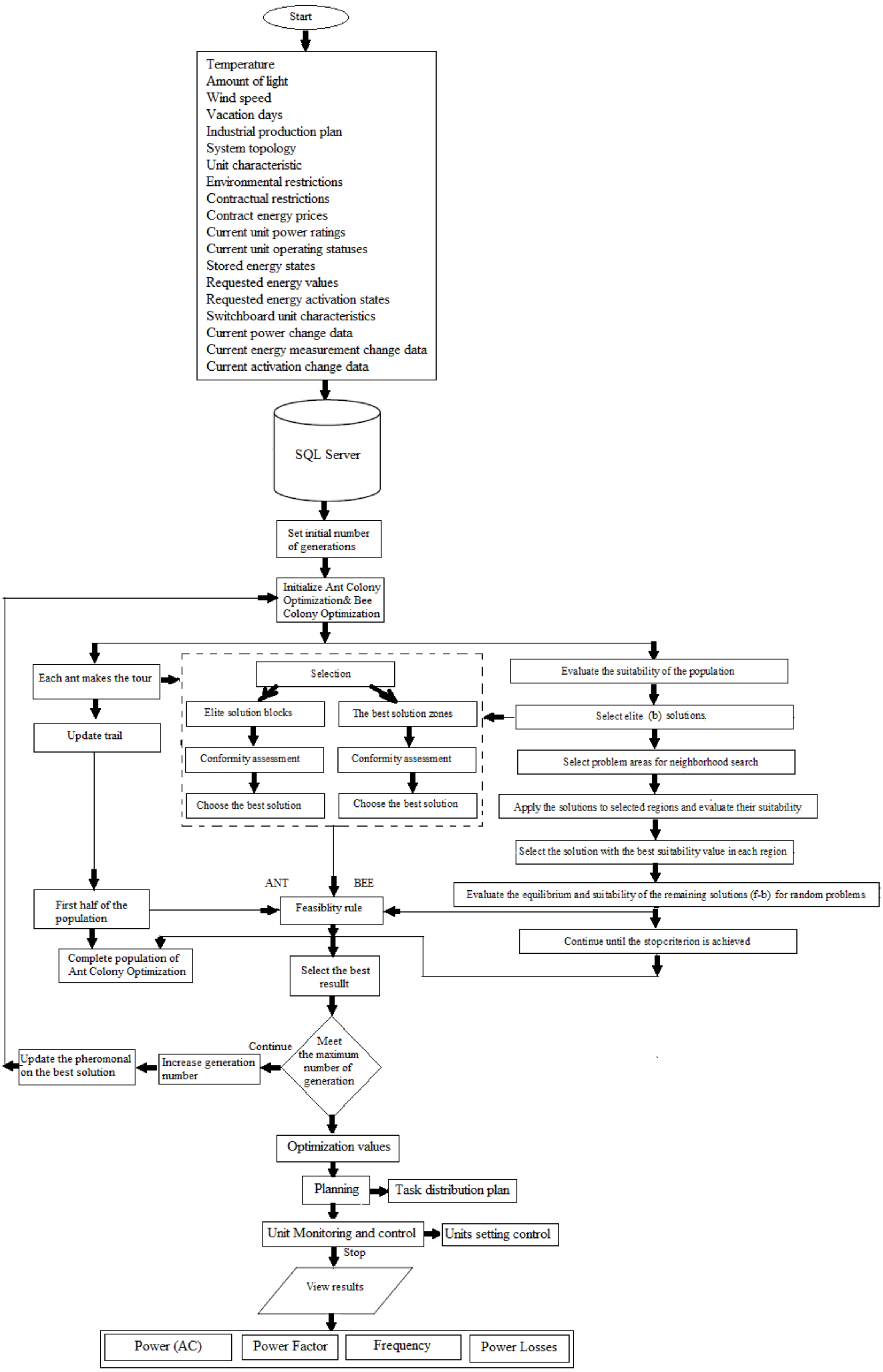

Figure 2. The developed algorithm for power quality optimisation.

Temperature, amount of light, wind speed, vacation days, industrial production plan, system topology, unit characteristic, environmental restrictions, contractual restrictions, contract energy prices, current unit power ratings, current unit operating statuses, stored energy states, requested energy values, requested energy activation states, switchboard unit characteristics, current power change data, current energy measurement change data, current activation change data are entered as input parameters in the algorithm.

This algorithm determined the number of photovoltaic panels and wind turbines as the food source's parameters. Accordingly, the optimisation process has subjected the system parameters that will keep the amount of energy produced, energy quality, and energy losses within certain limits and meet the demand power within the desired reliability range. Thanks to the developed algorithm, the energy size optimisation of hybrid systems that will meet the energy needs of different regions can be easily done. It has been seen that the algorithm can reach the optimal solution in a short time [30-31].

The basic steps of the artificial bee/ant hybrid heuristic algorithm developed for optimisation of power quality optimisation in the integration of multidimensional and multimodal renewable solar/wind hybrid energy are as follows:

Step 1. Enter the number of experiments, the maximum number of generations, and the number of the population (N).

Step 2. Enter the substation information.

Step 3. Enter; temperature, amount of light, wind speed, vacation days, industrial production plan, system topology, unit characteristic, environmental restrictions, contractual restrictions, contract energy prices, current unit power ratings, current unit operating statuses, stored energy states, requested energy values, requested energy activation states, switchboard unit characteristics, current power change data, current energy measurement change data, current activation change data.

Step 4. Generate N chromosomes for the initial population.

Step 5. Generate random food sources using Equation 1.

Step 6. Reset Nutrient Resources non-growth limits ($limit$=0).

Step 7. Set the total number of bars, number of rows, number of columns, and depth of network embedding.

Step 8. Run the objective function.

Step 9. Calculate suitability for each solution.

Step 10. Identify and store the chromosome that best fits the experiment if the maximum number of generations is reached.

Step 11. Increase the number of experiments if a maximum number of generations is reached, but the maximum number of experiments is not reached.

Step 12. Start the experiment again.

Step 13. If the maximum number of generations is not reached, go to step 7.

Step 14. Go to Step 21 if the maximum generation number and the maximum number of experiments are reached.

Step 15. Divide the N number of chromosomes into binary groups and cross.

Step 16. Apply mutation to N chromosomes.

Step 17. Select the best N number of chromosomes for the next generation from the chromosomes obtained by N number of chromosomes, N number of chromosomes, and N number of mutations.

Step 18. Increase the number of generations by 1 and go to Step 7.

Step 19. Calculate core parameters of the 3N number of chromosomes when the eddying condition is not met.

Step 20. Identify the best chromosome in all experiments.

Step 21. Calculate the average of the best chromosome of each experiment.

Step 22. View results; ac power, power factor, frequency, power losses.

In this study, energy, energy quality, and energy losses obtained from photovoltaic panels in solar power plants and wind turbines in wind power plants were determined by combining the bee and ant algorithm, which is an intuitive optimisation algorithm. As the study area, two solar power plants and two wind power plants were selected in Turkey's Silifke district of Mersin province. The algorithm developed for power quality optimisation is written in the C++ programming language, which is object-oriented programming. A visual interface is also designed for entering the constraints to be used in the algorithm and displaying the results. The power quality optimisation program interface is created, shown in Figure 3.

The data, including annual wind speed and solar radiation to be used in the analysis of the study, were obtained from the measurement stations of the Mersin Metrology Provincial Directorate. According to these annual hourly data, the average annual hourly power values, power quality, and losses that can be produced by the photovoltaic panels used in the solar power plant and the wind turbines in the wind power plants are estimated with the help of mathematical models. By entering the data into the created Power Quality Optimisation Program, the AC power produced in renewable energy plants within one year (8760 hours) was estimated.

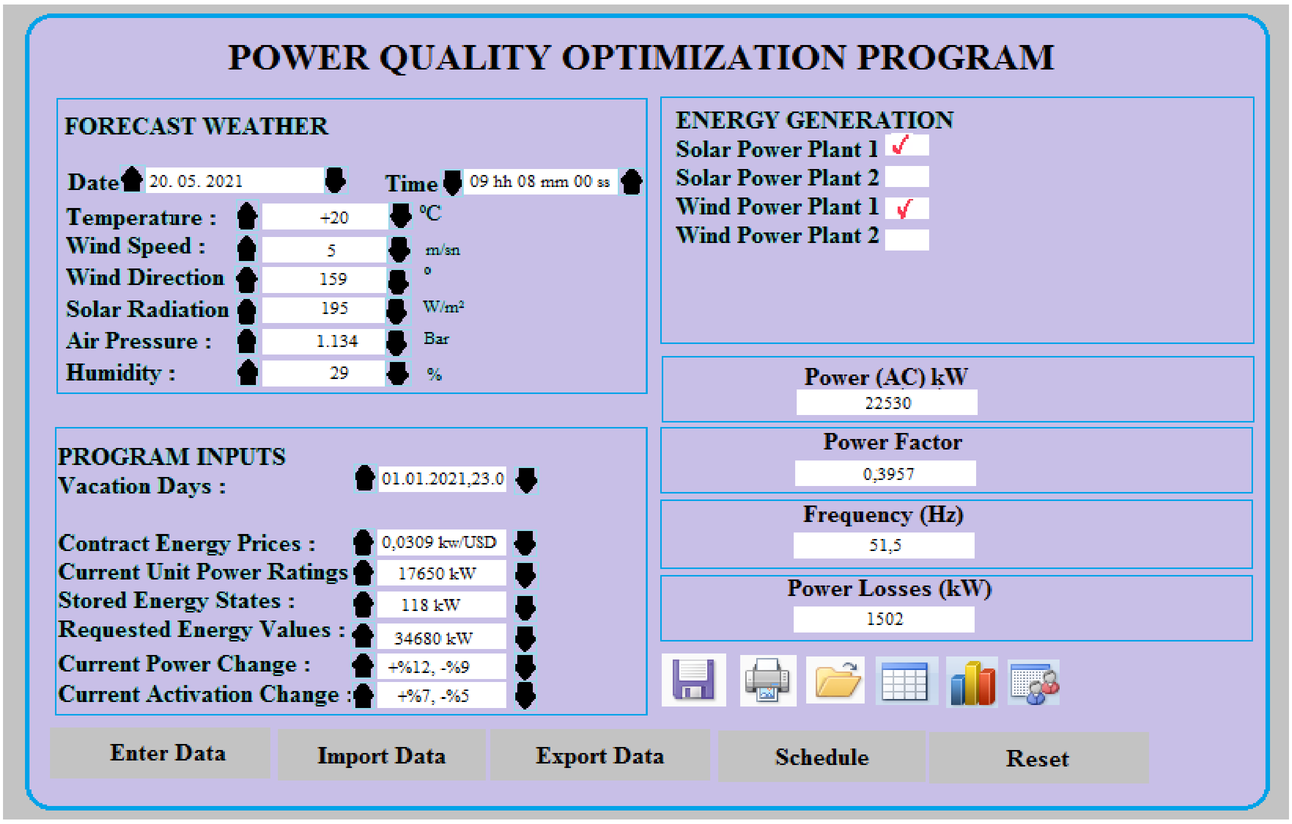

Figure 3. Power quality optimisation program interface.

3. RESULTS

As it can be understood from the program created, the energy produced in solar power plants in the summer months and the energy produced in the wind power plants in the autumn and spring months is a significant amount. The buttons at the bottom of the program interface make it possible to get the data obtained in the created program, either graphically or in a table form. AC Power output in the program interface is given in Figure 4.

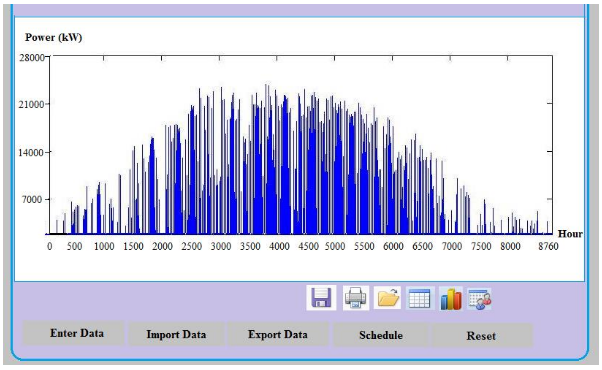

Figure 4. AC Power output in the program interface.

The power factor output in the program interface is given in Figure 5.

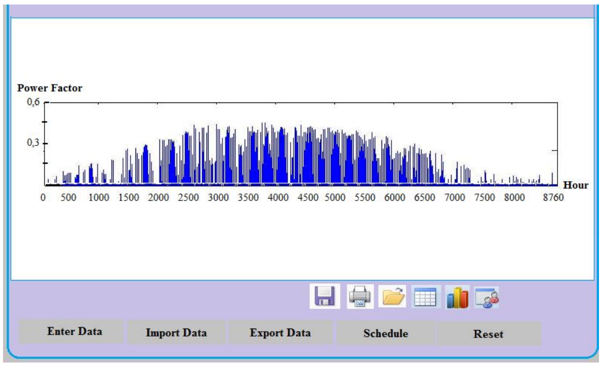

Figure 5. Power factor output in the program interface.

The continuity of the energy produced in the solar power plants in the summer and the continuity of the energy produced in the wind power plants in the autumn and spring months are sufficient. For this reason, it is understood that the power quality is sufficient during these months. The continuity of the energy produced in other months is not sufficient. For this reason, it is seen that the power quality is low during these months. This power quality problem is caused by the transient voltage, short circuits in the network, natural events, switching off the network, load changes, voltage distortions, imbalances, and operating with voltages different from the rated voltage of the system. Photovoltaic solar power plant installations have the potential to significantly affect grid voltage, especially voltage fluctuations, flicker, harmonic distortion, and high-frequency disturbances. The frequency output in the program interface is given in Figure 6. The power loss output in the program interface is given in Figure 7.

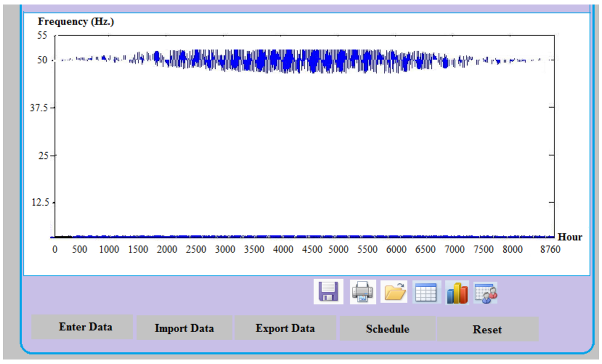

Figure 6. Frequency output in the program interface.

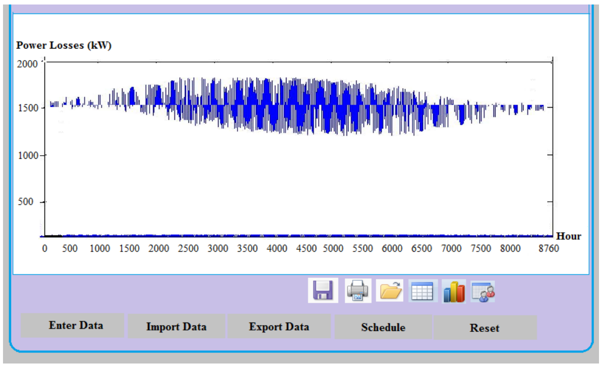

Figure 7. Power losses output in the program interface.

Power frequency changes are one of the most important factors in quality. Imbalances in power supply and demand cause frequency oscillations. Therefore, grid and system frequency must be synchronised in grid-connected systems. These losses are caused by radiation, aerodynamics, mechanical system, inverters, and energy transmission. These losses are understood to be higher in the summer months when energy is intensely produced.

In the study, solar radiation, temperature, wind speed, humidity, PV panel temperature, and power values obtained from the plants were measured and recorded for one year with the measurement stations established in two solar power plants and two wind power plants in *Silifke* District of *Mersin* Province. Power estimation, power quality estimation, and power loss estimation were made using the heuristic artificial bee/ant hybrid algorithm created on the large data set. Estimation and real value comparison of produced energy is given in Table 1.

Table 1. Estimation and real value comparison of produced energy.

Time (hour)	Estimated value (MW)	Actual value (MW)
500	6.1	6.5
1000	10.3	9.8
1500	12.7	12.1
2000	19.6	18.9
2500	21.3	20.7
3000	20.3	19.8
3500	18.6	17.4
4000	20.1	19.2
4500	18.3	17.8
5000	17.6	16.8
5500	16.5	15.7
6000	15.1	14.3
6500	11.3	10.3
7000	9.3	8.2
7500	6.1	5.8
8000	4.2	3.9
8760	4.1	3.7

Estimation and real value comparison of produced energy quality is given in Table 2.

Table 2. Estimation and real value comparison of produced energy quality.

Time (hour)	Estimated value (Power factor)	Actual value (Power factor)
500	0.11	0.1
1000	0.15	0.14
1500	0.32	0.3
2000	0.43	0.4
2500	0.44	0.4
3000	0.39	0.37
3500	0.39	0.36
4000	0.38	0.35
4500	0.39	0.38
5000	0.38	0.35
5500	0.37	0.34
6000	0.38	0.35
6500	0.28	0.24
7000	0.25	0.24
7500	0.15	0.15
8000	0.14	0.14
8760	0.12	0.11

The estimation of energy losses and real value comparison is given in Table 3.

Table 3. Estimation of energy losses and real value comparison.

Time (hour)	Estimated value (MW)	Actual value (MW)
500	1.55	1.65
1000	1.6	1.75
1500	1.75	1.84
2000	1.77	1.86
2500	1.8	1.94
3000	1.8	1.96
3500	1.79	1.82
4000	1.8	1.86
4500	1.81	1.86
5000	1.7	1.79
5500	1.55	1.62
6000	1.53	1.63
6500	1.52	1.63
7000	1.52	1.65
7500	1.5	1.68
8000	1.49	1.54
8760	1.47	1.52

The success rates of the predictions made with the created algorithm and computer program are shown in Figure 8, Figure 9, and Figure 10, with graphics presented comparatively.

In addition, the algorithm model created by taking the data of the Mersin Meteorology Directorate as a reference was trained, and the forecast success rates were presented with graphics using the real data of the power plants. It has been seen that the created algorithm and computer program are successful.

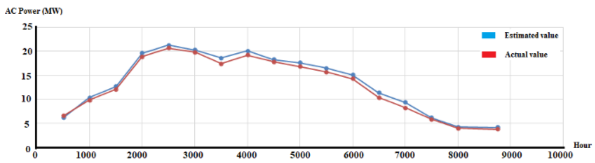

Figure 8. Algorithm estimation and real value comparison of produced energy

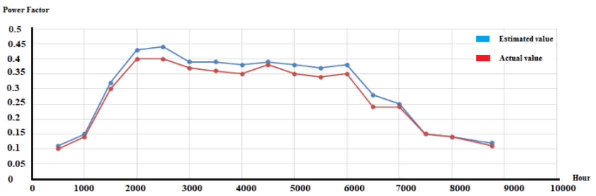

Figure 9. Algorithm estimation and real value comparison of produced energy quality

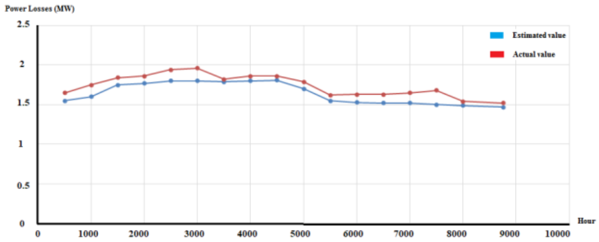

Figure 10. Algorithm estimation of energy losses and real value comparison.

4. DISCUSSION

Some findings can be discussed concerning tree growth and configuration. Firstly, the growth rate in similar samples is slightly different due to the minor variations in the material structure, and it can be attributed to the impurities and the non-uniform distribution of these impurities inside the material. Secondly, the tree growth in wet specimens is higher than in dry ones. The tree area contains various voids stressed by electrostriction forces associated with a high electric field. With the increase in absorbed water, these stresses are magnified, causing more influence on the tree propagation. Finally, the time to break down is a function of the condition of the specimen. Therefore, the longest time to break down is associated with dry samples, followed by wet (deionised) and ionised samples.

The results show that the tree shape and construction are affected by the growth mode concerning the configuration. In dry specimens, the tree developed slowly and did not have the chance to spread widely inside the sample. Therefore, the treed section is small, and the branches are concentrated around one primary channel. Thus, such a tree is compressed and compact. Then, these channels are gradually enlarged and darkened, which refers to internal material damage. A breakdown is initiated if one of the front branches approaches the earth electrode. Therefore, the last treeing hour is associated with a significant increase in vertical growth compared to the horizontal one.

The electrical tree developed in wet (deionised) conditions is characterised by long, thin, and fast-growing branches. Although the main direction of these branches is from the pin tip to the earth plane, many channels are randomly distributed in all directions, including the horizontal direction. The vertical and horizontal frames of the tree dictate the ratio of the treed region to the whole insulation area. However, the density of branches in the treed region determines the actual site of the tree. The treed neighbourhood, in this case, grows more extensive than the dry one, while the ratio of the existing tree to the treed section remains constant in both cases. It is attributed to the fact that the tree density and dimensions are proportionally increased. Despite the remarkable growth in the horizontal direction of wet samples, the fast vertical growth is the leading cause of the early breakdown of these samples compared to the dry ones.

The trees in the specimens treated with ionised water are characterised by fast growth and a high density of branches. Therefore, the treed region is significantly more extensive than the dry and distilled water cases. However, the limited number of branches decreases the tree's actual area, making it smaller than in other cases.

The tree branches behave like conductors in all studied cases, bridging the distance between the electrodes and causing the insulation to break down. With ionised water, the breakdown occurs earlier than in other cases, revealing the role of ions in increasing water absorption and breakdown under a high field. It agrees with the results obtained previously [19].

Finally, random growth is the ordinary course of action, which the electrical trees are demonstrated in the various studied cases. In most cases, the tree is not linearly grown with time. Therefore, it is customary to note that a lateral branch can be initiated from an existing tree stem or growing branch, and this newly developed branch can be in a horizontal or vertical direction.

5. CONCLUSION

Precautions to be taken in order not to reduce the electrical energy quality during integrating the energy produced in solar/wind hybrid renewable energy stations into the system are essential for the system's efficiency and the consumers' safety. Voltage and frequency are two crucial parameters of electrical energy quality, and it is vital that these are within the determined standards and that they are constantly checked. To reduce the losses on the line, the voltage regulation on the intelligent grids is optimised using the developed artificial bee/ant hybrid heuristic algorithm.

A computer program is developed to prevent the undesirable effects of electrical events while integrating renewable energy sources and making the system work more efficiently. Solar radiation, temperature, wind speed, humidity, photovoltaic panel temperature, and power values obtained from the power plants are measured and recorded for one year with the measurement stations established in two solar power plants and two wind power plants in *Silifke* District of *Mersin* Province. Power estimation, power quality estimation, and power loss estimation are made using the heuristic artificial bee/ant hybrid algorithm created on the large data set. The success rates of the predictions made with the created algorithm and computer program are shown with graphics and presented comparatively.

In addition, the algorithm model created by taking the data of the Mersin Meteorology Directorate as a reference is trained. Error rates are low, and accuracy rates are high, as expected. It can be seen that the created algorithm and computer program are successful. This algorithm and computer program, which determines the power obtained in hybrid renewable energy plants and the quality of this power in the shortest time in terms of accuracy and reliability, will be preferred in future applications.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interest affecting this publication.

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