Wind-photovoltaic hybrid system capacity optimization for cathode conservation station

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ABSTRACT: In this paper, an optimization method for hybrid wind-photovoltaic system capacity is proposed. Cathode conservation is known as an effective conservation method in order to prevent the corrosion of buried structures and is used widely in conservation of pipelines for transmission and distribution of gas, petroleum products, and water. The capacity optimization means that the optimal number of solar cells, wind turbine, and saving battery should be determined. Besides this, the cathode conservation station consuming value is low at the first of opening and increases during the years. So the number of solar cells, wind turbines, and saving battery should be determined in such a way that the minimum value of cost could be tolerated at the first year of utilization and also some years later. The proposed solution approach is applied on a cathode conservation system using the Particle Swarm Optimization (PSO) algorithm which is written by MATLAB software and the obtained results are reported. The obtained solution is described considering the cost and other related constraints. Finally, by considering the consuming and production values, the optimal way in which the minimum value of cost is tolerated can be obtained considering the optimal capacity assigned to the cathode conservation station. Totally, the proposed method can provide an optimal capacity for the hybrid wind-photovoltaic system of cathode conservation station and also the total system cost is reduced using the proposed method.

Keywords: optimal capacity, hybrid wind-photovoltaic system, cathode conservation station, optimal cost.

INTRODUCTION

Human population-intensive growing rate and the mortal fossil energy resources shortage and also the life energy requirements, force the human to use the new renewable energies which always are accessible and have the less losses and more efficiency in comparison to the non-renewable energies. These energies are without any deficient effects like greenhouse gases and Environmental Pollution (Mohamed, 2010). Two important renewable energies existed in the nature are solar and wind energies which can be implemented based on the location and circumstance of the nature surface. Moreover, according to the time limitation in the using of solar effective energy during a day and also low density of this energy, some solar panels should be used to obtain the required energy which is not efficient from the economical point of view. Beside this, the wind is not always available with the desired speed. In some regions which are windy and sunny with a high efficiency, the combination of these two energies can be implemented.

In order to obtain the required efficient energy from the hybrid wind-solar dispersed generation resources, some points should be considered. For example, in regions in which the combined resources are used, the time which wind turbines or photovoltaic cells consume to absorbed the energy (i.e., the power which a photovoltaic panel or wind turbine receives) should be considered in order to calculate the energy value absorbed by the each resource in a specific time period. Also, the consumer requirements should be regarded. However, the resource using circumstances depend on the location and weather conditions. Then the capacity of the energy saving battery obtained by the dispersed generation resources should be considered. Moreover, it should be pointed that the sum
of energy generated by the dispersed generation resources should be greater than the consumer need in each time interval.

Optimization of capacity in the dispersed generation resources especially in the hybrid systems is a more important problem which should be regarded strictly. This is because of this fact that the implementation of fraction of resources and the saving battery in the hybrid system and also consumer need have a significant impact on the cost of establishing and running the system. So the capacity of the dispersed generation resources should be determined in such a way that the consumer need be satisfied with the minimum value of expended cost.

Accordingly there are many related studies. For instance the optimization of the hybrid energy resources of the sun and also wind turbine integrated system applied in the networks and micro networks with the strategy of electrical integrated shop of bilateral pool using the PSO algorithm has been investigated by the Mohammadi et al. (2012). In their study the PSO algorithm which is implemented to optimize the micro network cost, is investigated. The Total cost consists of some cost terms including main costs, replacement cost, maintenance cost and extraction cost for the micro network and DG. Then an objective function has been considered in order to maximize the Net Present Worth (NPW) of the network. In order to obtain the minimum value of network cost the PSO algorithm has been used during the optimization process in which local DGs product and power exchange center should be connected to the main distribution network which results in lowering the total cost. In order to apply the LV network the optimization algorithm should be implemented under the different sale strategies (Mohammadi, 2012). In another study Hongxing Yang et al. (2008) have investigated the optimization of the capacity for each resource in the hybrid wind-solar system using the LPSP technology. They implemented a genetic algorithm. They suggested that the battery banks should be implemented in order to find the optimal capacity in the optimization of a hybrid wind-solar system formation using a genetic algorithm which has the capability of obtaining the global optimal solution with the desired value of the error. A suitable way in order to find the optimal capacity which is extended by the calculation of the optimal system formation, can reach to the probabilistic losses of the power resource (LPSP) with the minimum system cost during a year (ACS). The unstable result during the optimization includes the number of PV modules, number of wind turbines, number of batteries, the angle of the PV module and installation in the height of the wind turbine. Mentioned method has been implemented in order to obtain a good optimization performance and also to analyze a hybrid system which is a feeding resource for the connection with the station. Moreover, the relation of the system power reliability with the system formation should be determined (Yang 2008). J.K. Kaldellis et al. (2012) have suggested a method consists of two practical technologies for the different potential of wind and sun in the Greece based on the demands for the capacity of infinitive energy saving and also considerable initial cost of the installation and its special implementation (Kaldelis, 2010). Also Erdinc et al. (2012) have investigated different optimization techniques with different potentials using the existed software (Erdinc, 2012).

Based on the studies conducted on the dispersed generations and also optimization of the capacity of the hybrid systems of electrical energy generation and considering the necessity of using these generations and combinations (because they are always renewable and approachable and are less contaminant in the environment) and also regarding this fact that these energies are more efficient from the economical point of view in comparison to the fossil energy resources (Sudi, 2008) and the new energy resources are available in anywhere based on the location, can prepare the consumptions that may have some problems from the economical or other aspects. One of these consumptions which are unavaliable and their electrification by the overall network may be more expensive and troublesome is the cathode protection station on the gas pipelines. Based on the essential and vital importance of this station because of this fact that the absence of this station may cause the severe corrosions and destructive effects, the establishment of this station is more essential. In order to establish this station on the service it requires the electrical energy which in most of the cases the connection of the station input electricity to the overall network is troublesome. So the renewable energy resources especially hybrid renewable energy systems can resolve the needing to the electrical energy. In this paper we have studied the electrical energy preparation of the cathode protection station using the hybrid system of wind-photovoltaic which is solved by the PSO algorithm. The main objective of proposed study is to minimize the total system cost.

**Cathode conservation**

Cathode conservation is known as an effective conservation method in order to avoid the corrosions in the buried structures which are implemented widely in the conservation of the gas, water and petroleum transmission and distribution pipelines. The cathode conservation can be defined as the prevention or speed lowering of the metals corrosion by an output electrical current (direct) or its contact by the mortal anode on the corresponding metal surface which has the cathode and anode related regions (the corrosion is occurred on the anodic regions) (ZONG, 2012). In this situation the anode will transformed to the cathode and then all the device or metal will be a
cathode one. The cathode conservation is the most important and effective way in the corrosion controlling. Actually its implementing makes it possible to maintain a metal in a corrosive environment without any corrosion for a long time period. The cathode conservation mechanism is related to the output current which based on its result cathode elements of the local cells are polarized to the anodes open circuit potential. This means that all area of the metal surface has the same potential (the anode and cathode potential are the same) and the corrosion currents are stopped. Also it can be mentioned that because of creation of an output flow, a network consists of the positive current is extended in all surface of the metal and so the metal ions can be prevented from the interring to the solution or the surrounded area. The cathode conservation operation can be implemented in corrosion of metals like steel, copper, lead and brass in the ground (soil) and also different aqueous solutions. By using the cathode conservation one can avoid the pitting corrosion of the zincoid metals like stainless steels. Different methods of the cathode conservation can be described as follows:

**Different cathode conservation methods**

Cathode conservation can be implemented in two different ways of impressed current and sacrificial anode.

**Cathode conservation using the impressed current method**

In fact the conservation by this way is the construction and controlling of a huge corrosion cell. In this cell the negative terminal of the direct current is connected to the pipeline and the positive terminal is connected to the buried consumable conductor named anode. The direct current usually inters to the pipeline using a rectifier and actually an electrical circuit is established by the current which is flowed by the soil from the anode to the pipeline (figure 1). In fact the investment on the cathode conservation equipment is a little fraction o the overall system cost despite of the conservation by the covering. These costs should be expended continuously for the equipment and controlling the process. The discussion is about the measurement and assessment of equipments, their design and installation, measurement and analysis of the obtained results and finally the maintenance process.

**Cathode conservation using the sacrificial anode method**

In sections which it is impossible to create the cathode conservation station, this method can be applied. For example in sections in which there is not the electricity network or in the short paths or temporarily equipments. In this method based on the galvanic cell and using the table of electro-chemical standards (e.m.f) and by connection of the more negative metals in the table, the pipeline connected metal are transformed to the cathode and anodic poles respectively. By this transformation, the more negative metal is sacrificed for the engineering metal. Actually a galvanic cell is created (figure 2).

Since the gas pipelines take a large area based on the mentioned cathode conservation methods the cathode station on these pipelines are based on the applied current which require to the input feeding resource. Here the hybrid system of the wind-photovoltaic is considered as the input feeding resource of this station. This paper is investigated the optimal capacity of this hybrid system for the cathode conservation station. On the other hand the power value required for the cathode conservation station is negligible at the first of the implementation (figure 3) and then its consumption will be greater because of the following reasons (figures 4 and 5):
- Underground pipes covers lifetime
- Anodic bed anodes lifetime
- Specific resistance of the soil (soil type)
Optimization equations

The objective of the optimization of the hybrid wind-photovoltaic system is to minimize the CT cost which consists of the sum of the setup cost of CCpt and sum of the maintenance cost of CMtn :

\[ \text{Minimize } C_T = C_{\text{CCpt}} + C_{\text{CMtn}}. \]

The setup costs are related to the start of a project and the maintenance costs is about the implementation period of the project. Since these two cost functions are occurred in two different time intervals naturally can't be compared to each other. Here we first investigate the setup cost of the project P which is transformed to the annual system cost of A using the main recovery factor which can be calculated as follows:

\[ \frac{A}{P} = \frac{r(1 + r)^n}{(1 + r)^n - 1}, \]

Whenever the annual interest rate is matter the sum of the annual system cost or CCpt can be used.

In this equation NSol is the number of the solar cells and CSol is an existing solar panel unit cost. NWind is the number of wind turbines and also C Wind is the wind turbine unit cost. NBatt is the number of batteries and also CBatt is a battery unit cost. Moreover, CBackup is the cost of the backup generator which can be used whenever that the wind and solar energies are Inadequate and the saving battery is little. The solar panel unit cost of CSol includes the panel price and its installation cost. Also C Wind includes each turbine price and its installation cost. Number of batteries can be estimated using the following equation:

\[ \text{Max} \{ \text{NSol}(N_{\text{Sol}}, N_{\text{Wind}}) - \text{Roundup} \left[ \frac{S_{\text{Req}}}{(1 - N_{\text{Sol}})} \right] \} \]

In presence of Roundup(0) the function value is round up to a integer value. SReq Value depends on the battery capacity. N is the using percentage of the battery guarantee nominal capacity during its lifetime. SBatt is the nominal capacity of the battery. Saving capacity required by the SReq includes a function consists of the number of solar panels (NSol) and number of wind turbines (NWind).

\[ S_{\text{Req}}(N_{\text{Sol}}, N_{\text{Wind}}) = \sum_{t=1}^{n_{\text{Max}}} (P_{\text{Sol}}^t + P_{\text{Turb}}^t - P_{\text{Backup}}^t) - \sum_{t=1}^{n_{\text{Max}}} (P_{\text{Sol}}^t) - (P_{\text{Turb}}^t) \]

In this equation Max t is related to whenever that the energy (Kwh) has the low value. \( P_{\text{Sol}}^t \) is the power (kw) generated by the solar cells in the time interval of t. \( P_{\text{Turb}}^t \) is the power (kw) generated by the solar cells in the time interval of t. \( P_{\text{Backup}}^t \) is the required power (Kw) in the time period t. The power generated by the solar cells can be calculated as following equation:

\[ P_{\text{Sol}}^t = N_{\text{Sol}} \times P_{\text{Sol,Each}} \]

In this equation \( P_{\text{Sol,Each}} \) is the power generated by each solar cell in time period of t. \( P_{\text{Sol,Each}} \) can be estimated by the information related to the Solar radiation and power-solar radiation characteristic curve. The power generated by the wind turbines can be calculated as following equation:

\[ P_{\text{Wind}}^t = N_{\text{Wind}} \times P_{\text{Wind,Each}} \]

In this equation \( P_{\text{Wind,Each}} \) is the power (Kw) generated by each wind turbine in the time period of t. \( P_{\text{Wind,Each}} \) can be estimated by the information related to the wind speed and correction function of the upper center of the
turbine power-wind speed characteristic curve. The sum of annual the maintenance cost \((C_{\text{Mtn}})\) mentioned in equation 1 can be determined by the following equation:

\[
C_{\text{Mtn}} = \left( C_{\text{Mtn}^{\text{Sol}}} \times \sum_{i=1}^{24} (P_{\text{Sol}}^i \cdot \Delta t) + C_{\text{Mtn}^{\text{Wind}}} \times \sum_{i=1}^{24} (P_{\text{Wind}}^i \cdot \Delta t) \right) \times 365
\]

In this equation, \(C_{\text{Mtn}^{\text{Sol}}}\) is the maintenance cost for each solar panel based on the 1 kwh electrical energy. Also \(C_{\text{Mtn}^{\text{Wind}}}\) is the maintenance cost for each wind turbine based on the 1 kwh electrical energy. It should be pointed out that since the battery is the vulnerable in the renewable power generation system, the replacement cost of batteries are also considered in the objective function which is designed for all occurred costs. In the numerical example proposed by the (10) the actual value for this replacement cost is not considered. This cost is a matter in future studies whenever an optimal complicated renewable system is designed. The mentioned objective function is stated by equations 1 - 8 as following. The main constraint in the proposed optimization problem is that the sum of generated energy by the solar cells and also wind turbines should be equal to or greater than the sum of the energy required for all consumers.

\[
\sum_{i=1}^{24} (P_{\text{Sol}}^i \cdot \Delta t) + \sum_{i=1}^{24} (P_{\text{Wind}}^i \cdot \Delta t) \geq \sum_{i=1}^{24} (P_{\text{Dmd}}^i \cdot \Delta t)
\]

Also number of solar panels and wind turbines must be integer positive:

\[
N_{\text{Sol}} = \text{Integer}, \quad N_{\text{Sol}} \geq 0
\]
\[
N_{\text{Wind}} = \text{Integer}, \quad N_{\text{Wind}} \geq 0
\]

Also some other constraints can be regarded as follows:

\[
N_{\text{Sol}} \leq N_{\text{Sol}^{\text{Max}}^{12}}
\]
\[
N_{\text{Wind}} \leq N_{\text{Wind}^{\text{Max}}^{13}}
\]
\[
N_{\text{Batt}} \leq N_{\text{Batt}^{\text{Max}}^{14}}
\]

In these equations, \(N_{\text{Sol}^{\text{Max}}}^{12}\) and \(N_{\text{Wind}^{\text{Max}}}^{13}\) are the maximum number of solar panels and wind turbines respectively which are existed. Also \(N_{\text{Batt}^{\text{Max}}}^{14}\) is the maximum number of existing saving batteries.

**Numerical example**

A hybrid wind-photovoltaic system is designed in this paper based on the mentioned 1-14 optimization equations. This example is similar to what proposed in the (14). The parameters which are implemented in the proposed example using the (15) are reported in table 1. On the other side since a battery life time is assume to be 4 years, during the hybrid wind-photovoltaic system life time NBatt should be implemented 5 times. The required mean annual values at the first of the establishment are demonstrated in figure 3 and in the last years of the implantation are depicted in figure 4. Also the diagram which shows the consumption growth during the 30 years is demonstrated in figure 4. The powers generated by the solar panel and wind turbine are depicted in figures 6 and 7 respectively.

| Table 1. the values implemented in the wind-photovoltaic system design |
|---------------------|---------------------|
| Variable | Value |
| Annual interest rate (i) | 6% |
| System lifetime (n) | 20 years |
| The cost of each solar panel | 350 $ |
| The installation cost of each solar panel | 350 $ |
| 50 % of the cost of each solar panel | 20000$ |
| 25 % of the cost of each wind turbine | 170 $ |
| The cost of each wind turbine | 20000 $ |
| The installation cost of each wind turbine | 80 % |
| The unit cost of a battery (C Batt) | 2.1 Kwh |
| The backup generator cost (C Backup) | 1500 cycles (about 4 years) |
| The usage percentage of the nominal capacity of the battery is guarantee | 1 h |
| The nominal capacity of each battery | 0.5 cents per each Kw |
| Batter is lifetime | 2 cents per each Kw |
| Time unit (\(\Delta t\)) | Maintenance cost for the photovoltaic panels |
| Maintenance cost for the wind turbine |
Methods and the simulation results

The PSObin is a population based algorithm. Actually at first npop initial solutions are generated based on the predefined boundary conditions. Then the cost function calculates the objective function related to these solutions. Then by having the best objective function of gbest and gbestcost the solutions for the next stage can be generated.

![Figure 3](image)

**THE CONSUMING POWER BASED ON THE HOURE (AT THE FIRST OF THE ESTABLISHMENT)**

Figure 3.

![Figure 4](image)

**THE CONSUMING POWER BASED ON THE HOURE (AT THE LAST IMPLEMENTATION YEARS)**

Figure 5.

After running the psobin the program wants you to inter the boundary conditions. By interring the desired number the program starts to work. In each of iterations the best objective value of that iteration is shown. The optimal x and the best objective function in iteration are saved in the gbest and gbestcost respectively. The algorithm convergence is shown in figure 6. After the program running the x shows the number of solar and wind turbines. Also the NBatt shows the number of batteries. A main point which should be regarded strictly in order to find the feasible solutions is related to the boundary conditions. In fact the boundary of the feasible solutions should be determined before the program running. This means that xmin and xmax must be predefined. On the other side in this problem the number of solar and also wind turbines should be a positive integer numbers. So in each stage some integer positive values (x) should be generated. The pso program gives the x to the cost function. Based on the equation 4 and 5 this function first calculates the number of batteries. The most important point in this calculation is the min t and max t calculations. In fact whenever the cumulative energy of the battery (previous
saved value of the battery + the new value added to or minuses the previous value) is its maximum or minimum level should be calculated. The battery energy during a day is shown by the figure 5 (the values of Min t and Max t is obvious in this figure). By calculation of this time the nbuts values can be determined. Now by having the NBatt and x1 (number of solar cells) and x2(number of turbines) the cost function can be calculated by the equations 1,2,3,8. Finally this calculated value is saved in the z variable and this value is given to the pso algorithm.

![Photovoltaic power](image)

**Figure 6.** The mean power generated by each solar panel.

![Wind power](image)

**Figure 7.** The mean power generated by each wind turbine.

### Table 2. the optimal solutions at the first of the implementation of the cathode conservation station

<table>
<thead>
<tr>
<th>constraint</th>
<th>Optimal cost based on the Dollars (Best cost)</th>
<th>Number of solar cells (N Sol)</th>
<th>Number of wind turbines (N Wind)</th>
<th>Number of saving batteries (N But)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No constraint</td>
<td>11001.4295</td>
<td>174</td>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>Nwind= 1</td>
<td>10755.0486</td>
<td>169</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>Nwind= 0</td>
<td>8253.0453</td>
<td>169</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>pt&lt;=0.7*pt</td>
<td>22202.4656</td>
<td>194</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>Nsoilm = 20637.5721</td>
<td>36</td>
<td>8</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Nwind max = 10755.0486</td>
<td>169</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>Nbat = 10</td>
<td>4673.3279</td>
<td>46</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
After the program running the following results are obtained

At the first of the cathode conservations station establishment the optimal solution is obtained as table 2 considering the boundary conditions. Also during the last years of the implementation the optimal solution considering the boundary conditions is found as table 3.

**Table 3. the optimal solutions during the last years of the cathode conservation implementation**

<table>
<thead>
<tr>
<th>constraint</th>
<th>Optimal cost based on the Dollars (Best cost)</th>
<th>Number of solar cells (N Sol)</th>
<th>Number of wind turbines (N Wind)</th>
<th>Number of batteries (N But)</th>
<th>saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>No constraint</td>
<td>7716.9794</td>
<td>105</td>
<td>1</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Nwind= 1</td>
<td>7563.2223</td>
<td>102</td>
<td>1</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Nwind= 0</td>
<td>5000.0858</td>
<td>101</td>
<td>0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>pt&lt;=0.7*pt</td>
<td>17001.3979</td>
<td>137</td>
<td>4</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Nsolmax = 40</td>
<td>4343.6012</td>
<td>36</td>
<td>1</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Nwind max = 1</td>
<td>7563.2223</td>
<td>102</td>
<td>1</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Nbat = 10</td>
<td>4543.6702</td>
<td>40</td>
<td>1</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

**CONCLUSION**

In this paper the hybrid wind-photovoltaic system capacity for a numerical example is optimized using the PSO optimization algorithm which is run on the MATLAB computing software. Considering the obtained results at the first of the establishment of the cathode conservation station the optimal solution can be obtained in presence of the 46 solar panels and only 1 wind turbine. Also during the last years of the implementation of the cathode conservation station the optimal solution is obtained in presence of 36 solar panels, only a wind turbine and 9 saving batteries. An advantage of the PSO algorithm implemented in this study versus the other existing solution approaches is its independence to the initial solutions. Also this algorithm has the more efficient convergence to the optimal solutions in comparison to the other algorithms. The main objectives of this study were finding the optimal number of the solar cells, wind turbines and batteries with the system minimum cost. Using the PSOUBIN algorithm the more suitable solutions were found in comparison to other algorithms.

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