Cuckoo Search Algorithm for Sizing Optimization in Grid-Connected Photovoltaic System

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Abstract—**Cuckoo Search algorithm is a new metaheuristic optimization algorithm that was recently developed by Yang and Deb in year 2009. This paper presented the configuration of a photovoltaic (PV) array of a grid-connected photovoltaic (GCPV) system by using Cuckoo Search (CS) algorithm. The best PV module and inverter that can produce the optimal number of PV modules per strings and the optimal number of parallel PV strings was determined by using CS in order to make the GCPV system produce higher expected annual energy output with the given roof space.**

Keywords-grid-connected photovoltaic (GCPV); configuration; Cuckoo Search (CS); optimization; array

I. Introduction

Grid-Connected Photovoltaic (GCPV) system is a famous PV system that is connected to the local electricity grid where it allows any excess power produced to feed the electricity grid and it can be sell to the utility. This GCPV system usually used in developed areas for homes and businesses. The solar cells of the PV modules are used to convert solar energy from sunlight to DC power. After that, an inverter is used to convert DC power to AC power that can match with AC grid. [1]In the earlier of December, 2011, a feed-in-tariff scheme for renewable energy electricity has started and supervised by Sustainable Energy Development. [2]

During design activity, one of the problems that always occur isin the sizing part. The selection of PV module and inverter, the dimensioning of PV array and the determination of the expected annual energy output performance are including in the sizing procedure of GCPV system. The sizing process is very complicated, thus the CS is used to optimize the sizing process.

This paper present the cuckoo search algorithm is used for sizing optimization in GCPV. Cuckoo search algorithm is one of the algorithms that can be used for optimization.

I. Sizing Procedure For GCPV

The calculation of expected annual energy output and the selection of the dimension PV array or known as the number of PV modules per string and the number of parallel PV strings are including in the sizing process. The process that called trial and error is used in this procedure in order to find the number of PV modules per string, N_s and the number of parallel string, N_p that can fit with the dimension of the given roof space.

The objective function of the sizing part is to maximize the expected annual energy output that can produced by GCPV system from the given dimension of roof. The combination of the best type of PV module and the best inverter is found in order to make sure the objective function is achieved.

Besides that, the sizing process needed to be maximized that can fit with the expected energy output that had been calculated. The sizing procedure of a GCPV system using the following steps:

Step 1:

PV module and an inverter are choosing one by one. All the ratings of PV modules and inverters are listed. The respective ratings are obtained at irradiance of 1000Wm^{-2}, air mass (AM) 1.5 and cell temperature of 25°C. [3]

TABLE I. Required PV Inverter Ratings For Sizing

Rating	**Unit**
Nominal power output, P_{inv}	W
Maximum input voltage, V_{max_inv}	V
Maximum input window voltage, $V_{max\_win\_inv}$	V
Minimum input window voltage, $V_{min\_win\_inv}$	V
Maximum input current, $I_{dc\_max\_inv}$	A
Maximum efficiency, η_{inv}	%

II. REQUIRED PV MODULE RATINGS FOR SIZING

Rating	Unit
Maximum power, P_{mp_stc}	Wp
Voltage at maximum power, V_{mp_stc}	V
Open circuit voltage, V_{oc_stc}	V
Short circuit current. I_{sc_stc}	A
Temperature coefficient for maximum power, γ_{Pmp}	% per °C
Temperature coefficient for maximum power voltage, γ_{Vmp}	mV per °C
Temperature coefficient for open circuit voltage, γ_{Voc}	mV per °C
Reduction factor due to manufacturer's tolerance on output power, f_{mm}	decimals
Maximum system voltage, V_{sys_max}	V

Step 2:

Determine the range of total number of PV module that matches with the specific inverter using

$$\left(\frac{Pnom\_inv}{0.8 \times P_{mp\_stc}}\right) \leq N_{total_{mod}} \leq \left(\frac{Pnom_{inv}}{0.75 \times P_{mp_{stc}}}\right) \quad (1)$$

The left part need to be rounded up to the nearest integer and the right part need to be rounded down to the nearest integer. In this case, the value of total module is taken in between the above range.

Step 3:

Calculate the expected output voltages from PV array. The maximum PV module open circuit voltage, V_{max_oc} in Volts is calculated using

$$V_{\max\_oc} = V_{oc_{stc}} \times \left(1 - \left[\gamma_{Voc} \times \left(T_{cell\_min} - T_{stc}\right)\right]\right) \quad (2)$$

where T_{cell_min} is the minimum effective cell temperature of the PV array at site in °C and it is set at 20°C. The maximum voltage at maximum power of the PV module, V_{max_mp} in Volts is determined using

$$V_{\max\_mp} = V_{mp\_stc} \times \left(1 - \left[\gamma_{Vmp} \times \left(T_{cell\_min} - T_{stc}\right)\right]\right) (3)$$

The minimum voltage at maximum power of the PV module, V_{min_mp} in Volts is calculated using

$$V_{\min\_mp} = V_{mp\_stc} \times \left(1 - \left[\gamma_{Vmp} \times \left(T_{cell\_max} - T_{stc}\right)\right]\right) (4)$$

where T_{cell_max} is the maximum effective cell temperature of PV array at site in °C and it is set at 75°C.

Step 4:

Determine the number of modules in series per string. The number of modules in series per string based on open circuit voltage on PV module, $N_{s,\max\_oc}$ can be computed using

$$N_{s,\max\_oc} = \frac{V_{\max\_inv} \times (100\% - \lambda_{upper})}{V_{\max\_oc}} \quad (5)$$

On the other hand, the number of modules in series per string based on voltage at maximum power of PV module, $N_{s,\max\_mp}$ is calculated using

$$N_{s,\max\_mp} = \frac{V_{\max\_win\_inv} \times (100\% - \lambda_{upper})}{V_{\max\_mp}} \quad (6)$$

where λ_{upper} is chosen to be 5% that is the tolerance percentage for the upper limit of the inverter's input voltage window. [4] Both of the above equations are rounded down to the nearest integer and the smallest value between them is selected to be the actual number of modules in series per string.

Step 5:

Calculate the minimum number of module in series per string, $N_{s,\min}$ using

$$N_{s,\min} = \frac{V_{\max\_win\_inv} \times (100\% + \lambda_{lower})}{V_{\min\_mp} \times (100\% - \rho)} \quad (7)$$

where $N_{s,\min}$ is rounded up to the nearest integer. λ_{lower} is chosen to be 5% that is the tolerance percentage for the lower limit of the inverter's input voltage window. Besides that, the Malaysian Standard MS1837:2005 required that the value of the maximum percentage of voltage drop across DC cables, ρ is 5%. [5]

Step 6:

Estimate the maximum number of module in parallel per string, $N_{p,max}$ using

$$N_{p,max} = \frac{I_{dc\_\max\_inv}}{I_{sc\_stc} \times (100\% + \omega)} \quad (8)$$

where $N_{p,max}$ is rounded up to the nearest integer.
The value of ω is 25% that it is the percentage of oversized factor of PV module current. The value of module in parallel per string is taken from 1 to $N_{p,max}$, the next calculation need to consider this range of the number of module in parallel per string.

Step 7:

Calculate total number of PV module that can be produce by each module and each inverter by using

$$N_{total} = N_s \times N_p \quad (9)$$

where N_s is the lowest number of modules in series per string that have been calculated. Then, compare N_{total} with N_{total_mod} in equation (1) and make sure the value is in the range. If the value is out of range, the combination of the PV module and the inverter is automatically rejected from the list.

Step 8:

The N_{total} that have been choose is use to proceed with the next calculation that is calculate the value of PV array, P_{array} in kW using

$$P_{array} = P_{inv} \times N_{total} \quad (10)$$

Step 9:

Determine the value of the expected annual energy output, E_{sys_exp} in kWh using

$$E_{sys\_exp} = P_{array} \times H_{tilt} \ldots \times f_{mm} \times f_{temp} \times f_{dirt} \times \eta_{pv\_inv} \times \eta_{inv} \quad (11)$$

where H_{tilt} in peak sun hours that is the expected amount of radiation received. In this case, the value of H_{tilt} in Kuala Lumpur facing south is 1560.8 peak sun hours. Due to manufacturer's, $f_{mm}$is known as the PV array output dimensionless reduction factor. Due to temperature, f_{temp} is the value of dimensionless reduction factor of the PV array and it can be calculated using

$$f_{temp} = 1 - [\gamma_{Pmp} \times (T_{cell\_avg} - T_{stc})] \quad (12)$$

where the module temperature based on the standard test condition (STC) in °C is known as T_{stc} and the value is 25°C. $T_{cell_avg}$is the average effective cell temperature of PV module in °C. It can be calculated using

$$T_{cell\_avg} = T_{amb\_avg} + T_{stc} \quad (13)$$

where the expected daytime average ambient temperature of PV module in °C is known as T_{amb_avg} and it is set to 35°C.

Step 10:

Calculate specific yield (SY) in $\frac{WH}{m^2}\Big/\frac{W}{m^2}$ and performance ratio (PR) in % using

$$SY = \frac{E_{sys}}{Parray_{stc}} \quad (14)$$

$$PR = \frac{E_{sys}}{Parray_{stc} \times PSH} \quad (15)$$

Step 11:

Calculate either the maximum number of PV modules that can be mounted using lengthwise across orientation or lengthwise up orientation. The maximum number of PV modules that can be mounted using lengthwise across orientation is determined using

$$N_{roof\_\max\_LA} = \frac{W_{roof}}{(W_{mod} + l_g)} \times \frac{L_{roof}}{(L_{mod} + l_g)} \quad (16)$$

where W_{roof} is the width of roof that is 3000mm ,L_{roof} is the length of roof which is 14000mm, $W_{mod}$and l_g are width of module and length of air gap respectively. The maximum number of PV modules that can be mounted using lengthwise up orientation is determined using

$$N_{roof\_\max\_LU} = \frac{W_{roof}}{(L_{mod} + l_g)} \times \frac{L_{roof}}{(W_{mod} + l_g)} \quad (17)$$

Both equations above are rounded down to the closest integer value so that it can fit with the roof space. The largest maximum number of PV modules is choosing to proceed to the next step.

Step 12:

After that the N_{total} that is in range will be compare with $N_{roof\_\max\_LA}$ and$N_{roof_\max_LU}$either it can be arrange in lengthwise across or lengthwise up and it will be used for the next calculation. If it does not fit with both arrangements, it will be remove from the list. [3]

TABLE III. PSEUDO CODE FOR SELECTING THE ARRANGEMENT

```
For each possible PV array configuration
    if (NpX Ns) ≤ Nroof_max_LA
        Choose lengthwise across
    else
        if (NpX Ns) ≤ Nroof_max_LU
            Choose lengthwise up
        else
            Remove the PV array configuration
        end
    end
end
```

III. Cuckoo Search Algorithm-Based Sizing Algorithm

A. Cuckoo Breeding Behavior

The cuckoo population, in different societies, is in two types: mature cuckoos and eggs. [6] Cuckoo can produce the beautiful sounds and they also have their own aggressive reproduction strategy. For example Ani and Guira, species of cuckoo, they use communal nests to lay their eggs and they remove other's eggs. This happen because they want to increase probability of born of their own eggs. Some of the species act like brood parasitism where they lay their eggs in other host bird's nest. There are three types of brood parasitism that are intraspecific brood parasitism, cooperative breeding and nest takeover. They either throw away others eggs or left abandon in the nest and built another nest at the other place if a host bird knows the eggs are not theirs. [7,8,9]

In New World, some of cuckoo species brood-parasitic Tapera have a high sensitivity on their eggs. The female parasitic cuckoos can memorize the colour and the pattern of the eggs. This is one of the factors that cause the probability of cuckoos productivity is increase. Cuckoos have their own strategy in term of choosing the nest. They will choose the place where a host just laid its eggs. Normally, cuckoo eggs hatch faster than the other host eggs. After they hatched, they will chuck out the host eggs and this make they increase cuckoo's chicks sharing food that provided by the host bird. Studies also show that a cuckoo chick can also copy the call of the host in order to get more feeding opportunity.[7,8,9]

B. Lévy Flights

Recently, Reynolhs and Frye have shown that fruit flies or *Drosophila melanogaster*, using straight flight paths by sudden 90° turn to explore their landscape using a series of straight flight paths punctuated leading to a Lévy flight style intermittent scale free search pattern. The typical feature of Lévy flights shows the studies human behavior such as the Ju/'hoansi hunter-gatherer foraging patterns and light also can be related to this theory. Nowadays, it has been applied to optimization and optimal search.[7,8,9]

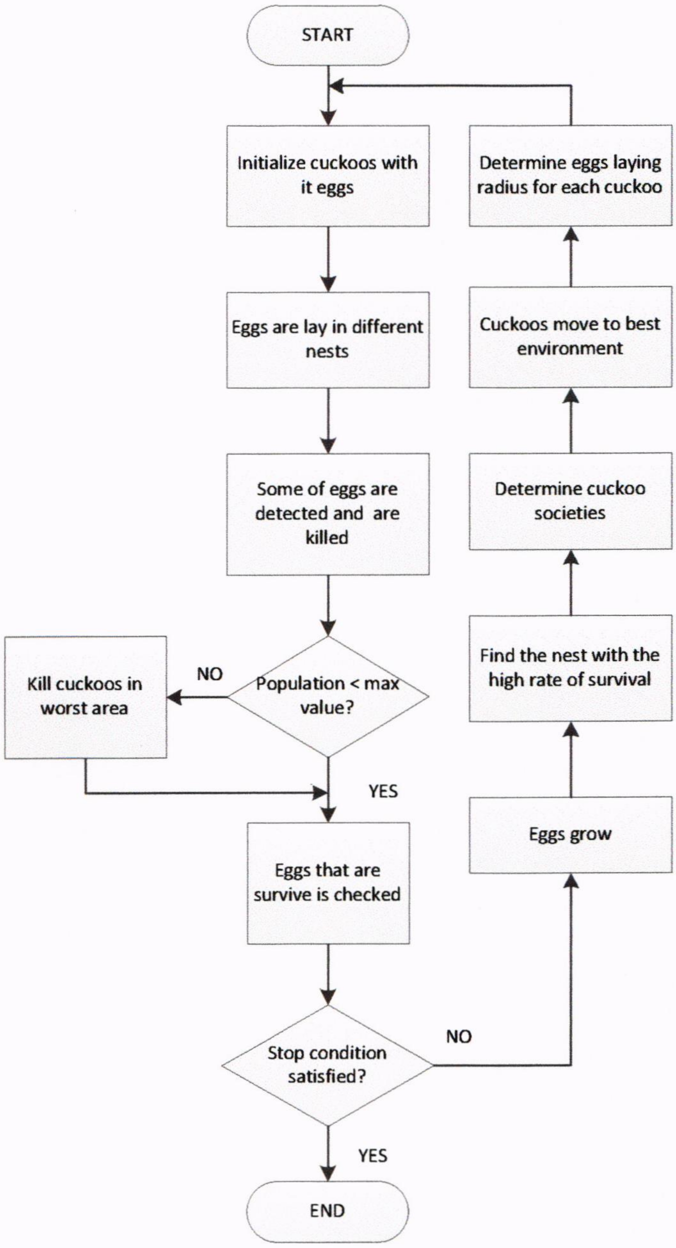

Figure 1. Flowchart of Cuckoo Search Algorithm

C. Cuckoo Algorithm

There are three idealized rules that had been describing by Cuckoo Search by Yang:

- Each cuckoo lays one eggs at a time, and cause dumps it in a random chosen nest;
- The best quality of eggs in the best nests will proceed to the next generations;
- Available host nests is not change, and it know the alien egg by using the probability $p_a \in [0,1]$. In this stage, there are two possibilities either the eggs will be throw away or the nest will be abandoned and built the new nests in a new place.

The last assumption can be done by a fraction of p_a to replaced nests,n with the new nests at random locations. For maximization option, the objective function needed to be proportional to the quality or fitness of a solution. [7] The three basic rules of Cuckoo Search can be defined as the pseudo code in Figure 1. [10]
In order to generated new solution $x_i^{(t+1)}$ for, the performance of Lévy flight is

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus \text{Lévy}(\lambda) \quad (18)$$

where the step size that related to the scales of the problem is α>0 but it also can be used as α = *O*(1). The entry-wise multiplication is represented by symbol ⊕. A random walk is provided by Lévy flight when their random steps came from Lévy distribution for large steps as follow

$$\text{Lévy} \sim u = t^{-\lambda}, (1 < \lambda < 3) \quad (19)$$

which has an infinite variance with an infinite mean. A cuckoo's consecutive jumps or steps form a random walk process that obeys a power-aw step-length distribution with a heavy tail. In the real world, when the cuckoo's egg is very same like a host's eggs, the possibility cuckoo's egg to be discovered is very low. This fitness has to be related to the difference in solutions. So, it is the main good idea to do a random walk with some random step sizes. [7,8,9]

IV. Result and Discussion

First, the result was obtained without perform the CS algorithm that is using conventional sizing method. Then the result was compared with performance of CS algorithm. Both way of sizing are conducted by using Matlab Software. Table IV shows the comparison between conventional sizing and sizing based on CS algorithm.

TABLE IV. Comparision Between Conventional Sizing And Sizing Based On CS Algorithm

Result	Conventional sizing	Sizing based on CS algorithm
Module code	1	
Inverter Code	6	
Array Configuration	3×8	
E_{sys} in kilo watt hour	5.0815× 10³	
Elapsed time, in seconds	2.096250	0.164984

Table IV shows that both ways produce the same module code, inverter code, array configuration and the energy produced,E_{sys}. The module had been chosen is module number 1 that is Mitsubishi PV-TD 190MF5 and inverter number 6 that is Fronius IG 40. The array configuration that can be produced by this module and inverter is 3×8 and the total number of PV module is 24. The maximum number of PV module can be mounted using lengthwise across orientation. The expected annual energy output,E_{sys} is

5.0815×10^3 kWh. The elapsed time sizing using conventional sizing is 2.096250s and sizing using CS algorithm is 0.164984s. There was a different in term of elapsed time where the conventional sizing takes a longer elapsed time as compared to sizing based on CS algorithm.

The specific yield (SY) and performance ratio (PR) for this module and inverter is $1114.36 \frac{WH}{m^2} / \frac{W}{m^2}$ and 71.4% which can be called as a good system. This is because a good system in Malaysia should produce SY more than 1000 $\frac{WH}{m^2} / \frac{W}{m^2}$ and PR more than 70%.

V. Conclusion

In conclusion, this paper presented Cuckoo Search Algorithm for sizing optimization in GCPV in order to select the best PV module and inverter with the given dimension of roof and at the same time the E_{sys_exp} was minimized.

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