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Cost Optimization of PV-Diesel Systems in Nanogrid using Cuckoo Search Algorithm and its Application in Mobile Towers

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ABSTRACT: The Nano-grids make a replication of a huge electricity grid that is centralized model in a smaller scale in locations that are remote in which the connectivity of grid may not be possible. They are used successfully in the hilly regions that are in remote locations that have renewable sources of energy. This develops an algorithm that is simple for the determination of the needed units of PV or Photo Voltaic array, DG or a Diesel Generator and battery models for a stand-alone Nano-grid. In order to use these effectively, the algorithm has been studied for calculating the generator unit's capacity which has a power system that is reliable along with lower cost. There are many methods of sizing that are iterative with the artificial methods of intelligence that is reported for designing an energy system that is hybrid and renewable and techno-economically optimum. The key challenge is the computing is expensive. Meta-heuristic methods are effectively used for finding the optimal solution in reasonable time and cost. This work proposes CS as Cost Optimization of PV-Diesel Systems. This is a powerful algorithm of search which is inspired by the cuckoos breeding behaviour. The experimental results show that the cost is reduced with the proposed method.

Keywords: Nano-Grid, Photo Voltaic (PV) array, Diesel Generator (DG), Renewable Energy and Cuckoo Search (CS).

Abbreviations: PV, Photo Voltaic;DG, Diesel Generator, CS, Cuckoo Search; NPC, Net present cost; HEV, Hybrid Electric Vehicle; HOCA, Hybrid Optimization Genetic Algorithm; GA, Genetic Algorithm; PSO, Particle Swarm Optimization; DP, Dynamic Programming; GPAP, Grid Power Absorption Probability; SOC, Stage of Charge.

I. INTRODUCTION

The PV or the Photovoltaic power systems that converts the sunlight into electricity. A PV power system which is residential helps an owner of a home to generate some of his duties that demand electrical energy from the energy that is derived from their own roof and nighttime usage for their future needs. The house continues to be connected to the energy continuously and any power needed above the system can produce one drawn from the available utility. These systems can also include a backup system with battery or an UPS or uninterruptible power supply to ensure the circuits chosen can operate in certain circuits for a particular number of hours at the time of a utility outage.

All the cellular networks in regions that are still under development still are dependent on diesel for providing coverage owing to the non-availability of a reliable grip of power. Sometimes cellular installations have gotten prominence however, have faced challenges of adoption which include their difficulty in providing 24 × 7 supply of power and the non-availability of an efficient storage system for power.

A system based on PV-Diesel is more reliable for the production of electricity than that of a system that has PV only as the production of a diesel engine is not influenced by the atmospheric conditions. This ensures better and higher flexibility and efficiency with a lower cost of energy production. There is also a reduction in the cost of operation as well as the air pollutants that get emitted into the atmosphere in this system.

In spite of the fact that the prices of the PV enabled modules have been brought down to a great extent in recent times owing to the improvement in efficiency and techniques of manufacture, identifying an optimal size of the PV panels inside the system of hybrid power is a needed step to completely bring down the cost of investment. The sizing of a PV battery diesel is an extremely complex task as various resources need to be employed for this as the various resources employed do not possess similar behavior [1].

The optimal size of the PV and the capacity of the battery have been calculated on the basis of the cost of the total life cycle and for this a methodology has been duly developed for this work by the panel number of the PV along with the batteries back can be simultaneously optimized. The PV battery diesel aims at providing reliable and sufficient electricity for meeting the demand of the end use power and also to store excess energy into the bank batteries. The efficiency of the energy is determined by the strategy of all the PV battery DG systems that are stand alone and the generator of diesel and lifetime of the battery depends on the manner in which they are used. In the case of PV-Battery-Diesel, the minimum charge of batteries bank that is allowed is decided by the manufacturer as this has an effect on the

life of the battery and this is normally either 20% or 30%. Sometimes there can be higher values provided by the manufacturers of a NPC or Net present cost value may be given [2, 3]. The generator of the diesel may have the minimal power value given by the manufacturers and in some cases they may even give low NPC values as opposed to the supply of low power levels when consumption is high.

Efforts of extensive research, demonstration and development on the micro-grips have given the laboratories and pilot installations many concepts of operation. But the micro-grids are normally tied to the grip and are developed only at the level of power in the kilo Watts of tens to hundreds for distribution of local energy. For the lower levels there are many kilo Watts like the residential system of electricity, the concept of the micro-grid may be applied and duly called the nano-grid [4]. This nano-grid may specifically be applied in the US military when the on-the-move soldiers have a larger micro-grid comprising of many nano-grids each one of them being lower than 100W~5kW with a structure that is applicable for every individual PV panels that are portable as well as Humvee batteries or solar tents. Every nano-grid has an energy management controller that can communicate duly with the other nano-grids for co-ordination of the power flow to the entire system.

The renewable energy is one solution that is a preferred one to the fossil fuels when they are deployed in systems that are off-grid and are steadily growing in the developed as well as in the developing countries. DC or Direct Current Nano-grids that employ energy systems that are hybrid in nature are being considered as an option that is viable for the electrification of sparsely and remotely populated areas [5, 6]. They also supply energy that is reliable and of improved quality to commercial users of small-scale and also to households mainly for boosting rural area commercial activity. The Nano-grid is a system of small power that can used a combination of both non-renewable as well as renewable sources of energy to supply power to small loads that are less than 20 kW. This employs power converters either a DC/AC or a DC/DC for the interfacing of the generators as well as the loads.

The GA or Genetic Algorithm in its meta-heuristics, PSO or Particle Swarm Optimization or the CS are used in the design of engineering and the problems of optimization with results that are promising [7]. The CS is characterized by three features to satisfy the requirements of global convergence and also support capabilities of global search while using Lévy flights as one of the global search strategies. The advantages of CS are: easy implementation, simplicity, speedup to convergence.

The objective is to minimize the cost of acquisition and maintenance of PV system, generator, and battery. Optimizing the cost on the power of battery model, DG fuel consumption and the PV generator model is achieved through the proposed mode.

II. LITERATURE SURVEY

Ahmad *et al*., (2015) brought about a cross-over boundary over which the installations of solar power were considered better than their alternatives of diesel power. An analysis that is based on the actual consumption of diesel from one of the larger telecom operator was taken to be sued in a developing region. By using this model that was proposed an analysis that is extended was easily performed on the basis of future projections on the efficiencies of solar energy and the future designs of cellular network [8].

An optimization of a PV diesel system by HOGA or Hybrid Optimization Genetic Algorithm was compared with that of a standalone system of PV which was dimensioned with a classical design on the energy available was made by Dufo-López & Bernal-Agustín [9]. Both the cases saw the demand and the solar irradiation as similar. The results of the computation proved the advantages of the PV-Hybrid system. The HOGA is often compared with commercial programs for the hybrid system optimization.

Sofiane *et al.,* (2013) made a presentation for optimal control as well as sizing strategy for all standalone PV battery Diesel. The method of sizing which was developed for the establishment of minimal capacity of the components of the system. But the strategy for optimal management of energy has been developed for increasing the lifetime and the reliability of the system. The algorithm of Cuckoo Search was also introduced to bring down the cost of this system by identifying suitable parameters for control [10].

Hamatwi *et al.,* (2016) made a stimulation and optimization of a DC nano-grid model for a hybrid solar and the PV as well as the wind that has an energy storage and a back-up generator for diesel in South Africa's Umzinyathi district in the Province of KwaZulu-Natal [11]. One survey of the site was conducted and the wind resource as well as the data of solar radiation for the forecasting of the load as well as the system modelling was conducted. The minimum cost optimization for this system was done by considering the component cost, the solar radiation on an hourly basis and the input rating parameters of the program of simulation. The variables of the sensitivity have been specified for the examination of the effect of uncertainties of this system. On the basis of the results of simulation it was decided that an optimal system should comprise of one 100kW PV array, thirteen 7.5kW of wind turbines, a diesel generator with 20kW, and a 96 Trojan T-105 with deep cycle batteries. The NPC, CoE or and the period of payback of optimal systems were determined at $459 545, $0.248/kWh for 4 years respectively. The analysis of both the economy as well as that of the environment showed that it was better ensure electrification of the remote settlements by making use of a DC nano-grid on the hybrid systems that have many renewable sources and lower cost of operation with an environment friendly atmosphere owing to low dependence on units that generate diesel.

Sheng *et al*., (2015) made a proposal of an approach for optimal management of power to bring down the cost of operation by management of the flow of power in a PV diesel generator and batteries. This algorithm uses DP or Dynamic Programming for optimization of the power flow for meeting the load of the demand and achieving maximum utilization of the solar energy that is available and also bring down the consumption of fuel and increase the life cycle of the battery. The results proved that in comparison with the rule based algorithm this proposed method was superior [4].

Nadjemi *et al*., (2017) made a presentation to update a review on the techniques of optimization that is used for the management of both the sizing and the energy of the hybrid, battery, wind and photovoltaic systems. Also, a new approach on sizing that is based on the CS algorithm has been proposed for those systems of hybrid energy that are gird-connected. The sizing optimization is a problem that is multi-objective that has environmental, technical and economic constraints. The criterion of reliability has been modeled with the help of GPAP or the Grid Power Absorption Probability parameter. This method was tested for a better residential and a farm load that was located in Ghardaia in Algeria. This method proved to have a better accuracy and was faster in its convergence with a lower time of computation in comparison to the PSO technique [12].

Sanajaoba & Fernandez (2016) further made an exploration of the application of CS which is a meta-heuristic algorithm in the hybrid system of energy design problem. This is applied for the sizing of three schemes that are PV-battery, the wind batter and finally the PV wind battery that is applicable to an area that was remotely located in the Almora district of Uttarakhand in India when minimizing the total cost taking into consideration the load variation owing to seasonal changes. The CS algorithm was considered effective in the solving of the design problem of hybrid energy that was investigated and the performance of this algorithm was compared with other algorithms of optimization like the PSO or the GA [13].

The problem of power in the hospitals are more frequent when compared to the industries that are hi-tech. but the Nano grid is becoming as a mechanism that is very popular for countering any outages of power from the grids that maintain high quality of power. There is a successful usage of Nano-grids for renewable sources of energy in remote hilly locations. For designing the renewable system of energy is efficiently very appropriate quantity of resources if their capability is based on requirements of long term load and the design is of a minimum cost. The optimal sizing is based on NP or non-deterministic polynomial as the state of the power production is dynamic in nature for renewable resources. An optimal sizing problem was solved using the BAT algorithm with the help of a cost function that was novel which was proposed by Hemalatha & Chandramohan [14]. Many simulations have proved that the BAT algorithm has effectively solved the problem of optimal sizing with better results when compared to the GA.

It is observed from the works available in the literature, that though various metaheuristic methods are used for sizing and cost, long term cost and immediate cost are not considered. In this work, a multi-objective fitness function to decrease the long-term cost and immediate cost based on weights are recommended in this work. The main importance of the proposed fitness is the flexibility to the designer requirement who needs to either obtain short term or long term savings.

III. METHODOLOGY

Here, the optimization cost on the power of battery model and also with the DG fuel consumption and the PV generator model along with the CS algorithm have been discussed.

A. Battery Power

The simulation of battery is a technique that is widely used for reduction of cost and time when the development and design process for EV or electric vehicles is underway. It is a cheaper method to perform the tests as no measurement or test equipment is needed and the simulation is used in a parallel manner simultaneously in various workstations that are feasible [15].

For the purpose of using the approach models that are simple and accurate is needed and many diverse models of battery have been published already. Also electrochemical as well as battery models that are equal to the circuit models have high chances for accuracy as well as the effort of parameterization. And the models of equivalent circuit they have a proper tradeoff among the usability, complexity as well as its exactness.

There is much diversity in the models of circuit as well and the effort of parameterization is quite complicated as well as time consuming. So here in this work the focus if mainly on a model of electrical batter that has a tradeoff among the parameterization, the performance and the complexity effort. There are three model structures that are used in terms of their parameterization and accuracy effort. The parameterization of the numerical aspects and the due differences in their optimization as well as time take are duly addressed. Also a simplified parameterization for models specifically taken is presented for proper practical usage.

A single application of the models presented and their respective parameterization can be an implementation of the BMS or their battery management systems of either an EV or a HEV or a Hybrid Electric Vehicle system. But inside the BMS, there is only a limited level of memory as well as capacity to calculate. So the models and their respective parameterization has to be kept simple and also accurate. In case a particular model of battery is implemented within the BMS it can also be forecast within the range of that EV along with SOC or the Stage of Charge.

The P_{CS} may be positive which is charging or negative which is discharging in accordance to various directions of power. The battery's SOC may be calculated using (1):

$$SOC(t) = \frac{1}{C_{CS}} \int_0^t P_{CS}(\tau) dt + SOC_{ini} \quad (1)$$

In which the C_{CS} denotes the capacity of the battery (kWh), SOC_{ini} which is the initial SOC. Even though the model of battery that is details is found in [15] as a simple treatment the power of the batter SOC in the entire range of SOC and the effect of the memory has not been included.

B. Battery model

The storage of energy is needed because the generation of renewable energy is not continuous. The supplies of energy that are stored can supply load when no electricity is available and the surplus power is used when the power generated is more than the load. The behavior of the battery is shown by the SOC. Now the technology of batter is considered as imported in the

area of research and development. In the model known as CIEMAT there is a performance that is good enough for representing dynamic as well as models that are complex for battery operation. These equations are duly normalized in accordance to the total number of ampere-hours that can be either charged or discharged in a C10 capacity or 10 h at 25ºC and it takes the current operation that is low and also its temperature and its effects of the capacity of the battery. The equations (2) and (3) prove the equation and its capacity [16, 17].

$$C_T = 1.67 C_{10}(1 + 0.005\Delta T_a) \quad (2)$$

$$C = \frac{C_T}{1 + 0.67\left(\frac{|I|}{I_{10}}\right)} \quad (3)$$

In which $\Delta T_a = T_a - 25$ denotes the variation of temperature from reference 25ºC, and T_a which are the ambient temperature in ºC, C_T here is the capacity of the battery at its maximum (Ah) and C here is the capacity of ampere-hours either at the charge or at the discharge of the constant current I(A).

C. PV generator model

The operation of the PV generator as well as its performance are interested to the maximum level of power and the models that describe the module's maximum power output and their behavior are practical for the assessment of the PV system. Here a model which is mathematical is used for estimating the output of the power where the models of PV are used. This estimation is done by a computer program that makes use of subroutine for the determination of the output of power in the PV module. The conversion of the sun in PV and its irradiation shows that the solar irradiation conversion to electrical energy is possible. The power that is produced by this system of PV is computed in the equation that follows (4) [18, 19]:

$$P_{pv} = \eta_{pv} A_{pv} G \quad (4)$$

In which: A_{pv} is the array area of PV (m2), G denotes solar irradiation (kWh/m^2) and η_{pv} depicts the efficiency of the PV generator as is shown as (5):

$$\eta_{pv} = \eta_{pv\_ref}\eta_{MPPT}[1 - \beta(T_c - T_c\_ref)] \quad (5)$$

In which η_{pv_ref} denotes the efficiency of the reference module, η_{MPPT} denotes the efficiency of the conditioning of power that is equal to 1 if an MPPT or a perfect maximum power tracker is made use of. β denotes the efficiency of the generator temperature coefficient and it is generally taken to be constant and in case of silicon cells the range is taken to be b is 0.004-0.006 per ºC, T_c_ref which is the reference cell temperature ºC and is usually taken to be 25oC and T_c denotes the cell temperature (ºC) that can be computed as (6):

$$T_c = T_a + [(NCOT - 20)/800]G \quad (6)$$

In which T_a denotes the temperature that is ambient (ºC) and the NCOT denotes the temperature of the operating of the nominal cell (ºC).

D. Diesel Generator (DG) Fuel Consumption

A generator that is a diesel stand-alone one that is comparatively less expensive to buy but very expensive for its operation should be used above a particular level of minimum load to maintain an efficiency and also for reducing the possibility of failures that may be premature. This is proved in figure 1 that depicts a curve that is typical of fuel consumption against ratio of load.

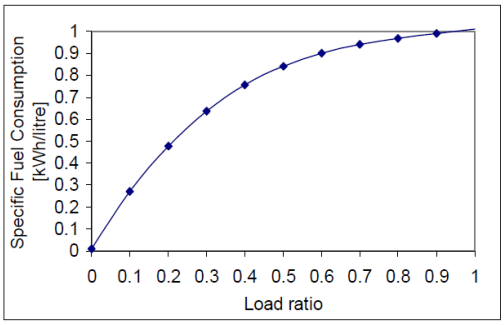

Fig. 1. This shows a typical curve for the specific consumption of fuel versus the ratio of load.

This curve shows the actual consumption of fuel as the ratio of load increases. The relationship here is that the ration when of low load the consumption of fuel is high [20].

The challenge of choosing a size of diesel generator for a community that is emerging or one that has never had a continuous supply of power earlier is extremely difficult when there is a fluctuation in population or a demand that is seasonal or when there is a sudden increase in the demand for electrical appliances etc., No generator should be operated at its highest power for a time that is more than thirty minutes. The power a generator can give for a longer time known as rated power is a better and more reliable type of power.

The approach that is considered as conventional in cases of stand-alone diesel is the selection of the generator in accordance to its peak load. In times of low loads these generators become poorly loaded owing to carbon deposits on the wall of the cylinder called glazing, we stacking, poor efficiency of fuel all of them leading to a premature wear and tear of engine. It is commonly known that in such cases dump loads are installed that dissipate the energy deliberately when the demand for energy is low in order to protect the engines.

The authors are also of the opinion that many approaches though considered to increase the operating economy of diesel generators there has to be one system that can operate parallel to others in achieving peak supply of load but at the same time is shut down when the load reduces automatically. Such a system needs a sequencing that is automatic and the controls need to be synchronized. There can be a system of two diesels one small and the other one larger that has a manual change over switch that can meet the requirements of the load. The smaller one is operated when the demands are low while the larger one can be used during the periods of high demand. This is a low cost scheme but the larger generator that has low demand may not be protected and therefore not suitable.

Even though the diesel generators do not have a high capital cost there has been proper support that is available on ways to operate and then to maintain them

and past experience has proved that there are many limitations that are part of this generation method. The process of getting a maintenance crew on time to isolated locations is a challenge. Transporting fuel is yet another problem. The diesel generators have a durability that is very short owing to the reason that they work quite inefficiently when they work below their capacity. Likewise, frequent starting and shutting down can also bring down their lifetime. These generators are sometimes very expensive to run and may release up to 3 kilos of CO_2 gas. This generator remains in the system for equalizing the battery to ensure it acts as a backup generator for a long period. These systems are normally installed in places where the fuel supplies are very costly and not reliable.

The diesel generator's consumption of fuel ConsG (l/h) is normally modeled as one that is dependent on the power of the output as in (7):

$$ConsG = B_G P_{N\_G} + A_G P_G \quad (7)$$

In which P_{N_G} (KW) denotes the nominal power, $P_G(KW)$ denotes the output power of the generator, A_G and B_G become the coefficients of the curve of consumption that is defined by the user (l/kWh) in (8).

$$A_G = 0.246l/\text{KWh and } \text{B}_G = 0.08145l/\text{KWh} \quad (8)$$

E. Cuckoo Search (CS)

The CS is an algorithm of optimisation that was developed in 2009 by Yang and Deb which is a novel one that is inspired by the brood parasitism of the species of cuckoos that lay eggs in the nests of other host birds belonging to a different species. In the space that is multi-dimensional, in which the solution that is optimal will the sought CS is continued for solving problems of maximization in which the fitness of the quality of one solution can be a value that is proportional to an objective function. This is quite similar to the algorithm of hill climbing. It is by far more efficient than GA as well as PSO in adapting to wider classes of problems of optimization [21].

This has been inspired by certain species of the family of birds known as the cuckoo as their special lifestyle and their strategy for reproduction is unique. They lay their eggs in the nest that belongs to a bird of another species known as the host birds and possess abilities like choosing a nest that is recently spawned, removing the eggs that are already in in to increase the chances of their eggs being hatched and so on. But at the same time some host birds may also be capable of understand this parasite behaviour of the cuckoos and throw away the alien eggs or build new nests [22].

This is an algorithm that has a population of either nests or eggs. To make it simple, these representations are made use of in which each egg denotes a solution and every cuckoo egg a new one. If the egg is similar to that of the host and its egg, then the chances of being discovered are less likely and so the fitness is related to the changes in solutions. The main aim here is to find better solutions of cuckoos to replace with those that are not good enough

CS here can be described by means of the following idealized rules [23]:

– A cuckoo lays only one egg at one time and dumps randomly the egg in the nest chosen;

– The nest that is best with highest quality of eggs carry over to the generations that follow;

– The actual number of nests of the hosts remain fixed and the egg that is laid by the cuckoo is found out by the host has a probability of pa Є [0, 1].

In general terms an animal's path in search for its food is a random walk as the next move is almost always based on the current location and the state of its transition to the location that is next. The direction it chooses entirely depends on the chances that can be mathematically modelled. For instance, studies have proved that the flight behaviour of some animals have shown traits of Levy flights which is a random walk based on which the increments get distributed to distribution of probability that is heavy-tailed.

In order to make it simple this assumption can be duly approximated by using a fraction pa belonging to nests n and replaced duly by new nests. The same fitness can be shown in the ways similar as done in case of GA.

In case a new solution $x_i^{(t+1)}$ is duly generated for the ith cuckoo, for that a Lévy flight is made as (9) [24]:

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus Levy(\lambda) \quad (9)$$

In which:

α > 0 indicates the size of the step as it should be connected to the problem's scales and in most cases it is taken as α = O (1).

⊕ indicates the multiplications that are entry-wise.

The Lévy flight is used for conducting a random walk that is taken from Levy distributions for huge steps as in (10):

$$Levy \sim u = t^{-\lambda}, (1 < \lambda \leq 3) \quad (10)$$

This works on an infinite variance that has an infinite mean. The jumps or the steps that the cuckoo makes successively for the sake of a random walk that obeys a step-length distribution of power law with a heavy tail.

The CS is as shown in Fig. 2 as a flow chart [25].

begin

Objective function $f(x)$, $x = (x1, ..., xd)^T$

Generate initial population of

n host nests xi$(i = 1, 2, ..., n)$

while$(t < \text{MaxGeneration})$ or (stop criterion)

Get a cuckoo randomly by Levy flights

evaluate its quality / fitness Fi

Choose a nest among n (say, j) randomly

if $(Fi > Fj)$,

replace j by the new solution;

end

A fraction (pa) of worse nests is abandoned and

new ones are built;

Keep the best solutions $(\text{or nests with quality solutions})$;

Rank the solutions and find the current best

end while

Postprocess results and visualization

end

The Pseudo code that is generalized for the CS

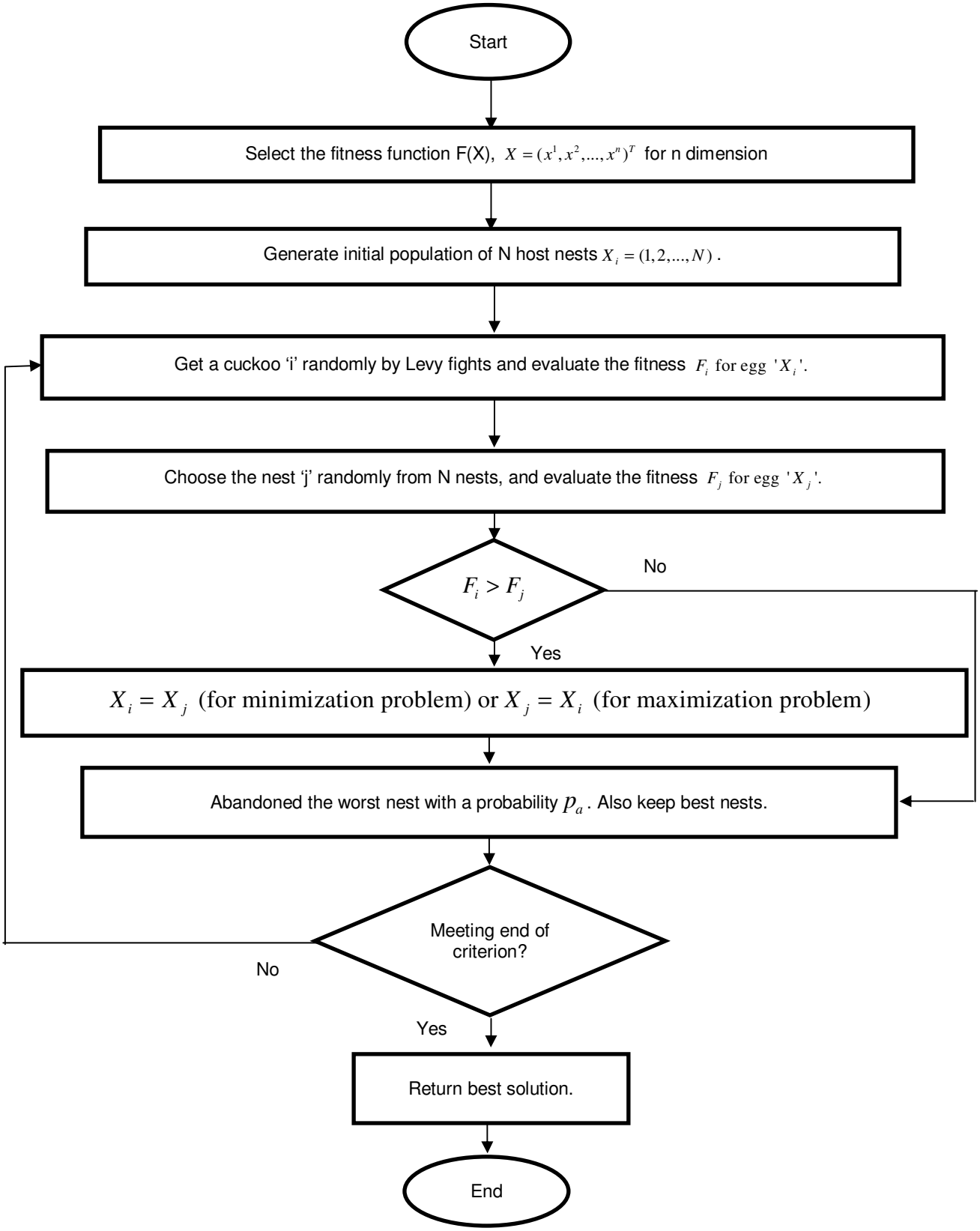

Fig. 2. The Flowchart of Cuckoo Search (CS) Algorithm.

IV. RESULTS AND DISCUSSION

For minimizing the system cost, the cuckoo search algorithm looks for configurations of batteries, AC generators, fuel cells, electrolyzers, wind generators, hydro turbines and inverters. In case all these are chosen, this is the general case, but, the user can decide which of these elements have to be contained in the system. Fig. 3 shows the cost per KW.

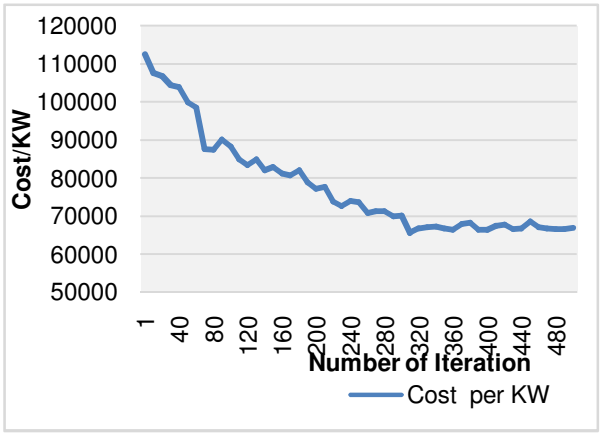

Fig. 3. Cost per KW.

The proposed CS algorithm uses a population of N_m vectors representing the configuration. The number of generations is 500. The optimal configuration of the elements minimizing the cost is obtained by the main algorithm. The Fig. 3 shows that the Cost per KW is reduced when the number of iterations are increased.

V. CONCLUSION

The Nano-grids make a replication of large model of a centralized electricity grid in which connectivity may not be possible. The renewable energy that is available is interfaced directly to a Nano-grid that has a higher level of reliability and finding an optimal sizing for the Nano-grid by using the PV-DG system. A proposal based on CS for a new meta-heuristic algorithm that is multi-objective has been made. This was inspired by the cuckoo's strategy of reproduction. A strategy to located best combinations of generators using solar energy DG and batteries is found by this system. In future, the hybrid techniques can be used to improve the efficiency of the existing work.

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