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Optimal Control Method of Stability for Standalone Micro Grids using Particle Swarm Optimization

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Abstract: Battery energy storage system (BESS) plays an important role in peak load sharing, providing real power regulating capacity and improving voltage quality. In isolated micro grids, balancing the energy demand is a critical issue, due to the presence of intermittent energy sources. BESS can be installed in such circumstances to supply the demand and act as a spinning reserve for an isolated micro grid. The integration of BESS and renewable energy sources with the existing distribution networks has many challenges. One of the major challenges is to determine the size and allocation of the BESS in the distribution system. However, due to the high installation costs and less life of BESS, there is a need for proper method to select such systems and size them optimally. In this paper, a stand-alone micro grid with Solar, Wind, Diesel and battery sources are considered. An optimization methodology for BESS using Particle Swarm Optimization (PSO) is applied which gives optimal battery capacity with minimum cost, good reliability and lower pay back periods. The proposed methodology for optimization is tested on three case studies and the results are validated.

Keywords: Battery energy storage system (BESS), Particle Swarm Optimization (PSO), Isolated micro grids, Renewable Energy sources (RES) and Battery sizing.

I. INTRODUCTION

With the rapid growth of eco-friendly renewable energy resources, they are typically used in distribution networks. It includes wind turbines (WT), combined heat and power (CHP), fuel cell and photovoltaic (PV) systems etc. Due to intermittent nature of such generation can have noticeable and negative effects on the entire grid [1]. The intermittency can be mitigated with integration of Battery Energy Storage Systems (BESS). This is one of the most viable solutions to overcome the intermittent nature of RESs [2]. Technological developments on the BESS which leads to draw more attention from system operators and employing them in distribution systems. This is the reason for extending application of BESS with distribution system become more economical and appropriate [3]. Therefore, optimal siting and sizing of BESS and RESs have more attention in distribution systems planning and operation. The lifetime characteristics of a BESS are very important while implementing. This is due to the BESS has short lifetime and high cost. The non-dominated sorting genetic algorithm (NSGA) is applied to Dongfushan island micro grid project in Zhejiang province, China for optimization. The life time characteristics of the battery are considered to achieve economic optimization [4]. The mixed liner integer problem (MLIP) method is used for optimal sizing of battery energy storage system in islanded and grid modes of micro grid [5]. An improved bat algorithm technique is implemented for optimal sizing of battery energy storage. The power capacity of BES, energy capacity of BES, charging and discharging rate, reserve capacity and load demand are considered in implementation of this technique [6]. A hybrid energy storage system with wind, PV, CHP generation is modeled. This model is based on power density, energy density, response speed, life time and load classification. The PSO technique is implemented for optimal sizing of the energy storage system [7]. This paper aims at analyzing the technical and economic aspects of distributed generators along with battery storage system on the distribution system. The PV, wind, diesel and BESS are considered for the power generation. For better utilization of renewable energy sources, the first priority will be given to PV and wind energy. The second priority to battery storage system for supplying power during the intermittency and also at peak loads. Particle Swarm Optimization Technique is implemented instead of bat technique for hybrid renewable energy system [11] for obtaining optimal battery size. The reliability and economic analysis are also evaluated in standalone system. The rest of the paper is organized as follows. Section II describes modeling of PV, wind and BESS systems. In section III, describes the proposed optimal sizing of BESS, reliability and economic analysis. Section IV presents the implementation of proposed methodology. Section V provides results and validation and conclusion in section IV.

II. MODELING OF MICROGRID

In this paper the solar, wind and battery systems are considered in micro grid structure. In general the micro grid controls the energy sources and power generation itself in both modes of operation. That is in islanded mode and grid connected mode. The output power depends on the availability of wind speed and solar radiation. The power calculation is required for modeling the each energy system.

A. PV System Modeling

The output power of PV module depends on solar radiation at that location and weather conditions of that day. The solar radiation availability changes continuously on hourly, daily, monthly and yearly. The output power of the PV cell is expressed as:

$$S_{ppg}(t) = S_r(t)*a*P_\eta \qquad (1)$$

Where S_{ppg} =output power of PV panel,
a = Panel area,
S_r = Solar radiation,
t = time in hours

The output r power of the PV module can be calculated as: [8]

$$Sppg\ (t) = Prscg * \frac{Sr^2}{Srs*Cr};\ 0 \le Sr \le Cr \qquad (2)$$

$$Sppg\ (t) = Prscg * \frac{Sr}{Srs};\ Cr \le Sr \le Sr \qquad (3)$$

$$Sppg\ (t) = Prscg;\quad Srs \le Sr \qquad (4)$$

Where,
$Prsc$=Solar cell generator rated power [MW]
S_r = Solar radiation
Srs =Solar radiation in standard conditions
Cr =Certain radiation point, 150w/m^2

B. Wind Turbine System Modelling

The output power of wind turbine system depends on the wind speed. Wind speed varies every hour, day and depends on season. If the wind speed lies between the speed limits the wind turbine can able to generate power. The real power output of wind turbine is as follows: [9]

$$Pwtg(t) = 0\ ;\ Ws(t) \le Vci\ \ or\ v(t) \ge Vco \qquad (5)$$

$$Pwtg(t) = WTGpr * \frac{Ws(t)-Vci}{Vco-Vrs}\ ;\ Vci < Ws(t) < Vrs \quad (6)$$

$$Pwtg(t) = WTGpr\ ;\ Vrs < Ws(t) < vco \qquad (7)$$

C. Battery System Modeling

If the total output power of the PV system and wind turbine system is greater than the load demand, the battery is in charging state. If the total output power of the PV system and wind turbine system is less than the load demand, the battery is in discharging state. The state of charge (SC) gives the information about the availability of battery capacity at the instant of time. The equation for state of charge can be expressed as: [10-13]

$$SC(t) = SC(t-1) + \mathrm{Bp(t)} \times \left(\frac{\Delta t}{\mathrm{Besc}}\right) \qquad (8)$$

Consideration of SC limits, $SC_{min} \le SC\ (t) \le SC_{max.}$ Where SC (t), SC (t-1) are the charge quantities at time t and (t-1) respectively, $B_p(t)$ is the battery power at instant t in KW and Δt is the time interval. Besc is the battery energy storage capability in KWH. The battery energy constrains limit is Be min ≤ Be (t) ≤ Be max. The Be (t) for discharging and charging is as follows:

$$\mathrm{Be\ (t)} = \max\left\{\left(\mathrm{Be}(t-1) + \frac{\Delta t \times \mathrm{Bp(t)}}{d\eta}\right), \mathrm{Be\ min}\right\} \qquad (9)$$

$$\mathrm{Be\ (t)} = \min\left\{\left(\mathrm{Be}(t-1) + \frac{\Delta t \times \mathrm{Bp(t)}}{C\eta}\right), \mathrm{Be\ max}\right\} \qquad (10)$$

Where, $\mathrm{Be\ (t)}$ and $\mathrm{Be}(t-1)$ are the energies present in the battery at t and (t-1) instants respectively. $d\eta$ and $C\eta$ are the discharging and charging efficiencies.

III. THE PROPOSED OPTIMAL SIZING OF BESS

A. Objective function:

The objective function is to minimize investment costs and losses. It is formulated as a summation of two terms. First term indicates battery cost (which is a function of battery size Besc in kWh). Second term indicates losses (which includes losses incurred due to wind power spilling and load shedding caused by insufficient storage). The losses are inversely proportional to the battery size. So, a larger battery ensures greater reliability and vice versa.

$Total\ cost = battery\ cost + cost\ of\ losses$ (11)

$battery\ cost = \mathrm{Besc} * x * crf * (1 + y)$ (12)

Where Besc =battery size (variable), x= cost of battery per KWh, y = maintenance to fixed cost ratio, crf **-** capital recovery factor.

The capital recovery factor is expressed as:

$Crf = ((idr*(1+idr)^{n}) / ((1+idr)^{n} -1))$ (13) Where ir= interest rate

idr = discount rate ; $idr=((1+ir) /(1+ifr))-1$

ifr = inflection rate

n = life time of the battery

Cost of losses: This includes spillage losses and shedding losses due to inadequate size of battery storage.

$Power\ loss = spillage\ loss + shedding\ losses$ (14)

Spillage loss**:** This loss occurs when generation is greater than demand and power spillage occurs if battery storage capacity is not sufficient to store the spilled energy.

Cost function of spillage loss:

$\sum_{n=1}^{365}[\sum_{t=1}^{24}(Pdiff * \Delta t - Besc) * 2.74]$ (15)

Where Δt – time interval, n- No of days

Cost of wind energy as stipulated by Tamil Nadu government is Rs.2.75/kWh.

Shedding loss: This loss occurs when both generation and battery storage cannot meet the load. The excess demand will be supplied by diesel generator. Cost of shedding is calculated based on diesel prices and the amount of load is shed.

Cost function of shedding loss:

$\sum_{n=1}^{365}[\sum_{t=1}^{24}(Pdiff * \Delta t - Besc) * 22]$ (16)

Where Δt – time interval, n- No of days, Cost of diesel energy = Rs.22/kWh. Shedding power loss and Spillage power loss are calculated hourly for 365 days.

1) Constraint Functions: Various constraints considered in the methodology. They are:

Power constraint: $Pg = Pd + Bp + Pdiesel$

SC constraint: $SCmin \leq SC(t) \leq SCmax$

Energy of battery constraint: $Bemin \leq Be(t) \leq Bemax$

Where,Pg-generated power by the system, Pd– load of the system, Bp–power delivered by battery,$Pdiesel$– power given out by diesel system, SC – state of charge,$SCmin$,$SCmax$ - minimum and maximum limits of SC and $Bemin$,$Bemax$ **-** minimum and maximum limits of battery energy.

B. *Optimal Sizing of BESS Based PSO Method*

PSO is a stochastic method which has many advantages like simplicity, high convergence rate, robust and minimal storage requirement. Compared to other methods, PSO can achieve less dependent on the set of the initial points. Hence, PSO is proposed for determine the optimal sizing of BESS, which prevents microgrid from instability and minimize the total cost of BESS. PSO method evaluates the optimal parameters of complex search spaces. PSO is initiated with a group of random particles for identifying optimal parameters. For each iteration, all particles are improved by two values. These values are called Pbest and Gbest respectively. Pbest is the best solution and Gbest is the best value obtained [14-19].

First, a case study is considered with the data like hourly demand for 365 days, total installed capacities of solar and wind energy resources, hourly solar radiation, hourly wind speeds. The total power generated from the sources is calculated by using the data.

$Pg(t) = Sppg(t) + Pwtg(t)$ (17)

Checking various conditions as mentioned in the flow chart shown in figure-1, the cost is calculated using the objective function for different sizes of batteries. Now by using Particle Swarm Optimization technique, the optimal battery size which is cost effective can be found.

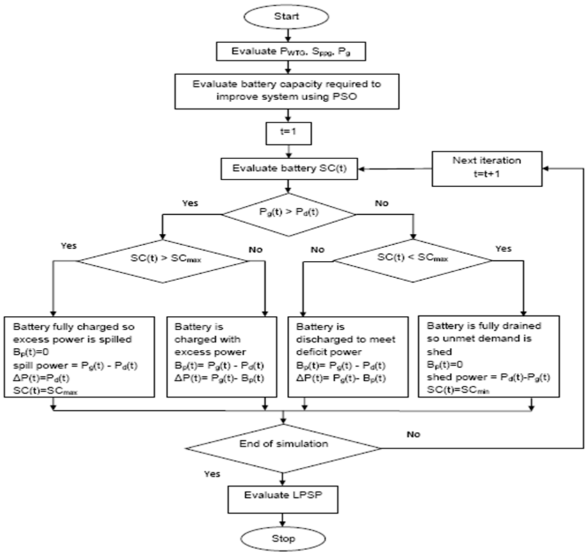

Fig.1 Flow chart for optimal sizing of BESS by using PSO

C. Reliability and Economic Analysis

Reliability is a measure of continuity in power supply service. There are two different power reliability criterions, Fractional Load Not Served (FLNS) and Loss of Power Supply Probability (LPSP).

LPSP = [n=1Σ365 [t=1Σ24Pdef (t)]]/ [n=1Σ365 [t=1Σ24Pdel (t)]]

Where, Pdef (t) = power deficient i.e. load that is to be shed at time instant t

Pdel (t) = power delivered to the load at time instant t

Under economic analysis, payback period and benefits gained by using battery storage are calculated.

Benefits gained = (cost of losses without inclusion of battery) – (total cost with inclusion of battery).

Payback period = total cost of battery / benefits gained.

IV. IMPLEMENTATION OF PROPOSED METHOD

A region of Tamil Nadu in India with PV and wind installed capacities of 75KW and 200KW hybrid renewable energy system is considered for investigation [11]. The total generation and load for a span of 24hrs is shown in figure-1.

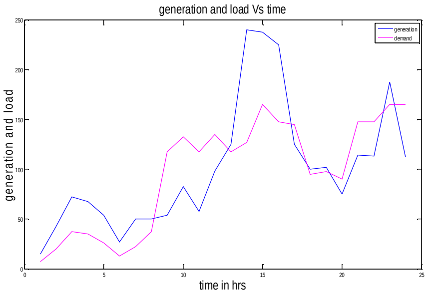

Fig.1 Generation and load curves for a day

After implementation of particle Swarm Optimization technique to the selected hybrid renewable energy system, the results obtained are:

A. Variation of battery size with iterations.
B. Power balance in the system under any load condition.
C. Reliability of the system through LPSP.
D. Payback period and benefit gained by the use of battery.

The variation of battery sizes with iterations by PSO is shown in figure-2.

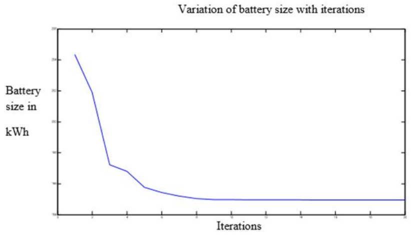

Fig.2 Variation of battery size with iterations

It is observed from the figure-2, the value of total cost of battery is decreasing with iterations and finally it settles at a particular value. The battery size corresponding to that cost is the optimal size. The battery size and total cost obtained for the system is 194.9563KWh and Rs. 2.4597*10^06/- respectively. The power balance of the system under any load conditions is shown in the figure-3. The difference between the generation and the load is met by battery power. The figure-4 shows the state of charge for different instants of time.

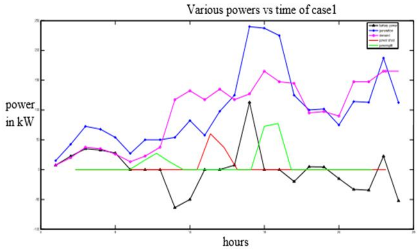

Fig.3 Variation of different powers with time

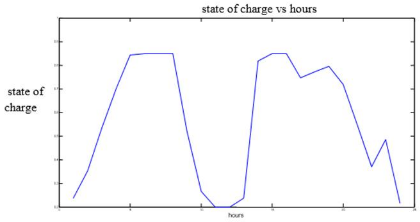

Fig.4 State of charge for different instants of time

After implementation of the PSO technique, the reliability analysis of the system with BESS and without BESS in terms of loss of power supply probability (LPSP) are 4.38% and 18.83% respectively. It is observed that the percentage of LPSP decreases. Hence the obtained size of the battery improves the reliability. The economic analysis of the system in terms of payback period and benefits gained per year are obtained. The values are 3.3076years and Rs.1.9451*10^06/- respectively.

V. RESULT ANALYSIS

A. The power balance is achieved by the battery energy storage system along with little spilling and shedding of power (economical point of view).This is illustrated from the above results.
B. The battery size is converging after some iterations proving that optimization is done and the converged value sustains for a very long time making the value more strongly optimized.
C. The reliability of power is greatly increased as seen from the results of LPSP.
D. The payback periods are moderate thus encouraging more battery usage.

Comparing with BAT algorithm results, proposed method obtains result reduced by 2.58%. In higher rating equipment, this reduction in size gives significant effect on cost feasibility.

VI. CONCLUSION

This paper proposes optimal size of BESS by PSO technique and evaluates the reduction in cost of BESS compared with BAT technique. The proposed method reduced the size by 2.58% and payback period have been carried out. The proposed approach improves the dynamic stability and reliability of the stand alone micro grid. This approach can be implemented for large systems to get more technical feasibility and cost viability.

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