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Impact of Battery Storage with DG Integration in Distribution Network Using Combined Dispatch Strategy for Loss Minimisation

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Abstract: Renewable energy integration has become an integral part of the distribution system. The energy storage devices with the high penetration of wind and solar are becoming key components to support the power mismatch due to intermittency in power available from the renewable sources. The renewable energy sources, along with storage devices, require their optimal placement for the efficient operation of the distribution system. In this paper, the impact of battery energy storage along with Distributed Generation (DG) in the hybrid distribution system, has been analysed. The main contribution of this paper is: (i) optimal siting and sizing of DGs using combined power loss sensitivity index, (ii) optimal position and sizing of battery energy storage based on combined power dispatch strategy, (iii) minimisation of the total power loss and fuel cost of the system. The voltage profile, fuel cost, battery installation cost, size of battery storage, and energy of battery during the charging and discharging have been calculated. The results have been obtained for IEEE-33 bus test system and compared with existing methods in the literature also. An optimisation problem has been solved using the General Algebraic Modeling System (GAMS) and MATLAB interfacing.
Keywords: Radial distribution system, Renewable Energy sources, Battery energy storage device, Loss minimisation, optimal sizing and siting.,

1. Introduction

The distribution systems operation and planning has shifted its paradigm from the passive network to the active networks with the integration of the renewable energy sources (RESs). With the intermittent nature of the RESs, the variations in the power fed to the system can be determinate to the faster changes in the voltages and may have adverse impact on the system operation. In such scenarios, the energy storage devices and the distributed generation integrated in the system can have significant effect on the voltages variations and the losses minimization. The battery storage thus can play a crucial role in renewable energy storage to meet power deficiency and also improving the effeicency of the system. The optimal location and size of DGs along with battery storage determination in the distribution network have become an essential task to micro-grid operator. The suitable dispatch strategy can be used for optimal operation and control of the battery storage in the network for better planning. The co-ordination between battery storage and renewable energy sources must be in control manner to reduce the losses and an overall cost of the system. In this paper; solar-based, wind-based, diesel generator-based, DGs along with battery storage have been analysed for obtaining the optimal dispatch with minimization of the losses in the system. A lot of research work has been carried out for obtaining the best siting and sizing based meta-heuristic approach [1]. The multi-objective based approach has been taken into account to minimise the total power loss [2]. On the other hand, the power loss minimisation has been carried out by many researcher [3]- [4]. The siting of DGs was obtained based on the power loss sensitivity (PLS) using a nonlinear programming (NLP) approach by [4]. Authors in reference [5] obtained the cost of energy losses and cost of a component of DG for providing real and reactive power considering the objective of loss minimization. The sensitivity analysis has been used for the DGs location, but the different reconfiguration scenario has evaluated using meta-heuristic Harmony Search Algorithm (HSA) algorithm by the authors in [6]. D. Suchitra, R. Jegatheesan, and T. J. Deepika proposed an optimal design of hybrid power generation system and its integration in the distribution network [7]. Dufo-Lopez et al. [8] proposed the Dispatch Strategy using the current calculation and determined state of charge (SOC) using HOGA and HOMER software. A Monte Carlo simulation approach has been utilised for the PV and wind-based energy modelling in small isolated systems by R. Karki et al. [8], The impact of the battery

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energy has not been considered.

The DGs has been placed along with the capacitors for taking the reconfiguration of the distribution system in [9]. The energy storage has not been taken into account for the analysis. An improved analytical method (IA) was used for finding the size of four different DGs type and location in [10], although the LSF has been introduced. It represents the fast approach of finding the optimal power factor with the position of DGs. The single and multi objective problem has been solved based on the PSO algorithm. The method of voltage stability margin (VSM) was utilized for finding the position and sizing of DGs [11]. Many authors have carried out analysis and impact of the RESs for loss minimization, improvement in the efficiency and voltage profile improvement in the network [12], [13]. In this context, the solar PV has been installed using the Technology Computer-Aided Design (TCPD) based simulation for the cost calculation [14]. P. V. Babu et al. [4] have used the NLP and PLS techniques for location and sizing, although they did not consider the battery storage along with DGs. By using mixed-integer nonlinear programming, the voltage stability margin becomes an important optimisation tool for placement of distributed generation [15]. The distributed generators (DGs) position and sizing are obtained taking into account the load growth scenario. Singh et.al. [16] have used the MINLP approach for an objective function to minimise the cost of all the renewable energy sources to identify the location of DGs. The DG placement issues were analyzed considering the various objective functions, however, the impact of the energy storage systems with the battery energy storage need to be addressed for lowering the losses and improvement in the voltage profile.

Korpaas et al. [1] address the Water value method for hydro power planning along with the size of the energy storage system (ESS) as 150 MWh/8 MW. Ce Shang et al. [2] have focused on the dispatch-coupled sizing method. The prediction for the state of charge, internal losses, polarisation effect within a battery and the terminal voltage have been considered by [3]. The consideration of wind power forecast error has proposed, although the hybrid energy storage with an extensive integrated network has not been considered [4]. Authors in [5] proposed two different dispatch strategy taking into consideration: (i) load following (LF) and (ii) Cycle-charging (CC) along with different system controls. The best performance of the LF strategy was in a high renewable penetration environment, whereas the CC strategy was in low renewable penetration. Many of the researchers have not considered the degradation cost of battery [6], although the risk factor of Micro-grid has been considered. Most of the researchers are focused on the DGs sizing and location for the loss minimisation only. However, there is a need to study the optimal location and size of energy storage device along with the consideration of dispatch strategy for active power support. The impact of battery storage with a multi-objective problem is considered in this paper. The result is compared with the other existing method and techniques, likewise MOPSO [7], HOMER and HOGA [8]. With the above literature reviews, it has been found that there is need to address the issues of battery energy storage (BES) devices along with the distributed generation . Most of the researcher have represented the BES devices, but very few of them have considered the optimal control of the BES. Therefore, it is essential to determine the size and location of BES with renewable energy support and power mismatch. Furthermore, determining the optimal dispatch strategy for the installation and optimal control of BES is another task for the Micro-grid operator. To fulfil this research gap, the key contribution of this research paper is as follows; (i) The optimal size and location of both BES and DGs have been found to solve the single and multi-objective problems (ii) The optimal dispatch strategy [5] for the installation of BES has been used. (iii) The power loss sensitivity approach has been used for the installation of DGs. Moreover, in this paper, the new methodology to integrate hybrid renewable energy sources into the distribution system along with storage devices has been proposed. The new algorithm has been analyzed taking interfacing of GAMS and MATLAB. The optimal siting of DGs with battery, which has been carried out in two phases as follows;

- In part 1: the optimal siting of DGs with the battery has been analyzed using MATLAB software.
- In part 2: the optimal sizing of DGs with the battery has been obtained utilizing mixed-integer nonlinear programming (MINLP) solver in GAMS software.

In the analysis, five Case studies have been analyzed and solving the optimization problem for obtaining the minimum losses and the dispatch schedule. Rest of the paper is organised as follows; In Section 2, the problem formulation and mathematical modelling have been explained. In Section 3 the algorithm and methodology used in this paper are explained. In section 4 the required data for the analysis has been presented. In Section 5 the validation and comparisons of the results have been discussed. Finally, the conclusion has been made in Section 6.

2. PROBLEM FORMULATION

The main objective of the paper is to obtain the optimal location of the BESS, along with the DGs considering loss minimisation. The dispatch strategy is also obtained for different cases. The location of the storage device has been obtained, determining combined dispatch strategy, and the location of the DGs is obtained, based on loss sensitivity considering both active and reactive loss. The problem has been formulated as mixed-integer nonlinear programming as follows;

1) To minimise the power loss with battery energy storage and DGs and obtaining their sizes. The number of batteries for minimum power loss is also determined.

In this paper, the problem has been solved in two parts. In the first part

1) The location of Battery storage device has been obtained determining the combined dispatch strategy and location of the DGs are obtained determining the combined power loss sensitivity (CPLS) approach.
2) The size of DGs and Battery energy has been obtained solving an objective (i)

Based on the results obtained solving the optimisation problem, the fuel cost of diesel generator (DEG) along with the operational and maintenance costs are also obtained. The voltage profile and power loss profile are also obtained. In the analysis, DGs considered are of Type 1 and Type 3. In Type 1 DGs, the DGs supply only real power. In Type 3, the DGs supply both the real and reactive power.

The multi-objective problem has been formulated as:

1) Minimisation of the power loss and the total cost of the system. The total cost is the fuel cost of diesel generator, acquisition cost, replacement cost, operation and maintenance cost of DG, PV, battery, regulator, invertors etc.

In the multi-objective optimisation problem, the sizes of the energy storage device and DGs are again obtained minimising the power loss along with the total cost of the system. The mixed-integer nonlinear programming (MINLP) has been used for solving both the single and the multi-objective problem.

A. Mathematical Model

In this section, the mathematical modelling of DGs, solar, wind and battery energy storage has been represented as follows;

1) Solar PV based source modelling

The PV generator is the renewable source which provides the DC current at 48 V. The Monte Carlo Simulation (MCS) has been taken for the exact modelling of solar power output. In this scenario, 1000 numbers of the sample have been taken for simulation. The solar PV model is:

$$P_{solar}\left(I_{\beta}\right) = N_{PV} \bullet FF \bullet V \bullet I \quad (1)$$

where, P_{solar} is the output power, FF is the fill factor, V is the rated voltage, I is the current output, and N_{PV} is the total number of the solar panel [9]. The Figure 1 shows the solar PV-based DG power output for 24 hrs.

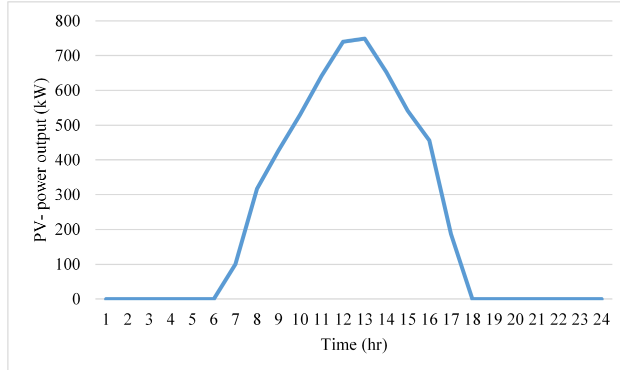

Figure 1. Solar power output curve for 24 hrs

2) Wind Power modelling

In this paper, the quadratic model of wind has been taken. The wind turbine model is as:

$$P_{wind} = \begin{cases} P_{rated} \bullet \left((v - v_{in})^2/(v_r - v_{in})^2\right) \;;\; v_{in} \le v \le v_r \\ P_{rated};\; v_r \le v \le v_{out} \\ 0; \quad v > v_{out} \text{ and } v < v_{cut} \end{cases} \quad (2)$$

where, P_{rated} is the rated wind power, P_{wind} is the wind power output. v_{in} is cut in the velocity of wind, v_{out} is cut out wind velocity. v_r is the rated wind speed (m/s). From Equation 2 the current is calculated as:

$$I_{wind} = P_{wind}/V_{wind} \quad (3)$$

where, V_{wind} is the rated voltage of wind generator. Figure 2 shows the wind turbine power output curve.

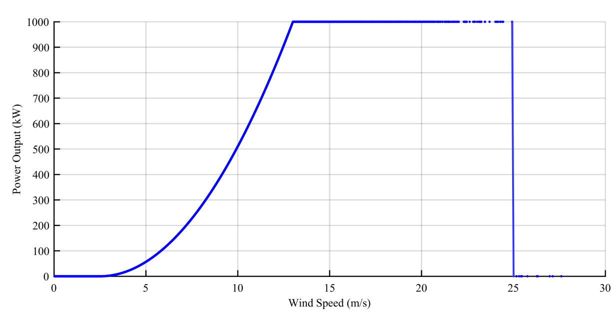

Figure 2. Wind turbine power output curve

3) Mathematical Model of Battery Storage

The battery power is taken as a backup power. The limits of battery for discharging and charging power are taken as controlling parameters. These parameters are function of the strategy of dispatch as proposed in reference [10]. The state of charge has been calculated for each battery in such a way to balance the power. The maximum value depends on the nominal capacity, while the minimum amount depends on its Depth of Discharge (DOD).

$$SOC_{min} = N_{bat} C_n \left(1 - DOD_{max\_bat}\right) \quad (4)$$

$$SOC_{max} = N_{bat} C_n \quad (5)$$

$$SOC(k + \Delta k) =$$

$$\mathrm{SOC}(k)\,.\,(1 - \delta_{batt}) + \left(P_{ch}.\eta_{ch} - P_{dis}.\frac{1}{\eta_{dis}}\right).\Delta k \quad (6)$$

$$E_{batti}(k) = [\max(SOC_i(k)) \; - \; \min(SOC_i(k))] \bullet V_{DC} \quad (7)$$

Equation 4 and 5 represents the minimum and maximum SOC of the BES. The minimum SOC is a function of depth of discharge maximum (DOD_{max_bat}). Where, C_n is the nominal capacity of battery (Ah), N_{bat} total number of battery, δ_{batt} is the depth of discharge, SOC is a state of charge, P_{ch} charging power, P_{dis} is discharging power, $\eta_{ch}$and η_{dis} are the charging and discharging efficiency of the battery. E_{batti} is the energy capacity in (kWh) and V_{DC} is the DC bus voltage. The BES Constraints are as follows;

$$SOC_i^{min}(k) \leq \; SOC_i(k) \; \leq \; SOC_i^{max}(k) \quad (8)$$

$$N_{bat}(i) \bullet P_{ch\_min_i}^{\;k} \leq \; P_{ch_i}^{\;k} \leq \; N_{bat}(i) \bullet P_{ch\_max_i}^{\;k}$$

$$N_{bat}(i) \bullet P_{dis\_min_i}^{\;k} \leq \; P_{dis_i}^{\;k} \leq \; N_{bat}(i) \bullet P_{dis\_max_i}^{\;k} \quad (9)$$

where i is the total number of buses in the network .i.e. P_{ch_min} and P_{ch_max} are the maximum and minimum charging power limits for 24 hrs of the battery, respectively.

4) Diesel generator

The diesel generator is used as a backup and has been considered in the study for obtaining the dispatch meeting the load requirements. Based on the dispatch strategy, the diesel generators can supply the load, or charge the battery. The hourly fuel consumption is considered as a linear model [8]. The fuel consumed can be represented by:

$$fuel_{consumed} = B.P_{NGen} + A.\; P_{Gen}.\frac{1}{h} \quad (10)$$

where, P_{NGen} is rated power of Diesel Generator in kW, P_{Gen} is the Diesel Generator (DEG) output power. A and B are the fuel curve coefficient [7].

$$A = 0.246\left(\frac{l}{kWh}\right)\;;\; B = 0.08415 \quad (11)$$

The following are the constraints taken for DGs.

$$P_{degmin^i}^{k} \leq \sum_{k\; i \neq 1}^{24} P_{deg_i} \leq P_{degmax_i}^{\;k},\quad i \neq 1, \in S_{DEG}$$

$$\mathrm{Q}_{degmin^i}^{k} \leq \sum_{k,\; i \neq 1}^{24} Q_{deg_i} \leq Q_{degmax_i}^{\;k}, i \neq 1, \in S_{DEG} \quad (12)$$

where, $P_{degmin_i}^{\;k}$, $P_{degmax_i}^{\;k}$ are the minimum and maximum active power limits of DEGs for the ith bus at kth hour respectively. $Q_{degmin_i}^{\;k}$, $Q_{degmax_i}^{\;k}$are the minimum and maximum reactive power limits of DGs for the ith bus at kth hour respectively.

Limit for a power factor of DEGs

$$pf_{deg_i}^{\;lo} \leq pf_{deg_i} \leq pf_{deg_i}^{\;up},\quad i \neq 1, \in S_{DEG} \quad (13)$$

$pf_{deg_i}^{\;lo}$ and $pf_{deg_i}^{\;up}$are the lower and upper power factor limits of DEGs for the ith bus at the kth hour, respectively.

5) Model of strategy based on on Combined Dispatch

In this paper, the strategy proposed in [10] is implemented with BESS obtaining the location of the BESS In the this strategy, the functions as load following (LF) and cycle charging (CC), have been considered as explained in the reference [7]. The decision parameters for dispatch strategy are critical discharging load (L_d) and the critical charge load (L_c). The L$_d$ and Lc are obtaijned using the following equations;

$$L_c = \left(L_{deg} * \eta\right)/L_{cc} \quad (14)$$

$$L_d = \left(\; \eta_{inv} * L_{deg}\right)/(C_{cyclbatt} - \; \eta_{inv} * A * Pr_{fuel}) \quad (15)$$

Where, the L_{deg} is the net cost coefficient of diesel generator, L_{cc} is cycle charging coefficient for battery and is obtained as follows:

$$L_{deg} = B.P_{NGen} * Pr_{fuel} + Cost_{O\&Mgen} + Cost_{Rep} \quad (16)$$

$$L_{cc} = \eta_{ch}\eta_{batt} * C_{cyclbatt} + (1 - \eta * A * Pr_{fuel}) \quad (17)$$

where, $\eta = \eta_{ch} * \eta_{batt} * \eta_{inv}$ is the overall efficiency, η_{ch}, η_{batt}, η_{inv} are the efficiency of the charger, battery and inverter respectively. $C_{cyclbatt}$ is the cost of cycling energy [8].

The value of net DC load ($Pd_{net\_Load_{i=idg}^{k}}$) for the highest CPLS index at the bus is obtained by using Equation 18

$$Pd_{net\_Load_{i=\mathrm{idg}}^{k}} = Pd_{net\_Load_i^{k}} - P_{DEG0_i^{k}} \quad (18)$$

According to the LF and CC;

$$If \begin{cases} Pd_{net\_Load_i^{k}} < L_c \;;\; CC \\ Pd_{net\_Load_i^{k}} \; > L_d;\; LF \end{cases} \quad (19)$$

Where, the value of the bus (i$_{dg}$) is obtained by solving the CPLS approach. Initially the value of $P_{DEG0_i^{k}}$ is taken as the rated value of diesel generator of 11 kW. The value of $P_{DEG0_i^{k}}$ is used for finding the cost coefficients for diesel generator Equation 16 and location only.

In the proposed algorithm, the CLPS and Combined dispatch strategy have been used together for obtaining the location of DGs and battery storage devices.

6) Radial Distribution System (IEEE 33 bus)

The radial distribution system as shown in Figure 3, comprises of the source at one node and load at the end connected node with the help of line. The designed power generation system consists of the static load for 24 hrs of variation, solar PV-based DG, wind-based DG, diesel generator- based DGs and batteries. In Figure 3 the equivalent circuit model of IEEE-33 bus network is shown.

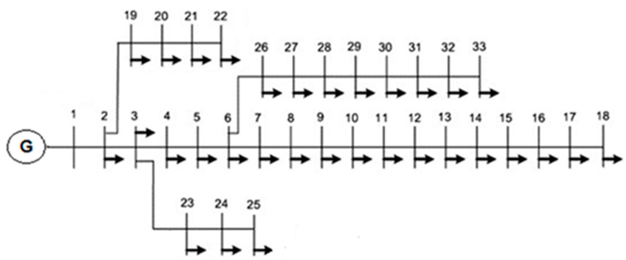

Figure 3. IEEE-33 bus radial distribution test system

B. Mathematical model formulation

The following objective function has been formulated as:

1) Objective function formulation

The objective function OF1 (i) is the minimisation of total power loss as given by:

$$OF1=\sqrt{\left[\left(\sum_{i,j=1}^{k} PL_{ij}\right)^2+\left(\sum_{i,j=1}^{k} QL_{ij}\right)^2\right]} \quad (20)$$

where, PL_{ij} and QL_{ij} are the total active and reactive power loss in line respectively. The value of PL_{ij} and QL_{ij} are obtained from the optimal power flow algorithm.

The second (ii) objective function OF2 is:

$$OF2=\sum_{k=1}^{T}\left(\sum_{i}^{nb} N_{PV}(i)\bullet NPV_{PV}+\right.$$

$$\sum_i^{nb} N_{wind}(i)\bullet NPV_{wind}+\sum_i^{nb} N_{batt}(i)\bullet NPV_{batt}+$$

$$\sum_i^{n} N_{reg}(i)\bullet NPV_{reg}+\sum_i^{nb} N_{inv}(i)\bullet NPV_{inv}+$$

$$\left.\Pr_{fuel}\bullet\left(\sum_i^{nb} fuel_{consumed}\right)\bullet T\right) \quad (21)$$

where,

$$NPV=Cost_{Aqu}+Cost_{O\&M}+Cost_{Rep} \quad (22)$$

$Cost_{Aqu}$, is the acquisition cost, $Cost_{O\&M}$ is the operation and maintenance cost, $Cost_{Rep}$ is the replacement cost. N_{PV}, N_{wind} , N_{batt}, N_{reg}, N_{inv} are the number of PV panel, wind turbine, battery, regulator, investors, respectively. NPV_{PV}, NPV_{wind}, NPV_{batt}, NPV_{reg}, NPV_{inv} are the net present value for PV, wind, battery, regulator, and inverter, respectively. $fuel_{consumed}$ is fuel consumed by the DEGs, Pr_{fuel} is the fuel price (litter/kWh), and T is the total time period of operation.

2) Optimal power flow formulation

$$P_i^k=\left(Pg_i^k-Pd_i^k\right)=V_i^k\sum_{j=1}^{n}V_j^k\left(G_{ij}^k cos\left(\delta_i^k-\delta_j^k\right)+B_{ij}^k sin\left(\delta_i^k-\delta_j^k\right)\right) \quad (23)$$

$$Q_i^k=\left(Qg_i^k-Qd_i^k\right)=$$

$$V_i^k\sum_{j=1}^{n}V_j^k\left(G_{ij}^k sin\left(\delta_i^k-\delta_j^k\right)-B_{ij}^k cos\left(\delta_i^k-\delta_j^k\right)\right) \quad (24)$$

$$\forall\ i\ \epsilon\ S_B\ \&\ k\ \epsilon\ S_T$$

where, S_B is the set of buses, and S_T is the set of Time k. Pd_i^k and Qd_i^k are the active and reactive power demand for ith bus at kth time period.

Following are the Inequality constraints as:

3) Power generation

$$Pg_i^k=P_{deg_i}{}^k+N_{wind}(i)\bullet P_{wind_i}{}^k+N_{PV}(i)\bullet P_{PV_i}{}^k+$$

$$N_{batt}(i)\bullet\left(P_{ch_i}{}^k-P_{dis_i}{}^k\right) \quad (25)$$

$$Qg_i^k=Q_{deg_i}{}^k+N_{wind}(i)\bullet Q_{wind_i}{}^k \quad (26)$$

where, $P_{deg_i}{}^k$ and $Q_{deg_i}{}^k$ are the active and reactive power supplied by a diesel generator for ith bus at kth time period.

4) Power Loss

$$\left|PL^k\right|=\left|P_{ij}^k\right|=$$

$$\left|V_i^kV_j^k\left(G_{ij}^k cos\left(\delta_i^k-\delta_i^k\right)+B_{ij}^k cos\left(\delta_i^k-\delta_i^k\right)\right)-(V_i^k)^2G_{ij}^k\right|$$

$$\leq\ Pl_{max}^k \quad (27)$$

5) Transmission line sending end and receiving end power constraints

$$P_{fsmin_j}{}^k\leq P_{fs_j}\leq P_{fsmax_j}{}^k,\quad i\in S_{fs}$$

$$Q_{fsmin_j}{}^k\leq Q_{fs_j}\leq Q_{fsmax_j}{}^k,\quad i\in S_{fs}$$

$$P_{frmin_j}{}^k\leq P_{fr_j}\leq P_{frmax_j}{}^k,\quad i\in S_{fr}$$

$$Q_{frmin_i}{}^k\leq Q_{fr_j}\leq Q_{frmax_j}{}^k,\quad i\in S_{fr} \quad (28)$$

6) Limits of the capacity of the distributed generators are

$$P_{Gi}^{min} \leq Pg_i \leq P_{gi}^{max}, \quad i \in S_G \tag{29}$$

$$Q_{gi}^{min} \leq Qg_i \leq Q_{gi}^{max}, \quad i \in S_G \tag{30}$$

- Variation of *voltage*

$$V_i^{min} \leq V_i \leq V_i^{max}, \quad i \in S_B \tag{31}$$

- Variation of *angle*

$$\delta_{min}{}_j^k \leq \delta_i \leq \delta_{max}{}_j^k, \quad \forall i = 1, 2 \ldots .nb \tag{32}$$

7) Loss Sensitivity Method (CPLS)

In the CPLS method [?], both active and reactive power losses are considered. The CPLS thus obtained has been used for the location of DGs.

$$\begin{aligned} \frac{\partial P_{loss}^k}{\partial Q_i^k} &= \frac{2Q_i^k R_l}{(V_i^k)^2}; \frac{\partial Q_{loss}^k}{\partial Q_i^k} = \frac{2Q_i^k X_l}{(V_i^k)^2} \\ \frac{\partial P_{loss}^k}{\partial P_i^k} &= \frac{2P_i^k R_l}{(V_i^k)^2}; \frac{\partial Q_{loss}^k}{\partial P_i^k} = \frac{2P_i^k X_l}{(V_i^k)^2} \end{aligned} \tag{33}$$

CPLS is obtained as follows taking derivaties as

$$\begin{aligned} \frac{\partial S_{loss}^k}{\partial P_i^k} &= \frac{\partial P_{loss}^k}{\partial P_i^k} + j\frac{\partial Q_{loss}^k}{\partial P_i^k} \\ \frac{\partial S_{loss}^k}{\partial Q_i^k} &= \frac{\partial P_{loss}^k}{\partial Q_i^k} + j\frac{\partial Q_{loss}^k}{\partial Q_i^k} \end{aligned} \tag{34}$$

3. ALGORITHM

The algorithmic steps to solve the optimization problem using mixed-integer nonlinear programming (MINLP) algorithm with CONOPT solver in GAMS is explained in this section. The interfacing of GAMS and MATLAB tool has been utilised for solving the optimisation problem. The location of the DGs and the storage device has been obtained first developing MATLAB code which is based on the combined power loss sensitivity index and combined dispatch strategy.

In the proposed algorithm form Step 1 to Step 4; first, the location of the candidate node has been obtained. Whereas in Step 5 to Step 7, the objective function has been solved, and the size of DGs and battery storage devices are obtained using MINLP solver in GAMS. Step 1 Set k=1, and Set i=1;

Read the data for a network as given in section 4.

Step1

1) Solve the equations for power calculations from Equations 1 to 3.
2) Solve load flow for the 24-hrs and obtain the base Case total power losses using Equations 23 - 32. Obtain the load current at each bus.
3) Calculate the CPLS at each node for 24 hrs. Select the node having the highest factor. Solve Equation 33 and 34.

Step 2 Select the candidate bus with highest values of loss sensitivity index i=i$_{dg}$, for the installation of DGs. Save the location of DGs at $i_{dg} = S_{DG}\left\{i_{dg1},\ i_{dg2}\ldots i_{dgN}\right\}$. Find the total number of DGs .i.e. N_{DG}.

Step 3 The iteration for ith bus and kth time solve up to $i \leftarrow i+1; k \leftarrow k+1$. If $i < nb$ and k< T; go for step 1 otherwise go to next step.

Step 4 Solve the combined dispatch strategy for each buses i=1to nb and k=1 to 24 hrs.

1) Calculate the location of bus numbers for 24 hrs using combined dispatch strategy Equation 14 - 19. Put the value of i from Step 1(b), and obtain the BESS position.
2) Save the location of the battery to determine the optimal sizing, obtain the set of battery location as; $s_{batt}^k = S_B\left\{s_{batt1}^{k1},\ s_{batt2}^{k2}\ldots s_{battnb}^{24}\right\}$.

Step 5 send all the control parameter from environment of MATLAB to GAMS.

1) Solve Equation 20 and 21 with all the constraints Equation 25 to 32 and obtain the SOC using MINLP solver.
2) Obtain the size of BESS Equation 7, SOC, battery charging and discharging, and solve Equation 8 and 9
3) Obtain the size of DG by solving constraints Equation 25 and Equation 26.

Step 6 Send all optimized objective variables form environment of GAMS to MATLAB.

1) Get the results
2) Obtain the power loss profile and voltage profile by solving load flow.

Step 7 Print the obtained results.

The flow chart of the proposed algorithm solving the optimization problem is shown in Fig.4.

4. SYSTEM DATA

In this paper, the data of IEEE 33 bus RDS is taken from [11]. The seasonal load with a variation for 24 hrs has been carried out for the analysis. The diesel generator has been considered at bus number, 2nd, 3rd, 21st, 23rd and 29th based on combined dispatch strategy.

A. *Load data*

The seasonal load variation is given in Table I for IEEE 33-bus system; the load is taken in kW. The load flow analysis for Distribution system has been carried out using

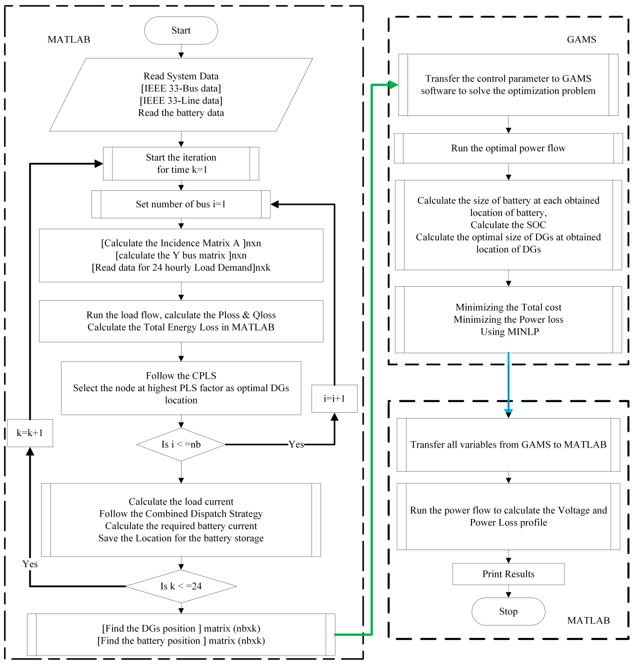

Figure 4. Flow chart for the proposed method

flow forward-backwards sweep method has been used. The peak load exist at 24^{th} and 25^{th} bus for 8^{th} to 11^{th} hrs.

B. *PV Solar and Wind Data*

The solar irradiation data and the wind speed data are taken from the online mode, i.e. National Renewable Energy Laboratory (NREL) [12], [13] & [14]. In Figure 5, the solar irradiation data is shown, which is taken from NASA meteorological data of Zaragoza (Spain).

In Figure 6, the hourly wind profile is shown, which is taken from NASA meteorological data of Zaragoza (Spain). The cut of velocity v_{in} of 2.6 (m/s) and cut out wind velocity v_{out} of 20 (m/s) are taken into account for the wind turbine operation.

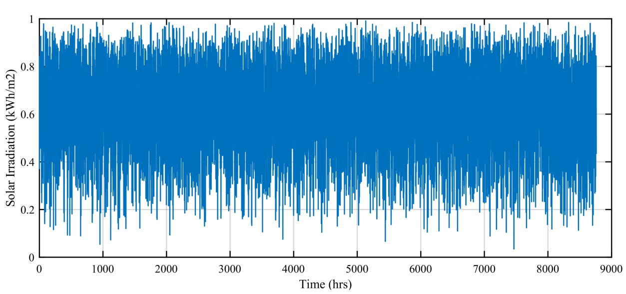

Figure 5. Hourly solar irradiation profile (Zaragoza, Spain)

C. *Solar and Wind Cost Data*

The input data used in this paper has been given in Table II. The cost estimation data for the PV-based DG and wind-

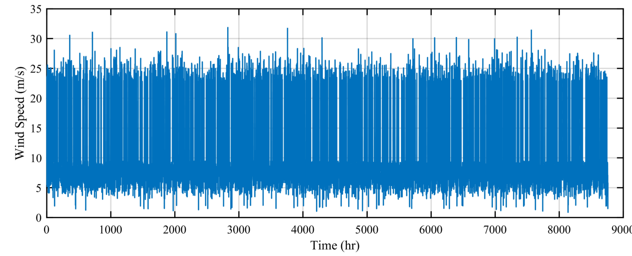

Figure 6. Hourly wind speed profile (Zaragoza, Spain)

based DG have been taken from the National Renewable Energy Laboratory (NREL) [12], [13], and [14]. The data for battery, regulators and investors are taken from the literature [15].

5. RESULTS AND DISCUSSIONS

The results are obtained for radial distribution system in the presence of the storage devices along with the DGs. The optimisation problem has been solved for a single and multi-objective functions.

In objective (i), two Cases have been taken as follows;

1) Case 1: DG of type-1 with battery storage devices.
2) Case 2: DG of type-3 with battery storage devices.

In objective (ii), three Cases have been taken as follows;

1) Case 3: DG of type-1 with battery storage devices.
2) Case 4: DG of type-3 with battery storage devices.
3) Case 5: The impact of various renewable energy sources.

A. *Load Profile*

The load of IEEE 33 bus radial distribution is 3.0834+ j*1.909 MVA for 24 hrs. The average load profile of real and reactive power for 24 hrs duration is shown in Figure 7. The active power demand is higher at 24^{th} and 25^{th} bus, whereas the reactive power demand is higher at 30^{th} bus. The daily load current profile has been shown in Figure 8. The load current has been divided into three sections. In the first section, the load curve is almost flat for 1^{st} to 4^{th}, 9^{th} to 10^{th}, 14^{th} to 17^{th} and 22^{nd} to 24^{th} of hrs. In the second section, instant change in load curve for 6^{th} to 7^{th} and 17^{th} to 19^{th} have been taken. In the third section saddle point of load, variation has been taken at 5^{th}, 12^{th} and 20^{th} hrs.

B. *CPLS profile*

The combined power loss sensitivity has been determined to obtain the location of DGs. The CPLS profile is shown in Figure 9. The highest CPLS is obtained at the bus number 24^{th} and 25^{th}. The load is maximum at buses 24^{th} and 25^{th} bus as shown in Figure 7. Based on the sensitivity, the DGs has been installed at bus number 24^{th} and 25^{th}. Thus, the set of DG's position is $S_{DG}\{24, 25\}$.

TABLE I. Yearly Load data profile for 33- bus radial distribution system

	Winter		Summer		Winter/fall	
hrs	Week day	Week end	Week day	Week end	Week day	Week end
12-1	67	78	64	74	63	75
1-2	63	72	60	70	62	73
2-3	60	68	58	66	60	69
3-4	59	66	56	65	58	66
4-5	59	64	56	64	59	65
5-6	60	65	58	62	65	65
6-7	74	66	64	62	72	68
7-8	100	100	96	94	92	88
8-9	100	99	93	95	96	92
9-10	96	88	95	86	99	89
10-11	96	90	99	91	100	92
11-12	95	91	100	93	99	94
12-13	95	90	99	93	93	91
13-14	95	88	100	92	92	90
14-15	93	87	100	91	90	90
15-16	94	87	97	91	88	86
16-17	99	91	96	92	90	85
17-18	59	66	56	65	58	66
18-19	59	64	56	64	59	65
19-20	96	97	92	95	98	100
20-21	91	94	92	100	96	97
21-22	83	92	93	93	90	95
22-23	73	87	87	88	80	90
23-24	63	81	72	80	70	85

TABLE II. The input data for the energy sources [12], [13], and [14]

Sources	**Acq.cost ($)**	**O&M Cost ($/year/kW)**	**Rep.Cost ($/Lifetime)**	**Life-Cy**(year)	**Rating**
PV	2400	18	2.85 @ 25 year of life time	25	800 (kW)
WT	3724.5	31	3009.5	20	1000 (kW)
BES	600	20	4.64 @ 1.45 year	1.45	100(kWh)

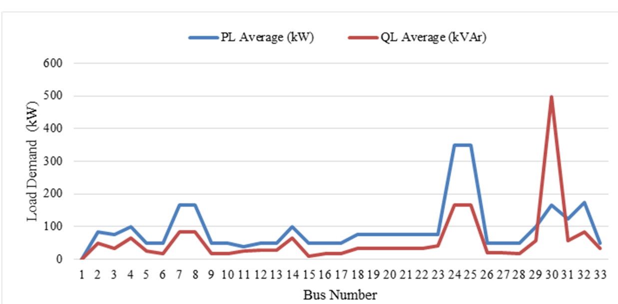

Figure 7. Average Load Demand Profile for 24 hrs

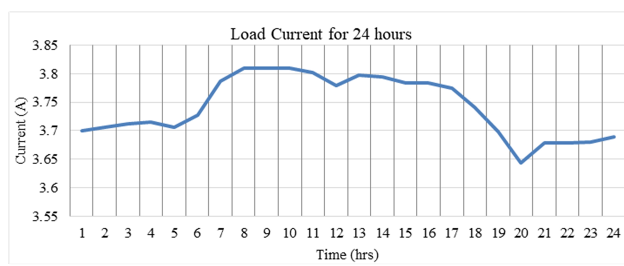

Figure 8. Load Current profile for 24 hrs load for test system

C. Results for Single Objective Function

The results are obtained for total loss minimisation considering two Cases, as explained in Section 5. Based on the optimisation results, the loss, size of the DGs and the battery storage device have been obtained. In the analysis, Type 1 and Type 3 DGs have been considered.

The DGs types taken for the study are as follows:

1) Type 1: DGs operating at unity power factor and capable of injecting real power to the distribution system.
2) Type 3: DGs operating at lagging power factor and capable of injecting real and reactive power to the distribution system.

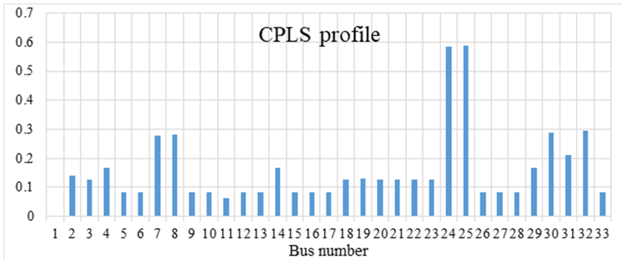

Figure 9. CPLS profile for test system

The total power loss, the size of DGs, %loss reduction are given in Table III. The location is also given in Table III. The results are compared with existing methods, as given in Table III.

The optimal size of the diesel generator obtained is 15.40 kW. The power loss with a single DG is 111.63 kW, which is higher than the power loss obtained with two DGs. Thus, the power loss reduces with an increase in the number of DGs.

1) Case 1: DG Type-1 with BESS

In this case, the analysis of system with BESS and DG to share the real power injection as well as to maintain the power deficiency is carried out. The total size of the battery is 304.128 kWh, and the total size of two DGs Type-1 is 1701.05 kW. In Figure 10, the blue bars show the size and location of battery storage, whereas the red bar shows the size of DGs. In this work, the battery of a nominal capacity of 144 Ah, maximum depth of discharge (DOD_{max_bat}) of 0.8, depth of discharge (δ_{batt}) of 0.03 and the investment cost of 288 € have taken for a test system. The total number of battery ($N_{bat}(i)$) is taken as a variable for obtaining the total size of the storage device. Initially, the SOC value is set at 94%, and the maximum amount is at 100% when the battery gets fully charged.

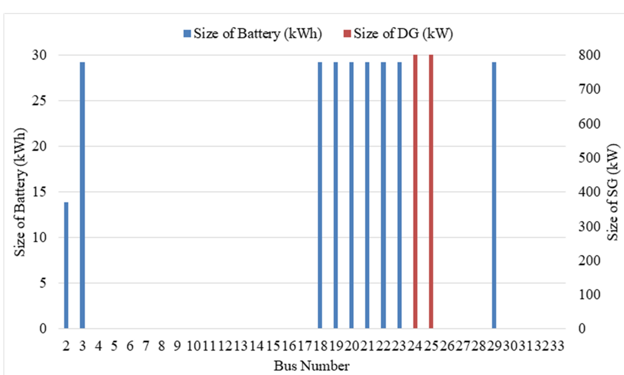

Figure 10. Size and location of DGs type-1 and battery storage devices

The minimum value of SOC is set at 40%, beyond this value battery get fully discharged, and it stops supplying the real power. The power output profile of wind-based, PV-based DG type-1, diesel generator and battery energy storage for 24 hrs load have been shown in Figure 11. The total power loss has reduced from after the integration of wind and solar PV based DGs along with battery storage and diesel generators.

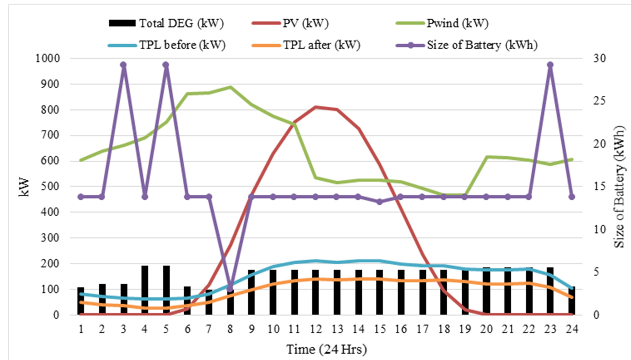

Figure 11. Power output profile of Renewable energy sources with Battery Storage for 24 hrs load variations

The solar power based DG of 800 kW rating at bus number 24^{th} and wind power based DG of rating 1000 kW at bus number 25^{th} have been installed according to the CPLS approach. The maximum power output for the solar PV at 12^{th} hour. The battery storage size is obtained at each hour variation, as shown in Figure 11. The maximum size of battery storage obtained is 27.6 kWh at 3^{rd}, 5^{th}, and 23^{rd} hours respectively, since the net energy demand is higher and not supplied by solar PV also. The minimum size of battery storage obtained at 8^{th} hour since the power met by wind energy source is higher for this time duration. Moreover, the maximum generation of wind power at 8^{th} hrs and minimum generation at 18^{th} hrs have been obtained.

2) Case 2: DG Type-3 with battery Devices

In this Case study, the single wind power based DG of Type-3 has been installed at 24^{th} bus. The 10 % of rated power has been consumed from the point of common coupling by the wind-based DG Type-3 as reactive power consumption. The size and location of DG along with battery has been shown in Figure 12. The obtained size of single DG is 948.0621 kW at 24^{th} bus, and the total size of the battery is 630.91 kWh.

The power output of wind-based DGs of Type-3 along with battery storage is shown in Figure 13. The four number of batteries in series, each of 144 Ah capacity and 12 V were obtained solving the optimisation problem. It is observed that the number of batteries has increased with a single DGs.

The size of storage devices has been increased up to twice with single DG. The four numbers of batteries have been obtained at each location to meet the variation of wind power generation. It results in the reduction of the overall size of wind-based DG.

TABLE III. Results obtained with a single objective function

Method	PSO [16]	ELF [17]	NM [18]	CPLS [18]	Proposed method (Case-1)	Proposed method (Case-2)
Location (bus)	6	6	6	8	24, & 25	24
Optimal DGs Size (kW)	2590	2600	2494.8	1800	861.05	948.06
BES (kWh)	—	—	—	—	304.12	630.91
Diesel Gen.(kW)	—	—	—	—	14.85	15.40
Losses Without DG (kW)	211.2	211.2	210.98	210.98	211	211
Losses With DG (kW)	110.1	111.1	111.14	111.14	110.51	111.63
Loss Reduction(%)	47.39	47.39	47.32	47.32	47.77	47.09

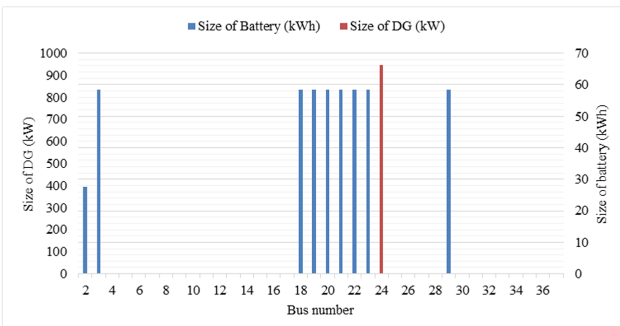

Figure 12. Size of DGs with battery storage for DGs type-3

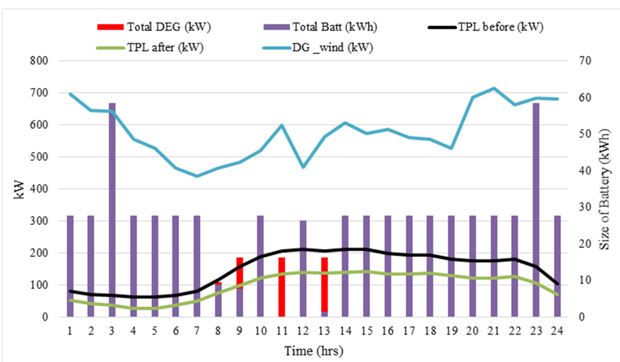

Figure 13. The power output of wind-based DGs Type-3 with battery storage

The initial SOC set point taken is 90%, and the minimum SOC is 40% at each location of the battery. The total power loss has reduced up to 47%. In Figure 13 the total power loss (TPL) before and after the DGs placement is shown for 24 hrs load variation.

3) *Comparison between Case-1 and Case-2 for single-objective function*

In this section, the comparisons of results obtained with DG Type-1 and DG Type-3 have been given for single objective function. In the above Table IV, the total power loss is reduced to 97.974 kW and 102.93 kW with 2-DGs of Type-1 and single DG of Type-3, respectively.

The number of batteries has increased from 2 to 4 with a single DG of Type-3 integration. Therefore, the size of battery storage increased to 630.91 kWh. The charging and discharging time of the battery depends on the dispatch strategy. The charging energy for battery storage obtained is 9.617 kWh with single DG Type-3 and 14.086 kWh with 2-DG of Type-1. It is clearly given in Table IV, the batteries get charged at the time of excess generation of power from the DGs. The charging power has increased with increasing the number of DGs in the network. However, the required size of the battery has been reduced with increment in the number of DGs. The fuel consumed by the diesel generator has increased to 1375.8 (litres) with single DG also.

D. *Results for multi-objective function*

The multi-objective function consists of two objectives functions as follows; (i) minimisation of total power loss and (ii) minimisation of the total cost of the system. The total cost of the system consists of net present value (NPV), operation and maintenance cost, replacement cost, acquisition or installation cost, and replacement cost of the components. The various components likewise wind, solar PV, Battery, regulators, investors and Diesel Generator are taken into account for the analysis. The results have been obtained solving the multi-objective optimisation problem for three different Cases.

1) *Results for Case-3 and Case-4 for multi-objective function*

In this section, results of Case-3 and Case-4 have been compared for the multi-objective scenario.

The variations in the size of DGs and battery devices have been given in Table V. The total cost with Type-1 and Type-3 DGs, total load in kWh, total power loss, location of DGs along with the size are given. It is observed from Table V that cost is more for Type-1 DGs. It is also observed that the size of the battery is big with a single DG of Type-3. The power loss, the number of battery and cost of the battery storage increased with DG of Type-3.

2) *Case 5: The impact of various renewable energy sources*

In this section, the impact of different renewable energy sources has been analysed in the multi-objective scenario.

As from Table IV and Table V, the multi-objective Case has better results. Therefore, the impact of various renew-

TABLE IV. Result and comparison of DG Type-1 and DG Type-3

Parameters	**Case-1**	**Case-2**
Total load for 24 hrs (kWh)	73929	73929
Total Power Loss of base Case (kW)	210.98	210.98
Total Power Loss with the proposed method (kW)	97.974	102.93
Location of DG At Bus number	24 & 25	24
Size of DG (kW)	861.05 & 840	948.0621
Rated Power of Diesel Generator (kW)	25	11
Fuel used (liter)	1275.7	1375.8
Total Size of Battery (kWh)	366.423	630.91
The capacity of Battery (Ah)	1442	1444
Number of Battery in Parallel (Nbatt)	2	4
Total Battery Discharging Energy for 24 hrs (kWh)	17.227	17.56
Total Battery Charging Energy for 24 hrs (kWh)	14.086	9.6917

TABLE V. Result and comparisons of various parameters for DG Type 1 and DG Type-3

Parameters	**Case-3**	**Case-4**
Total Cost of System (€)	105281.39	105225.078
Total load for 24 hrs (kWh)	73929	73929
Total Power Loss (kW)	119.21	128.65
Location of DG At Bus number	24 & 25	24
Rated Wind Power Generation (kW)	900 & 0-	1000
Rated PV solar Power (kW)	0- & 800	0-
Size of Battery (kWh)	650.34	720.54
Number of Battery in Parallel	2	4
Total Battery Discharging Power for 24 hrs (kW)	17.465	21.202
Total Battery Charging Power for 24 hrs (kW)	14.027	13.952
Rated Diesel Generator (kW)	11	11
Fuel used (liter/day)	945.9	983.8
NPV PV (€)	13262	-
NPV wind (€)	34634	34634
Grid Cost of Electricity (€)	58.163	1.2962

TABLE VI. Comparison of various energy sources for a hybrid-micro grid with RES

Description	PV + BES	WT+ BES	PV + WT + BES	PV +WT + BES +Diesel
Total Power Loss (kW)	129.46	142.94	165.49	119.2
Number of battery (series × parallel)	4×8	4×8	4×3	4×2
Maximum Size of Battery (kWh)	172.03	172.03	64.512	43.008
Total Size of Batteries (kWh)	1413.1	1437.7	781.87	359.424
Total number of Batteries	96	96	36	24
Number of Batteries in Parallel	8	8	3	2
Rated Capacity of Battery (Ah)	8×144	8×144	3×144	2×144
Total Battery Discharging Power (kW)	68.594	57.769	26.908	17.35
Total Battery Charging Power (kW)	35.072	41.966	21.871	13.89
NPV of battery	60096	60096	22536	15024
Total Solar Power Required (kW)	810.95	-	810.95	293.81
NPV PV Solar	13262	-	13262	13262
Total Wind Power Required (kW)	-	900	888.22	900
NPV Wind Power	-	34634	34634	34634
Fuel used (litter/day)	-	-	-	945.89
Cost (€)	73358	94730	70432	129258

able energy sources has been considered for best reliable operation in the multi-objective scenario only.

The four combinations of sources have been taken for study as given in Table VI. The maximum power loss obtained is 165.9 kW for combination –III and minimum power loss obtained is 119.2 kW for combination-IV. However, the highest cost obtained for the combination-IV, since a large number of energy sources (PV/Wind/Battery& Diesel Generator) have been used and the higher value of carbon emission cost for a diesel generator. The maximum number of batteries obtained is 96 for both the combination of I&II. Therefore, the total size of batteries, the number of batteries in parallel combination, and NPV of batteries are higher for the combination of I and II. Furthermore, the total cost obtained with combination-I is lower than combination –II, with the lower NPV of PV solar PV. Therefore, the decrement in total power loss emphasises the increment in the cost for the combination. Furthermore, the combination-IV is also explained and compared with other methods in Table VII.

E. Results and comparisons with other methods and techniques

In this section, the results of the proposed method are compared with another method of i- MOPSO and i-HOGA [7]. In Table7, the proposed MINLP technique is superior then i-MOPSO and i-HOGA [2],[19]. In the proposed method, the overall cost and carbon emission of the system has reduced to 129258 (€) and 3310.647(kg), respectively.

F. Comparison of Results for the Combined Dispatch Strategy

The comparison between the outcomes of the proposed method with the existing method for dispatch strategy is given in Table VIII. In the proposed method, the total Net Present cost obtained is 175886(€), due to the larger size of the diesel generator. The size of the battery storage of 13.8 kWh is taken for analysis. There are four no's of batteries in series and two no's connected in parallel. The critical discharge load (L_d) and Critical charging load (Lc) have obtained 3213.144 W and 1466.129 W, respectively.

G. Voltage Profile

The proposed algorithm has been used to obtain the voltage profile for several Cases. The output voltage has accomplished by using the load flow after obtaining the size of the battery storage along with DGs.

The comparison of results obtained with direct approach method as reported in [19], without DGs and proposed method with DGs along with battery storage for voltage profile are shown in Figure 14. It is observed that the voltage profile improved considerably with the proposed method. The voltage profile is better obtained for Case-1. The maximum voltage is obtained at 24th and 25th bus obtained are 0.9966 pu and 0.9950 pu for Case-1. The maximum voltage increased to 1.16% and 1.18% at bus number 24th and 25th with Case-1. In Figure 15, it is clear that the

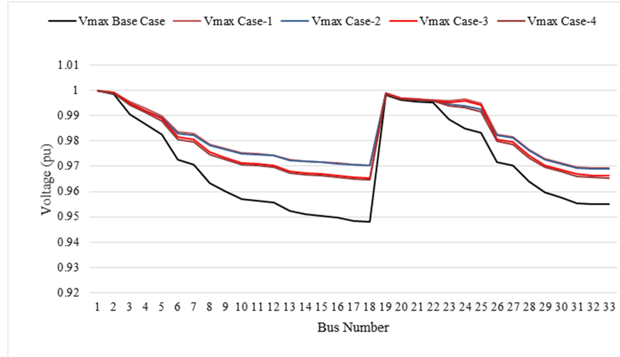

Figure 14. Voltage profile for Proposed with DGs and Direct approach method

voltage has improved at the location of DGs at the bus number 24th and 25th. The voltage of remaining buses also enhanced with the installation of the BESS. Power loss and

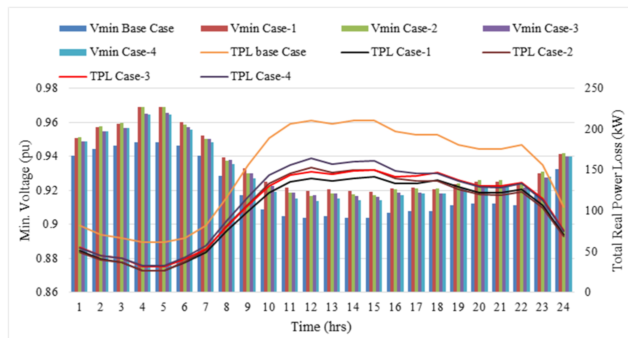

Figure 15. Power loss and voltage profile with DG

minimum voltage throughout the distribution network for several Cases are shown in Figure 15. The highest value of the minimum voltage at 5^{th} hrs and the lowest value of the minimum voltage at 12^{th} hrs have obtained. It results in the minimum voltage has been improved with the installation of DG along with battery storage for minimisation of total power loss. It is clearly shown that the maximum voltage and total power loss have been improved in the Case-1 of single objective .i.e. DG Type-1, since in Case-1 only the power loss has been minimised (single objective function) as explained in the starting of this section.

6. Conclusions

In this study, the multi-objective problem in renewable-based DGs integration along with battery storage device is solved to minimise total power loss, NPV and improvement in voltage profile has been solved using GAMS and MATLAB interfacing. The optimal size of DG's along with BESS have been obtained. The proposed algorithm is implemented in two parts; (i) an optimal location of DGs and battery storage; (ii) sizing of DGs and battery. It is observed that the results are obtained with better optimal solution of NPV, fuel used, loss and voltage improvement.

TABLE VII. Results and comparisons of the proposed method and other methods

Objective Parameters	PV + WT + BES+ Diesel[7]		(Proposed Method)
	i-MOPSO	i-HOGA	MINLP- CPLS
Cost in (€)	138513	137480	129258
Emission (kg CO_2)	5235	5251	3310.647
PV Type	7	1	7
Number of PV	12	14	14
Number of Wind	1	1	1
Number of Batteries	5	2	2
Diesel Type	5	1	6

TABLE VIII. Comparison between different methods

	PV + Diesel + BES [8]			PV+Diesel+BES
	HOGA (PV+Diesel)	HOGA (Diesel Only)	HOMAR (PV+Diesel)	Proposed Method
Size of Battery (kWh)	13.8	13.8	13.8	13.8
Nominal capacity of Battery (Ah)	144	144	144,	144
Batteries are in series & parallel	(2× 4)	(2× 4)	(2× 2)	(2× 4)
Voltage rating of battery (V)	12	12	48	12
Charge Regulator Current (A)	107	63	-	107
Dispatch Strategy	Cycle Charging	Combined	Cycle Charging	Combined
Critical discharging load (Ld in W)	2768	3391	-	3213.144
Critical charging load (Lc in W)	1186	1452	-	1466.129
Battery Replacement Cycle (year)	2.21	1.45	3.85	1.45
Rated Capacity of Diesel Generator (kW)	3	4	4	11
Total Net Present cost (€)	162388	179938	168239	175886

It results loss reduction to 47.77 % with two DGs of type-1, and 47.09% with single DG of type-3. A total saving of 9255 (€) with a combination of wind, solar-based and battery. NPV has saved to 4052 (€) for battery storage with the proposed method.

The annual cost of energy loss (CEL) for the base Case, Case-1, Case-2, Case-3 and Case-4 obtained are €77903.73, €51329.55, €52910.18, €54961.82 and €57214.52, respectively. Therefore the maximum saving of annual CEL obtained is €26574.18 for Case-1.

The combined dispatch strategy can be adopted by the network operator for planning and operation and provides efficient installation of the battery along with DGs. The simulation study has been carried out on 64-bit operating system, Windows 10 with i7 Processor Speed of 3.4 GHz. The proposed algorithm has taken the simulation time is 13.932627 seconds.

References

[1] M. Korpaas, A. T. Holen, and R. Hildrum, “Operation and sizing of energy storage for wind power plants in a market system,” *International Journal of Electrical Power & Energy Systems*, vol. 25, no. 8, pp. 599–606, 2003.

[2] C. Shang, D. Srinivasan, and T. Reindl, “An improved particle swarm optimisation algorithm applied to battery sizing for stand-alone hybrid power systems,” *International Journal of Electrical Power & Energy Systems*, vol. 74, pp. 104–117, 2016.

[3] N. Jantharamin and L. Zhang, “A new dynamic model for lead-acid batteries,” 2008.

[4] H. Bitaraf, S. Rahman, and M. Pipattanasomporn, “Sizing energy storage to mitigate wind power forecast error impacts by signal processing techniques,” *IEEE Transactions on Sustainable Energy*, vol. 6, no. 4, pp. 1457–1465, 2015.

[5] B. U. Kansara and B. Parekh, “Dispatch, control strategies and emissions for isolated wind-diesel hybrid power system,” *Int. J. Innov. Technol. Explor. Eng*, vol. 2, pp. 152–156, 2013.

[6] J. Shen, C. Jiang, Y. Liu, and X. Wang, “A microgrid energy management system and risk management under an electricity market environment,” *IEEE Access*, vol. 4, pp. 2349–2356, 2016.

[7] D. Suchitra, R. Jegatheesan, and T. Deepika, “Optimal design of hybrid power generation system and its integration in the distribution network,” *International Journal of Electrical Power & Energy Systems*, vol. 82, pp. 136–149, 2016.

[8] R. Dufo-López and J. L. Bernal-Agustín, “Design and control strategies of pv-diesel systems using genetic algorithms,” *Solar energy*, vol. 79, no. 1, pp. 33–46, 2005.

TABLE IX. List of Symbols

P_{solar}	Solar output power
P_{wind}	Wind output power
NPV	Net present value
N_{wind}	Number of wind Turbine
FF	Fill factor
v_{in}	Cut in velocity of wind,
V	Rated Voltage
v_{out}	cut out velocity of wind,
N_{PV}	Total number of the solar panel
SOC_{min}	minimum state of charge
i	Index for bus
SOC_{max}	maximum state of chare
k	Index for time
N_{batt}	total number of battery
$P_{dis_i}^{k}$	Discharge power for ith bus at kth time
DOD_{max_bat}	maximum depth of discharge of battery
$P_{ch_i}^{k}$	Charge power for ith bus at kth time
A, B	Fuel curve constant
L_{cc}	Cycle charging coefficient
P_{NGen}	Rated power of Diesel Generator
$Pd_{net\_Load_i}^{k}$	Net DC load for ith bus at kth time
pf_{deg_i}	Power factor of Diesel Generator
S_{DG}	Set of DG location
L_{deg}	Net cost coefficient of Diesel Generator
S_B	Set of Battery location
Pr_{fuel}	Fuel price for Diesel Generator
nb	Total number of buses
δ_i	Voltage angle at bus i

[9] Y. Atwa, E. F. El-Saadany, M. Salama, R. Seethapathy, M. Assam, and S. Conti, "Adequacy evaluation of distribution system including wind/solar dg during different modes of operation," *IEEE Transactions on Power systems*, vol. 26, no. 4, pp. 1945–1952, 2011.

[10] A. S. Aziz, M. F. N. Tajuddin, M. R. Adzman, M. A. Ramli, and S. Mekhilef, "Energy management and optimization of a pv/diesel/battery hybrid energy system using a combined dispatch strategy," *Sustainability*, vol. 11, no. 3, p. 683, 2019.

[11] M. A. Kashem, V. Ganapathy, G. Jasmon, and M. Buhari, "A novel method for loss minimization in distribution networks," in *DRPT2000. International conference on electric utility deregulation and restructuring and power technologies. Proceedings (Cat. No. 00EX382)*. IEEE, 2000, pp. 251–256.

[12] L. A. Bird, K. S. Cory, and B. G. Swezey, "Renewable energy price-stability benefits in utility green power programs," National Renewable Energy Lab.(NREL), Golden, CO (United States), Tech. Rep., 2008.

[13] I. Irena, "Renewable power generation costs in 2017. report," 2018.

[14] S. Carley, "Distributed generation: An empirical analysis of primary motivators," *Energy policy*, vol. 37, no. 5, pp. 1648–1659, 2009.

[15] M. H. Mostafa, S. H. A. Aleem, S. G. Ali, A. Y. Abdelaziz, P. F. Ribeiro, and Z. M. Ali, "Robust energy management and economic analysis of microgrids considering different battery characteristics," *IEEE Access*, vol. 8, pp. 54 751–54 775, 2020.

[16] N. Jain, S. Singh, and S. Srivastava, "A generalized approach for dg planning and viability analysis under market scenario," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 11, pp. 5075–5085, 2012.

[17] D. Q. Hung and N. Mithulananthan, "Multiple distributed generator placement in primary distribution networks for loss reduction," *IEEE Transactions on industrial electronics*, vol. 60, no. 4, pp. 1700–1708, 2011.

[18] V. Murthy and A. Kumar, "Comparison of optimal dg allocation methods in radial distribution systems based on sensitivity approaches," *International Journal of Electrical Power & Energy Systems*, vol. 53, pp. 450–467, 2013.

[19] J.-H. Teng, "A direct approach for distribution system load flow solutions," *IEEE Transactions on power delivery*, vol. 18, no. 3, pp. 882–887, 2003.

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