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SUSTAINABLE ENERGY SCHEDULING OF GRID-CONNECTED MICROGRID USING MONTE CARLO ESTIMATION AND CONSIDERING MAIN GRID PENETRATION LEVEL

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Abstract- Power scheduling and energy management of battery energy storage systems (BESS) and renewable energy resources (RES) in microgrids (MG) is essential for their reliable and optimal operation. Also, BESS play a vital role in increasing operation stability and efficiency of a RES in MG systems. Thus, in this paper, the operation scheduling of BESS in a MG system is modeled. Two-stage simulation is executed to determine the optimal BESS capacity and RES sizing by considering the weather conditions and economic factors to reduce the total cost. Also, some restrictions, such as reducing the dependency of the MGs on the main grid, the budget, the geometry limits for installing the RES components and the BESS management by considering market price and the cost of charging and discharging is applied. The uncertain nature of RES such as wind has led to difficulties in ensuring power quality and in balancing generation and consumption. Hence, wind speed is estimated using wind statistics-based Monte Carlo strategy. The Khalkhal-Ardabil climatic information is considered as a case study. Optimal short-term planning has been done to reduce costs using Mixed-Integer Linear Programming (MILP) and GAMS software.

Keywords: Renewable Energy Sources, Optimal Management, Monte Carlo, Energy Storage, Main Grid penetration Level.

1. INTRODUCTION

The exponential increase of the power demand led to install a more conventional source of energy. Nevertheless, challenges such as scarcity of fossil fuel, pollution hazard, and cheaper total cost of renewable energy generation have led to the use of RES, as a source of energy, in an efficient energy network known as the microgrid (MG). Renewable energies such as photovoltaic (PV) and wind turbines (WT) are rapidly growing and developing because they are the most effective way to manage energy [1].

Besides the RES, the battery energy storage (BESS) can be incorporated for compensating the intermittency and variability of renewable resources and improving the power quality and reliability. Increasing penetration of RES in the power system implies that system operators will need to manage the variable and uncertain nature of RES [2, 3]. As a result, an energy management system (EMS) is necessary to tackle this problem. EMS for a microgrid represent relatively new and popular topics that attracted lots of attention, recently [4].

Microgrid (MG), as a small part of the power system, consists of several intermittent and non-intermittent resources. It can be considered as an essential device to attain favorable targets. It makes the system safe, reliable, flexible, efficient and sustainable [5, 6].

Because of the unpredictable nature of RESs, it is always possible that the real-time values of them are different from corresponding planned values. In this regard, the integration operation of BESS with MG can improve reliability on delivering uninterrupted power to the load.

In the MG system, BESS is deemed to be one of the most important devices as it reduces operation cost and increase the efficiency of the system. Therefore, optimal scheduling of the BESS and RESs is one of the means to reduce the cost of MGs.

Notable studies have addressed the optimal scheduling of hybrid power generation systems in MGs, but challenges such as the integration of the main grid with the MG and efficiency and reliability improvement of the grid without further investment are the key issues [7]. The connection of the MG and main grid is obtained by the energy management system (EMS). It is necessary to tackle the intermittent nature of loads and RESs [4]. It controls MG components such renewable resources, load, and energy storage system (ESS) to achieve predefined goals. These goals include reducing cost [8-19], increasing profit [11], and system reliability [8], reducing environmental pollutants [20], and increasing system stability [21].

In Ref. [8] two constraint-based iterative search algorithms have been used for optimizing renewable and battery size. In Ref. [9], a nested energy management strategy has been reported for the day-ahead scheduling of grid-connected MGs. Compared to conventional EMS, the operation cost of the grid-connected MGs with a proposed strategy is more cost-effective. In Ref. [10] the uncertainties associated with the real-time market price signals, renewable power sources, and forecasted load values have been considered. Firstly, a deterministic model has been considered, and then a similar mixed integer problem has been formulated by using linear duality and other optimality conditions.

Imperialist competitive and improved swarm optimization algorithms have been considered to optimally measure of MG components size to reduce the costs of investment, operation, installation, and reduction of carbon footprint and power cost purchased from the upstream grid [11]. In Ref. [12] a modified particle swarm optimization (PSO) algorithm has been used for energy management to find optimal battery size. Ref. [13] has been provided optimal pricing with demand response in the grid. In this paper, two types of flexible and inflexible loads have been considered. Flexible loads have been provided based on dynamic market price.

In Ref. [14], the uncertainty problem in the consumption behavior of price based responsive loads have been reported. A model based on robust optimization to consider this uncertainty on a typical risk-constrained optimal operation of a smart MG has been investigated. The economic operation strategy for reducing costs has been proposed based on the neural network prediction [15].

In Ref. [16, 17], a rolling horizon strategy and improved Bat algorithms have been used to manage the system and determine the optimal size of ESS in the presence of the electricity market. The MG generation cost function was formulated as a mathematical model in Ref. [18]; the load was considered to be fluctuation and unpredictable. In Ref. [19], islanding issues and risk constraints have been addressed. Autoregressive Average-Moving (ARMA) has been used for generating wind scenarios. But, in this paper the season variation and geometric constraints have not been considered.

In [20], the main objectives are operating cost and pollution rate, which have been managed and optimized the MG by the multi-objective PSO (MOPSO) algorithm. Wang et. al [21] improved the system stability in addition to increasing the profit using game theory.

Noted that as reviewed the literature, seasonality variation and its effect on the configuration of MGs, geometric and dependency limits on the main grid, are not investigated. In order to consider these realistic limitations, in this paper, a reliable hybrid MG, which proposed to the electrification of an area at Khalkhal-Iran, is investigated. For investigation the feasibility of MGs installation in Khalkhal, maximum available budget, and geometric constraints are considered.

For a reduction in the dependency of the MGs on the main grid, the new index is defined and considered as dependency limit constraint. With the expansion of renewable energy sources, the role of the BESS to overcome electricity fluctuations has been highlighted. Therefore, in this study, the optimal size of the battery is determined by considering the seasonal variations, wind speed, and solar radiation variations during the daytime and different seasons. It's important to determine the optimal size of the BESS by considering the market price at peak hour and cost of discharging the BESS to achieve the lowest total cost for the MG.

The main contributions of this paper can be summarized as:

1. Monte Carlo simulation is used for modeling wind speed distribution based on historical wind speed data and autocorrelation effects in wind distribution. For performance evaluation, the result of Monte Carlo simulation is compared with the results found by Weibull distribution function.
2. MILP based optimization algorithm is applied to find component size and energy management for total cost reduction, which includes capital, fuel, and maintenance costs.
3. In addition to conventional technical constraints, limitation of charge/discharge of storages, maximum available budget, and geometric constraints and dependency of the MGs on the main grid are considered.
4. The seasonality variation and its effect on the optimization problem are applied to management of RES configuration.

This paper organized as follows, application of the Monte Carlo approach for wind speed modeling is presented in the next section. Section 3 gives the configuration of hybrid MG and model input data. In section 4, planning results are presented and discussed. Finally, concluding remarks are presented in Section 5.

2. WIND SPEED MODELING

Proper selection of wind speed distribution function strongly effects the wind turbine (WT) generated power, its performance, and on amount of harvested energy. Researchers reported various probability density functions for explanation the wind speed. Weibull distribution is most commonly and widely used in the assessment of wind speed distribution [22]. The Weibull distribution can be expressed as a Probability Density Function (PDF) given as follow:

$$p(v) = \left(\frac{A}{k^A}\left(v^{A-1}\right)\right)\exp\left(-\left(\frac{v}{k}\right)^A\right) \quad (1)$$

where, v is the wind speed, A is the shape factor (unit of speed) and, k is the dimensionless scale parameter.

In this paper, the Monte Carlo approach and statistical properties of wind speed like autocorrelation is considered to achieve an accurate model for wind speed. The advantages of this method are using historical wind data speed for ten years, not using predefined distribution for the wind speed. The study has been conducted at Khalkhal city of Iran. Autocorrelation in Khalkhal wind data has been investigated for 12 months by Matlab software. Autocorrelation measures the degree of similarity and relationship between a given signal and a lagged version of itself as a function of delay. The analysis of autocorrelation is a mathematical tool for finding repeating patterns in wind data. Wind data's start from April 2014 with two weeks' time lag, which is 2016 lags.

It can be concluded that autocorrelation becomes noninfluential at lags from one day (144 lags) to approximately five days (720 lags). The correlation after 720 lags is small and negligible. Therefore, wind speed data's at Khalkhal are regrouping into five-day blocks because the wind speed for five consecutive days is correlated. Therefore, instead of simulation each 10-min average of wind speed data independently, correlated wind speed data's will be simulated in the wind Monte Carlo simulation. Consequently, each year divided into 73 × (365/5) blocks of five-days.

In order to represent an accurate simulation of wind speed, ten years of actual wind data for the intended site is evaluated. Scenarios are obtained by the sampling of ten years historical data from five-day blocks for 1000 times with equal probability equation. Finally, we have 1000×52560 matrix, which is made by maintaining correlation of the ten years data.

The result and comparison of the Monte Carlo simulation and Weibull simulation versus measured data at Khalkhal city are shown in Figures 1 and 2. As shown in Figure 1, the probability density of the Monte Carlo simulation results gives a good fit to measured data. By comparing Figures 1 and 2, the validity of the Monte Carlo simulation is proved. A slight deviation is at the top of the Weibull simulation curve, which is more than the Monte Carlo simulation.

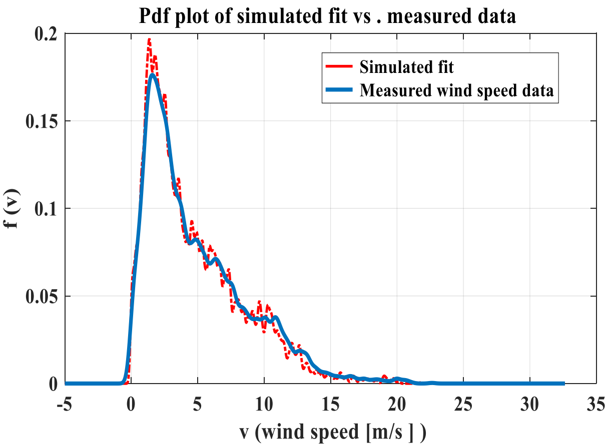

Figure 1. Monte Carlo simulation result

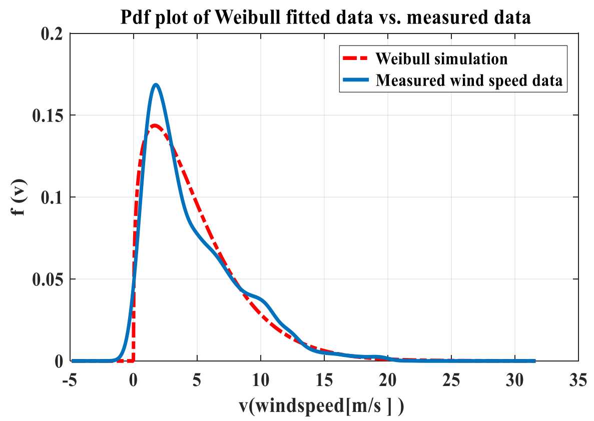

Figure 2. Weibull simulation results

The mean, median, and the standard deviation (STD) of wind speed for the two simulations and measured data at Khalkhal city are calculated. The summary statistics in Table 1 confirm that the MC wind speed simulation has good agreement with the observed data.

Table 1. Statistics information of simulated wind speed

	Mean [m/s]	Median [m/s]	STD [m/s]
Weibull simulation	8.50	7.73	5.09
Monte Carlo simulation	8.51	8.00	4.99
Measured wind speed	8.53	8.04	4.98

3. OPTIMIZATION PROBLEM FORMULATION

The task of the optimization problem is optimal management and total cost reduction of the MG. The mathematical formulation of MG energy management problem comprising objective function and constraints can be described as follows.

3.1. Objective Function

The cost function is one of the most well-known and used indicators of economic profitability of MGs. It comprises of the initial or capital cost, operation, and maintenance cost. The time of allocation for the capital cost is at the beginning of the project, and the operation and maintenance cost are annual during the project. Therefore, the capital recovery factor is used to convert the capital cost to the annual cost. The objective function is to minimize the overall cost of MG as well as the interconnection between MG and the main grid:

$$\min \ \{F^{\text{cost.MG}} + F^{\text{cost.Grid}}\} \quad (2)$$

$$F^{cost.MG} = \sum_{t=1}^{24} C_{PV}(t) + C_{WT}(t) + B_{BESS}(t) \quad (3)$$

$$C_{PV\&WT}(t) = \sum_{i=1}^{N_{PV\&WT}} P_{PV\&WT}(t).NPC(t) \quad (4)$$

$$B_{BESS} = P_{dch}(t)C_{dch}(t) - P_{ch}(t)C_{ch}(t) \quad (5)$$

$$F^{cost.MG} = \sum_{t=1}^{24} C_{grid}(t) \quad (6)$$

$$C_{grid}(t) = \begin{cases} B_G(t)P_G(t) & \text{if } \mathrm{P}_G(t) > 0 \\ (1-tax)B_G(t)P_G(t) & \text{if } \mathrm{P}_G(t) < 0 \\ 0 & \text{if } \mathrm{P}_G(t) = 0 \end{cases} \quad (7)$$

where, $N_{PV\&WT}$ is the decision variable consists of the size of RES components (WTs, PVs) over a 24h time interval, C_{PV}, C_{WT}, B_{BESS}, C_{dch}/C_{ch} are PV, WT, BESS, BESS charging/discharging cost, respectively. *NPC* is net present cost of *RES* component in MG. B_G is the bid of the main grid, *tax* is the rate of the main grid and set to 10% in this study. P_G and C_{grid} are the power and cost of the main grid.

3.2. Constraints

To solve the optimization problem, the following constraints must be considered.

• Load-Generation Balance

To determine the feasible solutions the cost function must satisfy the energy balance equation as follows:

$$\sum_{i=1}^{N_{WT}} P_{WT}(i,t) + \sum_{i=1}^{N_{PV}} P_{pv}(i,t) + P_{dch}(t) + P_{Grid.b}(t) = D_t + P_{ch}(t) + P_{Grid.s}(t) \quad (8)$$

where, N_{WT}, N_{PV} are the number of WTs, and PV panels, respectively, $P_{WT}(t)$, $P_{PV}(t)$ are the rated power of WT and PVs. $P_{ch}(t)$ and $P_{dch}(t)$ are the charge and discharge power of BESS, and D_t is the load power, $P_{grid.s}(t)/P_{grid.b}(t)$ are selling/ purchasing power to/from main grid.

Since MGs may not able to supply the load in some situations. Therefore, the main grid provides inquired load power as a backup. The power supplied by the main grid is modelled as:

$$P_{Grid}(t) = D_t - \sum(P_{WT}(t), P_{PV}(t), P_{ch}(t), P_{dch}(t)) \quad (9)$$

• BESS Constrains

The BESS is used for balancing generation power and load balance. The state of charge for the BESS is given by:

$$SOC(t) = SOC(T-1) + P_{ch}(t)\eta_{ch} - P_{dch} / \eta_{dch} \quad (10)$$

where $SOC(t)$ and $SOC(t-1)$ are the BESS state of charge at the times t and $t-1$, respectively. η_c and η_d are the charging and discharging efficiency of battery, respectively.

The constraint in the below equations is imposed for charge and discharge to prevent a reduction in the useful life of each BESS.

$$SOC(0) = SOC_b E_{b\max} \quad (11)$$

$$E_{bat.\max} = S_{batt} \quad (12)$$

$$E_{bat.\min} = S_{batt}(1-dod) \quad (13)$$

$$SOC(t) \le N_b(t) E_{b\max} \quad (14)$$

$$SOC(t) \ge N_b(t) E_{b\min} \quad (15)$$

where, SOC_b is 0.2, $E_{b\max}$ is a maximum capacity of the battery, $SOC(0)$ is the initial state of charge, $E_{bat.\min}$ is the minimum charge quantity of the BESS, and S_{batt} is the value of BESS capacity [23]. $N_b(t)$ is the number of BESS, $E_{b\max}$, and $E_{b\min}$ is the maximum and minimum capacity of the BESS.

To prevent simultaneous charge and discharge of the BESS, we have:

$$P_c(t) \le L.bcs(t) \quad (16)$$

$$P_d(t) \le L.bcds(t) \quad (17)$$

$$bcs(t) + bcds(t) \le 1 \quad bcs \text{ and } bcds \in \{0,1\} \quad (18)$$

where, L is the large positive number that must be greater than the capacity of the batteries. bcs and $bcds$ are the charge and discharge status of the BESS at the time t, respectively.

• Management of Charging and Discharging of the BESS

In order to reduce the cost function based on the real-time market price at 24 hours, the decision to charge and discharge of the BESS is applied based on the maximum and minimum instantaneous prices of the main grid and MG.

In charging mode, if the market price is lower than the MG generated power price, then the BESS will be charged by the power purchased from the main grid, and if it is lower than the market price, the MG will be charged the BESS. It should also be noted if the BESS charging costs more than the purchased power cost from grid and power generation cost by the MG, so the BESS will not charge. This condition is true for discharging the BESS. The relations of BESS management are as follow:

$$P_c(t) = \begin{cases} P_{L,t} - P_{MG,t} & \text{if } B_{P_{ch,t}} < B_{p_{grid,t}} \\ 0 & \text{if } B_{P_{ch,t}} > B_{p_{grid,t}} \end{cases} \quad (19)$$

If the purchased power cost from grid is higher than the discharge cost, the BESS supply the load, and so it will not exchange with the market. Also, if the discharging cost is more than the market, the BESS discharge is not economical.

$$P_{dch}(t) = \begin{cases} \left| P_{L,t} - P_{MG,t} \right| & \text{if } B_{p_{dch,t}} < B_{p_{grid,t}} \\ 0 & \text{if } B_{p_{dch,t}} > B_{p_{grid,t}} \end{cases} \quad (20)$$

Therefore, the load-generation balance management by considering BESS operation mode has the following three cases:

$$\begin{cases} N_w(t)P_w(t) + N_{pv}(t)P_{pv}(t) = P_{load}(t) + P_c(t) \\ N_w(t)P_w(t) + N_{pv}(t)P_{pv}(t) + P_d(t) = P_{load}(t) \\ N_w(t)P_w(t) + N_{pv}(t)P_{pv}(t) = P_{load}(t) \end{cases} \quad (21)$$

• Dependency Limit on the Main Grid

To reduce the dependence of the MG on the main grid, a power generation ratio is defined as:

$$FR = \frac{P_{WT} + P_{PV}}{P_{WT} + P_{PV} + P_{grid}} \quad (22)$$

So, the purchased power limitation from main grid is given by:

$$0 \le P_{grid} \le P_{(PV,WT)} \times \frac{1 - FR_{\min}}{FR_{\min}} \quad (23)$$

• Economic Constraints

The installation cost of MG components should not exceed assuming maximum available budget so, we have:

$$C_{\text{int\_}pv} N_{pv} + C_{\text{int\_}wind} N_{WT} + C_{\text{int\_}BESS} N_{BESS} \le C_{bg} \quad (24)$$

where, $C_{int\text{-}pv}$, $C_{int\text{-}wind}$, $C_{int\text{-}bat}$ are the installation cost of a PV panel, WT, and BESS, C_{bg} is the maximum available budget.

• Geometric Constraints

According to the number of WTs and PV panels, an available installation area is considered as

$$N_{WT} A_b \le A_{\max} \quad (25)$$

$$N_{PV} S_b \le S_{\max} \quad (26)$$

where, A_b and S_b are the base ground area for a WT and PV, respectively, $A_{\max}$ and $S_{\max}$ are the available area for WT and PV units, respectively.

• Capacity Constraints of MGs

The minimum and maximum number of the WTs and PVs should be limited as

$$N_{PV}^{\min} \le N_{PV}^{k} \le N_{PV}^{\max} \qquad (27)$$

$$N_{WT}^{\min} \le N_{WT}^{k} \le N_{WT}^{\max} \qquad (28)$$

where, $N_{PV}^{\min}$, $N_{PV}^{\max}$, $N_{WT}^{\min}$ and $N_{WT}^{\max}$ are the minimum and the maximum number of the WTs and PVs. They can be calculated as:

$$N_{PV}^{\min} = \frac{\alpha \sum_{t=1}^{24} P_L(t)}{\sum_{t=1}^{24} P_{PV}(t)} \qquad (29)$$

$$N_{PV}^{\max} = \frac{\beta \sum_{t=1}^{24} P_L(t)}{\sum_{t=1}^{24} P_{PV}(t)} \qquad (30)$$

$$N_{WT}^{\min} = \frac{\gamma \sum_{t=1}^{24} P_L(t)}{\sum_{t=1}^{24} P_{WT}(t)} \qquad (31)$$

$$N_{WT}^{\max} = \frac{\lambda \sum_{t=1}^{24} P_L(t)}{\sum_{t=1}^{24} P_{WT}(t)} \qquad (32)$$

where, α, β, γ, and λ are the scaling factors.

• BESS Size Determination

The following steps are taken into determine the maximum BESS size account associated with renewable sources.

Step 1: The minimum number of solar panels and wind turbines specified by (29) and (31) is considered.

Step 2: The worst and best season in terms of wind and solar power generation is considered.

Step 3: The BESS is removed from the simulation

Step 4: The MGs power generation in each season is calculated by (33)

Step 5: The purchased/sold power to/of main grid is calculated by (34) in each season.

Step 6: Finally, the maximum capacities of the BESS that can charge or discharge are obtained in each season as:

$$P_{MG}^{S}(t) = N_{PV_{\min}}^{S} P_{PV}^{S}(t) + N_{WT_{\min}}^{S} P_{WT}^{S}(t) \qquad (33)$$

$$P_{gap}^{S}(t) = P_{L}^{S}(t) - P_{MG}^{S}(t) \qquad (34)$$

$$BESS_{\max}^{S} = P_{gap,\max}^{S} \qquad (35)$$

4. SOLUTION PROCEDURE and CASE STUDY

The proposed optimization algorithm to solve the optimal operation management problem of MG is described in Figure 3. As the Wind have a probabilistic nature, the output power of it is intermittent. Therefore, to model uncertainty of wind speed, Monte Carlo simulation is implemented, firstly. Then, two-stage simulation is executed to determine the optimal BESS capacity and RES sizing. In the first stage, generated power, sold and purchased power are calculated without BESS in each season.

In the second stage, the optimal size of solar PV and WT are determined considering first stage results for maximum BESS capacity.

The targeted system for the case study is the hybrid micro-grid system mainly contains the wind power generation system, PV system, and BESS, which is shown in Figure 4. In general, MG operates in grid-connected mode, connecting with the external distribution system through a static switch as the point of common coupling (PCC).

In this study, weather and geographical information of Khalkhal city in Iran are used to investigate the scheduling of a hybrid MG system. Characteristics of typical daily load and power market price are shown in Figure 5 and 6 [24, 26]. Techno-economical parameters of MG components are tabulated in Table 2. The solar radiation [27] at each ten minute in the desired area, for four days, in different seasons of the year 2014, is shown in Figure 7. Solar radiant intensity, panel area, cell temperature, and absorption capacity specify the power production of the PVs [28, 29]. The power of the PVs per hour is shown in Figure 8. PV power formula can be found in Ref. [30].

In order to simulate wind power production, the wind speed at the height of the turbine hub is obtained by averaging the Monte Carlo results. Then, the values of wind speed for one year is achieved. Figure 9 shows the estimation of wind speed results in Khalkhal city during a year 2014, which achieved by Monte Carlo simulation.

The generated power of WT is dependent on the aerodynamic characteristic of the WT, such as, size, shape, orientation, and wind speed. Linearized type of equation correspondent to different values of wind speed can be found in Ref. [31]. Since wind speed depends on the weather condition, wind turbine generation of 4 days in each season is considered and shown in Figure 10. This variability stems from the fact that wind patterns vary not only by the region, but also by the time of the year. In turn, the amount of power generated by wind turbine can change considerably from season to season.

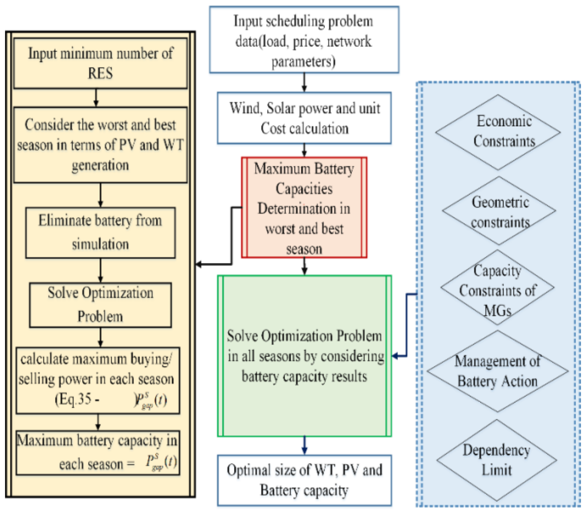

Figure 2. Flowchart of the optimization problem

Table 2. The grid data

Wind		Battery		PV	
v_{cut-in}	2.5 m/s	voltage	12 V	P_N^{PV}	1 kw
$v_{cut-out}$	13 m/s	$E_{b\max}$	70 kWh	Life span	25 year
v_r	9.5 m/s	$E_{b\min}$	13.2 kWh	η_{PV}	0.85
P_r	5 kW	η_{batt}	85%	Available area for PV	1.7
Life span	20 years	Life span	5 years	Budget available	5000000 $
Available area for wind	80 m^2	*dod*	0.8	η_{inv}	0.95
		soc_0	13.2 kwh	*i* (interest rate)	0.06

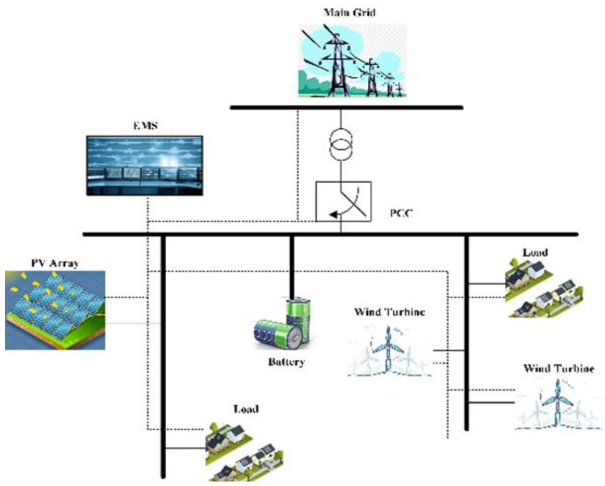

Figure 4. Schematic of the hybrid MG

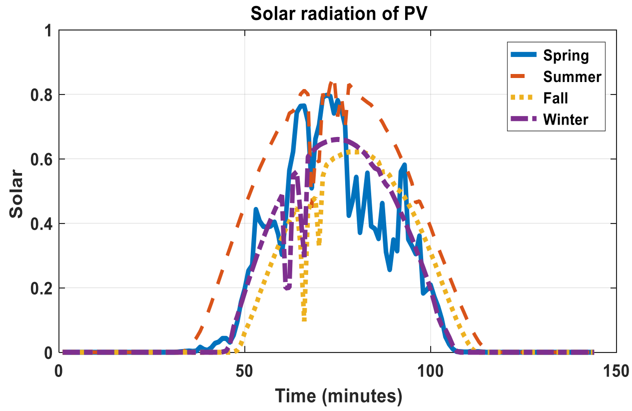

Figure 7. Solar radiations in minute

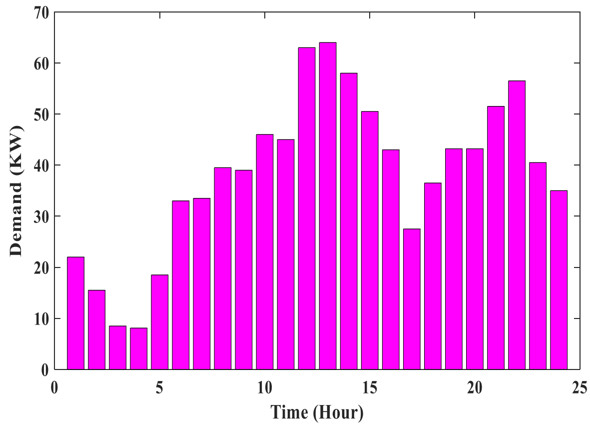

Figure 5. Daily load profile

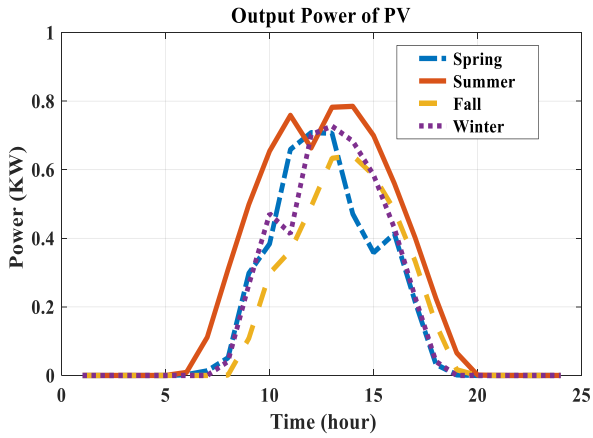

Figure 8. Hourly power supplied by the panels

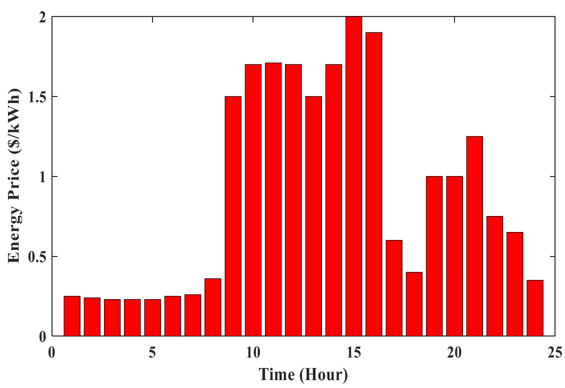

Figure 6. Market Price

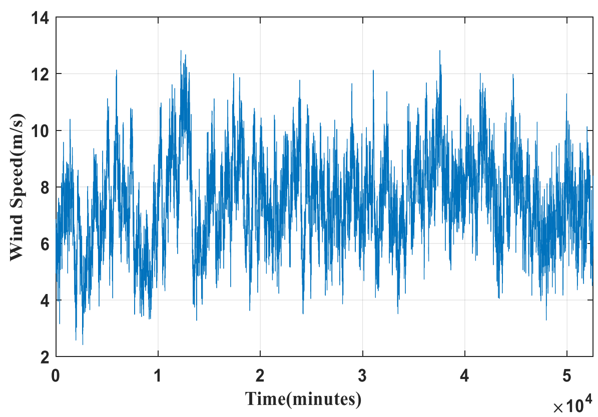

Figure 9. Mean wind speed for one year

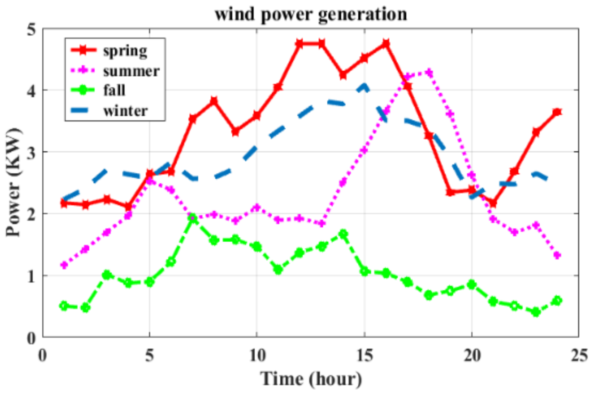

Figure 10. Mean wind power generation in each season

5. RESULTS AND DISCUSSIONS

For the application of the proposed methodology, GAMS is employed. The power management strategy for a hybrid MG system is performed to maintain continues power of the loads. MILP method is applied to obtain the best configuration of the system and the components sizing. The objective function is the total cost minimizing.

As aforementioned, to determine the optimal size of the BESS, at first, the minimum number of WT and PV is calculated by the Equations (29) and (31). Then the simulation is done in two-steps.

Step 1: In the first step, the simulation is investigated without utilizing the BESS in the worst and best season in terms of wind and solar power generation. Therefore, the maximum amount of power sold and purchased is achieved. These results are as optional capacity for BESS.

Step 2: by considering the achieved results, the simulation is investigated by the presence of BESS and RESs to find the optimal number and size of them. The cost function is decreasing total cost and dependency on main grid.

Figure 11 shows the result of the total energy of RESs, sold and purchased power without BESS for 24 hours in all seasons. The maximum amount of power sold, and purchased to and from the grid is occurred in the spring and fall season, respectively. The numerical results of spring and fall season are presented in Table 3. Also, Figure 12 shows the generated power and load in spring without the installation of BESS.

During the spring season, the wind speed is very high, and also its produced power is high in all hours. The PV power system produces energy in the most hours of the day (6-19 o'clock) because spring days are long. Therefore, the most power is sold to grid, which is shown in Table 3. During the fall season, days start getting smaller, and solar panels produced energy is lower because of cloudy days in fall. So, to balance generation-load the power must purchase from grid.

According to the achieved result in the first step, the maximum power purchased and sold in the two fall and spring season can be considered as maximum BESS capacity.

Therefore, in the second step, two scenarios are considered, and in each scenario, the optimum BESS capacity is equal to the spring and fall maximum sold and purchased power, respectively.

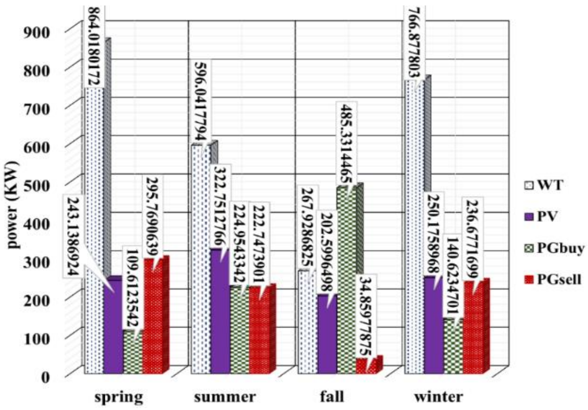

Figure 11. The total energy of MGs, total sold and purchased power without BESS

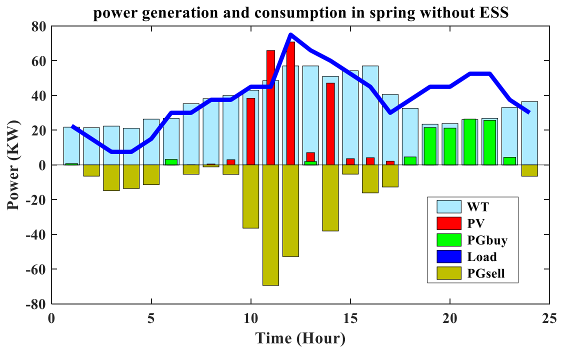

Figure 12. Power generation and consumption in spring without installation of BESS

Table 4 shows the simulation results for the four seasons and two scenarios. By considering geometric, dependency limit on the main grid and other constrains, optimal sizing of PV and WT have been set. In the fall season, the required number of WT and PV is more than the other seasons due to low wind speeds and short days. Therefore, the fall season is considered as a decision criterion. In this season sold power is low; and so the total cost is more than another season. In the first and second scenarios, the total costs are 580.787×10^6 and 565.15×10^6 \$, respectively.

Therefore, the maximum capacity of BESS is considered 68 kWh for satisfying the load in fall and decreasing the total cost in the worst situation. Adding BESS with 68 kW capacity reduces the total cost about 47.6%. Figure 13 shows the variation of cost by adding and removing BESS. Also, it shows cost variation by changing BESS capacity.

Figure 14 and 15 show the results of the fall season for two different scenarios. In the second scenario, charge and discharge of the BESS is more than the first one, consequently, less power is purchased from the grid and total cost is decreased. Table 5 shows the generated power and load of the second scenario.

Table 3. The numerical result of power generation and consumption without installation of ESS in spring and fall

Spring										Fall									
Time	P_{WT}	P_{PV}	P_{gbuy}	P_{gsell}	Time	P_{WT}	P_{PV}	P_{gbuy}	P_{gsell}	Time	P_{WT}	P_{PV}	P_{gbuy}	P_{gsell}	Time	P_{WT}	P_{PV}	P_{gbuy}	P_{gsell}
T1	21.7	0	0.7	0	T13	57	7.1	1.9	0	T1	5.02	0	17.4	0	T13	17.7	6.3	41.9	0
T2	21.4	0	0	6.4	T14	50.9	47.1	0	38.01	T2	4.8	0	10.1	0	T14	20	64.1	0	24
T3	22.3	0	0	14.8	T15	54.2	3.5	0	5.3	T3	10.1	0	0	2.6	T15	12.7	5.83	33.8	0
T4	21.1	0	0	13.6	T16	57	4.1	0	16.1	T4	8.8	0	0	1.2	T16	12.4	4.8	27.7	0
T5	26.3	0	0	11.3	T17	40.5	2.1	0	12.7	T5	9.02	0	5.9	0	T17	8.9	3.3	17.7	0
T6	26.8	0.02	3.1	0	T18	32.5	0.3	4.5	0	T6	12.17	0	17.82	0	T18	6.8	1.4	29.1	0
T7	35.2	0.1	0	5.3	T19	23.4	0.02	21.5	0	T7	19.1	0	10.8	0	T19	7.1	0.14	37.3	0
T8	38.1	0.5	0	1.1	T20	23.8	0	21.1	0	T8	15.7	0.01	21.74	0	T20	8.2	0	36.4	0
T9	39.9	2.9	0	5.4	T21	26.1	0	26.3	0	T9	18.9	1.07	17.5	0	T21	6.95	0	45.1	0
T10	43	38.3	0	36.4	T22	26.8	0	25.6	0	T10	17.5	29.7	0	2.37	T22	5.18	0	47.3	0
T11	48.5	65.9	0	69.4	T23	33.1	0	4.3	0	T11	13.1	36.3	0	4.4	T23	4.06	0	33.4	0
T12	57	70.8	0	52.8	T24	36.3	0		6.5	T12	16.5	49.26	9.21	0	T24	5.9	0	24	0

Finally, by comparing the whole seasons based on the capacity set for the BESS, the number of MG, sold, and purchased power, as well as the cost function are compared in Figure 16. The most cost function is occurred in the fall and requiring 117 panels and 50 wind turbines to supply the load. Table 6 shows the dependency limit on the main grid in the four seasons of the year. It is clear that wind turbines play an important role in providing load demand. Also, accurate prediction of wind speed increases the reliability of the MG. It decreases the dependency limit on the main grid.

Table 4. Simulation results for four seasons and two scenarios

Season	Scenario	WT	PV	BESS (kW)	Sold power (kW)	Cost
Spring	first	46	114	48	1840.5	95.916
	second	43	112	68	1778.6	90.687
Summer	first	48	117	48	1242.4	364.46
	second	46	115	68	1240.3	355.88
Fall	first	50	117	48	490.40	580.78
	second	50	116	68	491.50	565.15
Winter	first	49	116	48	1586.2	209.99
	second	48	115	68	1526.5	207.67

Table 5. The numerical result of power generation and consumption in Fall for the second scenario

Results of Second Scenario																
Time	P_{WT}	P_D	P_C	P_{PV}	P_{gbuy}	P_{gsell}	Load	Time	P_{WT}	P_D	P_C	P_{PV}	P_{gbuy}	P_{gsell}	Load
T1	6.03	0	0	0	16.47	0	22.5	T13	73.78	0	0	74.09	0	81.87	66
T2	4.81	0	0	0	10.19	0	15	T14	83.34	0	0	75.04	0	98.38	60
T3	10.17	0	33.18	2	30.51	0	7.5	T15	53.23	0	0	68.32	0	69.05	52.5
T4	8.75	0	27.49	0	26.24	0	7.5	T16	51.92	0	0	56.44	0	63.35	45
T5	9.02	0	6.15	0	12.13	0	15	T17	8.96	0	0	33.29	0	12.25	30
T6	12.18	0	0	0	17.82	0	30	T18	6.85	0	13.8	14.95	29.5	0	37.5
T7	19.2	0	0	0	10.8	0	30	T19	9	1.26	0	1.94	32.81	0	45
T8	15.74	0	0	0.12	21.64	0	37.5	T20	11.15	0.42	0	0	33.44	0	45
T9	15.76	9.97	0	11.77	0	0	37.5	T21	5.77	46.6	0	0	0.13	0	52.5
T10	73.24	0	0	34.84	0	63.08	45	T22	13.36	0	0.1	0	39.25	0	52.5
T11	54.6	0	0	42.53	0	52.13	45	T23	9.36	0.07	0	0	28.07	0	37.5
T12	68.76	0	0	57.64	0	51.4	75	T24	7.78	0	1.1	0	23.33	0	30

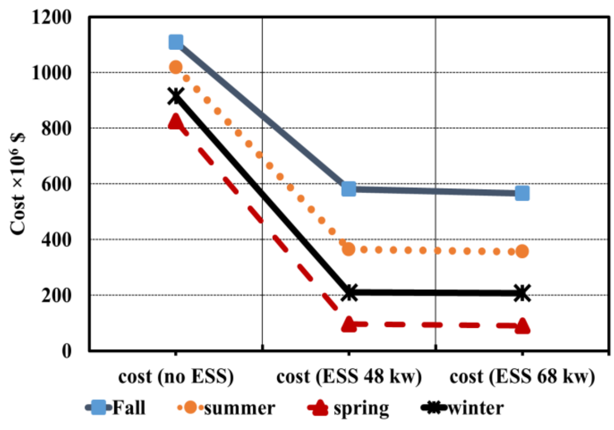

Figure 13. Cost variation with and without BESS

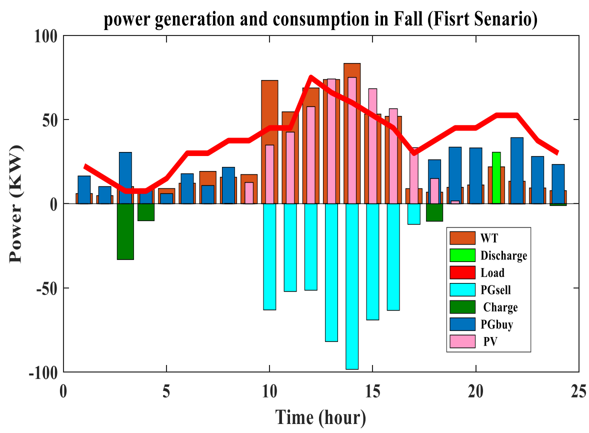

Figure 14. The generated power and load in Fall (the first Scenario-BESS-48kW)

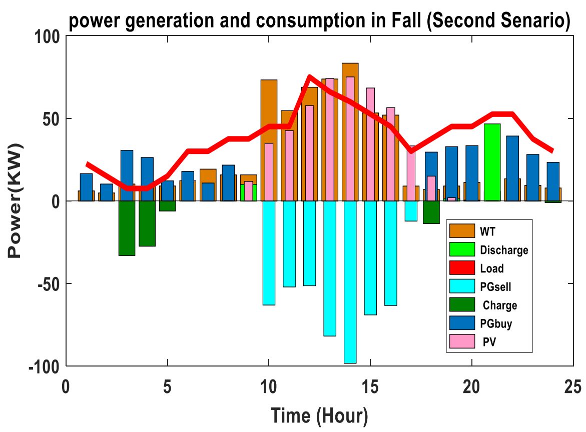

Figure 15. The generated power and load in Fall (second Scenario-BESS-68 kW)

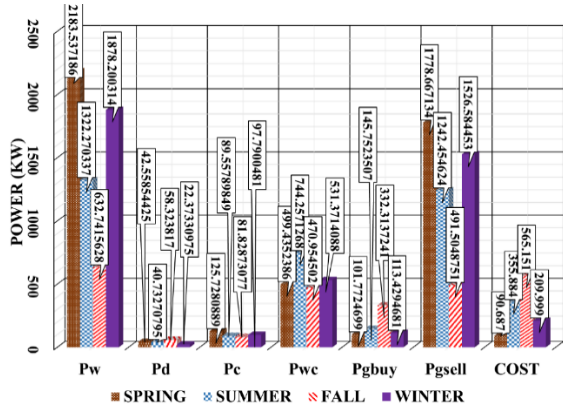

Figure 16. Final result for all season

Table 5. Dependency limit on main grid

Season	Dependency limit on main grid
Spring	0.963
Summer	0.934
Fall	0.768
Winter	0.955
Average of Dependency limit for one year	0.905

6. CONCLUSION

In this paper, a technique has been proposed for the optimization of RE sources sizing and associated BESS in grid-connected MG system. The scheduling problem was formulated by various constraints related to the operation of MG components and limitation of dependency on the main grid and geometrical. Measured solar radiation and wind speed in Khalkhal city of Iran are utilized in this study. The Monte Carlo simulation approach for accurately estimating wind speed based on the historical wind data and autocorrelation effects in wind distribution is presented. The estimated model is compared by Weibull simulation. The result of comparison verifies the performance of the proposed Monet Carlo method. Two-stage simulation is executed to determine the optimal BESS capacity and RES sizing. In the first stage, generated power, sold and purchased power are calculated without BESS in each season. BESS is an optimal device to ensure operational stability and efficiency of RES.

Therefore, in the first stage, the effect of BESS in energy management and cost is investigated. In this stage, maximum total cost has been achieved 1187.65×10^6 \$ in fall season. In the second stage, the optimal size of solar PV and WT are determined considering first stage results for maximum BESS capacity. The procedure considers the power required by the loads, the site geographical properties that is seasonally vary for estimation of wind power. For 48 and 68 kW BESS capacity, the total costs have been achieved 580.787×10^6 and 565.15×10^6 \$, respectively. Adding BESS with 68 kW capacity reduces the total cost about 47.6%.

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BIOGRAPHIES

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