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Optimal Scheduling of Battery Energy Storage System in Distribution Network Considering Uncertainties Using Hybrid Monte Carlo- Genetic Approach

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Abstract- *This paper proposes a novel hybrid Monte Carlo simulation-genetic approach (MCS-GA) for optimal operation of a distribution network considering renewable energy generation systems (REGSs) and battery energy storage systems (BESSs). The aim of this paper is to design an optimal charging /discharging scheduling of BESSs so that the total daily profit of distribution company (Disco) can be maximized. In this study, the power generation of REGSs such as photovoltaic resources (PVs) and the network electricity prices are studied through their uncertainty natures. The probability distribution function (PDF), is used to account for uncertainties in this paper. Also, the monte carlo simulation (MCS) is applied to generate different scenarios of network electricity prices and solar irradiation of PVs. Optimal scheduling of BESSs can be performed by genetic algorithm (GA). In this paper, firstly, the charging and discharging state of BESSs (positive or negative sign of battery power) is determined according to the variable amount of the electricity prices and power produced from PVs, which have been obtained from the Monte Carlo simulation. Then by using the GA, optimal amount of BESSs is determined. Therefore, a hybrid MCS-GA is used to solve this problem. Numerical examples are presented to illustrate the optimal charging/discharging power of battery for maximizing the total daily profit.*

Keyword: Optimal Scheduling, Distributed Generation, Battery Energy Storage Systems, Uncertainty, Daily Profit, Monte Carlo Simulation, Genetic Algorithm, Distribution Company.

1. INTRODUCTION

1.1. literature review

Nowadays the use of renewable energies has a special place in the power industry due to the increasing need for energy resources, reducing fossil fuel resources, fluctuations in the price of these fuels, the necessity of keeping the environment healthy, reducing air pollution, electrification restrictions and fuel supply to outlying regions, etc.

Therefore, use of Renewable Energy Generation Systems (REGSs), such as photovoltaic (PV) and wind turbines (WT), due to much less environmental impact, more flexibility, being unending, and decentralization possibility has been increasing within distribution networks in the past few years.

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In most cases, among the advantages of using the REGSs in distribution networks are expressed as follows [1-6]:

- Reliability enhancement.
- supplying high power quality.
- reducing the cost of energy payments and increasing profits.
- limiting the risks (economic or technical risks).
- reducing energy losses.
- Improving voltage profile.
- improving stability.
- expansion of distribution networks, etc.

For example, in [3], both dispatchable and renewable distributed generations (DGs) are used in distribution networks for reliability improvement and losses reduction. Reference [4], presented real time economic dispatch approaches considering wind turbines and photovoltaic renewable resources to minimizing the cost of all generations. In [5], photovoltaic solar systems can be used as STATCOM for voltage regulation and power factor correction. The aim of this paper is minimizing system losses and improving voltage profile with genetic algorithm(GA). Renewable DGs such as PV and WT, and gas turbines as non-renewable generation are considered in [6] to minimize the sum of economic and CO2 emission costs over planning horizons.

Besides the advantages of renewable resources, they also have some disadvantages. For example, power produced by renewable resources, is dependent on weather conditions such as wind speed, solar irradiation, temperature, etc. Thus, the uncertainty nature of output power of REGSs can be complicated the operation of distribution networks. In addition to the power uncertainty, other parameters such as load or electricity price may not be accurately predicted. In other words, output power of renewable resources, demand load and electricity prices are main types of uncertainty in the distribution networks [7-12].

There are several methods to evaluate these uncertainties in the literatures, such as probabilistic or possibilistic methods. In some papers, the historical data of the parameters under uncertainty (e.g., wind speed or solar irradiation in the region under study), are available. In these cases, the probabilistic methods such as probability density function (PDF) or autoregressive moving average (ARMA) model, are used for uncertainty modeling [7-10]. Otherwise, the possibilistic methods such as fuzzy membership function is used [11, 12]. In [7], the uncertainties of solar irradiance and wind speed are modelled by Beta and Weibull probability density functions, respectively. The objective of this paper is to minimize the energy losses in the distribution system for all possible combinations of load and output power of DGs.

In [8-10] the forecasted amount of uncertain parameters are produced by PDF for each hour, then a Monte Carlo Simulation (MCS) method is used for generating different scenarios. The PDF method is also used for modeling uncertainty in [11], but the imperialist competitive algorithm (ICA) is applied to solve proposed problem and obtained results are compared with Monte Carlo simulation method. Reference [12], considered the uncertainty of future wind power, electricity price and load demand. A Gaussian PDF is used to modelling hourly load forecast errors. Also, the ARMA model is used to predict hourly market prices and wind speed forecast errors. Also, a fuzzy approach for modelling uncertainties is presented in [1, 14].

Integration of Energy Storage Systems (ESSs), is one of the best solutions to mitigate the effects of intermittent output power of renewable generations in distribution systems. Most important kinds and characteristics of energy storage systems, has been described in [15, 16]. The economic benefits of Battery Energy Storage Systems (BESSs) in electric distribution system are also presented in [17]. A number of recent publications used the BESS to reduce the intermittent output of REGSs, such as PV and WT, and make them dispatchable.

Some benefits of combining BESSs with high renewable penetrations in distribution networks can be expressed as follows [18-26]:

- Capacity support.
- distribution loss reduction.
- voltage regulation.
- reduction of peak demand charges.
- mitigation of operational risk from price volatility.
- maximizing profit.
- improved power quality, etc.

For example, an optimal charging/discharging scheduling for BESS is designed in [19] such that the line loss of distribution systems interconnected with sizeable PVs can be minimized. Also, the GA method is used to solve optimal problem in this work. Reference [26], presents a probabilistic framework for the operation of distribution networks considering PVs and BESSs to calculate the daily profit of the distribution network. The risk assessment and sensitivity analysis of Value at Risk (VaR) is discussed in this paper.

1.2. Contributions

It is observed from the above literature survey that the existent uncertainties in distribution network should be modelled correctly. Also, due to the impact of BESSs in maximizing profit and reducing the peak demand charges and reducing the effects of intermittent output power of renewable generations, the commitment between PVs and BESSs should be determined effectively.

Since the aim of this paper is maximizing the daily profit of distribution company, then it focuses on the uncertainties of electricity prices and output power of PVs. In this work, the existent uncertainties are modelled by PDF method and different scenarios are generated by MCS. Therefore, the main contributions of this paper are expressed as follows:

- Considering the effect of uncertain nature of electricity prices and output power of PVs in the optimal scheduling of BESSs. The PDF is used for this aim.
- Optimizing the charging/discharging scheduling of BESSs by hybrid MCS-GA in this paper.
- Modeling the impact of BESSs on the profit of Disco and renewable uncertainty management.
- Maximizing the profit of Disco by optimal scheduling of BESSs.

1.3. Paper organization

This paper is organized as follows: In section 2, the mathematical formulation of problem is presented, that contains BESSs model, uncertainty model, and objective function. In section 3, the solution technique is described. algorithm for BESS control is illustrated in Section 4. Section 5, presents test system data and results and discusses the numerical of test system. Concluding remarks are presented in section 6.

2. MATHEMATICAL FORMULATION

2.1. Battery Energy Storage System modeling

The BESS can be installed in distribution networks to reduce renewable generation problems in order to allow a higher penetration of renewable resources.

Electrical energy can be stored in batteries in the following cases:

a. When the variable electricity price is low. (The cost of power purchased from network is low.)
b. When the energy from non-dispatchable renewable sources is in excess in the system. (The load demand is lower than the generation power of PVs.)

Also, the BESS can be discharged when the network electricity price is high or when the generated renewable power is insufficient to supply the system load demand. Furthermore, the operation of BESS and charging/discharging states of battery should be controlled to provide as much benefit for network as possible.

There are some mathematical models that are used to estimate the battery status and to simulate charging/discharging procedure of batteries [19, 27-28]. Therefore, the BESS can be modelled as [19]:

$$P_{min}^{Batt} \le |P_{t,s}^{Batt}| \le P_{max}^{Batt} \quad \forall t \in T, \forall s \in S \tag{1a}$$

$$if \;\; P_{t,s}^{Batt} \ge 0 \quad SOC_{(t+\Delta t),s} = SOC_{\,t,s} + \eta^{ch} \Delta t P_{t,s}^{Batt} \quad \forall t \in T, \forall s \in S \tag{1b}$$

$$if \; P_{t,s}^{Batt} < 0 \quad SOC_{(t+\Delta t),s} = SOC_{\,t,s} - \frac{1}{\eta^{dch}} \Delta t P_{t,s}^{Batt} \quad \forall t \in T, \forall s \in S \tag{1c}$$

$$SOC_{min} \le SOC_{t,s} \le SOC_{max} \quad \forall t \in T, \forall s \in S \tag{1d}$$

$P_{t.s}^{Batt}$ is the charging or discharging power of battery at the time t and scenario s, P_{max}^{Batt} and P_{min}^{Batt} are the maximum and minimum charging or discharging power of battery, respectively. $SOC_{\,t,s}$ presents the state of charge that is a measure of the stored energy in a battery at the time t and scenario s, SOC_{min} and SOC_{max} are the allowable minimum and maximum $SOCs$, respectively.

Also, η^{ch} and η^{dch} are the charge and discharge efficiencies of the BESS unit, respectively. In Eq. (1), when the sign of $P_{t.s}^{Batt}$ is positive (+), battery is charged, and when the sign of $P_{t.s}^{Batt}$ is negative (-), battery is discharged. As can be seen from Eqs. (1b) and (1c), the stored energy at any hour depends on the stored energy of the previous hour.

In this paper, charging/discharging state of BESS (the positive or negative sign) is determined according to system conditions such as electricity price and output power of renewable resources which are obtained from MCS. A more detailed description is provided in section 3 and 4.

2.2. Uncertainty considerations

This paper considers the uncertainties of the production of PV units and electricity prices. To account for uncertainties, an algorithm combining Monte Carlo Simulations (MCS) and Probability Density Function (PDF) is proposed. In this method, each uncertain variable is described by a PDF and various scenarios are generated using the MCS.

2.2.1. PV generation systems modeling

The power output of a PV module is dependent on the weather conditions such as solar irradiance and temperature. Due to the probabilistic nature of solar irradiance, the generation of PV is also an uncertain variable.

Uncertainty of solar irradiance can be described using the Beta probability density function (PDF) as [19]:

$$\mathbf{f_b(s)} = \begin{cases} \dfrac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} s^{(\alpha-1)}(1-s)^{(\beta-1)} & 0 \le s \le 1, \alpha, \beta \ge 0 \\ 0 & \text{otherwise} \end{cases} \quad (2a)$$

$$\beta = (1-\mu)\left(\frac{\mu(1-\mu)}{\sigma^2} - 1\right) \quad (2b)$$

$$\alpha = \frac{u\beta}{1-\mu} \quad (2c)$$

where $\Gamma(*)$ is the gamma function, α and β are the parameters of Beta distribution function, s is the random variable of solar irradiance ($\mathrm{kW/m^2}$), $f_b(s)$ is the Beta distribution function of s, and μ and σ are the mean and standard deviation of s, respectively.

Then, the maximum power output of PVs at solar irradiance s, can be calculated as:

$$T_{cy} = T_A + s\left(\frac{N_{OT} - 20}{0.8}\right) \quad (3a)$$

$$I_y = s[I_{sc} + K_i(T_{cy} - 25)] \quad (3b)$$

$$V_y = [V_{oc} - K_v * (T_{cy})] \quad (3c)$$

$$FF = \frac{V_{MPPT} * I_{MPPT}}{V_{oc} I_{sc}} \quad (3d)$$

$$P_o(s) = N * FF * V_y * I_y \quad (3e)$$

Where T_{cy}, T_A and N_{OT} are the cell temperature, the ambient temperature and nominal operating temperature in $°C$. V_{MPPT} and I_{MPPT} are voltage and current at maximum power point and V_{oc} and I_{sc} are open circuit voltage and short-circuit current in V, A. K_v is the voltage temperature coefficient in V/°C and K_i is the current temperature coefficient in A/°C. N is the number of cells, P_o is the maximum generation of the PV and FF is the fill factor.

The expected output power at solar irradiance s is calculated as:

$$EP(s) = Po(s) * f_b(s) \quad (4a)$$

Hence, the total expected output power during a specified time period t, Pt (t = 1 h for this study) can be calculated as:

$$TEP(s) = \int_0^1 Po(s) * f_b(s)\, ds. \quad (4b)$$

2.2.2. Electricity prices modeling

The uncertainty in the electricity price is taken into account using Normal probability distribution function with mean value μ and standard deviation σ, which enable constructing a set of scenarios with MCS methods.

The normal distribution is defined as follow [11]:

$$f_n(l) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-(l-\mu)^2/2\sigma^2} \quad (5)$$

Where $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$ are the mean and standard deviation of load $\boldsymbol{l}$, respectively.

2.3. Objective Function

The aim of this paper is to maximize the total profit (profit = revenue - cost) over a day by optimal charging /discharging scheduling of the BESSs.

The charging/discharging scheduling of BESS should be changed hourly at least with respect to the electricity price variations and intermittent output power of PVs.

In this paper, it is assumed that the PVs generation resources and the battery storage system belong to a private company.

The objective function is to maximize daily profit can be formulated as:

$$\textit{Objective Function} = Max\ (\boldsymbol{prf_s}) \quad (6)$$

Where

$$\boldsymbol{prf_s} = \sum_{t\in T}[(\mathbf{D_t} * \mathbf{prc_{ret}}) - (\mathbf{P_{net_{t.s}}} * \mathbf{prc_{net_{t.s}}}) - (\boldsymbol{P_{PV_{t.s}}} * \boldsymbol{prc_{pv}}) - (\boldsymbol{P^{dch}_{t.s}} * \boldsymbol{prc_{dch}})]$$

In Eq. (6), prf_s is the total daily profit in each scenario, which is obtained from the difference between the revenues from the sale of electricity to consumers, and the cost of purchasing energy to supply the demand.

In this equation, the first term is the revenue of selling electricity to the customers, D_t is total demand. $\mathrm{prc_{ret}}$ is selling price to consumer in €/MWh and it is considered constant in this paper. The second term is defined as the cost of power purchased from network which is obtained by multiplying the network electricity price ($prc_{net_{t.s}}$) in purchasing power from network ($P_{net_{t.s}}$), at scenario s and time t.

The third term is the generation cost of PVs. In this term, $P_{PV_{t.s}}$ is the production of PVs at scenario s and time t, and prc_{pv} is the generation price of PVs which is considered as a constant price in this paper. The last sentence expresses the cost of discharging power of battery to supply the demand. $P^{dch}_{t.s}$ is the discharging power of battery at scenario s and time t, and price of battery discharge has been shown by prc_{dch} .In other words, the third and last terms are the money that are paid to PVs and battery owners.

The constraints of the problem are given as follows:

$$\mathbf{P}_{\mathbf{net}_{\mathbf{t,s}}} + \mathbf{P}_{\mathbf{PV}_{\mathbf{t,s}}} = \mathbf{D}_{\mathbf{t}} + \mathbf{P}_{\mathbf{t,s}}^{\mathbf{Batt}} \quad \forall \mathbf{t} \in \mathbf{T}, \forall \mathbf{s} \in \mathbf{S} \tag{7a}$$

$$\mathbf{P}_{\mathbf{PV}_{\mathbf{t,s}}} \leq \mathbf{P}_{\mathbf{PV}_{\mathbf{max}}} \quad \forall \mathbf{t} \in \mathbf{T}, \forall \mathbf{s} \in \mathbf{S} \tag{7b}$$

$$\mathbf{P}_{\mathbf{min}}^{\mathbf{Batt}} \leq |\mathbf{P}_{\mathbf{t,s}}^{\mathbf{Batt}}| \leq \mathbf{P}_{\mathbf{max}}^{\mathbf{Batt}} \quad \forall \mathbf{t} \in \mathbf{T}, \forall \mathbf{s} \in \mathbf{S} \tag{7c}$$

$$\mathbf{SOC}_{\mathbf{min}} \leq \mathbf{SOC}_{\mathbf{t,s}} \leq \mathbf{SOC}_{\mathbf{max}} \quad \forall \mathbf{t} \in \mathbf{T}, \forall \mathbf{s} \in \mathbf{S} \tag{7d}$$

In Eq. (7), $P_{t,s}^{Batt}$ represents the charging or discharging power of battery. The $P_{t,s}^{Batt}$ represents the charging power of battery when it is positive, and $P_{t,s}^{Batt}$ represents the discharging power of battery when it is negative at time *t* and scenario *s*.

Equation (7a) is the load balance constraint. Equations (7b) and (7c) are the output power constraint and charging or discharging power constraint for PVs and BESS, respectively. Equation (7d) is also the *SOC* constraint of BESS.

3. Solution Technique

The method has been used in this paper to optimizing problem, is the combination of genetic optimization algorithm and Monte Carlo simulation method.

The Monte Carlo Simulation is used for generating different scenarios. This method is the general designation for stochastic simulation using random numbers. Applications of Monte Carlo techniques can be found in many fields such as complex mathematical calculations, stochastic process simulation, medical statistics, engineering system analysis, and reliability evaluation [29]. This method is a class of computational algorithms that depends on repeated random sampling for calculating their results.

Also, the genetic algorithm is used to find the optimal solution for problem by considering uncertainties of the electricity price and output power of PVs which is modelled by MCS method.

A genetic algorithm (GA) is a metaheuristic inspired by the process of natural selection that belongs to the larger class of evolutionary algorithms (EA). high-quality solutions to optimization and search problems are generated by using of Genetic algorithms. This algorithm generates the solutions by relying on bio-inspired operators such as mutation, crossover and selection. Genetic algorithm is described in more detail in the following.

Main steps of this method can be summarized as follows:

1. Electricity prices modeling by normal distribution function.
2. Solar irradiance modeling by beta probability density function and obtaining the output power of PVs.
3. Generating scenarios by MCS.
4. Determining the state of charging/discharging state of BESSs by considering uncertain parameter values.
5. Optimizing the objective function by GA in each scenario.
6. Recording probabilistic optimal results in each scenario.
7. Create PDF of total maximum profit.

In this paper, by considering the historical data, the hourly mean value and standard deviation of solar radiation and electricity prices can be obtained by using the probability density functions. In other words, random variable of solar irradiance and electricity price generates for hour t at each scenario s. then, the generation of PV and electricity price at each hour t is obtained by fitting random variable to Beta distribution and Normal distribution, respectively for scenario s.

Eventually, the vector of uncertainties for hour t at each scenario s is obtained. That way, the Monte Carlo simulation is used for generate different scenarios of electricity price and generation power of PVs.

In step 5, the GA is used for optimization problem and it is summarized as follows:

1. Coding: the decision variables to solve an optimization problem with a GA, are represented by a chromosome. Any individual or chromosome presents only one candidate solution. In this paper, each chromosome is composed of 24 genes. Each gene represents the amount of charging or discharging power of the battery in each hour t. Fig .1, shows the structure of chromosomes in this paper. According to this figure, charging or discharging power of

battery for the analysis period is generated in each population .The amount of battery power is generated randomly in each hour but the state of charging or discharging of battery (positive or negative sign) is determined according to the system conditions such as electricity price and PVs output power in each scenario and each hour. As also shown in (1), the battery is charged when the sign of battery power is selected positive. Also, the battery is discharged when the negative sign is selected for power of the battery. A more detailed description to control the battery is expressed in section IV.

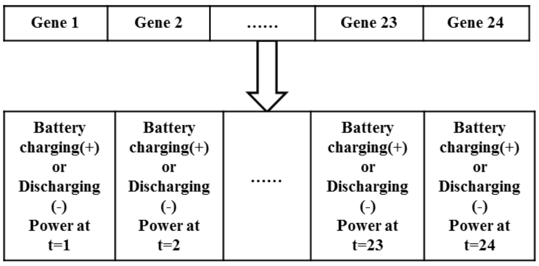

Fig.1. Structure of chromosomes

2. Initialization: GA operates with a set of populations. In this paper, all initial populations are generated randomly. But the allowable maximum and minimum charging and discharging power of battery and SOC should be according Eqs. (7c) and (7b), respectively. If these constraints are violated, the initial population must be regenerated.
3. Fitness evaluation: The fitness evaluation requires to determine which population is the better. In other words, the fitness value of each population is determined through the fitness evaluation procedure. In this paper, the fitness function is defined as follows:

$$\begin{aligned} Fitness = & \sum_{t\in T}[(D_t * prc_{ret}) - (P_{net_{t.s}} * prc_{net_{t.s}}) \\ & - (P_{PV_{t.s}} * prc_{pv}) - (P_{t.s}^{dch} * prc_{dch})] \\ & + \sum_{t\in T}[PF_{PV_{t.s}}] \\ & + \sum_{t\in T}[PF_{Batt\,t.s}] \\ & + \sum_{t\in T}[PF_{soc\,t.s}] \end{aligned} \quad (8)$$

Equation (8) is the summation of objective function and penalty factors caused by the violations of constraints formulated in Eqs. (7b-7d), where $PF_{PV_{t.s}}$, $PF_{Batt\,t.s}$, $PF_{soc\,t.s}$ are the penalty factors for constraints of Eqs. (7b), (7c), (7d), respectively. For example, to determine the $PF_{soc\,t.s}$, can be act as follows:

$$\begin{aligned} & if \quad soc_{min} \leq soc_{t.s} \leq soc_{max} \\ & PF_{soc\,t.s} = 0 \quad else \quad PF_{soc\,t.s} = K_{SOC} \end{aligned} \quad (9)$$

4. Crossover: In genetic algorithms, Crossover is a process of taking more than one parent solutions and producing a child solution from them.
5. Mutation: Mutation alters one or more gene values in a chromosome from its initial state. In mutation, the solution may change entirely from the previous solution. Hence GA can come to a better solution by using mutation.

Therefore, according to the above description, the method of this paper can be shown as Fig. 2.

In the flowchart of Fig.2, sample and s correspond to the total number of different probabilistic scenarios and scenario counter in Monte Carlo observations, respectively, t correspond to the hour in the time horizon(24h). Finally, k corresponds to the counter of iteration in genetic algorithm.

As can be seen in Fig.2, at first, the uncertain electricity price and generation of PV units are calculated by using of probability distribution function and historical data, then these values are considered as input data for MCS-GA. According to these parameters, the state of charging or discharging of BESSs is determined for hour t at each scenario s. More detailed description of determine the state of BESSs is illustrated in flowchart of Fig.3.

The next step is optimizing the problem by GA. In this step, the amount of charging or discharging power of battery for the analysis period is generated in each population randomly. Then with regard to the BESSs power, the daily maximum profit can be obtained in each scenario s. In the last step, considering that the optimal amount of obtained profits is probabilistic over the scenarios, the probability density function can also be obtained for the output parameters. Therefore, using the method shown in Fig .2, the optimal scheduling of battery energy storage system (amount and state of charging or discharging power), can be achieved to maximize the daily profit.

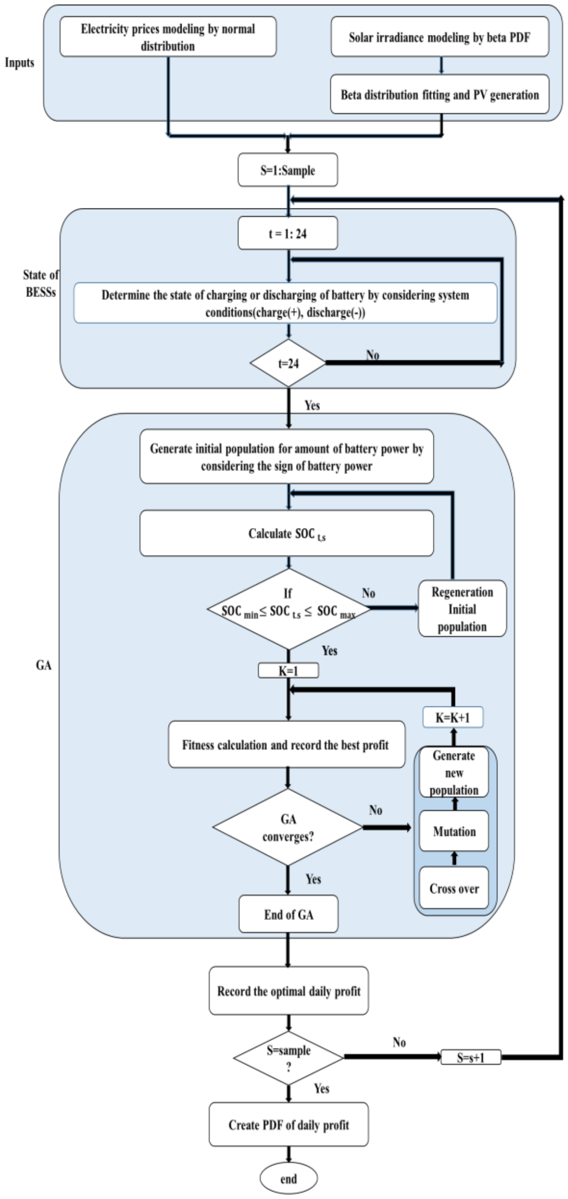

Fig. 2. Flowchart of MCS-GA

4. ALGORITHM FOR BESS CONTROL

As previously mentioned, for optimal scheduling of battery, need to know the conditions of the system. In fact, the BESS is charged or discharged by considering electricity prices and generated power of PVs at each scenario s and each hour t. In other words, the state of charging or discharging of battery is determined by the uncertain parameters. The flowchart of BESS control is depicted in Fig.3.

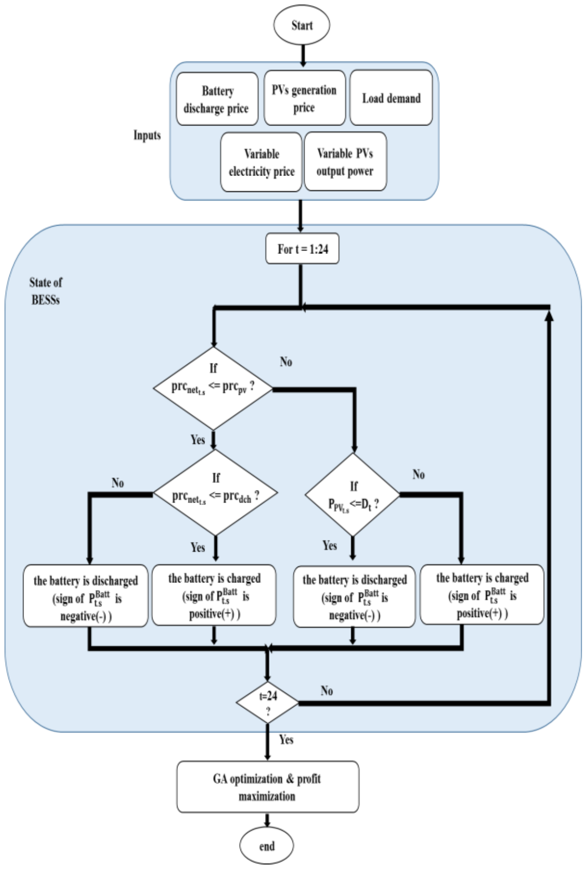

Fig. 3. Flowchart of BESS control in each scenario

As can be seen in Fig. 3, battery can be charged or discharged at each hour t in the scenario s, in below cases:

1. When the network electricity price is lower than the generation price of PVs and the price of discharging power from battery. In this case, the sign of battery power is positive and battery is charged.
2. When the generation price of PVs is lower than the network electricity price and the load demand is lower than the generated power from PVs. In this case, the positive sign is selected for the power of battery, too.
3. When the network electricity price is lower than the generation price of PVs but it is higher than the price of discharging power from battery. In this case, the sign of battery power is negative and battery is discharged. In this case, to meet demand, at first the battery discharges; then, If the load demand is not met yet, power can be purchased from the network.

4. When the generation price of PVs low and the load demand is higher than the generated power from PVs.
   In this case, the sign of battery power is negative and battery is discharged, too.

After determining the charging and discharging state of the battery, by using of the genetic algorithm, the problem can be optimized in each scenario. For calculating the daily profit, it is necessary to consider the below points:

- When the case 1 occurs, the required energy for charging the batteries and supplying the load demand is purchased from network.
- When the case 2 occurs, the required energy for charging the batteries and supplying the load demand is purchased from PV units.
- When the case 3 occurs, the required energy for supplying the load demand, at first is provided from discharging power from battery then if it is needed, is purchased from network.
- When the case 4 occurs, the required energy for supplying the load demand, is provided from generation power of PVs and discharging power from battery.

Another conclusion that can be derived from expressions, is that the load demand can be met from three sources as follows:

a) from network
b) from PV generation units
c) from battery energy storage systems

Also, the BESS can be charged from two sources as follows:

a) from network
b) from PV generations

5. TEST RESULTS AND DISCUSSIONS

5.1. Test System Data

The proposed method was implemented with MATLAB on a Windows based PC. A distribution feeder acquired from Taiwan Power Company is used as the test system. The 24-hour real power of loads for the typical summer days are shown in Fig.4. Table 1 presents the parameters of PV module and BESS which are used in this paper as [19]. By considering of maximum solar irradiance (s =1 kw/m2), the number of PV modules can be obtained by (3). The mean value and standard deviation of electricity prices for each hour of the day are illustrated in Table 3 as [30]. The corresponding hourly solar irradiance for the summer days acquired from Taiwan Weather Bureau are illustrated in Table 2. More detailed description of the test system, is presented in [19]. PVs generation resources with 1500 Kw maximum power are installed in the network. A BESS with 3MWh installed capacities (C) is installed at the test system. The time step considered in this paper is 1 hour.

Table 1. Parameters of PV module and BESS

Parameter	Unit	Value
Ambient temperature of PV module, TA.	°C	30.76
Nominal operating temperature of PV module, Not.	°C	43
Current at maximum power point, Imppt.	A	7.76
Voltage at maximum power point, Vmppt.	V	28.36
Short-circuit current, Isc.	A	8.38
Open circuit voltage, Voc.	V	36.96
Current temperature coefficient, Ki.	A / ° C	0.00545
Voltage temperature coefficient, Kv.	V / ° C	0.1278
Minimum power of battery, $\mathbf{P}_{\mathbf{min}}^{\mathbf{Batt}}$.	MWh	0.025*C
Maximum power of battery, $\mathbf{P}_{\mathbf{max}}^{\mathbf{Batt}}$.	MWh	0.25*C
Initial state of charge, $\mathbf{SOC}_{\mathbf{0,s}}^{\mathbf{BES}}$.	-	0.33
Allowable minimum state of charge, $\mathbf{SOC}_{\mathbf{min}}$.	-	0.05
Allowable maximum state of charge, $\mathbf{SOC}_{\mathbf{max}}$.	-	1
Charge and Discharge efficiencies of the BESS, $\boldsymbol{\eta}^{\mathbf{ch/dch}}$.	-	0.95

Table 2. Solar Irradiances of the Test System

Hour	Mean (Kw/m2)	Standard Deviation (kw/m2)
1-5	0.000	0.000
6	0.007	0.021
7	0.081	0.036
8	0.237	0.56
9	0.400	0.087
10	0.523	0.127
11	0.632	0.156
12	0.663	0.162
13	0.657	0.164
14	0.612	0.147
15	0.497	0.143
16	0.349	0.116
17	0.203	0.081
18	0.068	0.063
19	0.003	0.012
20-24	0.000	0.000

The prices of selling electricity to consumers(prc_{ret}), PVs production (prc_{pv}) and battery discharge (prc_{dch}) are 70 €/MWh, 60 €/MWh and 65 €/MWh, respectively. These prices are considered constant in this paper.

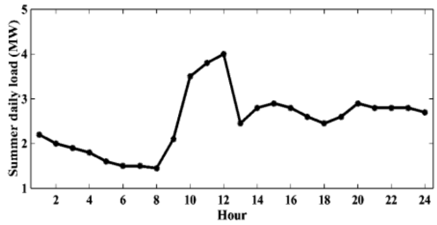

Fig. 4. Daily load profiles of the test feeder

With regard to these prices, it is observed that the price of PVs production has been assumed less than battery discharge price. The parameters of MCS-GA method are also presented in Table 4.

5.2. Test System Results

Considering that the electricity prices and solar irradiance are uncertain, so the probability density function of electricity prices and solar irradiances can be obtained for each hour. For example, the PDF of electricity prices and solar irradiances and PV power at hour 10 are depicted in Fig. 5.

Table 3. Mean Value and Standard Deviation of Electricity Price

Hour	Mean Price [€/MWh]	Standard Deviation [€/MWh]
1	28.55	3.64
2	28.30	5.26
3	28.95	4.56
4	27.71	3.23
5	27.53	3.48
6	26.55	4.63
7	26.40	2.43
8	60.20	12.89
9	61.98	8.09
10	69.04	7.89
11	70.34	6.29
12	68.89	8.90
13	68.76	9.20
14	68.68	8.57
15	70.16	8.14
16	70.41	5.61
17	69.52	8.07
18	64.48	8.08
19	61.67	12.09
20	57.34	13.78
21	58.04	12.74
22	61.85	11.46
23	41.80	8.79
24	41.50	8.59

Table 4. Parameters of MCS-GA method

Parameter	Value
Iteration number of GA	200
Population number of GA	150
Crossover rate	0.7
Mutation rate	0.2
Number of scenarios	100
Time horizon (hour)	24

Uncertain parameters such as electricity prices can be generated in different scenarios by MCS method. For example, Fig. 6 illustrates different generated scenarios of electricity price. This figure provides the forecasted electricity price and the generated prices at the 25th, 44th, 50th, 75th and 100th scenarios.

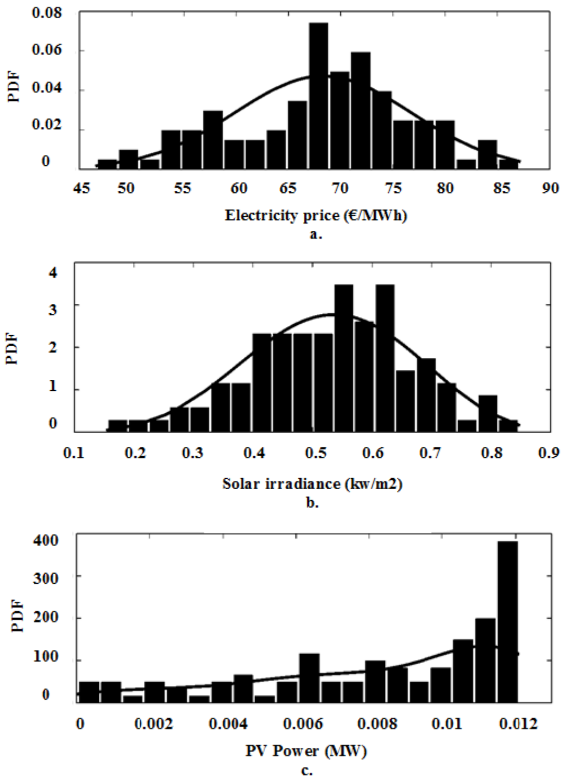

Fig. 5. .PDF of a) Electricity prices. b) Solar irradiance c) PV power at hour 10

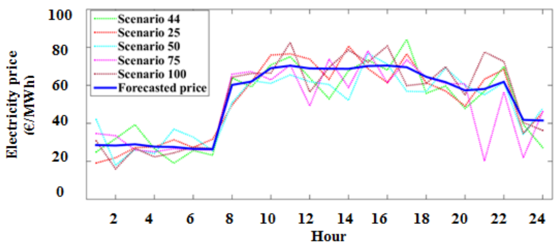

Fig. 6. Electricity price in different scenarios

According to the described method to optimize, an optimal solution for daily profit is obtained for each Monte Carlo iteration by using the genetic algorithm. So, the PDF and cumulative distribution function (CDF) of the maximum daily profit can be achieved during time horizon. Figure. 7. illustrates the PDF and CDF of maximum daily profit. It is observed from Fig.7 (a), that the daily profit which is ranged between 2200 and 2500 (€), has the highest probability of occurrence at all scenarios. Furthermore, it can be assumed that the scenario which has the profit with highest probability of occurrence to be selected as the best scenario. Considering this assumption, the electricity prices (€/MWh), purchased power from network (MW), purchased power from PV units (MW), optimal charging/discharging power of battery (MW) at this scenario, are depicted in Fig. 8.

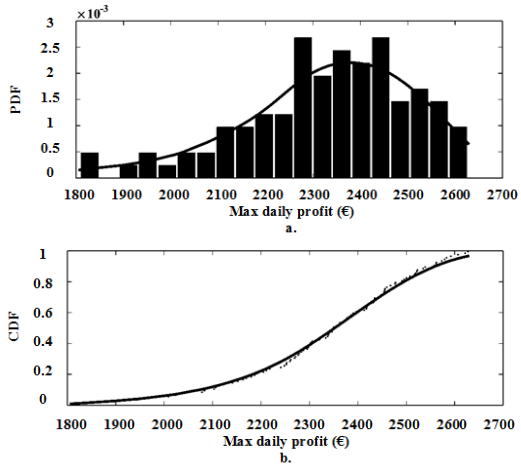

Fig.7. a) PDF of maximum daily profit. b) CDF of maximum daily profit

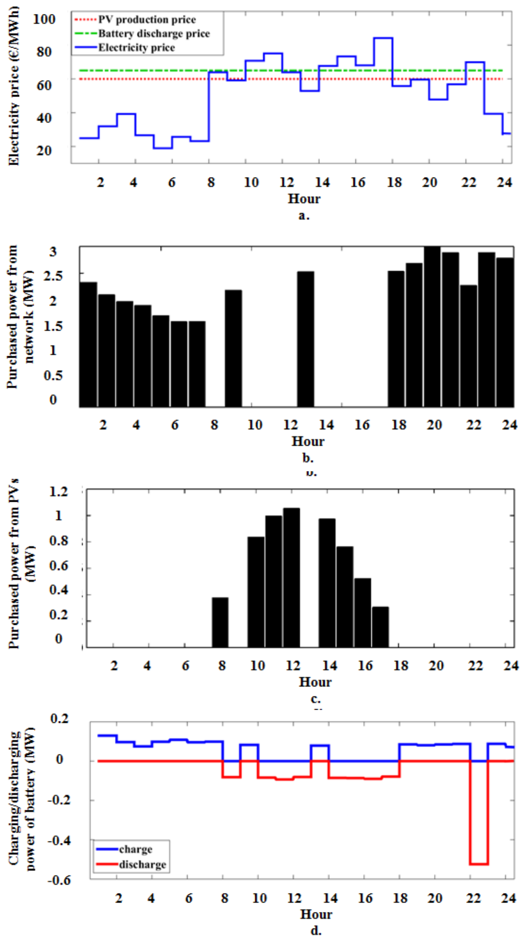

Fig.8. Results of a) Electricity prices. b) Purchased power from network(MW). c) Purchased power from PV generation units (MW). d) Charging/Discharging power of battery (MW)

In this paper, the 44th scenario is the best scenario. Maximum daily profit in this scenario is 2377.8(€). For example, the value of this parameters at 44th scenario and hour 22, are depicted in Table 5. As can be expected, according to the Fig. 8, when the electricity price is lower than the generation price of PVs and discharging price of battery, required power for supply the demand and charge the battery is purchased from network (hours 1-7, 9,13, 18-24), at other times, power is supplied through the PV units. On the other hand, in these hours (8,10-12,14-17), since the demand is higher than the generation power of PVs, the battery is also discharged to supply the demand.

Table 5. Obtained value of parameters in scenario 44 and time 22

Parameter	Value
Generation price of PVs	60 (€/MWh)
Discharging price of BESSs	65(€/MWh)
Network electricity price	72.511(€/MWh)
State of BESSs	Discharge (-)
Load demand	2.8(MW)
P_{net}	2.5139(MW)
P_{pv}	0
P_{Batt} (P^{dch})	-0.28609(MW)

It should be noted that in the hours that PVs generation cannot generate electricity, such as night, regardless of the electricity prices, power for supply the demand and charge the battery, is purchased from network. Hour 22 is a sample for this type. In this hour, electricity price is high. Thus, due to the low price of battery discharge, firstly battery discharged to meet demand. Then due to the PV units cannot generate any power in this hour, power is purchased from network. Also, the PDF of total purchased power from network and PV units are depicted in Fig.9.

6. CONCLUSIONS

This paper proposed an optimal charging/discharging scheduling of BESS to maximize the daily profit. The MCS-GA method is used for optimizing problem. A probabilistic method is used to uncertainty modelling. Different scenarios for electricity price and PVs output power are generated by PDF and MCS approach. Because of probabilistic behaviour of input vector such as electricity price and renewable power generation, the extracted results for maximum daily profit are defined in PDF and CDF forms. According to the results, it can be observed that the presence of battery energy storage in the distribution network, can reduce the impact of electricity prices and PVs generation uncertainties. In other words, the battery can reduce the cost and increase the profits, by saving the energy during the hours that electricity price and demand are low and by delivering the power at hours with high price and high demand. Further work will include the modelling of other renewable DG technologies with uncertainty in the primary energy sources and electricity demand.

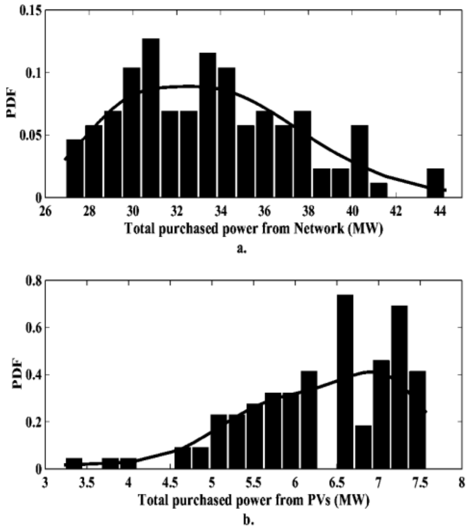

Fig. 9. PDF of total purchased power from a) Network b) PV generation units

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