Analysis of the Uncertainty Effect in Power System Losses: Uncertainties of Renewable Energy and Load

İbrahim Çağrı Barutçu[1*], Ali Erduman[2]

[1*] Hakkari University, Çölemerik V.H.S., Departmant of Electricity and Energy, Hakkari, Turkey, (ORCID: 0000-0001-6164-2048), ibrahimcagribarutcu@hakkari.edu.tr
[2] Sakarya University of Applied Sciences, Hendek V.H.S., Departmant of Electricity and Energy, Sakarya, Turkey, (ORCID: 0000-0003-4116-3159), alierduman@subu.edu.tr

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Abstract

The energy loss minimization problem is increasingly gaining prominence as a result of widespread integration of renewable energy sources into the power systems. Thus, the optimal planning of power system is required to handle the technical issues due to the uncertainties in load demands and the intermittent characteristics in photovoltaic (PV) and wind turbine (WT) systems. In this paper, the impacts of various uncertainty scenarios have been considered while mitigating the total energy losses in the power network, where PV and WT systems are installed. Particle Swarm Optimization (PSO) algorithm has been implemented to determine the optimal values of control variables while taking into account the power system technical constraints. The influences of different uncertainty scenarios have been considered while alleviating total energy losses in the implementation of planning.

Keywords: Energy Loss Minimization, Power System Planning, Uncertainty, Renewable Energy Sources.

Güç Sistemi Kayıplarında Belirsizlik Etkisinin Analizi: Yenilenebilir Enerji ve Yük Belirsizlikleri

Öz

Yenilenebilir enerji kaynaklarının güç sistemlerine yaygın şekilde entegre edilmesi sonucunda enerji kaybı minimizasyonu problemi giderek daha fazla önem kazanmaktadır. Bu nedenle, fotovoltaik (PV) ve rüzgar türbini (WT) sistemlerindeki kesikli karakteristikler ve yük taleplerindeki belirsizlikler nedeniyle teknik sorunları ele almak için güç sisteminin optimal planlanması gerekmektedir. Bu makalede, PV ve WT sistemlerinin kurulu olduğu güç şebekesindeki toplam enerji kayıplarının azaltılmasında çeşitli belirsizlik senaryolarının etkileri dikkate alınmıştır. Güç sistemi teknik kısıtları dikkate alınarak kontrol değişkenlerinin optimal değerlerinin belirlenmesi için Parçacık Sürü Optimizasyonu (PSO) algoritması uygulanmıştır. Planlamanın uygulanmasında toplam enerji kayıpları azaltılırken farklı belirsizlik senaryolarının etkileri dikkate alınmıştır.

Anahtar Kelimeler: Enerji Kaybı Minimizasyonu, Güç Sistemi Planlaması, Belirsizlik, Yenilenebilir Enerji Kaynakları.

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* Corresponding Author: ibrahimcagribarutcu@hakkari.edu.tr

1. Introduction

Distributed generation (DG) integration into the power system yields optimal results when central generation units are insufficient for the demands far away from the source. DG has gained great importance with the increasing load demand in power systems. DG units, which have small capacity, are integrated in the proximity of load demands. Minimizing power network losses, improving voltage profile, enhancing system reliability, stability can be acquired by optimal integration of DGs [1 – 3].

However, the renewable DG resources and load demands in the power systems have uncertainties in practical operating conditions. In the planning investigations, the importance is emphasized on the uncertainties of electricity demands, solar irradiance and wind speed because of the growing penetrations of PV and WT units in the power systems. From the uncertainty standpoint, the examinations on the suitable planning of renewable integrated power systems are inevitable for analyzing these active power networks properly. In that manner, the density functions with probabilistic features are utilized to model the input variables such as load, solar irradiance and wind speed uncertainties. The research studies related with the power system planning consist of these variabilities. With the consideration of renewable installation, the power system technical problems are expected to maintain their prominence. By the integration of PV and WT units, the planning on power quality is needed to be performed by power system owners. The energy loss minimization while considering the security problems in the renewables installed active power systems has an important role in the optimization planning with uncertainties. This optimization problem is suitably planned so that the power can be transmitted to the consumption demand of power system in a reliable and efficient way.

In the literature, the uncertainties related with the load demand, photovoltaic distributed generation (PV), and wind turbine distributed generation (WT) are handled as presented in Table 1.

Table 1. Uncertainty modelling in the literature

Literature	Load	Solar Irradiance	Wind Speed
[4]	Normal Distribution	-	-
[5]	Normal Distribution	-	-
[6]	Triangular Fuzzy Number	-	-
[7]	Gaussian Distribution	-	Weibull Distribution
[8]	Normal Distribution	-	Weibull Distribution
[9]	Gaussian Distribution	-	Weibull Distribution
[10]	Normal Distribution	Beta Distribution	Weibull Distribution
[11]	Normal Distribution	Beta Distribution	Weibull Distribution
[12]	Normal Distribution	Beta Distribution	Weibull Distribution
[13]	Normal Distribution	Lognormal Distribution	Weibull Distribution
[14]	Normal Distribution	Beta Distribution	Weibull Distribution
[15]	Bivariate Normal Distribution (active and reactive load variables)	Beta Distribution	Weibull Distribution
[16]	Normal Distribution	Beta Distribution	Weibull Distribution

As seen in Table 1, the uncertainties of load, solar irradiance and wind speed are modelled in various ways. The studies can be separated into the three categories in terms of uncertainty modelling. The first category is observed as the papers, where only load uncertainty has been considered [4 – 6]. Load uncertainty has been modelled by using normal distribution in [4, 5] and triangular fuzzy number in [6]. Both load and wind speed uncertainties are taken into account by utilizing normal and Weibull distribution functions as the second category [7 – 9]. In the third category, all of the load, solar irradiance and wind speed uncertainties have been considered [10 – 16]. In this category, normal, beta and Weibull distributions have been implemented for representing the uncertainties in some of the studies [10 – 12, 14, 16]. As a difference, the solar irradiance has been modelled by lognormal distribution in [13] and the load has been represented by bivariate normal distribution in [15].

In the relevant literature, the papers related with the impacts of DG systems on the loss issues can be observed [17 – 21]. In [17], selective particle swarm optimization (SPSO) algorithm has been applied to solve the reconfiguration problem of distribution system with light, normal, and heavy loading conditions while considering power loss mitigation and voltage profile improvement as multi objectives. This problem has also been addressed for radial distribution system considering DG placement by implementing hybrid simulated annealing – modified PSO in [18]. It is worthy to note that optimal

installation of DG systems can present economical savings in terms of costs concerned with these renewable units and power system losses. In that manner, these costs have been taken into account in the objectives for optimal capacity and location of DGs by applying PSO approaches [19 – 21].

In the present study, the influences of different uncertainty scenarios have been taken into account while alleviating the total energy losses in the power system, in which renewable sources are interconnected. In the optimization framework, the technical inequality constraints including bus voltages, line flows, reactive powers of synchronous generators and active power of slack bus generator have been considered while evaluating the optimal control variables such as active powers of generators except for the slack bus, generator bus voltages, transformer tap settings, PV and WT sizes by using PSO. The planning with the consideration of the impacts of different uncertainty scenarios has been implemented by minimizing total energy losses together with the inclusion of technical limits.

2. Methodology

2.1. Input the Grid Network Parameters

In this paper, the 9 bus power network, which is presented in Figure 1, has been handled to implement the study simulations of proposed approach. The power system data can be found in [22].
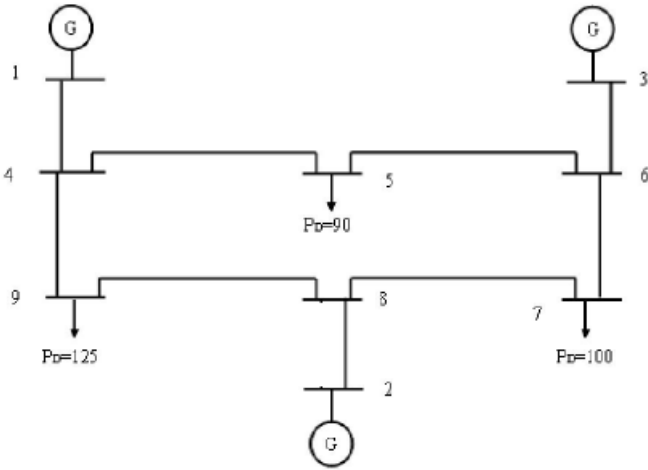

Figure 1. 9 bus power network [22]

2.2. Load, Solar Irradiance and Wind Speed Uncertainties

2.2.1. Load Uncertainty

In this work, the load demand data is produced with the consideration of normal distribution [4, 5, 7 – 16]. The distribution function that shows the uncertainty of load is presented as follows:

$$f(P_{Load,m}) = \left(\frac{1}{\sigma_{L,m}\sqrt{2\pi}}\right) exp\left(-\frac{(P_{Load,m} - P_{Load,m,avg})^2}{2\sigma_{L,m}^2}\right) \quad (1)$$

where $P_{Load,m,avg}$ is the average of load power at bus m, $P_{Load,m}$ is the load power at bus m, $\sigma_{L,m}$ is the standard deviation of load power at bus m.

2.2.2. Solar Irradiance Uncertainty

In this paper, the solar irradiance data is generated by taking into account beta distribution [10 – 12, 14 – 16]. The function of probability distribution representing beta distribution is given as:

$$f(SR_m) = \begin{cases} \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} SR_m^{(\alpha-1)}(1 - SR_m)^{(\alpha-1)} & 0 \leq SR_m \leq 1, \alpha \geq 0, \beta \geq 0 \\ 0 & otherwise \end{cases}$$

$$(2)$$

where SR_m is the solar radiation falling on the PV system at bus m of distribution system, α and β are the parameters of beta distribution function. These parameters can be evaluated as:

$$\beta = (1 - \mu)\left(\frac{\mu(1 - \mu)}{\sigma^2} - 1\right) \quad (3)$$

$$\alpha = \frac{\mu\beta}{1 - \mu} \quad (4)$$

where μ and σ show average and standard deviation values, respectively. Depending upon the solar radiation, the PV active powers can be obtained as in the following:

$$P_{PV,m} = P_{PV,rated}SR_m \quad (5)$$

where $P_{PV,m}$ is the active power of PV at bus m, $P_{PV,rated}$ is the rated active power of PV for the solar radiation of 1000 W/m^2.

2.2.3. Wind Speed Uncertainty

In this study, the long term data of wind speed is produced by considering Weibull distribution [7 – 16]. The distribution function, which represents wind speed, is presented as:

$$f(v_{WT,m}) = \left(\frac{2v_{WT,m}}{c^2}\right) exp\left(-\left(\frac{v_{WT,m}}{c}\right)^2\right) \quad (6)$$

where $v_{WT,m}$ is the speed of wind on the WT at bus m, c is the parameter of distribution function. The WT active power at bus m can be determined as follows:

$$P_{WT,m} = \begin{cases} \left(\frac{v_{cut-in} - v_{WT,m}}{v_{cut-in} - v_{WT-rated}}\right)P_{WT,rated} & v_{cut-in} \leq v_{WT,m} \leq v_{WT-rated} \\ P_{WT,rated} & v_{WT-rated} \leq v_{WT,m} \leq v_{cut-out} \\ 0 & otherwise \end{cases}$$

$$(7)$$

where $P_{WT,rated}$ is the rated active power of WT, $v_{WT-rated}$ is the rated speed of WT, v_{cut-in} and $v_{cut-out}$ are the cut-in and cut-out speeds of WT, respectively.

Due to the increasing installation of PV and WT systems in the power network, solar irradiance, load consumption and wind speed uncertainties are maintaining their prominence in the planning studies. The accurate analysis of PV and WT units integrated power grids requires the proper active power network planning investigations with the consideration of uncertainties. In this context, the inputs of grid planning studies are composed

of load, solar irradiance and wind speed variabilities that match the distributions with probability characteristics. The uncertainties of these input variables are required to be contained in the power flow planning researches. Therefore, the intermittencies of PV and WT systems and uncertainties of consumption demands are represented by the expressions with probabilistic features.

2.3. Optimization Process

In this paper, Particle Swarm Optimization (PSO) has been implemented to determine the optimal values of control variables comprising of active powers of generators except for the slack bus, generator bus voltages, transformer tap settings, PV and WT capacities by considering the technical constraints such as bus voltages, line flows, reactive powers of synchronous generators and active power of slack bus generator in optimization planning process. The investigations on the grid network optimization planning require the inclusion of both intermittent features of PV and WT systems and uncertainties of electricity consumptions. Under different uncertainty cases, the total energy losses have been minimized taking into account the constraints. Minimizing the energy losses and maintaining the grid network technical constraints within the corresponding limits are the main purposes by considering the uncertainty effects in the planning examination. The objective function is illustrated as in the following:

$$E_{Losses} = \sum_{st=1}^{Nst} \sum_{n=1}^{NLine} P_{Loss,n}^{st} \quad (8)$$

where E_{Losses} is the total power network energy losses, Nst is the total number of states in the uncertainties, $P_{Loss,n}^{st}$ is the loss corresponding to active power on the nth line of power system for the st^{th} state, $NLine$ is the total amount of lines in the power network. The technical state variables, which have been evaluated from the repetitive power flow analysis, have been considered as the constraints in the optimization process. These constraints have been determined from the power flow algorithm implemented for Nst states at every epoch of PSO algorithm. The constraints representing the inequalities are demonstrated as in the following:

$$V_{m,min} \leq V_m^{st} \leq V_{m,max} \quad m = 1, \ldots, NBUS \; st = 1, \ldots, Nst \quad (9)$$

$$S_{flow,n}^{st} \leq S_{flow,n,max} \quad n = 1, \ldots, NLine \; st = 1, \ldots, Nst \quad (10)$$

$$Q_{gen,m,min} \leq Q_{gen,m}^{st} \leq Q_{gen,m,max} \quad m = 1, \ldots, NGEN \\ st = 1, \ldots, Nst \quad (11)$$

$$P_{gen,1,min} \leq P_{gen,1}^{st} \leq P_{gen,1,max} \quad st = 1, \ldots, Nst \quad (12)$$

where V_m^{st} is the magnitude of voltage at bus m of the power network for st^{th} state, $S_{flow,n}^{st}$ is the apparent power flow on the line n of power system for st^{th} state, $Q_{gen,m}^{st}$ is the reactive power generation of synchronous generator at bus m for st^{th} state, $P_{gen,1}^{st}$ is the active power generation of slack bus generator for st^{th} state, $V_{m,min}$ and $V_{m,max}$, which are 0.9 pu and 1.1 pu, are the lower and upper limits of voltage magnitude at bus m, $S_{flow,n,max}$ is the maximum limit of apparent power flow on line n, $Q_{gen,m,min}$ and $Q_{gen,m,max}$ are the minimum and maximum limits of reactive power generation at bus m, $P_{gen,1,min}$ and

$P_{gen,1,max}$ are the lower and upper limits of active power generation at slack bus, $NBUS$ and $NGEN$ are the total amount of buses and generators, respectively.

The constraints, which represent the equalities, are illustrated as given by:

$$P_{gen,m} - P_{load,m} - \sum_{l=1}^{NBUS} |V_m||V_l||y_{m,l}| cos(\delta_{m,l} - \theta_m + \theta_l) \\ = 0 \quad (13)$$

$$Q_{gen,m} - Q_{load,m} - \sum_{l=1}^{NBUS} |V_m||V_l||y_{m,l}| sin(\delta_{m,l} - \theta_m + \theta_l) \\ = 0 \quad (14)$$

where $P_{load,m}$ and $Q_{load,m}$ represent the loads corresponding to active and reactive powers, $|y_{m,l}|$ and $\delta_{m,l}$ show the magnitude and angle values of admittance matrix corresponding to m^{th} row and l^{th} column, θ_m depicts the angle of voltage at bus m, respectively.

In this article, the violations of inequality constraints have been considered to construct the total objective function by using the penalty function methodology.

$$f_{total} = \sum_{st=1}^{Nst} \sum_{n=1}^{NLine} P_{Loss,n}^{st} \\ + cp_V \sum_{st=1}^{Nst} \sum_{m=1}^{NBUS} |V_m^{st} - V_{m,min/max}| \\ + cp_{S_{flow}} \sum_{st=1}^{Nst} \sum_{n=1}^{NLine} |S_{flow,n}^{st} - S_{flow,n,max}| \quad (15) \\ + cp_{Q_{gen}} \sum_{st=1}^{Nst} \sum_{m=1}^{NGEN} |Q_{gen,m}^{st} - Q_{gen,m,min/max}| \\ + cp_{P_{gen,1}} \sum_{st=1}^{Nst} |P_{gen,1}^{st} - P_{gen,1,min/max}|$$

where cp_V, $cp_{S_{flow}}$, $cp_{Q_{gen}}$, and $cp_{P_{gen,1}}$ are the coefficients of penalties when voltage magnitudes, apparent power flows, reactive powers of synchronous generators and active power of slack bus generator violate their corresponding limits, respectively. The total power network energy losses are minimized with the consideration of maintaining the inequality constraints as demonstrated in (15). Hence, the objective function gets greater numbers because of the coefficients of penalties when the inequality constraints violate their limits. In this context, the PSO planning process investigates more convenient outcomes while dealing with (15). The control variables, which are the optimal solutions of PSO planning process, are given as in the following:

$$X = \begin{pmatrix} P_{gen,2}, \ldots, P_{gen,m}, \ldots, P_{gen,NGEN}, \\ V_{gen,1}, \ldots, V_{gen,m}, \ldots, V_{gen,NGEN}, \\ TR_1, \ldots, TR_n, \ldots, TR_{NTR}, \\ P_{PV,rated,1}, \ldots, P_{PV,rated,m}, \ldots, P_{PV,rated,NPV}, \\ P_{WT,rated,1}, \ldots, P_{WT,rated,m}, \ldots, P_{WT,rated,NWT} \end{pmatrix} \quad (16)$$

where

$$P_{gen,m,min} \leq P_{gen,m} \leq P_{gen,m,max} \quad m = 2, \dots, NGEN \quad (17)$$

$$V_{gen,m,min} \leq V_{gen,m} \leq V_{gen,m,max} \quad m = 1, \dots, NGEN \quad (18)$$

$$TR_{n,min} \leq TR_n \leq TR_{n,max} \quad n = 1, \dots, NTR \quad (19)$$

$$P_{PV,m,min} \leq P_{PV,rated,m} \leq P_{PV,m,max} \quad m = 1, \dots, NPV \quad (20)$$

$$P_{WT,m,min} \leq P_{WT,rated,m} \leq P_{WT,m,max} \quad m = 1, \dots, NWT \quad (21)$$

where $P_{gen,m}$, $V_{gen,m}$, $P_{PV,rated,m}$, and $P_{WT,rated,m}$ are active power of generator at bus m, generator voltage at bus m, active power capacity of PV system at bus m, and active power capacity of WT system at bus m, respectively. $P_{gen,m,min}$, $V_{gen,m,min}$, $TR_{n,min}$, $P_{PV,m,min}$, $P_{WT,m,min}$ represent the minimum limits of generator active powers, generator bus voltages, transformer tap settings, PV system active powers, WT system active power outputs, whereas $P_{gen,m,max}$, $V_{gen,m,max}$, $TR_{n,max}$, $P_{PV,m,max}$, $P_{WT,m,max}$ show the maximum limits of these technical parameters, respectively. NTR, NPV, and NWT are the total amount of transformers, PV and WT systems.

2.4. PSO Implementation

The attitudes of crowds of birds and training of fishes are socially imitated by the perception algorithm, which is PSO [23]. The particle community, which has resemblance to individuals, is utilized while the exploration is being administrated by this approach. The possible outcome is represented by every particle of community for the problem, which is to be handled. The randomly beginning that belongs to the community, which is composed of individuals, is launched and the attitude that corresponds to the particles is socially processed. Accordingly, the orientation that is owned by every individual is basically calibrated to its most suitable position and the finest particle of the community while discovering the global optimization outcome at every iteration in the algorithm. In this paper, PSO algorithm [23] has been applied to solve the constrained energy loss minimization problem. According to this optimization method, the velocities and positions of particles are updated with the consideration of equations (22) and (23), respectively.

$$\gamma_{s+1}^{m,n} = w\gamma_s^{m,n} + c^1 rn^1(Pbest_s^{m,n} - \theta_s^{m,n}) + c^2 rn^2(Gbest_s^n - \theta_s^{m,n}) \quad (22)$$

$$\theta_{s+1}^{m,n} = \theta_s^{m,n} + \gamma_{s+1}^{m,n} \quad (23)$$

where $\gamma_s^{m,n}$ and $\theta_s^{m,n}$ are the velocity and position corresponding to the nth member of the mth particle for s^{th} iteration, respectively. c^1 and c^2 are the personal and social acceleration coefficients, rn^1 and rn^2 are the random numbers, w is the inertia coefficient, $Pbest_s^{m,n}$ is the best position corresponding the mth particle for s^{th} iteration, $Gbest_s^n$ is the swarm's global best position for s^{th} iteration.

The iteratively variation of inertia coefficient is presented as in the following:

$$w = max_w - \frac{max_w - min_w}{max_s} s \quad (24)$$

where max_w and min_w are the upper and lower limits of inertia coefficient, max_s is the maximum number of iterations. The flowchart of proposed methodology is shown in Figure 2.
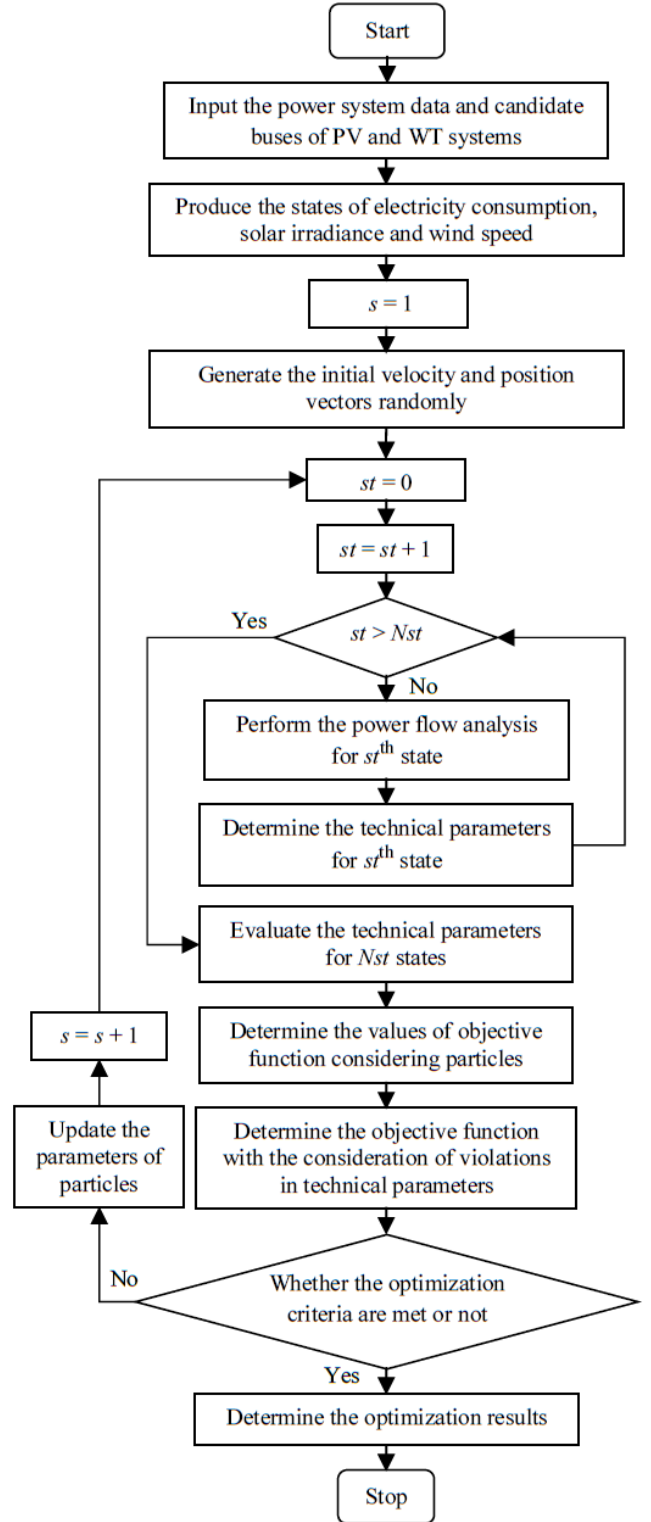

Figure 2. The flowchart of PSO process

From the standpoint of exploration domain, the optimization outcome is globally guaranteed by the vigorous PSO approach [23]. The problems consisting of optimal power flow [24], optimal renewable units capacity [25], energy loss minimization with optimal DG systems planning [26], optimal inverter based DG units penetration levels [27] have been handled by PSO approach, which presents the most convenient optimization results. According to [27], this global evolutionary algorithm has been implemented since the simulation time has no vital prominence in the planning process and the efficiencies of optimization algorithms have no considerable difference. Therefore, PSO approach has been chosen for handling the proposed problem in this article.

The steps of PSO planning process are illustrated as in the following:

1) Input the grid network parameters.
2) Produce the states of electricity consumption, solar irradiance and wind speed from their density functions.
3) Produce the initial velocity vector and individual population randomly.
4) Calculate the demand, PV system and WT system active powers for Nst states ($st = 1, \dots, Nst$).
5) Perform the repetitive power flow algorithms to obtain the technical parameters for Nst states.
6) Determine the values of objective function with the consideration of particles.
7) In case the technical parameters violate their corresponding limits, evaluate the objective function considering the inequality constraints.
8) Assess whether the criteria of PSO planning process are satisfied or not.
9) If the criteria are not met, go to step 3, otherwise go to step 10.
10) Print the optimization results.

In this study, the power system data and the candidate bus locations of PV and WT systems have been firstly included as the inputs in the proposed methodology. The states of electricity consumption, solar irradiance and wind speed have been produced by using their respective density functions. Secondly, the PSO framework has been started by producing the initial velocity and position vectors randomly. The repetitive power flow algorithms have been performed to obtain the technical parameters by taking into account the demand, PV system and WT system active powers for Nst states. The objective function has been calculated by considering the violations of technical parameters about their corresponding limits. The penalty function approach has been implemented to evaluate the objective function considering the inequality constraints when the technical parameters violate their limits. The PSO algorithm has been carried out by taking into account the update of particle parameters in an iterative manner, and this optimization process has been completed when the criteria are met. The flowchart of approach performed for testing the optimization results has been given in Figure 3.
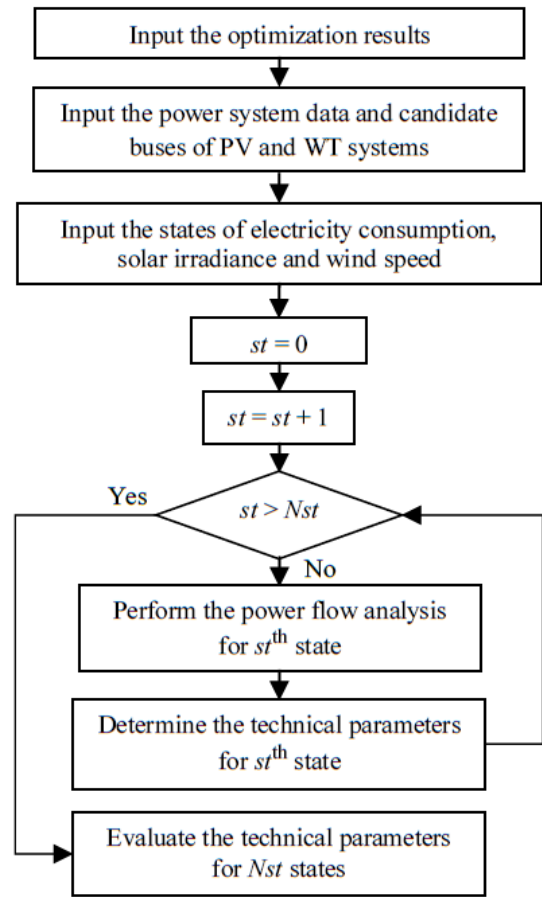

Figure 3. The flowchart of algorithm for testing the optimization results

3. Results and Discussion

In this article, the five different scenarios of load, solar irradiance and wind speed variabilities have been considered for the observation of the effects of these uncertainties on the energy losses on the power network taking into account technical limits in the planning studies. Firstly, the influences of load uncertainty on the power network energy losses have been considered without installing the PV and WT systems at the grid. Secondly, both the intermittent features of PV and WT units and the uncertainties of electricity consumptions have been taken into account for the examination of the impacts on the losses. After that, the additional three scenarios have been constructed by keeping one of the solar irradiance, demand and wind speed as constant and considering the uncertainties of the other two variables. These scenarios have been presented in Table 2.

Table 2. The scenarios considered in this study

Scenarios	Uncertainties			Information
	Load	Solar irradiance	Wind speed	
Scenario 1	1	0	0	Only load uncertainty has been considered.
Scenario 2	1	1	1	Load, solar irradiance and wind speed uncertainties have been simultaneously taken into account.
Scenario 3	1	1	0	Load and solar irradiance uncertainties have been simultaneously taken into account while considering the nominal power of wind turbine
Scenario 4	0	1	1	Solar irradiance and wind speed uncertainties have been simultaneously taken into account while considering original load profile of power network
Scenario 5	1	0	1	Load and wind speed uncertainties have been simultaneously taken into account while keeping solar irradiance constant as 1000 W/m^2

In this paper, the PSO parameters, which are maximum number of iterations, population size, personal and social acceleration coefficients, have been chosen as 100, 30, 2, and 2, respectively. The PC having 2.80 GHz CPU has been used to carry out the simulations of optimization problem, which is the energy loss minimization in the active power system in this article. The nominal capacities of PV and WT units have been considered as 100 MW at their corresponding integrated buses in the power network. The selected candidate buses of 4, 5, 6 are considered for the integration of WT systems and the nodes of 7, 8, 9 are taken into account for the PV systems, respectively. The synchronous generators bus numbers are 1, 2, 3, whereas transformer line numbers are 1, 4, 7 in the power system.

The uncertainty characteristic of electricity demand in the power network has been produced by considering normal probability distribution expression. The production of demand states has been achieved by regarding average values as original active loads of the power network and considering the standard deviation as 10 %. The variability of total active demand of grid network is denoted in Figure 4. The states of solar irradiance falling on PV units have been produced by taking α and β parameters as 7 and 3, respectively. These states are illustrated in Figure 5. The states showing the intermittent features of WT have been determined by considering 4 m/s for v_{cut-in}, 16 m/s for $v_{WT-rated}$, and 25 m/s for $v_{cut-out}$, respectively. These are demonstrated in Figure 6. The intermittent characteristics of renewable units and the variabilities of electricity loads result in the evaluation of power network in terms of proper planning. The various states of electricity consumption, solar irradiance and wind speed have been taken into account and the repetitive power flow analyses have been carried out for these states in the optimization planning process.
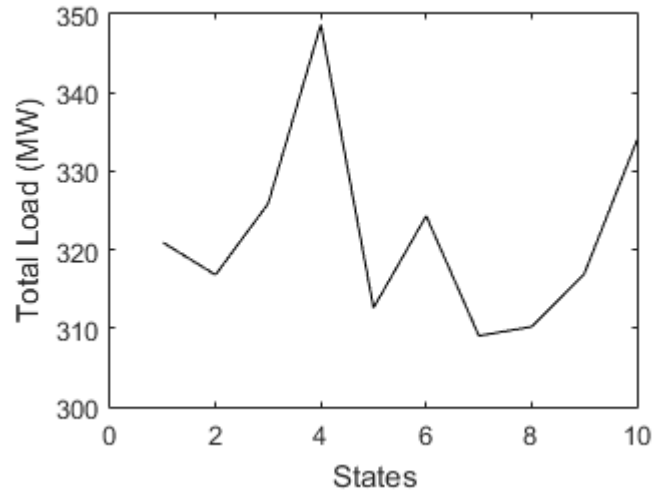

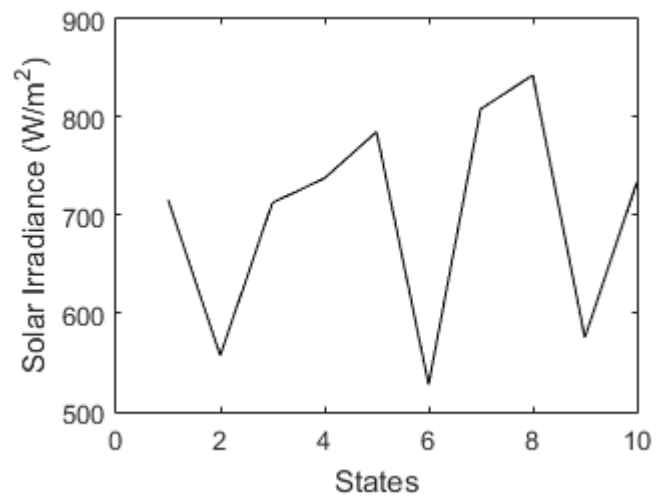*Figure 4. The total load uncertainty in the power network*

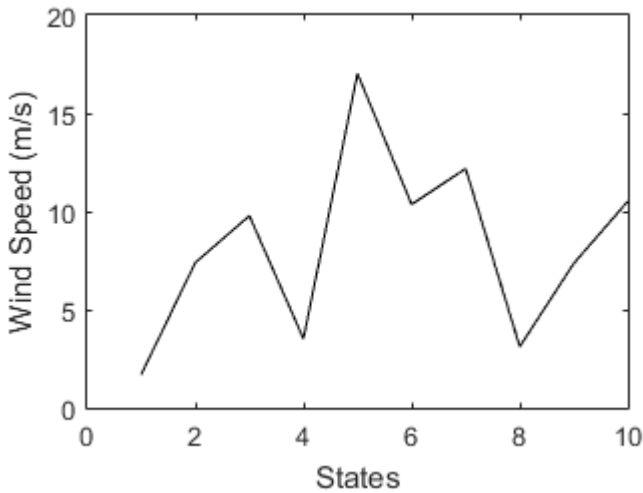*Figure 5. The solar irradiance uncertainty*

Figure 6. The wind speed uncertainty

The optimization outcomes have been illustrated in Table 3 for various uncertainty scenarios with the consideration of PSO implementation in the planning process. As depicted in Table 3, the optimal installations of PV and WT systems relieve the synchronous generators in terms of supplying power to the grid in scenarios 2, 3, 4, and 5. Thus, the synchronous generators produce the active power of 10 MW, which is their lower generation limit, in scenarios 2, 3, and 5, while one of the generators supply 27.50 MW in scenario 4 in the existence of renewable units. The optimization planning framework allows the connection of full capacities of PV systems at buses 7 and 9 in scenarios 2, 3, 4, and 5. Moreover, the upper limits of WT units have been integrated into bus 5 of the power network in these scenarios except for scenario 3, in which the wind power capacity of 93.28 MW has been installed at this bus location. However, the interconnection of WT systems to bus 6 has not been allowed by the optimization process in the scenarios, where the renewable units exist. In all scenarios, the optimal values of generator bus voltages and transformer tap ratios have been determined so as to maintain the technical parameters within their limits in the planning.

Table 3. The optimization results

| Control variables | Scenarios | | | | |
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
$P_{gen,2}$	90.11	10	10	10	10
$P_{gen,3}$	72.98	10	10	27.50	10
$V_{gen,1}$	1.08	1.10	1.10	1.10	1.10
$V_{gen,2}$	1.09	1.10	0.99	0.98	0.98
$V_{gen,3}$	1.06	0.97	1.04	1.10	1.00
TR_1	0.98	1.00	1.00	1.06	1.00
TR_4	0.97	0.90	0.96	1.10	0.92
TR_7	0.99	0.99	1.09	1.03	1.10
$P_{WT,4}$	-	60.76	0	100	96.80
$P_{WT,5}$	-	100	93.28	100	100
$P_{WT,6}$	-	0	0	0	0
$P_{PV,7}$	-	100	99.99	100	100
$P_{PV,8}$	-	54.13	35.70	30.75	2.74
$P_{PV,9}$	-	100	100	100	100

The objective functions, which are total power network energy losses, have been demonstrated with respect to the iterations in Figure 7. The energy losses have been minimized to 24.57 MWh for scenario 1, 8.41 MWh for scenario 2, 3.85 MWh for scenario 3, 8.38 MWh for scenario 4, and 5.56 MWh for scenario 5, respectively. The total grid losses have been mitigated by 65.77 % in scenario 2, 84.33 % in scenario 3, 65.89 % in scenario 4, and 77.37 % in scenario 5 with respect to the scenario 1, respectively.
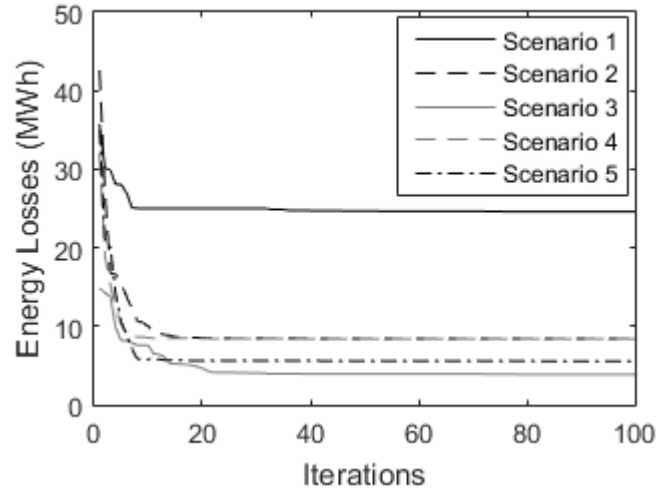

Figure 7. The total energy losses with respect to the iterations

For all scenarios, both the converged optimal values of objective functions and the execution times of the simulations have been presented in Table 4 by implementing PSO algorithm.

Table 4. PSO convergence in all scenarios

| Scenarios | Convergence | |
	Time (s)	Objective Function (MWh)
Scenario 1	306.57	24.57
Scenario 2	281.88	8.41
Scenario 3	301.13	3.85
Scenario 4	285.29	8.38
Scenario 5	279.40	5.56

The technical parameters have been observed by testing the optimization results for all load, solar irradiance and wind speed states with using the repetitive power flow analysis in scenarios 1 – 5. In testing the optimization outcomes, the states considered in the optimization process have been taken into account in the repetitive power flow algorithm.

After testing the optimization results in scenario 1, active power of slack bus generator, reactive powers of synchronous generators, power system bus voltages, power system line flows have been illustrated in Tables 5 – 8, respectively.

With the aid of proposed approach, the technical parameters have been observed to be within their limits. In all scenarios, the technical limits have been satisfied for the optimal values of control variables for all states.

Table 5. Active power of slack bus generator after testing the optimization results in scenario 1 (MW)

Buses	States									
	1	2	3	4	5	6	7	8	9	10
1	160.37	156.02	165.21	188.42	151.65	163.65	148.34	149.39	156.29	173.37

Table 6. Reactive powers of synchronous generators after testing the optimization results in scenario 1 (MVar)

Buses	States									
	1	2	3	4	5	6	7	8	9	10
1	18.08	15.79	16.85	21.41	13.33	17.20	16.29	15.31	16.91	16.42
2	-5.05	-5.09	-4.50	-2.65	-4.68	-4.63	-5.91	-5.97	-5.73	-3.40
3	-23.12	-22.80	-21.99	-20.58	-22.23	-22.40	-23.80	-23.23	-22.99	-20.29

Table 7. Bus voltages after testing the optimization results in scenario 1 (pu)

Buses	States									
	1	2	3	4	5	6	7	8	9	10
1	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
2	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
3	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
4	1.09	1.10	1.10	1.09	1.10	1.09	1.09	1.10	1.09	1.10
5	1.08	1.08	1.08	1.08	1.09	1.08	1.08	1.08	1.08	1.08
6	1.09	1.09	1.09	1.09	1.09	1.09	1.10	1.09	1.09	1.09
7	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
8	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
9	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07

Table 8. Line flows after testing the optimization results in scenario 1 (MVA)

Lines	States									
	1	2	3	4	5	6	7	8	9	10
1	161.39	156.82	166.07	189.63	152,23	164.55	149.23	150.18	157.21	174.15
2	60.58	62.96	69.67	74.51	63.48	65.53	57.26	65.24	68.13	82.22
3	36.22	33.43	32.70	30.44	29.38	33.21	38.82	37.92	38.87	30.03
4	77.48	77.37	77.10	76.65	77.18	77.24	77.72	77.52	77.44	76.56
5	46.75	50.11	51.60	56.00	55.82	50.68	44.29	45.09	43.87	56.60
6	49.00	56.19	59.64	60.41	64.87	56.11	47.75	54.01	52.25	71.90
7	90.59	90.59	90.53	90.37	90.55	90.55	90.68	90.69	90.66	90.43
8	49.50	43.32	40.80	41.12	36.62	43.60	50.28	44.79	46.42	32.64
9	102.72	96.23	98.38	115.68	91.51	100.94	94.66	87.91	91.62	93.84

4. Conclusions

In this article, the variabilities of electricity demands, solar irradiance and wind speed have been handled in the determination of total losses in PV and WT installed power network with the consideration of the impacts of various uncertainty scenarios. The technical issues may be influenced by the variations in uncertainties in case of integration of these renewable sources into the power system. With the consideration of uncertainties in load consumptions and intermittencies in PV and WT sources, minimizing the total network losses taking into account power quality is carried out in this study. Therefore, the most considerable improvement has been observed when the uncertainties of solar irradiance and load have been considered by keeping the wind speed as constant. In that manner, it is worthwhile noting that observation of total power system energy losses has a vital importance in terms of maintaining technical issues in the planning with uncertainty consideration. As a result, the electricity loads will be able to consume the power efficiently. The proper planning of total grid energy losses with the technical constraints is expected to be performed in the power network. According to the simulation results, the security

limits of power network are considered to gain importance depending on the interconnection of renewable energy units.

References

[1] Kiwan, S., Al-Gharibeh, E., & Abu-Lihia, E. (2021). Wind Energy Potential in Jordan: analysis of the first large-scale wind farm and techno-economic assessment of potential farms. Journal of Solar Energy Engineering, 143(1), 011007.

[2] Akdemir, H., Durusu, A., Erduman, A., & Nakir, I. (2018). Effect of energy management of a grid connected photovoltaic/battery/load system on the optimal photovoltaic placement on a national scale: The case of Turkey. Journal of Solar Energy Engineering, 140(2), 021009.

[3] Liu, J., Tang, Z., Zeng, P. P., Li, Y., & Wu, Q. (2022). Distributed adaptive expansion approach for transmission and distribution networks incorporating source-contingency-load uncertainties. International Journal of Electrical Power & Energy Systems, 136, 107711.

[4] Sanjari, M. J., & Karami, H. (2020). Optimal control strategy of battery-integrated energy system considering load demand uncertainty. Energy, 210, 118525.

[5] Abedi, M. H., Hosseini, H., & Jalilvand, A. (2019). Sub-transmission substation expansion planning considering load center uncertainties of size and location. International Journal of Electrical Power & Energy Systems, 109, 413-422.

[6] Esmaeili, M., Sedighizadeh, M., & Esmaili, M. (2016). Multi-objective optimal reconfiguration and DG (Distributed Generation) power allocation in distribution networks using Big Bang-Big Crunch algorithm considering load uncertainty. Energy, 103, 86-99.

[7] Mehrjerdi, H., & Rakhshani, E. (2019). Correlation of multiple time-scale and uncertainty modelling for renewable energy-load profiles in wind powered system. Journal of Cleaner Production, 236, 117644.

[8] Shargh, S., Mohammadi-Ivatloo, B., Seyedi, H., & Abapour, M. (2016). Probabilistic multi-objective optimal power flow considering correlated wind power and load uncertainties. Renewable Energy, 94, 10-21.

[9] Mohseni-Bonab, S. M., Rabiee, A., & Mohammadi-Ivatloo, B. (2016). Voltage stability constrained multi-objective optimal reactive power dispatch under load and wind power uncertainties: A stochastic approach. Renewable Energy, 85, 598-609.

[10] Huang, S., & Abedinia, O. (2021). Investigation in economic analysis of microgrids based on renewable energy uncertainty and demand response in the electricity market. Energy, 225, 120247.

[11] Zhang, S., Cheng, H., Li, K., Tai, N., Wang, D., & Li, F. (2018). Multi-objective distributed generation planning in distribution network considering correlations among uncertainties. Applied energy, 226, 743-755.

[12] Ebrahimi, J., Abedini, M., Rezaei, M. M., & Nasri, M. (2020). Optimum design of a multi-form energy in the presence of electric vehicle charging station and renewable resources considering uncertainty. Sustainable Energy, Grids and Networks, 23, 100375.

[13] Jithendranath, J., Das, D., & Guerrero, J. M. (2021). Probabilistic optimal power flow in islanded microgrids with load, wind and solar uncertainties including intermittent generation spatial correlation. Energy, 222, 119847.

[14] Nikmehr, N., & Ravadanegh, S. N. (2016). Reliability evaluation of multi-microgrids considering optimal operation of small scale energy zones under load-generation uncertainties. International Journal of Electrical Power & Energy Systems, 78, 80-87.

[15] Yang, J., & Su, C. (2021). Robust optimization of microgrid based on renewable distributed power generation and load demand uncertainty. Energy, 223, 120043.

[16] Alabi, T. M., Lu, L., & Yang, Z. (2021). Stochastic optimal planning scheme of a zero-carbon multi-energy system (ZC-MES) considering the uncertainties of individual energy demand and renewable resources: an integrated chance-constrained and decomposition algorithm (CC-DA) approach. Energy, 121000.

[17] Salau, A. O., Gebru, Y. W., & Bitew, D. (2020). Optimal network reconfiguration for power loss minimization and voltage profile enhancement in distribution systems. Heliyon, 6(6), e04233.

[18] Ali, M. H., Mehanna, M., & Othman, E. (2020). Optimal Network Reconfiguration Incorporating with Renewable Energy Sources in Radial Distribution Networks. International Journal of Advanced Science and Technology, 29(12s), 3114-3133.

[19] Moussa, S. A. M., & Abdelwahed, A. (2017). DG Allocation Based on Reliability, Losses and Voltage Sag Considerations: an expert system approach. Renewable Energy and Sustainable Development, 3(1), 33-38.

[20] Wang, Y., Luo, H., & Xiao, X. (2021). Joint Optimal Planning of Distributed Generations and Sensitive Users Considering Voltage Sag. IEEE Transactions on Power Delivery.

[21] HassanzadehFard, H., & Jalilian, A. (2021). Optimization of DG units in distribution systems for voltage sag minimization considering various load types. Iranian Journal of Science and Technology, Transactions of Electrical Engineering, 45(2), 685-699.

[22] Nikoukar, J., Haghifam, M. R., & Panahi, A. (2011). Transmission expansion cost allocation based on economic benefit and use of system. Journal of American Science, 7(4).

[23] Hamzaoğlu, A., Erduman, A., & Alçı, M. (2021). Reduction of distribution system losses using solar energy cooperativity by home user. Ain Shams Engineering Journal, 12(4), 3737-3745.

[24] Khaled, U., Eltamaly, A. M., & Beroual, A. (2017). Optimal power flow using particle swarm optimization of renewable hybrid distributed generation. Energies, 10(7), 1013.

[25] Sadeghi, D., Naghshbandy, A. H., & Bahramara, S. (2020). Optimal sizing of hybrid renewable energy systems in presence of electric vehicles using multi-objective particle swarm optimization. Energy, 209, 118471.

[26] Nasri, A., Hamedani Golshan, M. E., & Mortaza Saghaian Nejad, S. (2014). Optimal planning of dispatchable and non-dispatchable distributed generation units for minimizing distribution system's energy loss using particle swarm optimization. International Transactions on Electrical Energy Systems, 24(4), 504-519.

[27] Pandi, V. R., Zeineldin, H. H., Xiao, W., & Zobaa, A. F. (2013). Optimal penetration levels for inverter-based distributed generation considering harmonic limits. Electric Power Systems Research, 97, 68-75.