Placement of DG with Stochastic Generation

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***Abstract*— Due to environmental concerns interests in using renewable based distributed generation (DG) have been increased. Because stochastic nature of renewable energy resources such as wind speed and solar radiation, their effects on power system are different from dispachable distributed generation. In this paper, a method for distribution system planning and development is presented in presence of distributed generation with consideration of uncertainties. These uncertainties consist of uncertainties in power generation, failure rates and repair times of equipments as well as uncertainties in electricity market price. The proposed approach is based on optimization model including power loss reduction and reliability improvement. Stochastic generation of renewable DG is modeled by Monte Carlo Simulation (MCS). Uncertainties in failure rates, repair times and electricity price are calculated using fuzzy theory concepts. Also objective values are calculated in Monte Carlo Simulation and optimization is done by genetic algorithm (GA).**

***Index Terms*—Distributed generation, Renewable energy, Uncertainty, Risk, Loss, Reliability.**

I. Introduction

In recent years, distributed generation utilization has been increased in power distribution systems. Distributed generation (DG) has an important role in power distribution system planning because of its modularity, small size and low investment cost as well as environmental concerns and causes considerable reduction in required investment cost for supplying increased load in future years.

Due to future load growth, load demand exceeds the predetermined threshold capacity of distribution systems, therefore distribution companies should be used one or both of following options to succeed this problem [1]:

- Addition of new substations
- Expanding existing substations' capacities

Above methods require additional investment cost in generation and transmission infrastructures.

Distributed generation utilization is an effective alternative for reducing this cost by implementation of small generation near the load points.

On the other hand, system characteristics such as reliability and power losses will be improved if these resources preciously and correctly allocated in distribution systems. Therefore planners have concentrated on finding the suitable methods for DG placement in power distribution systems.

Due to existing uncertainty in power generation more challenges exists behind distribution system planners in presence of renewable distributed generations.

In recent years, several studies have considered techniques for locating DG units on distribution systems [2-19]. In all papers, improvement of system characteristics is the main objective of DG placement.

Power loss reduction is considered as an important objective function in most publications.

In addition to power losses, other objective functions such as reactive power compensation [1, 13, 18], reducing capital investment cost due to supplying future load growth [4, 7], as well as energy not supplied cost reduction [7] are considered in DG placement. Because of DG implementation imposed purchase, installation and operation cost to utilities, these costs must be considered in DG placement procedures [5, 8 , 12, 14, 16]. References [10, 19] have been considered renewable DG such as wind turbines in their studies. A consequential result table have been presented in [23] for comparable review of an important studies in this scope.

Due to the intrinsic uncertainties in distribution system such as uncertainty in load prediction, uncertainty in failure rate and repair time as well as uncertainty in electricity market price, methods should be used in system planning and development that cope with considering the above uncertainties.

In this paper, one of the main objectives of DG placement is reliability improvement. Distribution system reliability is assessed with consideration following options:

- Uncertainty in power production
- Uncertainties in failure rate and repair time

It is obvious that due to these uncertainties, reliability indices and other system performance indices have uncertainties.

Accordingly, in this context a new methodology for distributed generation placement is presented that reduces power losses as well as improves reliability indices.

A. Model Overview

In the proposed method, each objective function values should be calculated after DG placement. All of input variables are modeled mathematically and used in objective functions calculations. These input variables are as follows:

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- DG power production
- Load characteristic
- Equipment reliability indices; failure rate and repair time (λ, r)
- Electricity market price

In this paper, the random generation of renewable DG is represented with a probabilistic approach, in which a probability distribution function is utilized to deal with DG output modeling. The power production probability distribution function is calculated based on probability distribution function of DG's primary resource. With consideration of distributed generation technical characteristic and renewable primary resource behavior, probability density function of power output is calculated. Correlation between load and DG production values is considered in the proposed method. On the other hand uncertainties in failure rate and repair time are modeled using fuzzy numbers. According to the above description, all objective functions are calculated using Monte Carlo Simulation and fuzzy theory.

Finally, using optimization of objective appropriate solution is selected. GA as an optimization technique is utilized for determining the final optimal solution.

A new approach for optimal distributed generation placement is presented. Objective functions consist of system reliability, power losses and investment cost for DG installation and operation. Probabilistic approach and also fuzzy theory are used for uncertainty modeling. Due to probabilistic modeling of DG production, objective functions are calculated using Monte Carlo Simulation.

According to overall overview of proposed approach, this paper is organized as follows.

Modeling of input variables and correlation between load and wind speed is introduced in section II. Problem formulation is presented in section III, Monte Carlo simulation implementation for calculating final values of objective functions after DG placement is illustrated in section IV and optimization procedure is described in section V. Implementation of the proposed method on test system is presented in section VI and conclusions are introduced in section VII.

II. MODELLING OF UNCERTAINTIES

In this section, modeling of DG power production, failure rate and repair time with considering their uncertainties. Uncertainty in DG power production is modeled using a probabilistic method, where as a fuzzy number also is used to cope with electricity price and basic reliability indices' uncertainties.

A. Consideration of Renewable DG generation uncertainty

Renewable DG power production mainly depends on its primary energy values that are available at DG location. Since available primary energy values such as wind speed and solar density radiation are different in various locations and are not preciously predictable, power production calculation of such distributed generation has uncertainty. Power production of renewable distributed generation modeling is an important part of distribution system planning in presence of DGs. Proposed model should be able to encompassed power generation uncertainty.

Several studies have been done on renewable resources modeling in power system planning. These methods could be categorized into time series based methods [21,22], probabilistic methods [23] and fuzzy methods [24]. In this paper wind turbines are considered as renewable based DGs, although the proposed approach is applicable for other renewable based distributed generation allocation.

Time series based modeling approach is used for wind turbine power production modeling in power system [21]. In this approach, wind speed data for various years in wind turbine installation location gathered and accordingly time series based wind speed variation is predicted. Utilization of this approach introduces relative precise model for wind speed variation according to technical characteristics of wind turbine, this model is converted to DG power production. Additionally this model could present probabilistic nature of wind speed where DG has been installed. This model requires enormous data gathering about wind speed in various years. This model and its required data is basis of probabilistic approach implementation. Wind speed probability distribution function could be obtained from time varying wind speed curve [22].

Monte Carlo Simulation is one of the most important methods of probabilistic modeling [23] that operates in accordance to probability distribution function. Due to generating random numbers, this calculation method is very time consuming process. On the other hand, Monte Carlo simulation is simply implemented for power system reliability assessment.

As well as, fuzzy modeling [24] has been used for wind turbine power generation when adequate data is not available for using previous methods.

In this paper, wind speed probability distribution function is calculated for one year, and then probability distribution function of DG power production is calculated in accordance with wind speed probability distribution function. Therefore related objective functions are calculated using Monte Carlo simulation.

Wind turbine power generation with respect to wind speed is illustrated in (1).

$$P_{WT}=\begin{cases}0 & w<w_{cin}\\ P_r.(A-Bw+Cw^2) & w_{cin}\leq w<w_r\\ P_r & w_r\leq w<w_{co}\\ 0 & w\geq w_{co}\end{cases} \quad (1)$$

Where

P_{WT} Power generation of wind turbine

P_r Nominal power production of wind turbine
w Wind speed
w_{cin} Cut-in wind speed
w_r Nominal wind speed
w_{co} Cut-out wind speed

A, *B* and *C* coefficients are calculated according to wind turbine technical characteristics [25]. In the proposed method, time varying load curve is converted to probability distribution function. Therefore DG power production value is simulated by generating a random number based on wind speed probability distribution function.

B. Consideration of uncertainty in failure rate and repair time

Failure rate of power distribution system components vary with many different factors. For example, performances of overhead distribution lines are highly affected by weather because the lines are exposed to the atmosphere. Wind, lightening, ice, tornadoes and other weather related factors could cause line failures. High tree density near a line or negligence of tree trimming can also cause frequent interruptions. Therefore failure rate prediction exposed to different uncertainties due to these factors.

For description of inherent uncertainty in failure rate of feeders and other components of distribution system, fuzzy number is used as shown in Fig. 1.

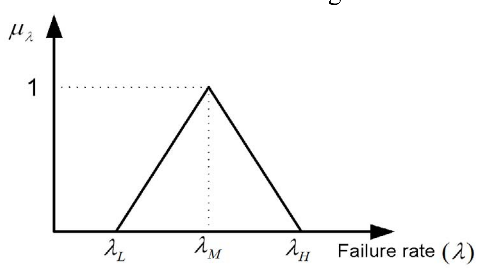

Fig. 1 Fuzzy representation of failure rate

C. Load Modeling

One of the efficient ways to model load in a distribution system is to model it with time varying characteristic. This model can describe actual load variation during planning horizon years. For simplicity, usually time varying load curve for one year is calculated and constant load growth rate is considered for each year.

In this paper time varying load curve is divided into specified levels.

D. Correlation between Load and Wind Speed

If load variation and wind speed specified with time varying characteristics, correlation between wind speed and load values should be considered in power distribution system.

For problem clarification, consider that if peak value of DG power generation and system peak load occur at same time, then system benefits due to DG placement will be more.

To reach this purpose, time varying load and power production curves are divided to equal time durations, in this way correlation matrix between these variables is specified. Wind speed is considered as independent variable and system load value considered as dependent variable.

Elements of correlation matrix are determined according to conditional probability law. This means that occurrence probability of each load level is calculated if specified wind speed occurred. Accordingly, each elements of correlation matrix is calculated as bellows:

$$c_{ij} = P(l = l_j | w = w_i) = \frac{P(l_j \cap w_i)}{P(w_i)} \qquad \mathbf{(2)}$$

Where c_{ij} represents the element of *i*th row in the *j*th column of correlation matrix, l_j is *j*th load level and w_i is *i*th wind speed level.

III. PROBLEM FORMULATION

An optimization function which is used in this study consists of the following terms:

A. Power Losses

Power losses of power distribution system are calculated after DG implementation. In accordance to probabilistic modeling of DG power production as well as load values, probabilistic load flow [26] is used for loss calculation. Probability distribution functions of load and wind speed are considered as input variables. Probabilistic load flow is modified to encompassed correlation between load and wind speed values.

B. Reliability

Reliability improvement and reducing energy not supplied (ENS) is one of the objective functions that considered in this paper for DG placement. Distribution system reliability assessment procedures with consideration of uncertain failure rate and repair time and in presence of renewable distributed generation will be discussed in the following section.

Distribution system Reliability Assessment in Presence of Wind Turbines:

DG placement in power distribution system can improve reliability by reducing the duration of customer interruption. In this paper, for assessing the DG effect on system reliability, energy not supplied (ENS) is calculated as reliability index as shown in (3).

$$\widetilde{ENS} = \sum_{i=1}^{N_b} \tilde{\lambda}_i . L_i .\Big(\sum_{j \in island} LP_j . r_{switching} + \sum_{j \notin island} LP_j . \tilde{r}_{repair} \Big) \qquad (3)$$

Where $\widetilde{ENS}$ is the fuzzy energy not supplied, N_b is the number of branches, L_i is the length of branch i, λ_i is the failure rate of branch i and LP_j is the power of *j*th load point. Also, *island* is the set of load points that supplied with DG after fault location. $r_{switching}$ is the switching time and $\tilde{r}_{repair}$

is the fuzzy presentation of fault repair time.

For island formation, power production of distributed generation should be equal or more than island load. Therefore, island limitation is determined by comparing DG production with island load.

Due to probabilistic modeling of DG generation and load, for each random DG power generation value, deterministic system reliability is assessed and also correlation between variables is considered.

In this problem we supposed that one dispatchable DG unit such as synchronous generator will be located near the renewable distributed generation units for guarantee their synchronism. This unit is considered only for island forming. Their capacities are not considered for load supplying and objective function improvement. Although this calculation could be done with consideration of synchronous generations and renewable DG units, simultaneously.

IV. Monte Carlo Simulation

Because of probabilistic modeling of DG power generation, final values of objective functions are calculated using Monte Carlo simulation as following steps:

1. A random number between (0,1) is generated to simulate wind speed value, v_i, as independent variable, then DG power production, P_{DGi}, is calculated by (1).
2. For each load level specified in correlation matrix, all objective function values are calculated with consideration correlation factors corresponding to wind speed value, v_i.
3. Objective functions are calculated according to previous section.
4. Final values of each objective function with consideration correlation factors are calculated as follows:
$$F_i = \sum_{j=1}^{N} F_{ij}.w_{ij} \tag{4}$$
Where F_i is objective function value at ith random number, N *is* number of load levels that specified at correlation matrix, F_{ij} is objective function value at ith random number and jth load level, w_{ij} is correlation factor at jth load level equal to the element of ith row of the jth column of correlation matrix.
5. Since final objective functions are fuzzy, their deffuzification values are used for ranking them.
6. Until objective function values converge, steps (1) to (5) repeat and finally probability distribution function and finally expected value for each objective function is calculated.

V. Optimization Procedure

Final objective function value for renewable DG placement with consideration of available uncertainties is defined as follows:

$$\begin{aligned}\tilde{f}_M &= \sum_{t=1}^{T} \alpha_t.(P_{loss}.\tilde{C}_T) + \sum_{t=1}^{T} \alpha_t.\,E\tilde{N}S.\tilde{C}_T \\ &+ \sum_{i=1}^{NN} C_{DGi}.IC_{DG} \\ &+ \sum_{t=1}^{T} \alpha_t.\left(\sum_{i=1}^{NN}\left(C_{DGi}.MC_{DG}\right)\right)\end{aligned}$$

(5)

Where $\tilde{f}_M$ is fuzzy cost function after DG installation due to power losses and expected energy not supplied as well as DG installation and operation cost, NN the total number of network nodes, C_{DGi} the DG capacity in the ith node (MVA), IC_{DG} the DG investment cost (\$/MVA), T the horizon planning year, MC_{DG} the DG maintenance cost (\$/MVA), P_{loss} is the network power losses after DG allocation, $E\tilde{N}S$ is the expected load not supplied after allocation of DG, $\tilde{C}_T$ is the electricity market price and α_t is the economical factor. By using this factor, future cash flow rate can be transformed to a present value.

Optimization constraint is defined as follows:

$$st. \quad \frac{P_{DG_i}}{PF_{DG_i}} \le C_{DG_i} \tag{6}$$

In this paper voltage constraints at load points and loading limits in feeders are neglected. We suppose that if these constraints are violated, utilities use capacitor placement as more economical procedure rather than considering constraints effect on DG placement, because DG installation and operation cost is very high.

For calculation of final result of this problem, GA is implemented as an optimization procedure. The GA is a search algorithm based on the mechanism of natural selection and natural genetics to obtain the best optimal solutions for optimization problem. In GA, a constant size population of individuals representing the possible solutions, is judged and reproduce to form the next generation. It is planned such that 'fitter' strings survive and propagate into the latter generations. The population is expected to converge to the 'fitter' solutions and, ideally, the algorithm ends with a population consisting only of the fit string or the global optimal solution [28].

The main stages of GA search method that we used to gain an optimal DG placement are described in the following subsections.

1) Coding

Coding of the potential solution is the first important aspect of a correct implementation of the GA. Since the solution of the mentioned problem are numbers, positions and sizes of DG unit, each solution can be coded using a vector, whose size is equal to the number of buses and each element of the vector contains the information about the presence or not of a DG unit and its size.

Sample of the proposed chromosome is shown in Fig.2 and its coding method is explained by (7).

x_1	x_2	....	x_{n-1}	x_n

Fig. 2. Coding table for DG placement solutions

$$x_i = \begin{cases} 0 & \text{if no DG is present} \\ 1 & \text{if DG size is } A \\ \vdots & \\ n & \text{if DG size is } N \end{cases} \qquad (7)$$

2) Initialization

For initialization, a random variable between 0 and n is generated for each gene. Repeating this procedure generates an initial population.

3) Crossover

The crossover operator is used for the generation reproduction. In this study, a uniform crossover is adapted which its probability is 0.5.

4) Mutation

All the vector elements are mutated, according to a small mutation probability.

5) Objective Function evaluation

In this step, the values of objective functions for each member of current population are evaluated.

6) Ranking

In order to ranking of fuzzy objective function values and select the best solution, in this paper the diffuzification of the aggregated objective function, shown in (5), is done using removal function $R(\widetilde{a})$ that for a TFN,

$\widetilde{a} = (a_L, a_M, a_R)$ describes as below [17]:

$$R(\widetilde{a}) = (a_L + 2a_M + a_R)/4 \qquad (8)$$

VI. Application Study and Numerical Results

The proposed approach for DG placement has been implemented in the MATLAB® and tested on primary distribution network studied in [16].

The test distribution network shown in Fig. 3 consists of one 132/33 KV substation of 75 MVA capacity to serve loads. With respect to operational limitations, maximum allowable loading of substation is considered as 50 MVA.

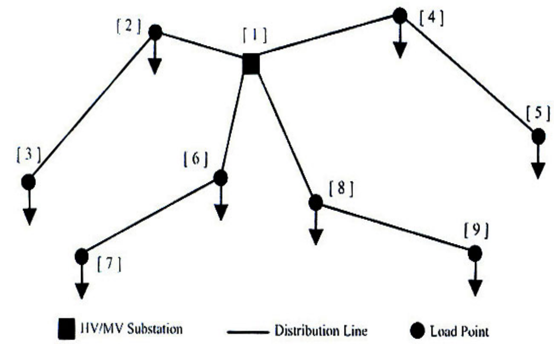

Fig. 3 Distribution network under study

Technical characteristics of the conductors used in line segments are given in Table 1 and 2.

TABLE 1 CHARACTERISTICS OF LINE SEGMENTS

Line segment from	to	R, Ω	X, Ω	Loading limit, A
1	2	1.390	2.255	210
2	3	2.780	4.510	210
1	4	2.085	3.383	210
4	5	2.780	4.510	210
1	6	1.738	2.819	210
6	7	2.085	3.383	210
1	8	2.259	3.664	210
8	9	2.433	3.946	210

TABLE 2 FAILURE RATE AND REPAIR TIME

Repair Time (*hour*)	**Failure Rate (*failure/yr/Km*)**
(1, 1.5, 2)	**(0.01, 0.07, 0.18)**

In this study load is considered as load varying model. Also, supposed that all load points have same load profiles with different peak load value. But this assumption does not restrict this method application. Time varying load curve is levelized for reducing calculation burden. If the considered levels increase, more precise results could be obtained.

Load variation in this network has been divided to 12 levels and accordingly, monthly peak load value is considered in objective functions calculations. Total time varying load curve is illustrated in Fig. 4.

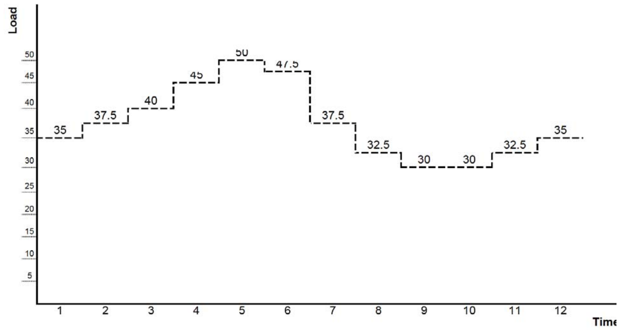

Fig. 4 Levelized time varying load curve

This levelized load curve is used for calculation of correlation between load and wind speed.

In this case study we utilized wind turbines as distributed generations. Wind speed information has been obtained from real data that introduced by [26] for a specific area in Iran. The wind speed time series and the corresponding probability distribution function of wind speed regime are shown in Fig.5 and Fig.6, respectively.

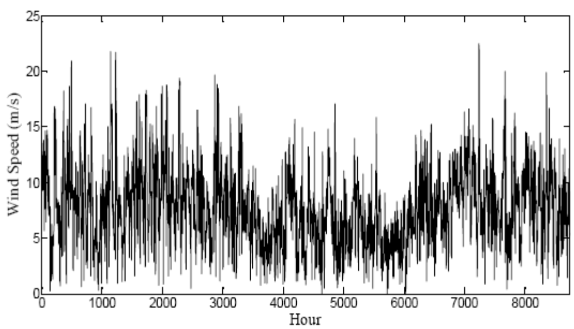

Fig. 5 Time varying wind speed curve

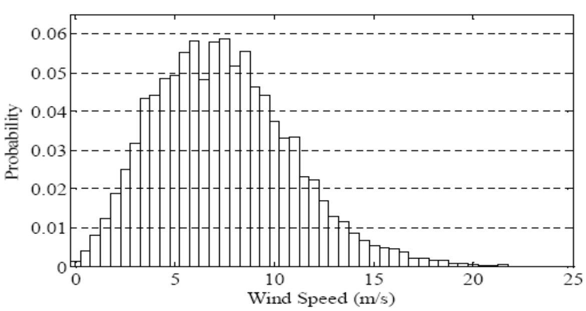

Fig. 6 Wind speed probability distribution function curve

Wind turbine characteristic is defined as follows:

$$P_{WT}=\begin{cases}0 & w<4\\ P_r.(0.032-0.0776w+0.01745w^2) & 4\le w<10\\ P_r & 10\le w<22\\ 0 & w\ge 22\end{cases} \tag{9}$$

All network nodes expect substation node are considered as candidate sites for DG placement. The candidates DGs have sizes of multiples of 1 MVA (maximum 4 MW) with power generation at load factor of 0.9.

In this study, a fix load growth rate is assumed for any year in planning horizon. The power factor of all load points is 0.95. Consideration of the cost data and some planning parameters are presented in Tables 3.

TABLE 3 COST DATA USED IN THE STUDY

Parameter	Unit	Value
DG investment cost, IC_{DG}	\$/MVA	455000
DG operation cost, MC_{DG}	\$/MVA	15000
electricity market price (as TFN), $\tilde{C}_T$	\$/MWh	(45,60,110)
horizon year, T	year	25
economic factor, α_t	_	1.05

The proposed optimization technique, GA, has been executed with the following parameters:

- Population size: 300
- Generation: 200
- Crossover probability: 0.9
- Mutation probability: 0.125

The final solution in the form of proposed capacity of DGs in the selected candidate nodes is shown in Fig.7.

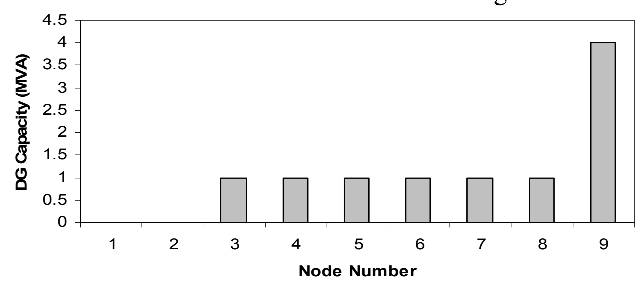

Fig.7 Final solution of DG placement

For illustrating the effects of DG placement, values of power losses and energy not supplied in the final solution as well as before DG installation are shown in Table 6.

TABLE 6 COMPARISON OF FINAL SOLUTION WITH INITIAL CONDITION

	Symbol	Unit	Value before DG placement	Value after DG placement
Power losses	P_{loss}	kW	13.604	5.465
Energy not supplied	ENS	kWh	39.244	29.434

VII. CONCLUTIONS

A new approach for renewable DG allocation in electric distribution system is presented. In this paper in addition to considering DG power generation uncertainty, other uncertainties in electricity market price, failure rates and repair times of equipments also are considered for DG placement. The model considered time varying load as well as correlation between load and wind speed values. In order to considering electricity market price, failure rate and repair time uncertainties, fuzzy models have been utilized. Because of stochastic nature of renewable DG production, a Monte Carlo based approach is proposed for evaluation of 'power losses' and 'expected energy not supplied'. Since all objective function presents monetary expenses, an aggregated multi-objective function is used for optimization. A GA based procedure has been applied as optimization algorithm. The proposed approach has been implemented on the test system and results have been shown. These results show that DG placement in power distribution system can reduce power losses as well as energy not supplied.

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IX. Biographies

Arezoo Hadian was born in Tehran, Iran, in 1982. She received the B.Sc. in Electrical engineering in 2005 from Bu-ali Sina university, Hamedan, Iran. She is currently pursuing the M.Sc. degree in electrical engineering from Islamic Azad University_South of Tehran Branch. Her research interests are distribution system reliability.

Mahmoud-Reza Haghifam was born in Iran in 1967. He received the BS, MSc and PhD degrees in electrical engineering in 1989, 1992 and 1995. He joined Tarbiat Modares University as assistant Prof. in 1965. He is now a Full Professor in Power Systems at the Tarbiat Modarres University (TMU), Tehran, Iran. He is a Senior Member of the IEEE (and IEEE Iran Section Industrial relationship officer). Also he is a research Fellow of Alexander Von Humboldt in Germany. He has been awarded by DAAD and AvH in 2001, 2006 and 2009 for research stays in German universities. He was as visiting Prof. in university of Calgary, Canada in 2003. His main research interests are Power System Restructuring, Power System Reliability, and Electric Distribution System.