



A nonlinear-hybrid fuzzy/probabilistic load flow for radial distribution systems

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ABSTRACT

Uncertainty analysis of future system operation is the key feature of current study. This paper shows that how subjective differences in representing fuzzy inputs can affect the final outputs. We consider a confined range of forecasted samples in terms of fuzzy membership functions as well as the range of historical forecasting errors in terms of probability density functions. On this basis, this paper proposes a combined fuzzy/probabilistic evaluation of distribution system voltages, considering hybrid fuzzy/probabilistic uncertainties for consumption and generation. The proposed method allows the sampled fuzzy inputs to incorporate in a Monte Carlo-based nonlinear fuzzy load flow including Wind Turbine Generating Units (WTGUs). As a result of hybrid uncertainty representation, the evaluation of fuzzy load flow results will be assessed in probabilistic framework. Numerical simulations are performed on the unbalanced IEEE 34-bus test distribution system equipped with WTGUs.

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1. Introduction

Generally many of observations in practical systems contain considerable amount of uncertainty. This fact forms a basis for employing especial analysis tools to evaluate the power systems under such observations. Power systems sustain a wide range of uncertainties from determination of system parameters, variables, and future decisions to future estimation of the system variables. Moreover, presence and increasing growth of WTGUs in distribution systems put a great deal of uncertainty in distribution system studies; because, these units strictly depend on the wind speed. Therefore an appropriate evaluation of the system under these uncertainties requires an appropriate analysis tool. Uncertainty analysis of power systems fundamentally is carried out by two primary approaches: probabilistic load flow and fuzzy load flow. Depending on fuzzy or probabilistic points of view, the power flow analysis differs in the nature of algorithm and results. In probabilistic methods as usual, system variables have been assessed by means of Monte Carlo technique with uncertainties in terms of Probability Density Functions (PDFs). Caramina in [1] provided a qualitative exploration of the probabilistic techniques existing in the power flow study such as linear, nonlinear Monte Carlo (MC) and convolution techniques. The exact non-linear form of the load flow equations has been used in most probabilistic load flow studies [1,2]. Some studies have incorporated wind farms and their

uncertainties in probabilistic load flow [2,3] and some have modeled the uncertainties in the fuzzy set [3–9]. Although some approaches in wind fuzzification is transferring the wind speed probability density function directly into possibility membership function [3], generally fuzzy load flow results in the uncertainty analysis of the state variables when there is insufficient statistic information to assign probability density function [4,9]. The key aspect of the fuzzy power flow is achieving the method through which the fuzzy inputs lead to the best befitted fuzzy outputs. In some approaches, system variables are assessed in the fuzzy set; however, evaluation of system variables is performed through the fuzzy arithmetic calculations [4,5]. Since fuzzy arithmetic roles hardly meet a feasible solution of power flows, Many of papers make an attempt to modify the fuzzy calculations even in a simple sum and subtraction operation to fit fuzzy solution [5]; Nevertheless, some fuzzy power flows do not outrage real calculation roles of power flow by attributing the fuzzy power flow as a sort of boundary power flow [6–8]. These techniques facilitate reaching the fuzzy results thanks to the system linearization. Although the linearization yields approximate results, invoking Jacobean matrix, it reasonably provides possible variations of results under the input variations.

Another approach determines the extremes of each line flow at α – level of possibility by solving a vast number of optimization problems under input bounds associated with α that $0 \leq \alpha \leq 1$ [9].

In the current study, we aim to perform a sort of short-term load flow analysis of uncertainty in the near future. Forecasting models provide necessary information about the state of future variations. One of the important aspects of this study is that in this case, fuzzy function is not indicative of that mere uncertainty but of prospective bound of the inputs. And somehow it reveals

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Nomenclature

α	alpha cut of a fuzzy number	P_{cal}, Q_{cal}	calculated active and reactive bus injected power
a_i	membership i of fuzzy number	[K]	nonlinear transformation matrix between power deviation and voltage deviation
\bar{a}_i	mean value of fuzzy membership	$(\Delta P)^{sp}$	the specified active power deviation
σ	standard deviation of members	$(\Delta Q)^{sp}$	the specified reactive power deviation
[BIBC]	Matrix of Bus Injection to Branch Current	w^{sp}	the specified wind speed
[BCBV]	Matrix of Branch Current to Bus Voltage	P^{as}, Q^{as}	active and reactive powers of asynchronous WTGU
ΔV_{abc}	voltage deviation of phases a, b and c	I_{as}, V_{as}	current and voltage of asynchronous WTGU
[DLF]	Matrix of Distribution Load Flow	R_1	stator resistance in Equivalent circuit of WTGU
e^k	real part of bus voltages at iteration k	R_2	rotor resistance in Equivalent circuit of WTGU
f^k	imaginary part of bus voltages at iteration k	X_{I1}	stator reactance in Equivalent circuit of WTGU
Δf^k	deviation of f^k	X_{I2}	rotor reactance in Equivalent circuit of WTGU
AR	real parts of DLF matrix	X_m	magnetizing reactance in equivalent circuit of WTGU
AX	imaginary parts of DLF matrix	s	slip of asynchronous WTGU
V^k	bus voltages at iteration k	V_{me}	extreme value of voltage number m
P_{sp}, Q_{sp}	specified active and reactive bus injected powers	V_{m0}	central value of voltage number m
\tilde{U}	fuzzy absolute of bus voltage	K_{mn}	deviation coefficient of voltage m by deviation of power n
$\tilde{\varnothing}$	fuzzy phase of bus voltage	P_{ne}	extreme value of power number m
U	absolute of bus voltage	P_{no}	central value of power number m
\varnothing	phase of bus voltage	f_{ai}	PDF function of membership a_i
UL_i	uncertain load number i	$(\tilde{P})^{sp}$	specified fuzzy number of active power
SL	system loss	$(\tilde{Q})^{sp}$	specified fuzzy number of reactive power
P_{UL}, Q_{UL}	uncertain active and reactive powers	$(P)^{sp}$	specified active power in load flow study
pf	power factor	$(Q)^{sp}$	specified reactive power in load flow study
σ_p	standard deviation of active power	$(P_{gen})^{sp}$	specified active power generation in load flow study
DLF	deterministic load flow	$(U_{gen})^{sp}$	specified at voltage regulated buses in load flow study
PLF	probabilistic load flow	σ_q	standard deviation of reactive power
FLF	fuzzy load flow	\bar{a}_i	mean value of the fuzzy member i
F/P LF	fuzzy/probabilistic load flow	σ_w	standard deviation of wind speed
WTGU	Wind Turbine Generating Unit	K_d	unbalance factor
PDF	Probability Distribution function	V_i	positive sequence of bus voltage
MC	Monte Carlo	V_d	negative sequence of bus voltage
Std	standard deviation	ts	time span of the forecasting horizon
F/B	forward/backward		
NLMCS	Nonlinear Monte Carlo Simulation		
SUF	system unbalance factor		

possibility spectrum of the future variations based on the prior knowledge that forecasting models provide. On the one hand, depending on the relationship between the impact factors and response variables, each forecasting model is expected to predict only up to a particular limited horizon; therefore, the period for which system analysis is going to be performed is the minimum horizon over which all forecasting models are quite reliable to predict. Input variables are introduced in terms of fuzzy function reflecting the state of variation of forecasted samples. On the other hand, deviation of forecasted samples from targets provoked by inherent error of forecasting models puts a new uncertainty in the variation-based forecast of fuzzy functions. In order to address this new uncertainty, we consider the historical rang of forecasting error in terms of probability density function. This consideration leads to the definition of a new hybrid fuzzy/probabilistic uncertainty under which the system demands a new methodology for uncertainty analysis.

This issue implies a new methodology that incorporates Monte-Carlo technique in the fuzzy load flow. In Monte Carlo iterations, the fuzzy load flow runs under fuzzy inputs randomly selected within the range of some predetermined probability density functions. Most fuzzy load flow methods that yields fuzzy solution based on Jacobean matrix, consider balanced line model similar to that in Newton–Raphson power flow [6,8]. Strongly asymmetric lines carrying unbalanced loads in distribution systems raise the issue of determination of Jacobean matrix which is not as straightforward as Newton–Raphson’s; nevertheless, some studies in

distribution systems use sensitivity matrix instead of conventional Jacobean matrix [7].

Moreover, this paper suggests a new approach to the issue of hybrid uncertainty to fulfill a successful nonlinear Monte Carlo based fuzzy load flow in distribution systems without the need for any sort of sensitivity matrix.

2. Hybrid fuzzy/probabilistic modeling of the future system variables

2.1. Fuzzy modeling of the future system variables

Probabilistic framework conventionally is used in the case of uncertain data, having a sufficient range of information to assign probability characteristics. The fuzzy set theory, on the other hand, has been recognized as a potential tool for enhancing the ability to deal with problems that are too complicated or ill-defined to be solved by conventional methods. Fuzzy membership functions establish relationship between possibility of the variables and their variations. A fuzzy model may describe both a degree of uncertainty in its exact value and a linguistic description of its nature or possible range of value based on human judgment [4,16–19].

Herein, uncertainty analysis of future state of the distribution system is accounted as the principal concern. The uncertainty is considered for consumption of some stations as well as generation of WTGUs, while the rest takes the certain values. Fig. 1 shows the

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