Voltage Stability Analysis of Electrical power transmission systems using Fuzzy set Theory

Prof. Pabitra Mohan Dash
(Dept. of Electrical engineering, BEC, Bhubaneswar)
E-Mail- pmdash.bbsr@gmail.com

Abstract *It is important to prevent voltage instability and hence the voltage collapse due to increasing demand of electricity so that utilities can maintain higher system stability. For this purpose it is essential to understand various aspects of economic and stable operation in the electric power transmission system. Most of the efforts and contributions in this field given by several researchers are based on crisp modeling which stands far from reality as it does not accommodate the uncertainties present in the input parameters. In this work, a platform for the study of voltage stability problem associated with the power system using fuzzy set approach is provided to make the findings more realistic*.

1. Introduction:-

The capability of electric power system to restore the bus voltages at the specified values in steady state and transient conditions is known as voltage stability [1]. In most cases it is called as load stability as the problem is basically load driven[2].Due to slow and gradual increase in load demand over time and complexity of the system, the existing utilities are likely to face voltage stability imposed limit, where the voltage instability is most likely to initiate[3].

In general, number of generators, transformers and loads with complex interconnection are operated in the transmission and distribution networking. Thus the system become complex-dynamic and needs dynamic study for better analysis [4]. As the active power demand grows in the system, it stresses the need for adequate generation and supply of reactive power to maintain the voltage at specified limit[4],[5].Keeping in view to the above facts efforts based on crisp modeling have been contributed by several researchers for studying and understanding the aspects of stable and economic operation of the electric power system. But it is observed that, the result of the crisp modeling deviate far from reality as the scenario in a realistic power system hardly maintains fixed allocation of loads and generation. The objective of this work is to provide a better alternative for study of voltage stability using fuzzy set theory which enables the operator to interpret the happenings linguistically and also offers a wider scope for modeling the uncertainties associated with the loads and generations as observed from past statistical data base of the system in order to make the findings more realistic. It may also be observed that some buses in the system behave critically in the process of initiating voltage instability as the overall system load demand grows monotonically.

2. VOLTAGE STABILITY ANALYSIS USING COMPOSITE LOAD MODELING

Power system loads form a major component in the modeling analysis. These loads can be classified into 3-categories such as industrial, commercial and residential loads. There may be variation in each category with respect to their characteristic as a function of system voltage.

The load component of each category of load can further be divided as constant impedance (Z) type, constant current (I) type and constant power (P) type loads. But the constant power loads have been considered in most of the studies for their simple design and easy simulation techniques. . However, for realistic study it is required to consider a proportionate mix of each of the above types of loads in the model. Such a type of load modeling can be called as composite (Z-I-P) load modeling [6].

In this work the static load model represents the voltage and power relationship in which the active power (P) and the reactive power (Q) are expressed as a composite function the above types of loads.

$P_S=P_0[X_1(V/V_0)^2 +X_2(V/V_0) +X_3]$………… (1),

$Q_S= Q_0[Y_1(V/V_0)^2 +Y_2(V/V_0) +Y_3]$…………(2)

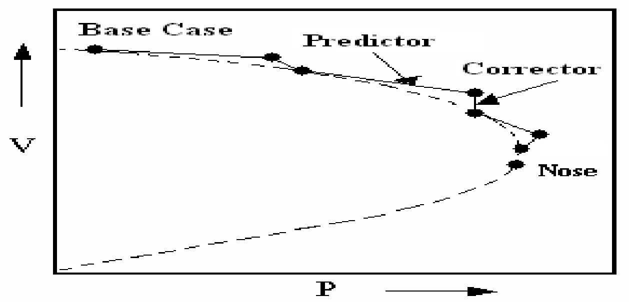
Equation (1) and (2) describe the mathematical formulation of this model, where P_S and Q_S represent active and reactive components of the system loads for a particular loading condition, P_0 and Q_0 represent active and reactive component of the system loads for base case, V and V_0 represent voltage levels for actual and base case load conditions respectively. The proportionate mix of Z-I-P co-efficient for active and reactive load components are represented by x_1, x_2, x_3 and Y_1, Y_2, Y_3. The approximate values of the co-efficient may be obtained from a local survey of the load components or from statistical methods.

3. STEADY-STATE VOLTAGE STABILITY ANALYSIS

Conventional load flow analysis through Newton-Rapson's method, Gauss-seidal's method and Fast decoupled method are inappropriate during higher and critical loading conditions as the result diverges far from the actual value. Therefore a versatile method called continuation power flow (CPF) has been implemented in this work to overcome the difficulties in which the conventional load flow equation is reformulated by including another load parameter (λ) along with the state variables θ and V. The value of (λ) is incremented by suitable steps until the critical point is reached. The solution for $\lambda = 0$ referred to base case and those of $\lambda > 0$ referred to higher loading level above the base case.

Continuation power flow employs predictor-corrector algorithm. The method starts with conventional load flow and solution thus obtained is called as base case solution. To predict the next step of the solution at higher loading a tangential predictor is drawn at the base case point. The tangent predictor is obtained by partially differentiating the modified static load flow equations. A suitable step size is selected to locate the predicted solution along the predictor. To get the exact solution for the system states, certain correction is applied in any one of the parameter out of θ, V, and λ around the predictor. The same procedure is repeated to get the next higher level of loading condition and continued until meeting the critical point. The value of $\partial(\lambda)$ is positive before the critical point, which turns zero at critical point and negative beyond it.

The predictor – corrector scheme for continuation power flow method is shown below.

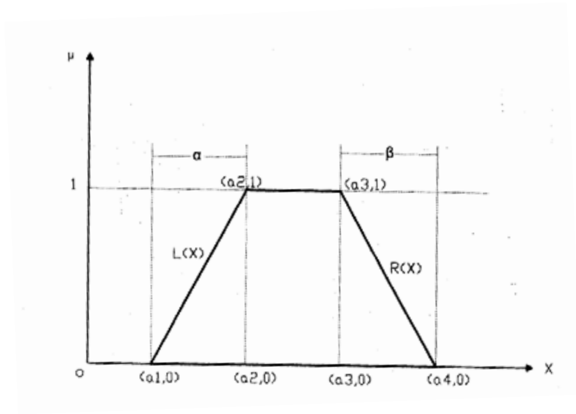


4. <u>PARAMETER MODELING BASED ON FUZZY-SET THEORY</u>

It observed that, the perception of human beings and imprecise knowledge in a more realistic way is to obtain more consistent distribution by using fuzzy set [8]. A fuzzy set($\widetilde{A}$)in its universal set'U' can be defined as a set of order pairs, where each subset includes some element (x) and its membership $\mu_{\widetilde{A}}(x)$ .The membership function indicates the extent to which (x) belongs to ($\widetilde{A}$).

Thu $\widetilde{A} = \{(X, \mu_{\widetilde{A}}(X)) / X \in U\}$ …………… (3)

Out of several types of membership function such as triangular, ramp and trapezoidal etc, an L-R type trapezoidal membership function seems to be best fit the modeling requirement of the input function in this work. A fuzzy number is defined to be L-R type if there are L-R shape functions with positive scalars 'α' (left spread) and 'β' (right spread).This membership function is expressed by the characteristic points (a_1, a_2, a_3, a_4) such that the fuzzy number under study can assume any value between a_1 and a_4.The values within a_2 and a_3 are most likely to take place and have membership value μ_x=1 indicating complete membership for the event. The values a_1 to a_2 and a_3 to a_4 have membership $0 \leq \mu_x \leq 1$, which indicate partial membership for the event. Any value before a_1 and after a_4 has membership μ_x=0 indicates non membership for the parameter.



(Trapezoidal L-R type Fuzzy membership function)

The uncertainty of the parameter 'x' is conveniently characterized by a trapezoidal fuzzy distribution with suitable left and right slope. A specific relationship for 'x' and its degree of membership

$$\mu_{\widetilde{A}}(x) = \begin{Bmatrix} L(x), a_1 \leq x \leq a_2 \\ R(x), a_3 \leq x \leq a_4 \\ 0, otherwise \end{Bmatrix}$$

<u>Mathematical Expression for L(x):</u>

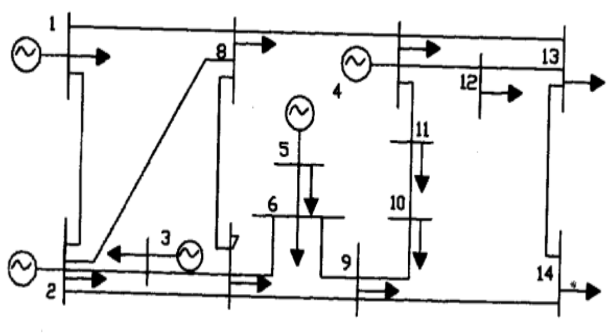
$$L(x) = \frac{x - (a_2 - \alpha)}{\alpha}, \alpha > 0$$

<u>Mathematical Expression for R (x)</u>

$$\Rightarrow R(x) = \frac{(a_3 + \beta) - x}{\beta}, \ \beta > 0$$

5. CASE STUDY ON IEEE-14 BUS SYSTEM

A case study on IEEE-14 bus system is conducted and the result so obtained is presented in this system. The bus data and line data for the system are obtained from [9].



(Single line diagram of IEEE-14 bus system)

Table.1. Fuzzy modeling of active load

Bus no	Active Power Demand in P.u					
	a_1	a_2	α	a_3	a_4	β
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.15	0.20	0.05	0.25	0.30	0.05
3	0.85	0.90	0.05	0.95	1.00	0.05
4	0.05	0.10	0.05	0.15	0.20	0.05
5	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00
7	0.40	0.45	0.05	0.50	0.55	0.05
8	0.01	0.06	0.05	0.10	0.15	0.05
9	0.20	0.25	0.05	0.30	0.35	0.05
10	0.02	0.07	0.05	0.11	0.16	0.05
11	0.01	0.02	0.01	0.04	0.50	0.01
12	0.03	0.05	0.02	0.08	0.10	0.02
13	0.05	0.10	0.05	0.15	0.20	0.05
14	0.08	0.13	0.05	0.17	0.22	0.05

Table.2 fuzzy modeling of reactive loads

Bus no	Reactive Power Demand in P.u					
	a_1	a_2	α	a_3	a_4	β
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.05	0.10	0.05	0.15	0.20	0.05
3	0.10	0.15	0.05	0.20	0.25	0.05
4	0.02	0.05	0.03	0.09	0.12	0.03
5	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00
7	0.01	0.03	0.02	0.05	0.07	0.02
8	0.00	0.01	0.01	0.02	0.03	0.01
9	0.10	0.15	0.05	0.20	0.25	0.05
10	0.03	0.05	0.02	0.07	0.09	0.02
11	0.00	0.01	0.01	0.02	0.03	0.01
12	0.00	0.01	0.01	0.02	0.03	0.01
13	0.04	0.05	0.01	0.06	0.07	0.01
14	0.03	0.04	0.01	0.06	0.07	0.01

Table.3 Fuzzy modeling of active generations

Bus no	Active Power Demand in P.u					
	a_1	a_2	α	a_3	a_4	β
2	0.30	0.40	0.10	0.50	0.60	0.10
3	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00

Table No.4 Fuzzy modeling of reactive generation

Bus no	Reactive Power Demand in P.u					
	a_1	a_2	α	a_3	a_4	β
2	0.30	0.35	0.05	0.45	0.50	0.05
3	0.20	0.25	0.05	0.30	0.35	0.05
4	0.05	0.10	0.05	0.15	0.20	0.05
5	0.10	0.15	0.05	0.20	0.25	0.05

Table. 5 Resulting Bus voltage as a function of μ

μ	0.0 (L)	0.4 (L)	0.8 (L)	1.0 (L)	1.0 (R)	0.8 (R)	0.4 (R)	0.0 (R)
V_6	1.0806	1.06849	1.05626	1.0501	1.02267	1.01630	1.00344	0.9904
V_7	1.0655	1.05314	1.04060	1.0343	1.00780	1.00126	0.98808	0.9747
V_8	1.0691	1.05730	1.04532	1.0393	1.01484	1.00860	0.99598	0.9832
V_9	1.0831	1.06862	1.05393	1.0465	1.01425	1.00658	0.99108	0.9753
V_{10}	1.0850	1.06968	1.05418	1.0464	1.01312	1.00570	0.98883	0.9724
V_{11}	1.0967	1.08246	1.06809	1.0608	1.03223	1.02489	1.01012	0.9952
V_{12}	1.1020	1.08782	1.07358	1.0664	1.03930	1.03211	1.01770	1.0032
V_{13}	1.0973	1.08271	1.06811	1.0608	1.03310	1.02570	1.01085	0.9959
V_{14}	1.0790	1.06243	1.04566	1.0372	1.00074	0.99206	0.97455	0.9568

The fuzzy load flow based CPF with fuzzy modeling of load and generation parameter provide the bus voltages represented in Table-5 follow trapezoidal membership pattern as expected.

6. Conclusion

In this work, principle of fuzzy set theory have been successfully applied for modeling the loads and generations by using L-R type trapezoidal membership functions for the purpose of power flow analysis. A case study on IEEE-14 bus test system is presented with proper validation of the power flow results which reveals that the voltage magnitude and angles, power generation and power losses in the system exhibit membership functions those are nearly trapezoidal.

Thus it concluded that fuzzy set theory and reasoning can be successfully applied in modeling the imprecision and uncertainty offered by the system parameters and variables to understand the system behavior in a realistic way.

7. Referances

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