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# Use Voltage Stability Indices and FDT for Voltage Security Assessment

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Now a-day power networks all over the world need to transfer bulk amount of power. This has resulted in vast interconnection of grids for assuring reliability, security, stability and economic operation. The different challenges to ensure smooth system operation with stressed grid and averting system blackout provided the stimulus for research on voltage security. Voltage stability indices aid the security studies. Real-time voltage security assessment is based on synchronized phasor measurement obtained from phasor measurement units (PMUs). For fast accurate handling of data to synthesize information in order to estimate system security state decision tree (DT) approach of data mining is opted. Power system operating constraints are soft constraints, to implement the situation in real-time and improve decision making abilities at the overlapping and conflicting security boundaries present scheme adopts fuzzy decision tree (FDT).

The decision tree is trained offline considering past representative operating conditions, identify critical attributes as security predictors and periodically updated incorporating new operating conditions for robustness improvement. The status of critical attributes are obtained from PMUs and compared with thresholds priorly defined by FDTs. The decision at the leaf nodes considers the whole path, i.e. from the root to the terminal node including membership function of security predictors.

The indices helps to identify security status from the solution of basic power flow equations, i.e. system real-time measurements such as voltage magnitude, phase angle, bus injected power, branch flows etc.

*Key terms*- Voltage security assessment, Phasor measurement unit, Decision tree, Fuzzy decision tree, Voltage stability indices

## INTRODUCTION

In recent years the thrust for electric power demand has grown exponentially. This has resulted in vast interconnection of formerly separated grids for assuring capacity expansion, reliability and security. In the present scenario grids operating with stressed operating point due to elevated load demand has resulted in noteworthy voltage limit deviations with respect to the imposed constraints due to which the issue of voltage collapse is looming prominently. The urgency for ensuring secure system operation has heightened the need for voltage security assessment. Due to emergence of fleet of sophisticated devices more and more data become available for the system study. Tactful utilization of data available for analysis and assessment of voltage security issues is fueled by machine learning, which has provided an evolutionary breakthrough in developing efficient and reliable tool for fast, accurate decision making under critical conditions with voltage stability indices acting as a vital tool in estimating system security status i.e. proximity to voltage collapse or signifying the stress of current operating point on power network.

## MAJOR GRID BLACKOUTS

Grid blackout synonymously termed as voltage collapse. Voltage collapse majorly occurs due to sudden change in network topology, strikingly large unbalance between demand and generation. This can be explained in short as a phenomenon traced by wide spread decline in voltage profile usually initiated by lines, transformers, and generators tripping and disturbances in consumption patterns resulting in voltage drop due to scarcity of reactive power reserves in power system [Shahidehpour, 2014].

**Table 1.1 Major Grid Blackout in world**
Source: [Shahidehpour, 2014]

| Sl. No. | Date | Country |
|---|---|---|
| 1 | 09/11/1965 | 10 states in northeast US |
| 2 | 5/1977 | Miami, US |
| 3 | 7/1977 | New York city, US |
| 4 | 7/1999 | New York city, US |
| 5 | 11/3/1999 | Brazilian power system |
| 6 | 2/01/2001 | India |
| 7 | 14/08/2003 | Northeast of US and CANADA |
| 8 | 28/08/2003 | South London |
| 9 | 7/11/2003 | Most of Chile |
| 10 | 25/5/2005 | Moscow, Russia |
| 11 | 4/11/2006 | European Power System |
| 12 | 30/7/2012-31/07/2012 | India(Worlds' largest blackout recorded) |

Mechanism of black out can be understood on a fly from the figure 1.1. Power system operating at normal operating conditions may subjected to the vagaries of system operations such as contingency conditions which may lead to instability events. These instability events results in voltage problems, power flow surges, overloads and unsymmetrical system configurations due to lines, transformers, and generators tripping. Cascading effect of outages results in frequency, voltage collapse problems which further accentuates power flow surges, overload issues. Non-reversal of power system state due to unavailable reactive power reserve, untimely action by operators lead to system divided into islands or blackout. At this stage restoration operations need to be undertaken as the last line of security to regain the system operating status which largely depends upon the blackstart capability of system.

**Figure 1.1 Mechanism of Blackout**
Source-[Shahidehpour, 2014]

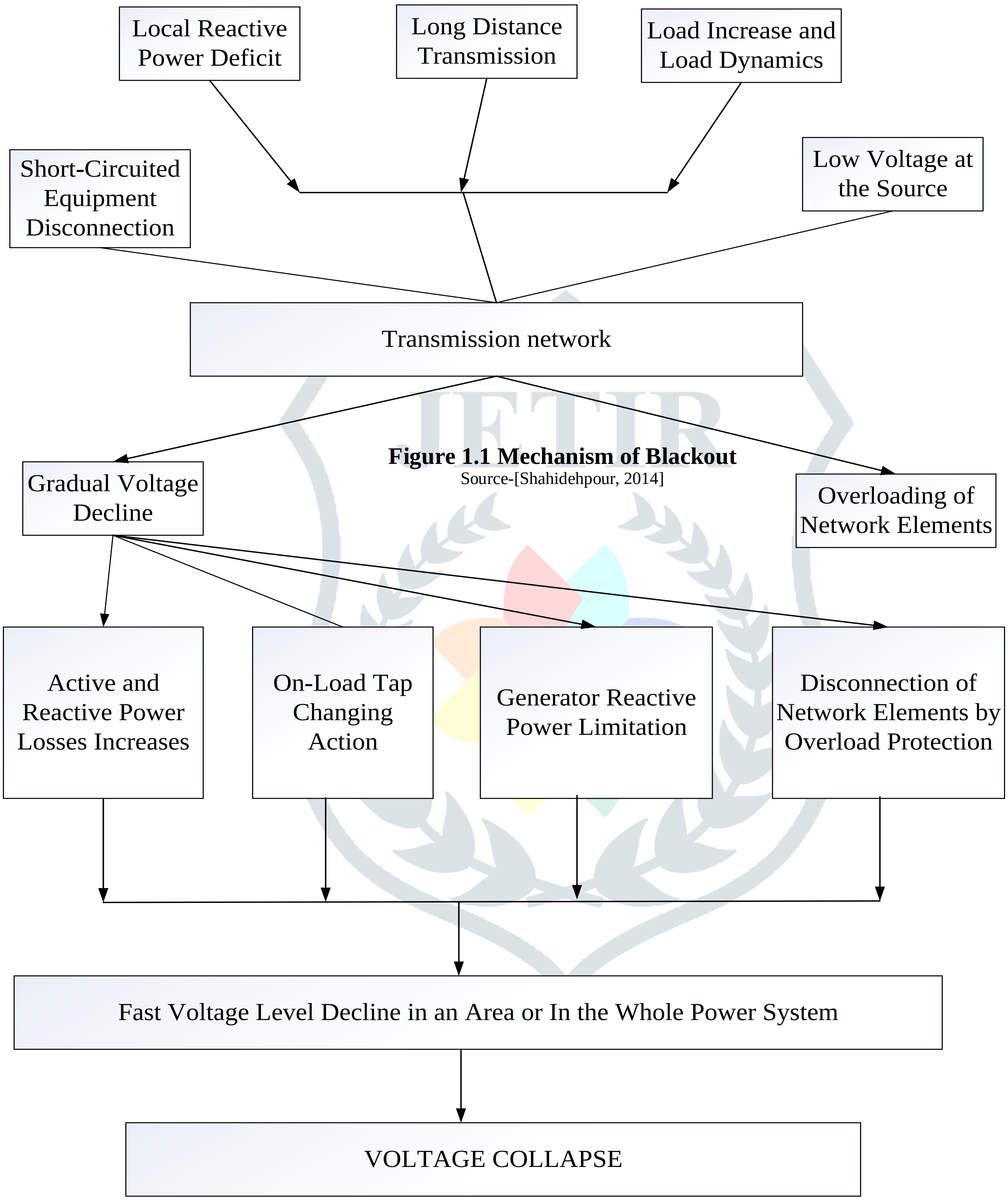


**Figure 1.2 Voltage Collapse Mechanisms in Power System**
Source- [Shahidehpour, 2014]

## RELATION BETWEEN RELIABILITY, SECURITY, and STABILITY

NERC (North American Electric Reliability Council) defines reliability as: *"Reliability, in a bulk power electric system, is the degree to which the performance of the elements of that system results in power being delivered to* *consumers within accepted standards and in the amount desired. The degree of reliability may be measured by the frequency, duration, and magnitude of adverse effects on consumer service".*

## POWER SYSTEM STABILITY

Power system stability can be defined as [Kundur, 2004], "*The power system stability is the ability of an electric power system for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact".* To support the demand of late the power system has been vastly interconnected. Interconnection improved the systems'stability, reliability, performance but it has also added new dimensions to stability problems. The various stability and security problems cannot be effectively understood and efficiently analyzed by considering them as a single problem.

This classification is based on following consideration [Kundur, 1994]:

a) The physical nature of the resulting mode of instability as indicated by the main system variable in which instability can be observed.

b) Size of disturbance considered which influences the method of calculation and prediction of stability.

c) The devices, processes and time-span that must be taken into consideration in order to assess stability.

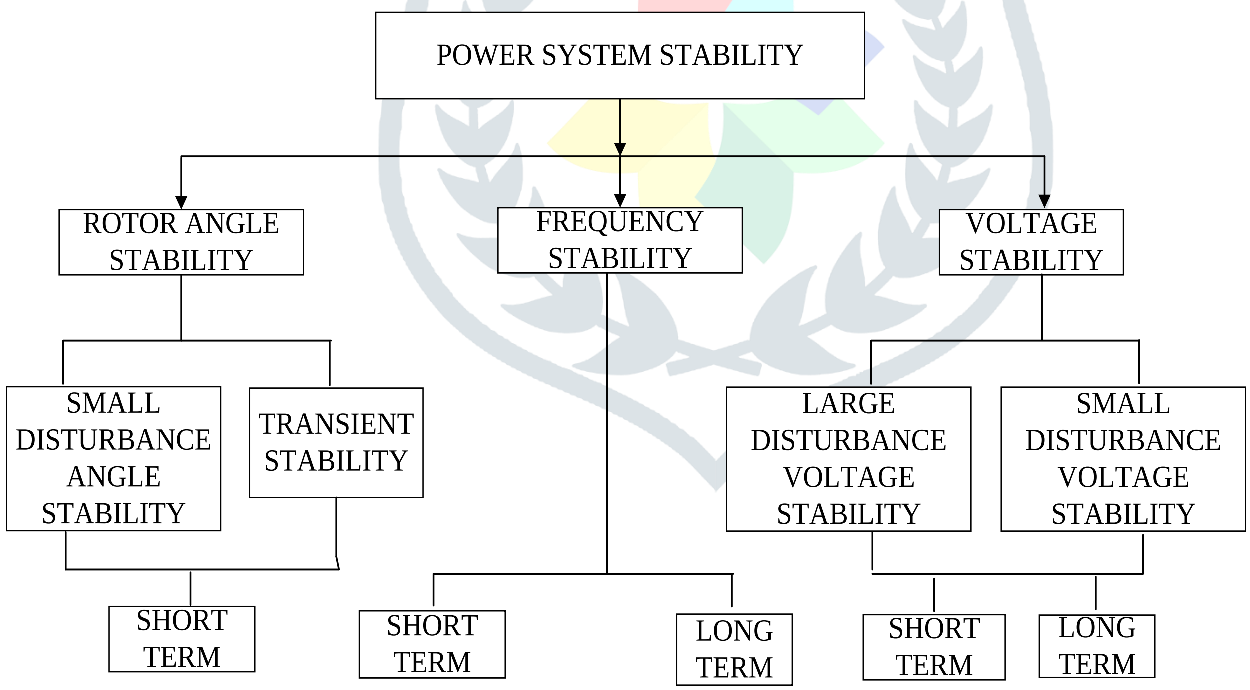


**Figure 1.3 Classification of Power System Stability**
Source-[Kundur, 2004]

## VOLTAGE SECURITY

Voltage security can be defined as [Kothari, 2012], "*Ability of a system, not only to operate stably, but also to remain stable following credible contingencies or load perturbations".* Hitherto has been to expand the gird capacity and accommodate the exponential increase in the load without keeping the network stability and security at stake. Probably the issue was taken up for the first in [Wehenkel, 1986].An objective of security study [Wood, 1996; Wehenkel, 1989] includes:

a) Operate the system in such a way that power is delivered reliably.
b) Within constraints imposed on the system operation for reliability considerations, the system will operate most economically.
c) Appraise the systems' capability to withstand major contingencies, and
d) Suggest viable preventive or remedial corrective actions to regain the network stability.

**SECURITY ASSESSMENT**

The power system can be seen as a "black-box", with a specified function to serve the loads connected. It should ensure operation irrespective of operating state. To accomplish this system need to withstand any disturbance. Assessment methods are adopted in order to identify vulnerable portions of the system, estimate current or predicted state of the system and develop appropriate measures to enhance the system security. In this regard the assessment methods should be fast, accurate enough to help the operators take requisite actions beforehand. Based on the simulation type and test performed to determine stability problems, the assessment methods are divided into:

a) Steady-State methods
b) Dynamic methods

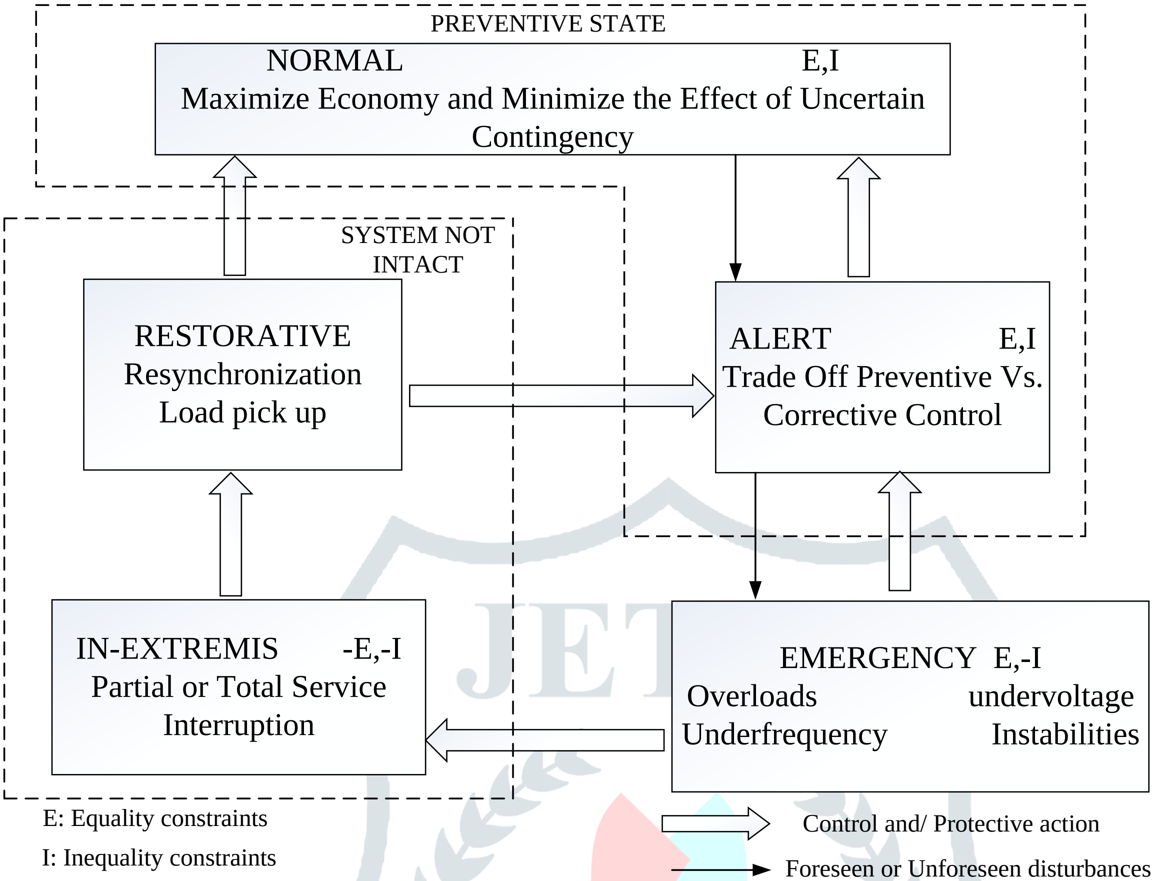


**Figure 1.4 Operating States and Transition**
Source- [Wehenkel, 1998]

Present research deals with the steady-state assessment. Steady-state methods are based on the fact that the main support for the voltage stability in a power system is its ability to wheel power to load centers under normal and disturbed operating conditions. This capability can be evaluated from solutions of power flow equations. The numbers of probable events are infinite and it's impossible to trace all the combinations. The practice is to assess the power system state using one or more indices for all events considered. The indices penalize the violation of transmission capacity limit, voltage magnitude violation, stability limits, generator reactive power generation limits and so on. These methods provide good results that are much faster than dynamic methods and also allow local and global voltage stability indices to be defined.

These indices employed to evaluate two aspects of security assessment:

a) Proximity to voltage collapse
b) Degree of stress impended by the disturbance considered.

One method considering voltage magnitude of all the busses is derived in [Ejeb**e**, 1979]. Reactive power support is vital for maintaining voltage profile, so incorporating reactive power generation a new index formulated by [Ejebe, 1979]. On similar lines [Kessel, 1986] proposed L-index. $L_{mn}$-index proposed in [Moghavvemi, 1999] considering power flow over a single line. In [El-Kateb, 1997] was proposed LVSI index incorporating probably all the important parameters of network, which later on modified by [Chakrabarty, 2010]. In the network, voltage magnitude at the busses play a vital role in estimation of security status, in this regard [Wood, 1996] proposed $PI_{vmv}$ index which was employed by [Vittal, 2010; Mohammadi, 2015] to calculate voltage magnitude violation aspect of voltage security assessment. A simplified method to obtain two-bus equivalent of a multi-bus system is adopted [Jasmon, 1993; Chakrabarty, 2010]. Above provides an approach to ascertain the systems' security level using real-time measurements under unpredictable scenario. The mathematical expressions for the stability indices are expressed as polynomial containing the system real-time measurements. Parameters considered for voltage stability indices:

a) Bus voltage magnitudes
b) Bus angles
c) Real power flow of lines
d) Reactive power flow of lines
e) Total real power generation of system
f) Total reactive power generation of system
g) Impedance of transmission line

## DECISION TREE IN POWER SYSTEM

Due to merits as in [Cutsem, 1993; Phadke, 2001; Ruisheng, 2009; Vittal, 2010; Vittal, 2012; Ranjbar, 2013; Mohammadi, 2015] decision tree is used as a decision tool in data mining. Decision tree support to determine the relation between the measured values and the target value. DTs blend swiftly with the fast measuring capabilities of PMUs and can be employed for classification or prediction purposes. [Breiman, 1984] laid down the theoretical base for data mining and decision trees, [Wehenkel, 1986] extended the work into the field of power systems .The induction of DT is based primarily on two approaches a) TDIDT b) BFIDT.

Now advantages of decision tree can be enumerated as follows:

a) Simplicity in size
b) Reliability of diagnosis
c) Interpretability of phenomena
d) Exploring the importance of parameters
e) Ability to cope with various kinds of candidate system parameters including electrical and topological types.
f) Ability to discover and describe the underlying mechanisms of intricate phenomena

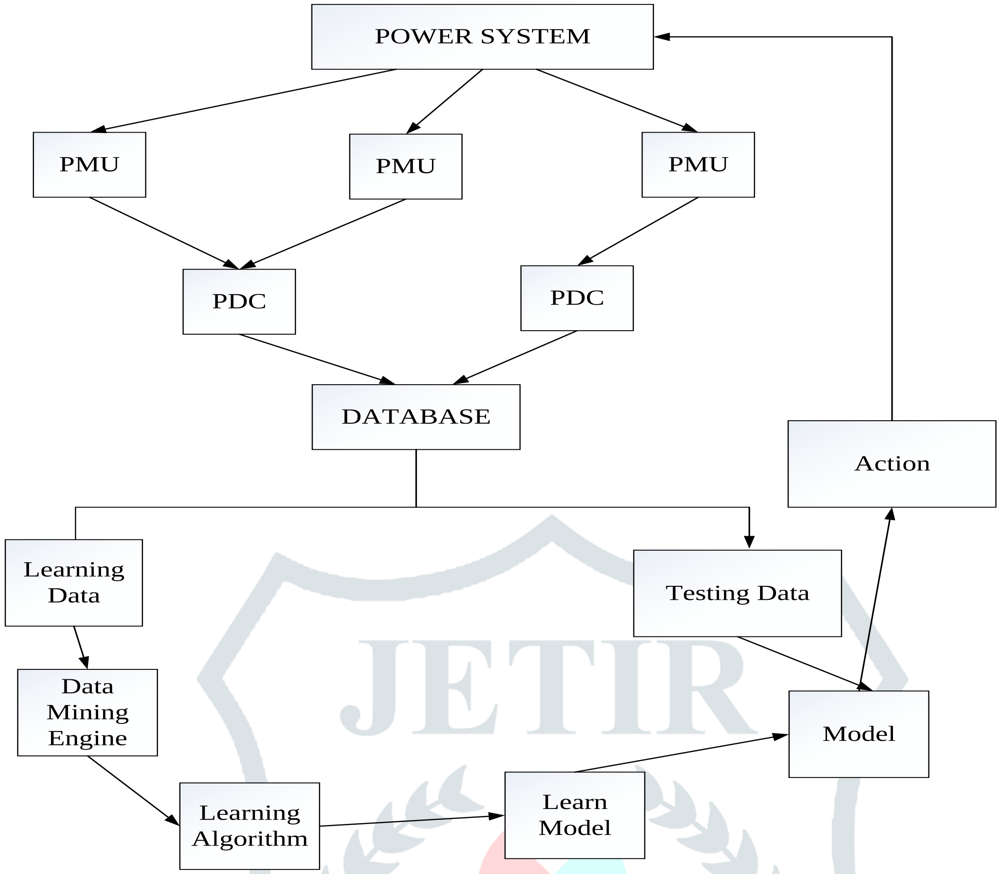


**Figure 1.5 Schematic Layout of Data Mining In Power System**

## CONCLUSION

The systematic and novel approach of designing fuzzy decision tree based voltage security assessment model by employing voltage stability indices. Motivation, proposed methodology and adaptive technology were discussed at an introductory level. The importance of introducing fuzzy rule into conventional DT has been discussed

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