Development of Real Time Radar Visual Style Information System of Power System Integrated Health Index

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Introduction

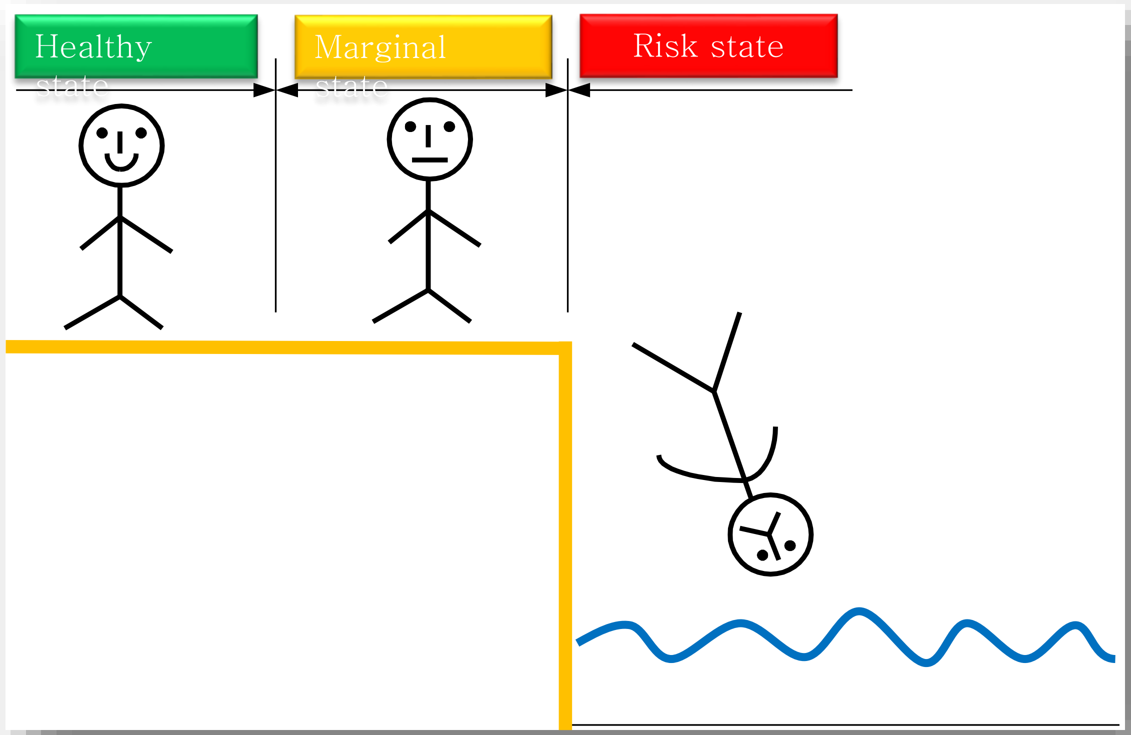
- Currently, there are a variety of system operation-related works such as voltage and frequency control through EMS, transmission line and transformer overload factor monitoring, reserve prediction management and transient stability prediction during contingency.

- In addition to this, there is a need of dealing with timely system operations and preventing problems, by predicting system integrity in advance, but in many ways, the present system is depending on capabilities of a real time system operation manager. Therefore, a visible and objective operation support tool must be necessarily introduced to judge situations of power systems intuitively and rapidly, to monitor them efficiently and to support decision making.

- This paper is focused on theoretical foundation establishment of reliability index and algorithm for monitoring a integrated index, which is called as PSHI(Power System Health Index).

1. Domains

1.1 Wellbeing Analysis Domain



New PSHI States	Adequate	Secure	Economics	Present States
Healthy Index:HI	O	O	O	Normal
Marginal Index: MI	O	X	X	Alert
Risk Index: RI	X	X	X	Emergency
	X	X	X	Extreme Emergency

1.2 PSHI Domain Definition

Based on KPX Expert Interview and Reliability Codes in Korea

Adequacy

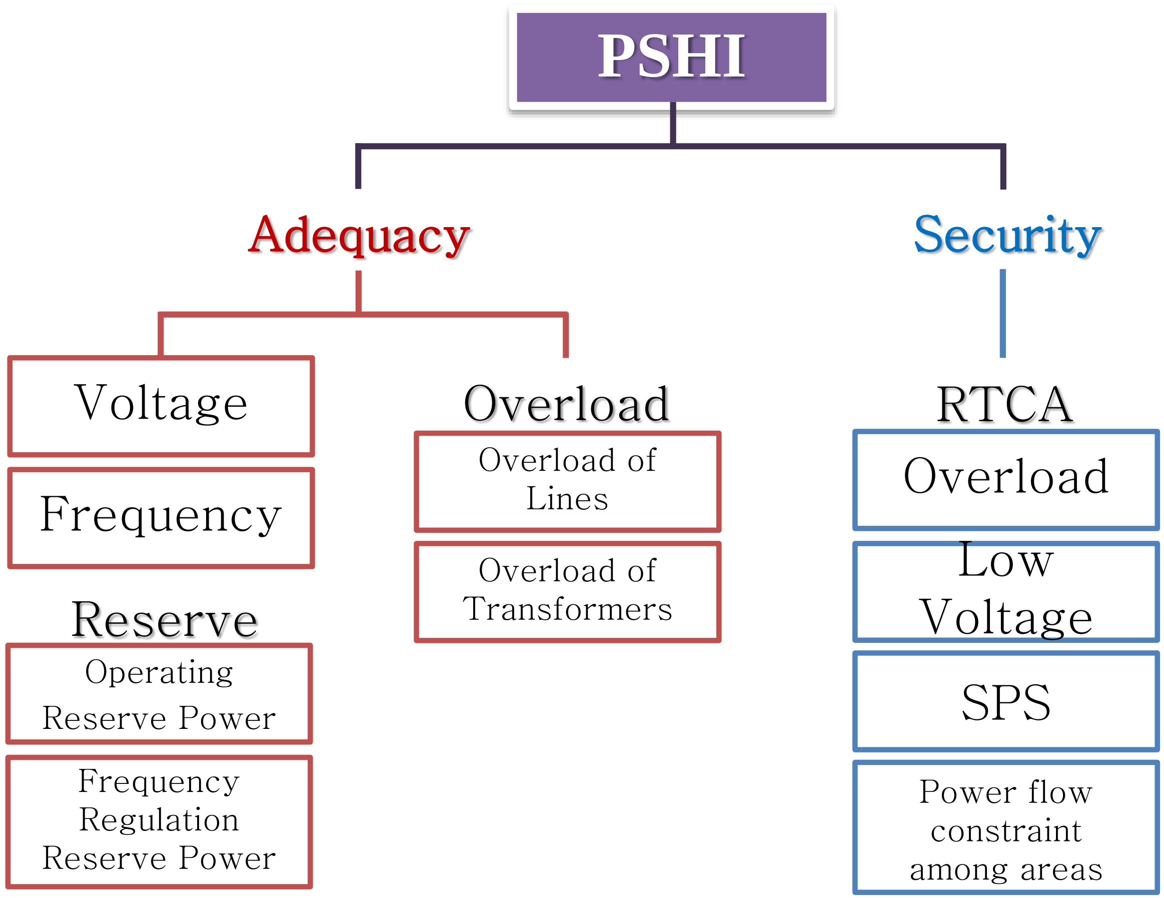
	Action Item			Domain H	Domain M	Domain R
Adequacy	Frequency			59.9≤FH≤60.1	60.1<FMH≤60.2 59.8≤FML<59.9	The rest
	Voltage	765		$745 \le VH_{765} \le 785$	$785 < VMH_{765} \le 800$ $726 \le VML_{765} < 745$	The rest
		345		$336 \le VH_{345} \le 360$	$360 < VMH_{345} \le 362$ $328 \le VML_{345} < 336$	The rest
		154	Heavy load	$156 \le VH_{154} \le 164$	$164 < VMH_{154} \le 169$ $139 \le VML_{154} < 156$	The rest
			Load regulation	$153 \le VH_{154} \le 161$	$161 < VMH_{154} \le 169$ $139 \le VML_{154} < 153$	The rest
			Light load	$152 \le VH_{154} \le 160$	$160 < VMH_{154} \le 169$ $139 \le VML_{154} < 152$	The rest
	Reserve Power	ORP		5000≤ORH<5100	2000≤ORM<5000	500≤ORP<2000
		FRP		1500≤FRH<1600	1000≤FRM<1500	500≤FRM<1000
	Over Load	OVL		0.7≤OVH≤0.85	0.85<OVM<1.0	1.0≤OVR≤1.25
		OTF		0.7≤OTH≤0.9	0.9<OTM<1.25	1.25≤OTR≤1.5

Security

Action Item			Domain		
			H	M	R
Voltage	765		$726 \le VH_{765} \le 800$	$800 < VMH_{765} \le 880$	The rest
				$653.4 \le VML_{765} < 726$	
	345		$328 \le VH_{345} \le 362$	$362 < VMH_{345} \le 398.2$	The rest
				$295.2 \le VML_{345} < 328$	
	154	Heavy load	$139 \le VH_{154} \le 169$	$169 < VMH_{154} \le 185.9$ $125.1 \le VML_{154} < 139$	The rest
		Load regulation			The rest
		Light load			The rest
Over Load	OVL		$1.2 \le OVH \le 1.5$	$1.5 < OVM < 1.8$	$1.8 \le OVR \le 2.1$
	OTF		$1.2 \le OTH \le 1.5$	$1.5 < OTM < 1.8$	$1.8 \le OTR \le 2.1$
Power flow constraint between areas			$0.85 \le RTLX1 < 0.9$	$0.9 \le RTLX1 < 0.95$	$0.95 \le RTLX1 \le 1.0$
SPS			$SPS = 0$	$0 < SPS \le 1$	$1 < SPS \le 2$

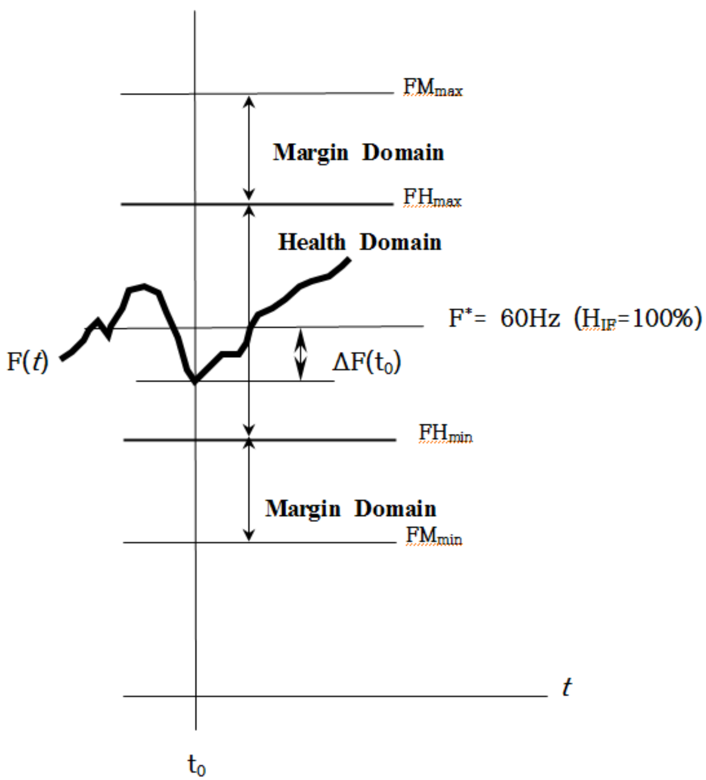
2. Formulation of PSHI

2.1 Target items for PSHI



2.1.1 Frequency

➢ **Health index of frequency (HI_F) in a time, t can be formulated measuring how close it is to the standard frequency based on the deviation of degree out of the standard and it is identical in the whole system. The formulation is as follows.**



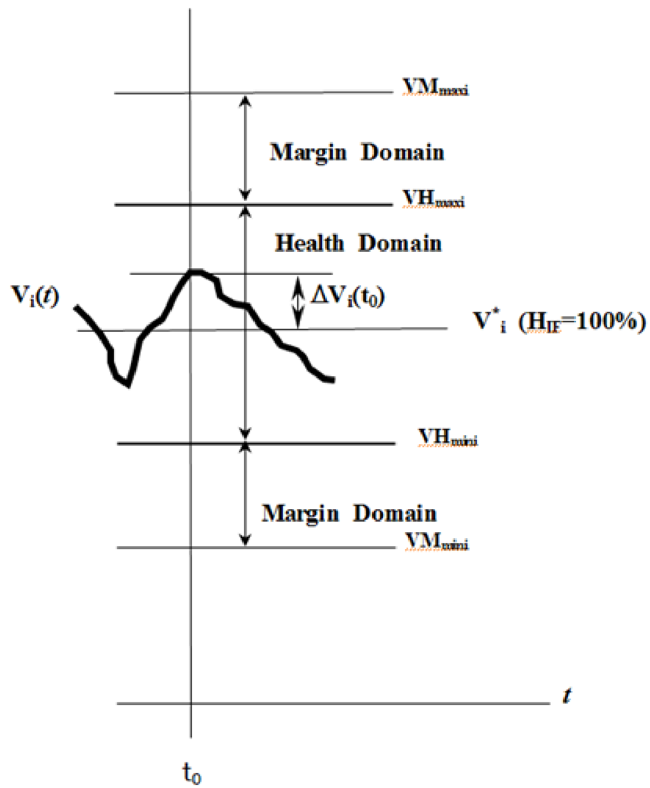
Frequency Domain and HI Model

$$HI_F(t) = (F^* - ABS(\Delta F(t)) / F^*$$

Where, $\Delta F(t)=F(t)-F^*$
$HI_F(t)$: Health index of frequency
F^*: Standard frequency

2.1.2 Voltage (RTCA: Low Voltage)

➢ **Health index of voltage(HI_V) in random time, t can be formulated, by measuring how close it is to the standard voltage, based on the deviation of degree out of the standard in each bus and voltage level. Its formulation is as follows.**



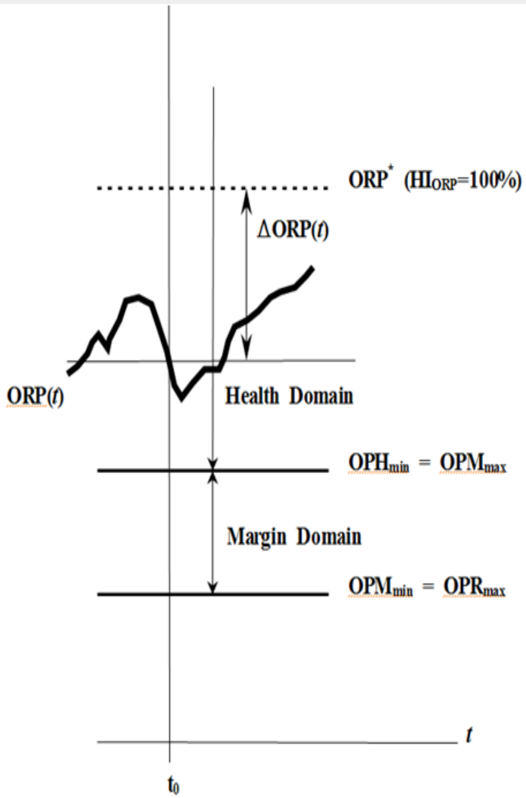
➢ Voltage Domain and HI Model

$$HI_V(t) = \text{minimum}[(V^* - ABS(\Delta V_i(t))) \times 100 / V_i^*] \quad i \in \Omega_V$$

Where, $\Delta V_i(t) = V_i(t) - V_i^*$
Ω_V: A set of voltage monitoring buses
$HI_V(t)$: Health index of voltage
V_i^*: Standard voltage

2.1.3 Reserve power

➢ **Operating reserve power(HI_{ORP})is determined, based on how much it satisfies the present reliability criteria. In other words, it can be used as an index to measure how close it is to the standard operating reserve power. The following shows its formulation.**



➢ Operating Reserve Power Domain and HI Model

$$HI_{ORP}(t) = (ORP^* - \Delta ORP(t)) \times 100 / ORP^*$$

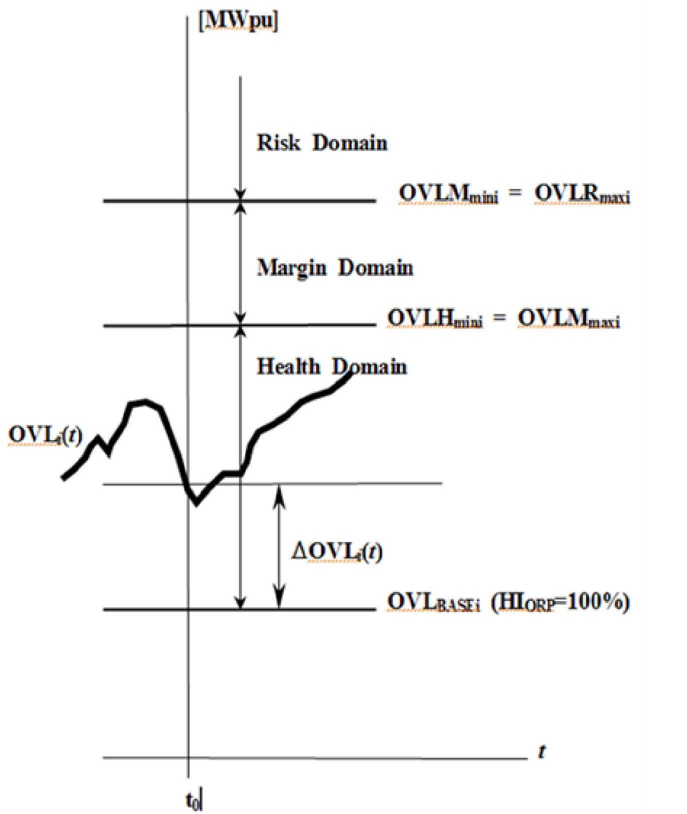
Where,
$HI_{ORP}(t)$: Health index of operating reserve power
ORP^*: Operating reserve power fixed by the reliability criteria

$$\Delta ORP(t) = ORP^* - ORP'(t)$$

$$\Delta ORP(t) = \mathrm{minmum}\{ORP(t), ORP^*\}[\mathrm{MW}]$$

2.1.4 Overload (RTCA: Overload)

➢ **Health index of overload factor(HI_{OVL}) can be formulated, by measuring the system overload factor which means how overloaded the system is during rated operation. The following shows its formulation.**



➢ Over Load Domain and HI Model

$$HI_{OVL_{\min}}(t) = \text{minimum}\{HI_{OVL_i}(t)\} \quad i \in \Omega_{OVL}$$

$$HI_{OVL_I}(t) = (OVL_{base} \times 100)(OVL - \Delta OVL'(t)) = (OVL_{base} \times 100) / OVL'_i(t)$$

Where,

$\Delta OVL'_i(t) = OVL_{base} - OVL'_i(t)$

$\Delta OVL'_i(t) =$ maximum$\{ OVL_i(t), OVL_{base}\}$ [pu]

$HI_{OVLi}(t)$: Health index of i system in random time, t

OVL_{base}: Overload factor of the minimum capacity considered to show 100% of health index [pu]

$OVL_i(t)$: Overload factor of i system in random time, $t(=OL(t)/CAP_{rated})$ [pu]

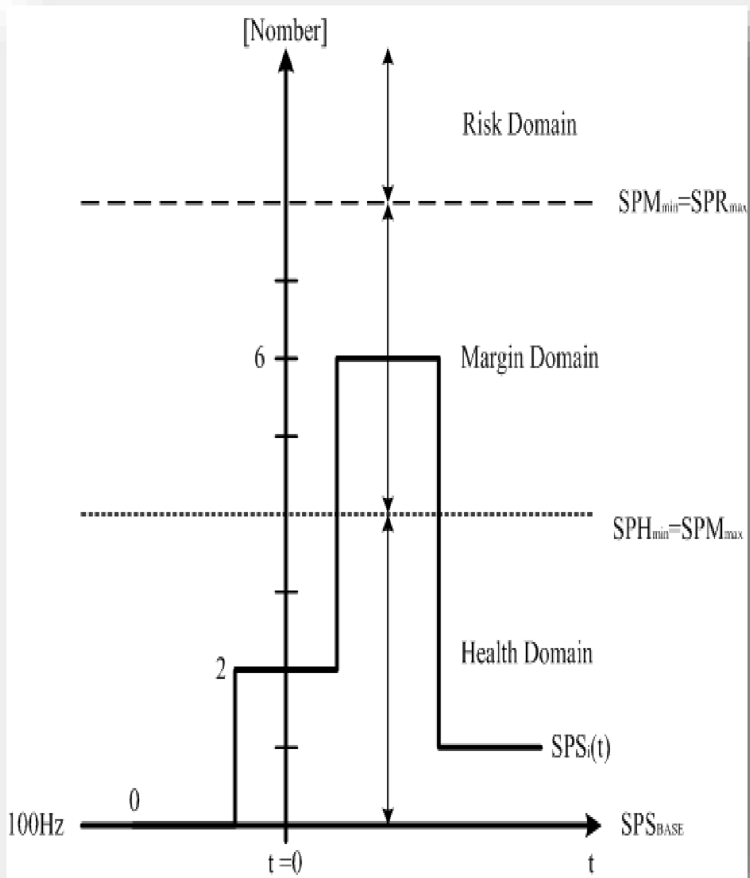
$OL_i(t)$: Actual capacity of i system in random time [MW]

CAP_{rated}: Rated capacity of i system [MW]

Ω_{OVL}: A set of system elements for overload monitoring

2.1.5 SPS

➢ **Health index of SPS(Special Protection System) factor(HI_{SPS}) can be formulated. The following shows its formulation.**

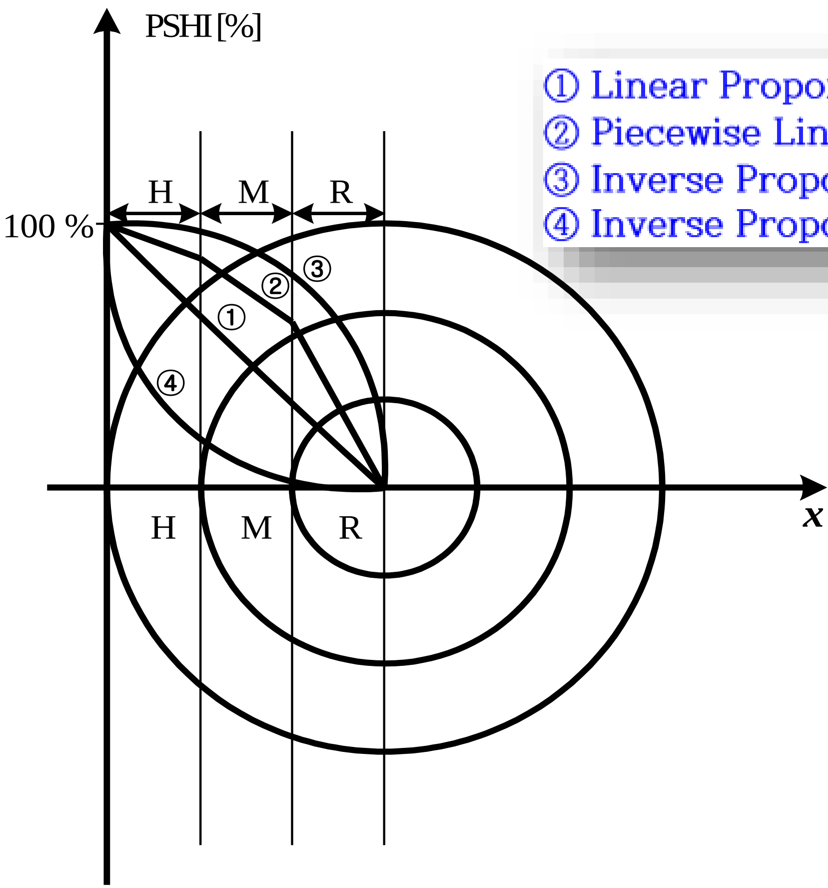


$$HISPS(t) = \text{minimum } HISPS_i(t) \quad i \in \Omega_{SPS}$$

$$Where, HISPS_i(t) = \begin{cases} 100 & SPS_i(t) = 0 \\ 70 & 0 < SPS_i(t) \le 1 \\ 30 & 1 < SPS_i(t) \le 2 \\ 0 & 2 < SPS_i(t) \end{cases}$$

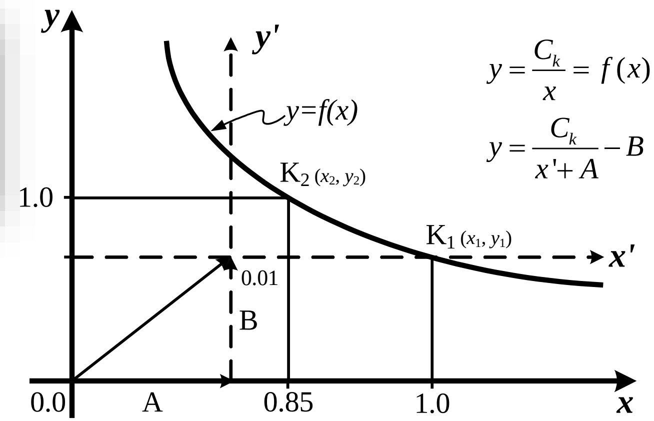
Ω_{SPS} : SPS Installation Station Set

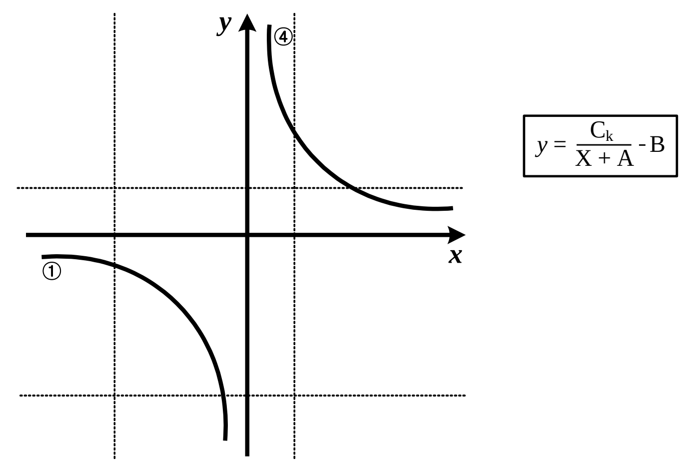
2.2 Function Models of PSHI



① Linear Proportional
② Piecewise Linear Proportional
③ Inverse Proportional A
④ Inverse Proportional B

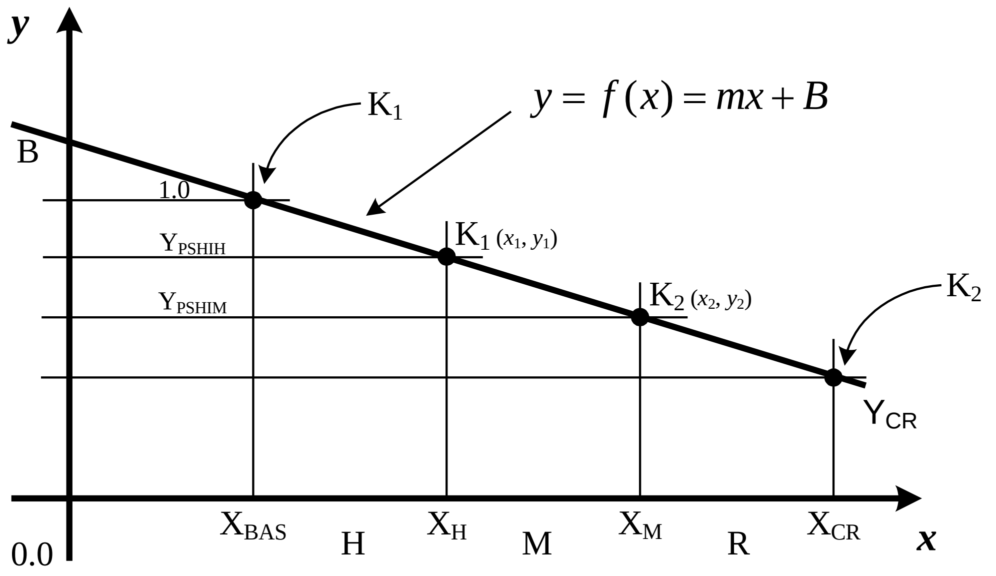
➤ **Inverse Proportional**





➤ **Various kind of output function models of PSHI proposed newly in this paper**

➢ Piecewise Linear Proportional



① H $\begin{cases} x_1 = X_{BAS} \\ x_2 = X_H \end{cases}$ $\begin{cases} y_1 = 1.0 \\ y_2 = Y_H \end{cases}$	② M $\begin{cases} x_1 = X_H \\ x_2 = X_M \end{cases}$ $\begin{cases} y_1 = Y_H \\ y_2 = Y_M \end{cases}$	③ R $\begin{cases} x_1 = X_M \\ x_2 = X_{CR} \end{cases}$ $\begin{cases} y_1 = Y_M \\ y_2 = Y_{CR} \end{cases}$
	$m = \dfrac{y_1 - y_2}{x_1 - x_2}$	
	$B = -mx_1 + y_1$	
$y = mx + B$	$y = (\dfrac{y_1 - y_2}{x_1 - x_2})x + (y_1 - mx_1)$	

2.3 Mapping PSHI

- The flow chart for mapping PSHI into domains

Normalization[pu]

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Equal Distance Transformation of Domain

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PSHI Function Solution and Calculation

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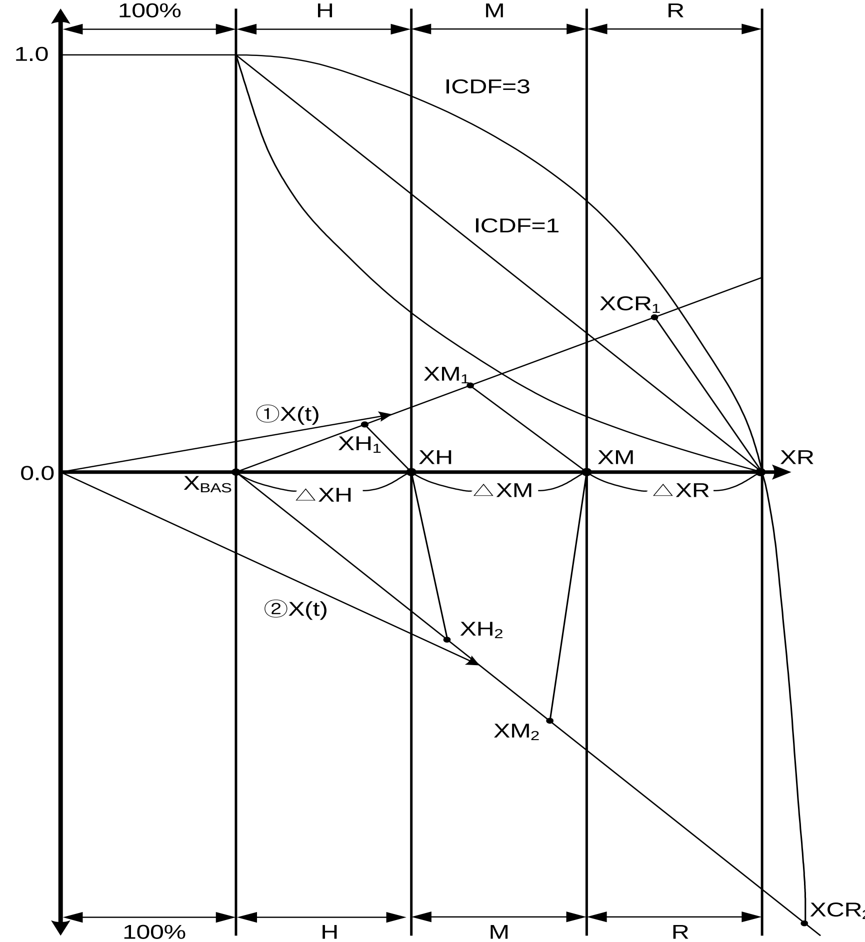
Mapping into Domain

- Equal interval adjustment concept of PSHI mapped into three domains



2.4 Average Value of PSHI

➢ Arithmetic mean method

① Adequacy PSHI1

$$PSHI1 = (HI_F + HI_{V154} + HI_{V345} + HI_{V765} + HI_{ORP} + HI_{FRP} + HI_{OVL} + HI_{OTF})/8$$

② Security PSHI2

$$PSHI2 = (RHI_{V154} + RHI_{V345} + RHI_{V765} + RHI_{OVL} + RHI_{OTF} + RTLX1 + RTLX2 + RSPS)/8$$

③ Composite PSHI

$$PSHI = (PSHI1 + PSHI2)/2$$

➢ Geometric mean method

① Adequacy PSHI1

$$PSHI1 = (HI_F \times HI_{V154} \times HI_{V345} \times HI_{V765} \times HI_{ORP} \times HI_{FRP} \times HI_{OVL} \times HI_{OTF})^{\frac{1}{8}}$$

② Security PSHI2

$$PSHI2 = (RHI_{V154} + RHI_{V345} + RHI_{V765} + RHI_{OVL} + RHI_{OTF} + RTLX1 + RTLX2 + RSPS)^{\frac{1}{8}}$$

③ Composite PSHI

$$PSHI = (PSHI1 \times PSHI2)^{\frac{1}{2}}$$

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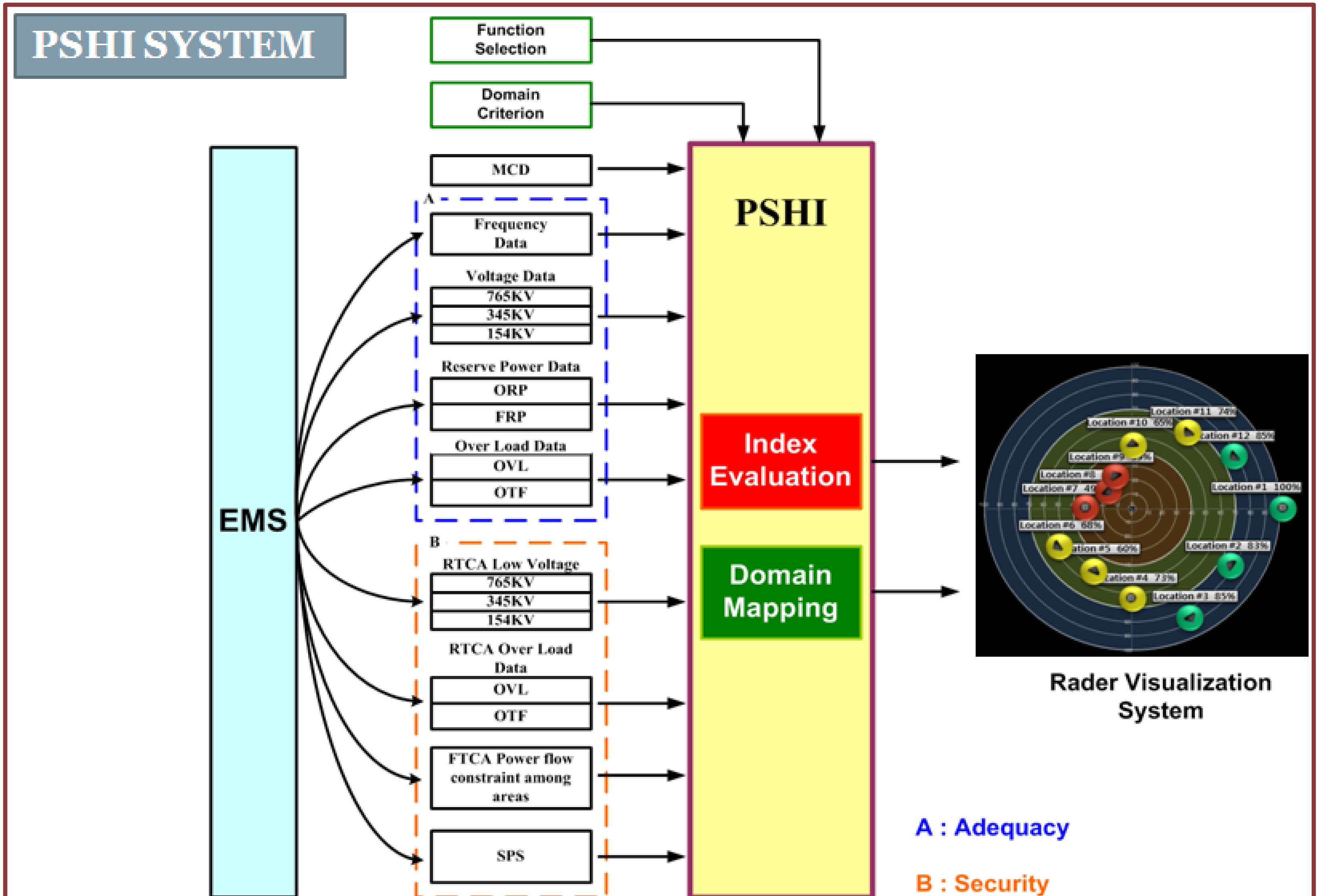
3. Conceptual Diagram of PSHI



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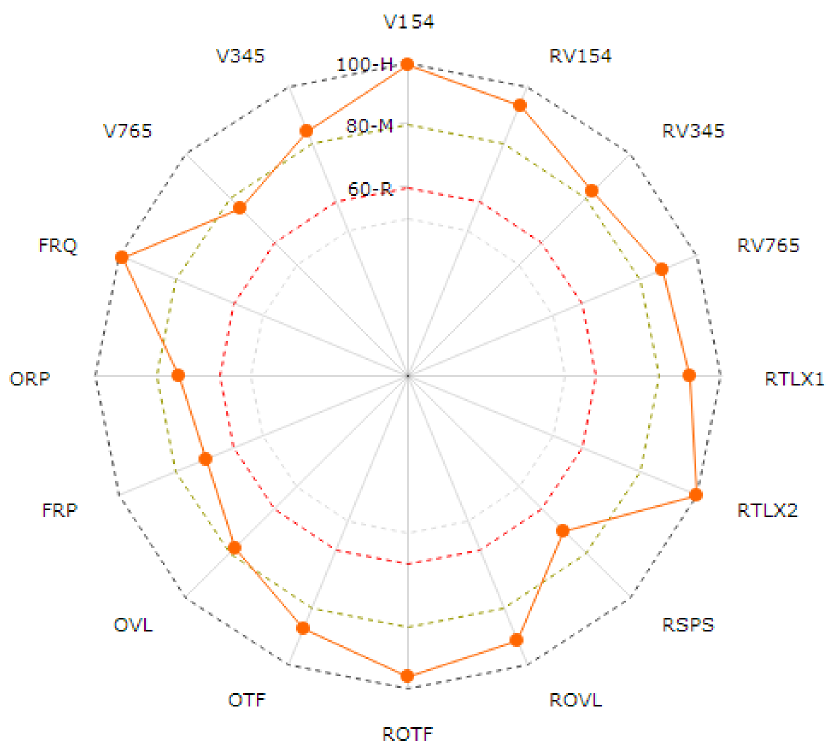
4. Case Study

chart by amcharts.com

PSHI = 85.75427

Time - 2013 9 3 13:00:05

OTF	87
OVL	78
FRP	70
ORP	73
FRQ	98
V765	76
V345	84
V154	99
PSHI1	82.85394



RV154	93
RV345	83
RV765	88
RTLX1	90
RTLX2	100
RSPS	70
ROVL	91
ROTF	96
PSHI2	88.75613

Rader style Visualization

5. Conclusions

- This paper aims to present a PSHI(power system health index) which is a new reliability index for easier real time power system health monitoring during a variety of system operation-related works like frequency and voltage control through EMS, transmission line and transformer overload factor monitoring, reserve prediction management and contingency planning.

- The paper classified three evaluation domains into health, margin and risk domains based on the reliability criteria and the results of interview with experts. The PSHIs suggested from virtual input data and results of sub-items classified from the viewpoint of supply adequacy and security were mapped on these domains.

- Additionally, it is considered that output function model should be applied to an actual system.

- Therefore, it is thought that the formulation of PSHI index proposed by this paper will establish a theoretical foundation of reliability index, help development of algorithm, and additionally, cope with changes of criteria and the demands of system operators very effectively through various verifications of actual input data values. In other words, PSHI index will make a contribution to a visible and objective operation support for intuitive and rapid situation judgment of power systems and efficient monitoring and decision making.

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