RISK AND RELIABILITY ANALYSIS OF SAS USING COST IMPORTANCE MEASURES

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ABSTRACT

Risk analysis of a system is important to guarantee the quality and safety operation of a system. To identify the risky or critical components and to prioritize the safety improvements, Importance Measures (IM) play vital role. Risk analysis of a system using cost based importance measures is essential for system cost-risk analysis to reduce the maintenance cost. This paper presents the cost-risk analysis of Substation Automation System (SAS) using existing Cost Importance Measure (CIM) and an advanced cost based importance measure i.e NCIM which is easier, computationally more accurate and produce necessary ranking. The non cost based importance measures criticality, Fussel-Vesely (FV) and cost based importance measures CIM and NCIM for redundant cascading architecture of SAS have been determined. The results of criticality, FV, CIM and NCIM measures have been compared and the cost based importance measures yield more useful information compared to non cost based importance measures. From the outcome of these measures the components ESW and EI are important in cost-risk point of view and DCP is most important in maintenance point of view.

KEYWORDS

Cost IM, Importance Measure, Reliability, Substation Automation System, cost- risk analysis

NOMENCLATURE

CIM	COST IMPORTANCE MEASURE
RBD	RELIABILITY BLOCK DIAGRAM
I^{CR}	CRITICALITY IMPORTANCE MEASURE
I^{FV}	FUSSELL-VESELY IMPORTANCE MEASURE
BE	BASIC EVENT
IM	IMPORTANCE MEASURE
NCIM	NEW COST IMPORTANCE MEASURE
SAS	SUBSTATION AUTOMATION SYSTEM

1.INTRODUCTION

In order to achieve desired objective of a system all the components of the system must work efficiently. Reliability importance measures are helpful to obtain the feeble elements in the system. From the results of the importance measures the predictor can rank contribution of each component for the overall system success. Birnbaum [1] introduced the importance to compute the involvement of individual component to the overall system performance. Many importance measures like Fussell-Vesely (FV), Improvement potential (IP), Risk Achievement Worth (RAW), Criticality Importance, Risk Reduction Worth (RRW), Joint importance measures, etc. were proposed later [2-4]. Criticality measures are useful in prioritizing the maintenance actions. These measures generally depend on the position of the component and its reliability. The importance of the cost of the component is identified by Rausand and Hoyland [5] and concluded that component cost should be considered, in addition to the position and reliability of the component. In order to get optimal results of a system, the analyst should consider the cost of the components also. Risk measures like Fussel-Vessely (FV) [6] give idea about the risk only and do not consider the component cost. For the system cost-risk analysis, cost based importance measures like CIM can be used [7]. The cost-risk analysis of substation automation system using CIM's has been considered in this work.

Substation Automation System consists of various components to substitute the human activity of inspection, declaration and action. The designers of the SAS face numerous options regarding system topology, equipment cost, and installation with commissioning costs, reliability [8]. Reliability computation of SAS for different architectures and analysis of component importance with Birnbaum's, criticality importance measures is given in [9]. Risk analysis of SAS using the measures Risk Achievement Worth (RAW) and Improvement Potential (IP) has been considered to illustrate the components performance in [10]. The cost-risk analysis as well as FV measure of SAS has not yet been reported in literature. In this paper the cost-risk analysis using CIM measures has been reported.

The remaining paper is organised as Section 2 presents cost importance measures. SAS architecture and respective reliability block diagram were described in Section 3. Illustration of results and discussion of various measures is given in Section 4. Section 5 concludes the paper.

2.COST IMPORTANCE MEASURES

Form the maintenance point of view, to prioritize the components risk based measures are useful. Cost based measures like CIM, NCIM gives idea about cost-risk analysis of every element to overall system, gives beneficial results to the analyst to direct the needful actions required in system design as well as for preservation. Xu et al. [7] proposed the following CIM.

$$CIM(x_i) = \frac{\dfrac{PD(x_i)}{c_i'(x_i)} dc_i}{\sum_{k=1}^{n} \dfrac{PD(x_k)}{c_k'(x_k)} dc_k} \tag{1}$$

where $c_i (x_i)$ is considered as cost function and x_i is considered as mean failure probability of component i. c_i is assumed to be differentiable function apart from being positive definite. In addition c_i boost rapidly as x_i gets near to one. PD (x_i) = $\partial R(x_i)/\partial x_i$ gives partial derivative of IM. $dc_i = c_i(x_i + \Delta x_i) - c_i(x_i)$ gives the fractional difference in the cost of considered element i.

A new CIM (NCIM) with the similar notations which is numerically easy to calculate and gives the required ranking of components proposed in [12] can be described as.

$$NCIM(x_i) = \frac{\dfrac{PD(x_i)}{c_i'(x_i)} dc_i}{c_s} \tag{2}$$

where $c_s = \sum_{k=1}^{n} c_k , c_i \rightarrow c_i^{'}(x_i)$

3.SUBSTATION AUTOMATION SYSTEM

This section presents the architecture and reliability block diagram of a redundant cascading architecture of SAS. Various components of SAS are DC power supply (DCP), Bay control unit (BCU), Intelligent electronic device (IED), Ethernet switch (ESW), Industrial personal computer (IPC), Human machine interface (HMI), Ethernet interface (EI), Network control center (NCC) server. In order to manage various power system devices in substation, all the components are interconnected to transfer data inside the substation and to receive control signals from remote users. In simple cascading architecture of SAS each Ethernet switch is connected through one of its harbour. Depending on the harsh delays that can bear by the system, number of switches can be cascaded will be decided. If anyone cascade connection is lost the BCU connected to the switch will lost. By making redundant network, the availability can be increased. Thus making ESW as a redundant component the redundant cascade architecture of SAS, provides higher level of availability. The redundant cascading architecture of SAS [9] is shown in Figure.1 with the respective reliability block diagram depicted in Figure.2 [9].

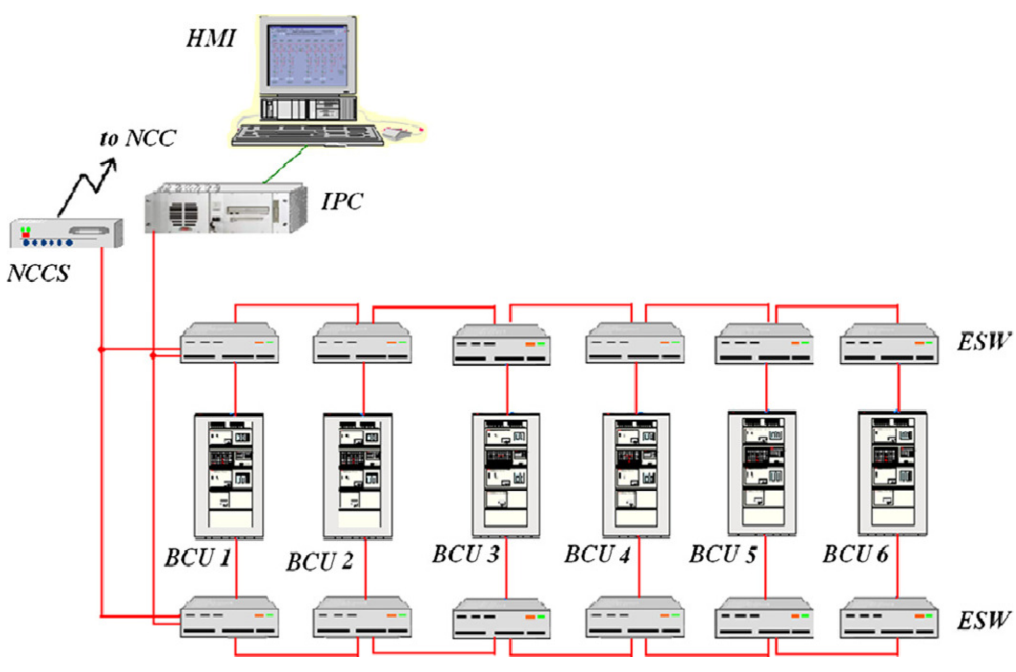

Figure1. Redundant Cascading Architecture of SAS [9]

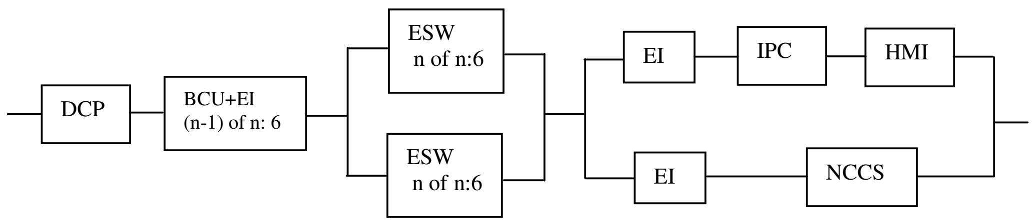

Figure2. Reliability Block Diagram of Redundant Cascading Architecture

4.RESULTS AND DISCUSSION

The cost function of each component has been considered as Pareto growth model [11], defined as

$$c_i(x_i) = \left(\frac{a_i}{x_i}\right)^{\frac{1}{b_i}} - \varepsilon_i \tag{3}$$

where a_i, b_i, ε_i are constants for each component or basic event. The advantage of this class of failure distribution is, in its exponential characteristics. The parameters for different components of the SAS system are tabulated in Table1.

Table1. Parameters of SAS System Components

Component	Mean failure Probability	Parameter		
		a	b	ε
DCP (x_1)	0.00912	2	2	0
BCU (x_2)	0.00966	1	2	0
EI (x_3)	0.00333	1	3	0
ESW (x_4)	0.08696	2	0.8	0
IPC (x_5)	0.06993	1	0.7	0
NCCS (x_6)	0.06993	1.5	0.8	0
HMI (x_7)	0.1000	1.5	0.7	0

From the reliability block diagram of the system minimal cut sets for the system can be identified as: $\{x_1\}$,$\{x_2\}$,$\{x_3\}$,$\{x_4, x_4\}$,$\{x_5, x_6\}$,$\{x_6, x_7\}$.

With the help of the failure probabilities the failure function of the system can be expressed as

$$F= x_1 \cup x_2 \cup x_3 \cup x_4.x_4 \cup x_5.x_6 \cup x_6.x_7 \tag{4}$$

The component x_2 is a (n-1) out of n: 6 structure

The generalized formula for k-out-of-n-G system is: $R(k,n;p) = \sum_{i=k}^{n} n_{c_r}\, p^r (1-p)^{n-r}$

So, $\dfrac{\partial F}{\partial x_2} = 30 x_2 (1-x_2)^4$

The component x_4 is n out of n: 6 structure

So, $\dfrac{\partial F}{\partial x_4} = 6(1-x_4)^5$

For all components, the measures CIM and NCIM results are calculated and listed in Table 2.

In case of multiple components CIM can be calculated from the sole element CIM's. The joint CIM for 1 and 2 can be evaluated as
CIM ($x_1 \cup x_2$) = CIM(x_1) +CIM(x_2) = 0.2178.

Table2.CIM and NCIM Results for Redundant cascading SAS Architecture

	DCP	BCU	EI	ESW	IPC	NCCS	HMI
I^{CR} [8]	0.2267	0.0018	0.0029	0.1186	0.0143	0.0340	0.0204
I^{FV}	1.99	11.73	38.94	214.4	0.068	0.065	0.062
CIM	0.1525	0.0653	0.178	0.54	0.013	0.024	0.012
NCIM	2.0302	1.66	3.16	7.99	0.234	0.294	0.1996

Order: I^{CR} ⟶ DCP > ESW > NCCS > HMI > IPC > EI > BCU
I^{FV} ⟶ ESW > EI > BCU > DCP > HMI > NCCS > HMI
CIM ⟶ ESW > EI > DCP > BCU > NCCS > IPC > HMI
NCIM ⟶ ESW > EI > DCP > BCU > NCCS > IPC > HMI

From the results, it can be observed that the ranking of all the measures is not same. Different measures give different ranking. It can also be noticed that the measures CIM and NCIM gives same ranking to the components. The advantage of the new CIM is that, it is free from complex calculations and gives the required ranking of the components. I^{CR} gives probability of system failure due to a specific component. That specific element must be critical prior to failure. I^{CR} gives highest rank to DCP where as ESW is ranked most important by CIM measures and FV measure. The reason for this is that to save every BCU at downstream of respective it is ranked first. Although the both components DCP and ESW are in series and should occupy the similar positions but, because of cost consideration CIM measure gives combined cost-risk ranking. The components NCCS, IPC, HMI occupy similar positions and they are in parallel structure so these components are not considerably critical components and results in their least ranking with all the IM's. BCU is the least important component from maintenance point of view and the component HMI is least important from FV, CIM and NCIM. So, the cost importance measures are more useful and yields practically meaningful results in ranking the components with respect to cost risk analysis.

5.CONCLUSION

In the risk and reliability analysis of a system, importance measures play important role, they describes how every component affects the system reliability, risk and maintainability. The economical considerations also play vital role in system's risk assessment. In this paper the cost-risk analysis of substation automation system has been considered. From the observations it is clear that the I^{CR} is good for maintenance, FV is good for risk and CIM's are good for cost-risk analysis. On the basis of the cost based measures it can be concluded that the component ESW of SAS is the most important component from both cost and risk point of view.

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