EVALUATION OF RELIABILITY OF NETWORK CONTROL SYSTEM USED IN PROCESS AUTOMATION

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Abstract: Network Control System (NCS) is increasing its accountability in communicating the real time data between the field devices configured in process automation. The process control industries are expanding to a greater extend which leads to enhancement of network size in which field devices are interconnected, making Network Control System complex. The transmission of controlled data through the NCS may be interrupted due to above failure of the network, which can hamper the entire process leads to huge economic loss. To maintain the failure rate of the network the study of the reliability of the Network control system is very much essential. This paper explains the control loop configuration in singular and redundancy modes of operation with its reliability evaluation. Also, this paper derived the reliability expression for complex interconnection of field devices in a network and shows that redundant mode of operation improves the reliability of the network.

Keywords: Network control system, Real time data transmission, Reliability, Process control Loop, Redundancy.

I. Introduction

Automation of the process control loop is becoming more popular due to its vast network capacity in which the real time data of field devices are transmitted. The interruption of transmitting data between the field devices, leading to malfunction of control loops due to which the process will hamper. In order to maintain uninterrupted data access over the communication network, a dedicate network is required and is popularly known as the network control system (NCS). The Network control system is an interconnection of control loop devices like sensors, actuators and controllers of process automation. In order to transmit the real time control data to the devices, a standard communication bus is required. The reliability of the network control system must be acceptable to achieve uninterrupted data access for longer period. Due to the above mentioned issues in process control loop network, the necessity of evaluation of reliability of the network control system used in process automation is very much essential. The literature on reliability of different fields towards network communication is mentioned below.

C.S. Raghavendra and S.V.Makam worked on the reliability of computer networks and discussed computational tasks related to mean time to first failure and mean time between failures [1]. Kent Fitzgerald and Shahram Latifi had given the reliability model and assessment of the star graph networks in which MTTF of star graphs is discussed [2]. Fulya Altiparmak, Berna Dengiz, and Alice E.Smith worked on a General Neural Network Model for Estimating Telecommunication Network Reliability. It deals encoding method for using neural network models to estimate the reliability of telecommunication network with identical link reliability and demonstrate both the precision of the neural network estimate of reliability and the ability the neural network model to generalize to a variety of network size [3]. Juan Feijoo, Jose Luis Rojo-Alvarez, Jesus Cid Sueiro and Jose Luis Mata-Vigil-Escalera has worked on modeling link events in high Reliability Network with the support vector machines and discussed a statistical learning model for link event prediction in high reliability communication network based on support vector machine for nonlinear regression. The model flexibility can be improved by grouping the predictor variable of different nature [4]. Jiajia Liu, Xiaohong Jiang, Hiroki Nishiyama, Nei Kato Presented Reliability assessment of wireless mesh network under the probabilistic region failure model in which the network reliability under a region failure can facilitate the design and maintenance of future of highly survivable wireless network. It provide a more general probabilistic region failure model to capture the key features of a region failure and apply it for the reliability assessment of wireless mesh network[5]. Shinuk Woo and Hwangnam Kim worked on An empirical interference modeling for link reliability assessment in Wireless network and deal the causes of frame losses that are directly related to intermediate link states and propose an interference modelling framework for estimating link states in the presence of wireless interference [6]. Pradhumna L. Shrestha, Michael Hempel, Hamid Sharif, Hsiao-Hwa Chen has given modeling Latency and Reliability of hybrid technology network in which a mathematical model to illustrate hybrid technology networking superior performance compared with conventional Zigbee-based wireless sensor network[7]. Hanlin Liu, Ruey-Huei Yeh and Baoping Cai worked on Reliability modeling of dependent competing failure processes of damage self-healing system and discussed about healing time and healing level concept to describe the self-healing process and a new reliability model subject multiple dependent competing failure process by considering the self-healing phenomenon[8]. R.E Stren, J. Song, D.B. Work presented accelerated Monte Carlo system reliability analysis through machine learning-based surrogate model of network connectivity in which logistic regression surrogate model is able to predict network connectivity and used Monte Carlo method with an exact connectivity check [9].

Unlike many researchers, the research on process automation field needs extended work as far as reliability is concerned. The present paper focused on control loop reliability for both singular and redundant mode of operations connected in a network. A common closed loop is considered with corresponding field devices as sensor and actuators connected to controller used in process automation.

II. Network Architecture of Process Control Loop

Basically a control loop consists of components like sensor or Transmitter, Controller and Actuator for controlling the process parameter or the control data is transmitted through the standard and dedicated communication bus. One of the architectures of process control loop with field devices connected as shown in figure 1. The loop components are indicated as T004 and T005 considering the controller as T001 which is a host. The data measured by the sensor (T004) are transmitted to Controller (T001) and the controlled data again transmits to Actuator (T005) to execute the process.

In order to analyze the reliability of the control communication over a loop, two modes of operations connected in the network are considered in this paper. Reliability with the singular configuration where only one component is available for operation and Reliability with redundant configuration where two identical components are available out of one is operating and the other is standby at a time. Evaluation of the reliability is done by selecting the failure rate of network components tabulated in Table 1 [10]. The reliability of each mode of operation is explained as follows.

Fig.1. Network Architecture of Process Control Loop

Mode 1: A series system configuration is considered with the proposed control loop in the Fig. 1 indicating T, C and A for transmitter, Controller and Actuator respectively. Also, all the components are assumed to be singular. The components in a set are said to be in series from a reliability point of view if they must all work for system success or only needs to fail for system failure.

Table.1 Control Loop Component with Failure rate

S. No.	Component	Failure rate (/h)
1.	Analog Input	1.45E-6
2.	Analog Output	2.9E-6
3.	Processor	3.35E-6

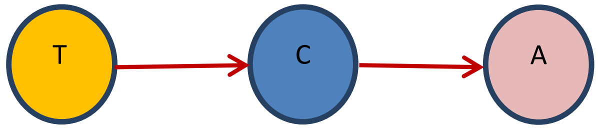

Fig.2.Proposed Singular Network Control System

Reliability of the Network,

R_{N1} = [Reliability of Transmitter] x [Reliability of control] x [reliability of actuator]

$R_{N1} = R_T \times R_C \times R_A = (1-Q_T) \times (1-Q_C) \times (1-Q_A)$

Where R_{N1} Reliability of network in mode 1

R_T, R_C and R_A are the reliabilities of transmitter, controller and actuator respectively.

Q_T, Q_C and Q_A are the failure rate of transmitter, controller and actuator respectively.

From Table 1,

R_{N1} = (1-1.456E-6) x (1-2.9E-6) x (1-3.3E-8)

= 0.9999985 x 0.9999971 x 0.9999999

R_{N1} = 0.9999954

Mode 2: In this case, transmitter, controller and actuators are considered redundant and identical components. The components in a set are said to be in parallel from a reliability point of view if only one need to be working for system success or all must fail for system failure.

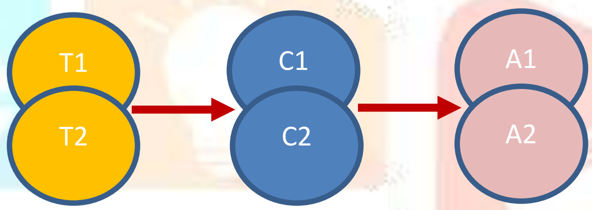

Fig.3. Proposed Redundant Network Control System

Reliability of the network R_{N2} = [Reliability of Transmitter] x [Reliability of control] x [reliability of actuator]

$R_{N2} = R_T \times R_C \times R_A$,

Where R_{N2} is the reliability of the network in mode 2.

R_T, Reliability of transmitter = 1- Q_{T1} x Q_{T2} since active and standby transmitters are connected in parallel.

Similarly, R_C, Reliability of control = 1 - Q_{C1} x Q_{C2}

R_A, Reliability of actuator = 1 - Q_{A1} x Q_{A2}

Where Q_{T1} and Q_{T2}; Q_{C1} and Q_{C2}; Q_{A1} and Q_{A2} are the failure rate of the transmitter, Controller and Actuator of active and standby modules respectively. Since the components are identical,

$T_1 = T_2 = T$; $C_1 = C_2 = C$ and $A_1 = A_2 = A$

$Q_{T1} = Q_{T2} = Q_T$; $Q_{C1} = Q_{C2} = Q_C$; $Q_{A1} = Q_{A2} = Q_A$

$R_T = 1-(Q_{T1} x Q_{T2}) = 1-(Q_T)^2$

$R_C = 1-(Q_{C1} x Q_{C2}) = 1-(Q_C)^2$

$R_A = 1-(Q_{A1} x Q_{A2}) = 1-(Q_A)^2$

Therefore, $R_{N2} = R_T \times R_C \times R_A$

$= (1-(Q_T)^2) x (1-(Q_C)^2) x (1-(Q_A)^2) = (1- (1.45E-6)^2) x (1- (3.30E-8)^2) x (1- (2.9E-6)^2)$

R_{N2} = 1 x 1 x 1

= 1 (unity)

III. Results and Conclusions

Based on the proposed network of control loop with reliability of singular and redundant modes, it is observed that the reliability of the network is more in redundant mode. The reliability of the singular module of all the components in the network considering sensor, controller and actuator is 0.999984 in mode 1 whereas in mode 2 considering all the components as redundant, the reliability is unity and is tabulated in Table 2 for reference.

Table 2. Reliability of proposed network

Sl.No	Reliability	
	Mode 1: Sigular Module	Mode 2: Redundent Module
1.	R_{N1} = 0.9999954	R_{N2} = 1.0

This is achieved as failure rate per hour of control loop components are less as per the Table 1 and in redundant mode, availability of standby component is to take action when active component is failed by which increasing the reliability. In other words, the failure rate of the components connected in the network is reduced by introducing the redundant components for each. This concludes the importance of reliability and its evaluation of the network control system is exists. The redundancy will be increased further by adding more standby components in parallel provided the cost and other network traffic issues permits.

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