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RESEARCH ARTICLE

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New concept and procedure for reliability assessment of an IEC 61850 based substation and distribution automation considering secondary device faults

Abstract Smart grid is a power grid consists of extensive monitoring systems which deal with the monitoring of attributes such as current, voltage, power, and energy at distribution transformers, substations transformers, distribution switching devices and smart meters. Smart grid with advanced communication technologies can be used for several purposes such as efficiency and reliability improvement. IEC 61850 is the core standard in the smart grid domain for distribution and substation automation. This paper introduces a vision of modern substation and distribution systems using the IEC 61850. Network operators mainly assume that the modern substation and distribution systems based on the IEC 61850 are reliable for a long-time of operation. However, similar to any other systems, the implemented IEC 61850 might fail because of the operational failures or aging failures. This paper proposes a novel method for reliability evaluation of modern substation and distribution systems. A typical IEC 61850 based distribution and substation system is developed and analyzed using the proposed method. The fault tree analysis (FTA) is used to quantify the reliability of the system. The technique is implemented and demonstrated on the Roy Billinton test system (RBTS). The analysis is further extended on a 400/63 kV substation with a breaker-and-a-half configuration. In addition, the technique proves to be robust under different operations. The results verify the feasibility and applicability of the proposed method.

Keywords IEC 61850, reliability assessment, fault tree analysis

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1 Introduction

The structure of existing electric power systems has been changed due to the development of renewable energies, environmental concerns, regulation of energy policy, economical issues and consumer demands which need reliable and efficient electricity [1–3]. A smart grid or future grid is referred to as a modernized power system with intelligent technologies which drastically help to control and monitor the power system [4,5]. Smart grid is based on the automated monitoring and control of data and communication in order to improve reliability, safety, and efficiency. At present, the communication infrastructures of the electric power systems are limited to low and simple data rate solutions or adopting wireless technology (e.g., UHF radio). On the other hand, the smart grid automation should consist of a robust communication layer for data exchange between all the sections involved in the system. IEC 61850 [6] is the core standard in the smart grid domain for distribution automation, substation automation, and the operation of power systems. IEC 61850 is a standard promulgated by the International Electrotechnical Commission (IEC), which is used for the automation of substation and distribution systems. The standard divides distribution or substation communications into the process level which consists of the I/O devices, intelligent sensors and actuators; the bay/unit level which includes the protection and control intelligent electronic devices (IEDs); and the substation level which includes the substation computer, operators desk and the interfaces with outside the substation. In the IEC 61850, the semantic entities are defined for the devices, components, and protection of the system with associated field data which can be used as the basis for future smart grid systems. In other words, IEC 61850 presents a comprehensive set of smart communication rules and protocols in order to facilitate protections and integration of distribute measurements in the power grid. IEC 61850 exchanges the service requests through the communication networks, e.g., ethernet switch (ES). Then, the services are classified based on the different criticality levels related to the time of the transferred data between the IEC 61850 entities involved in the service. The existing protection equipments in the power system handle coordination and protection using time curves and local data. However, the protection in the IEC 61850 based on the IEDs by gathering data from other IEDs through an Ethernet-based communication network will result in more coordination and protection efficiency. In recent literature, several aspects of the IEC 61850 have been investigated. For instance, the communication performance and data modeling in the IEC 61850 have been studied [7–11]. The harmonizing IEC 61850 based on the semantic matching of entities is investigated [12,13]. A method for automated monitoring and control based on the correlation, redundancy, and time-series analysis is presented [14]. Implementations of monitoring and controlling services for EMS/SCADA systems are investigated using web services of IEC 61850 standard [15]. The reliability of digital protection systems is evaluated [16]. The reliability and availability of IEC 61850 are studied based on the reliability block diagram method [17]. The reliability of the IEC 61850 based substation protection systems is estimated using the Markov method [18].

As a complement to the previous research works, this paper aims to move toward a comprehensive model of the IEC 61850. Several methods have been proposed for reliability evaluation of power systems such as analytical approach [19,20], Monte Carlo simulation [21], and combinations of the simulation and analytical techniques [22]. This paper proposes a novel method for reliability analysis of the IEC 61850. The fault tree analysis (FTA) serves as an applicable tool to quantify the reliability of the system. In this paper, the FTA is used to analyze the critical components of the IEC 61850 for both distribution and substation automation. The proposed approach has been applied to the the Roy Billinton test system (RBTS) as well as to a 400/63 kV substation with a breaker- and-a-half configuration, and various reliability case studies are analyzed.

2 Brief overview of the IEC 61850 based distribution and substation automation

A typical architecture of the IEC 61850 is depicted in Fig. 1. The process level consists of current transformers (CTs), potential transformers (PTs), actuators, and merging units (MUs). The currents and voltage signals measured by CTs/PTs are digitized by MUs and will be sent to the bay level by the Ethernet network. Following this, the bay level consists of microprocessor based relays (i.e., protection IEDs) and bay controllers. The data from the process level are calculated by the protection IEDs and then associated signals are sent through the Ethernet network. Furthermore, the station level consists of the human machine interface (HMI) and SCADA system where the statuses of components are available to operators for operation goals

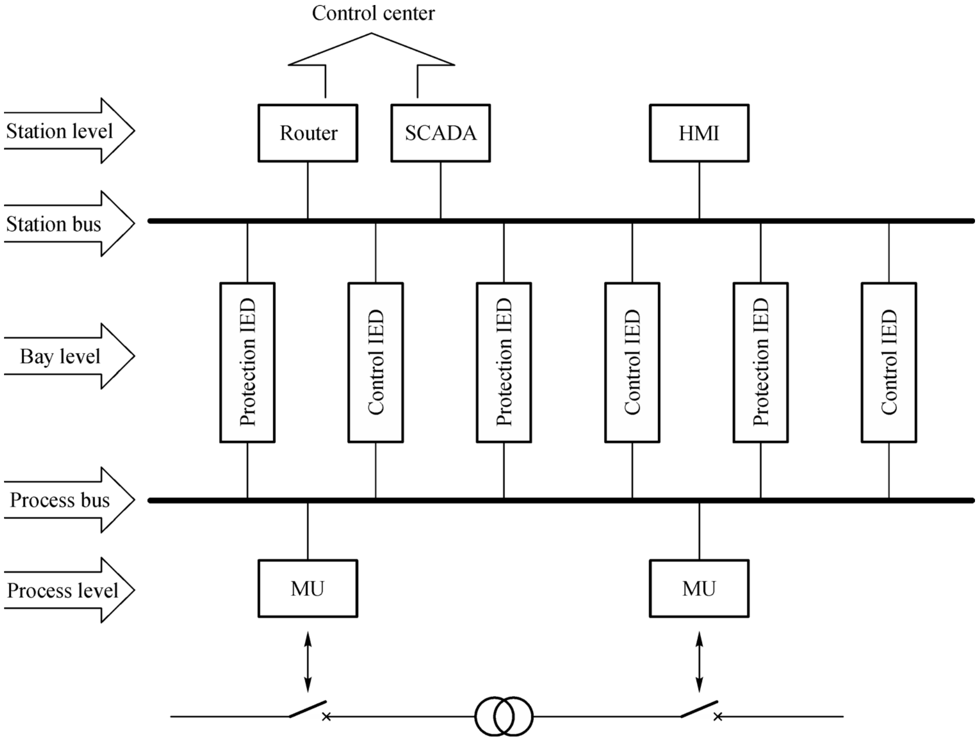


Fig. 1 Architecture of IEC 61850

and monitoring. The process bus (PB) creates a direct link for voltage and currents information by the MUs in order to make the time critical communication between the bay level and the process level. Finally, the station bus serves to exchange information between the station level and the bay level in order to assess the statuses of components [18].

In this paper, the IEC 61850 based protection system is performed on the main feeder line 4 of IEEE RBTS 6 and on the 400/63 kV substation with a breaker-and-a-half configuration, as shown in Figs. 2 and 3. Both systems consist of physical components, like circuit breakers (CBs), as well as cyber parts such as MUs, Ethernet switches, and protection IEDs, which are designed based on the IEC 61850 standard. Various fault locations associated with lines, buses, and transformers are considered which are also tabulated in Tables 1 and 2. All reliability data for components are listed in Table 3 which have been taken from Refs. [23–28]. The availability and unavailability of the IEC 61850 components are given in Table 4 which can be obtained from Table 3.

3 Proposed methodology

3.1 Definitions

The FTA method is an applicable tool for reliability and safety assessment of complex and critical engineering systems. The FTA specifies the undesired states of the system and analyzes the system in the context of its operation and environment in order to find all the possible ways which results in that specific undesired event [29]. The undesired state of the system is usually a state that is critical from the reliability point of view and is also known as the top event. The FTA consists of a fault tree which depicts a graphic model of the various sequential and parallel combinations of failures that can lead to the occurrence of the top event. The logical gates are used in the FTA which relate the primary events to the top event. The FTA consists of identification of the component of the system for the fault tree, determination of the top event, construction of the fault tree, and quantification of the fault tree in order to obtain the reliability of the system [30].

3.2 Quantitative FTA

Quantifying the fault tree is the process of finding the combinations of basic events (i.e., sequential and parallel combinations of failures) which cause the top event occurrence. The FTA can be written in the form of Boolean equations where the Boolean equations need to be obtained based on the logic of the gates. Then, in order to obtain an equation for the top event, the rules of the Boolean algebra are applied which consists of the sum of products of basic events. This procedure (i.e., the sum of products of basic events) is also called the minimal cut sets. In other words, the minimal cut set is the combinations of components failures which cause the failure of the system. In this study, probabilistic models are used to estimate failure probabilities of the component of the system. The component failure probability (P) can be obtained as

$$P = \frac{n_{\mathrm{f}}}{n}, \tag{1}$$

or

$$P = P(k) = P(X = k) = \binom{n}{k} P^k (1-P)^{n-k}, \tag{2}$$

where n_{f} is the number of failed operations, n is the number of all operations, k is a given component, X is the random number of failures. Additionally, the probability that the system is failed at time t can be expressed as

$$P = 1 - \mathrm{e}^{-\lambda t}, \tag{3}$$

where λ is the failure rate and t is time. If the component is repairable, there is

$$P = \frac{\lambda_0 T_{\mathrm{r}}}{1 + \lambda_0 T_{\mathrm{r}}}, \tag{4}$$

where T_{r} is the mean time to repair and λ_0 is the failure rate. Considering both failure and repair rates, it follows that

$$P = \frac{\lambda}{\mu + \lambda}, \tag{5}$$

where μ is the repair rate. For unrepairable systems, there is

Table 1 Fault locations in IEC 61850 based substation

Line		Transformer		Bus	
Fault	Related CBs	Fault	Related CBs	Fault	Related CBs
F1	CB1	F7	CB7, CB8, CB9	F9	CB8, CB14
F2	CB2	F8	CB10, CB11, CB12	F10	CB9, CB13
F3	CB3	–	–	F11	CB12, CB13
F4	CB4	–	–	F12	CB12, CB14
F5	CB5	–	–	–	–
F6	CB6	–	–	–	–

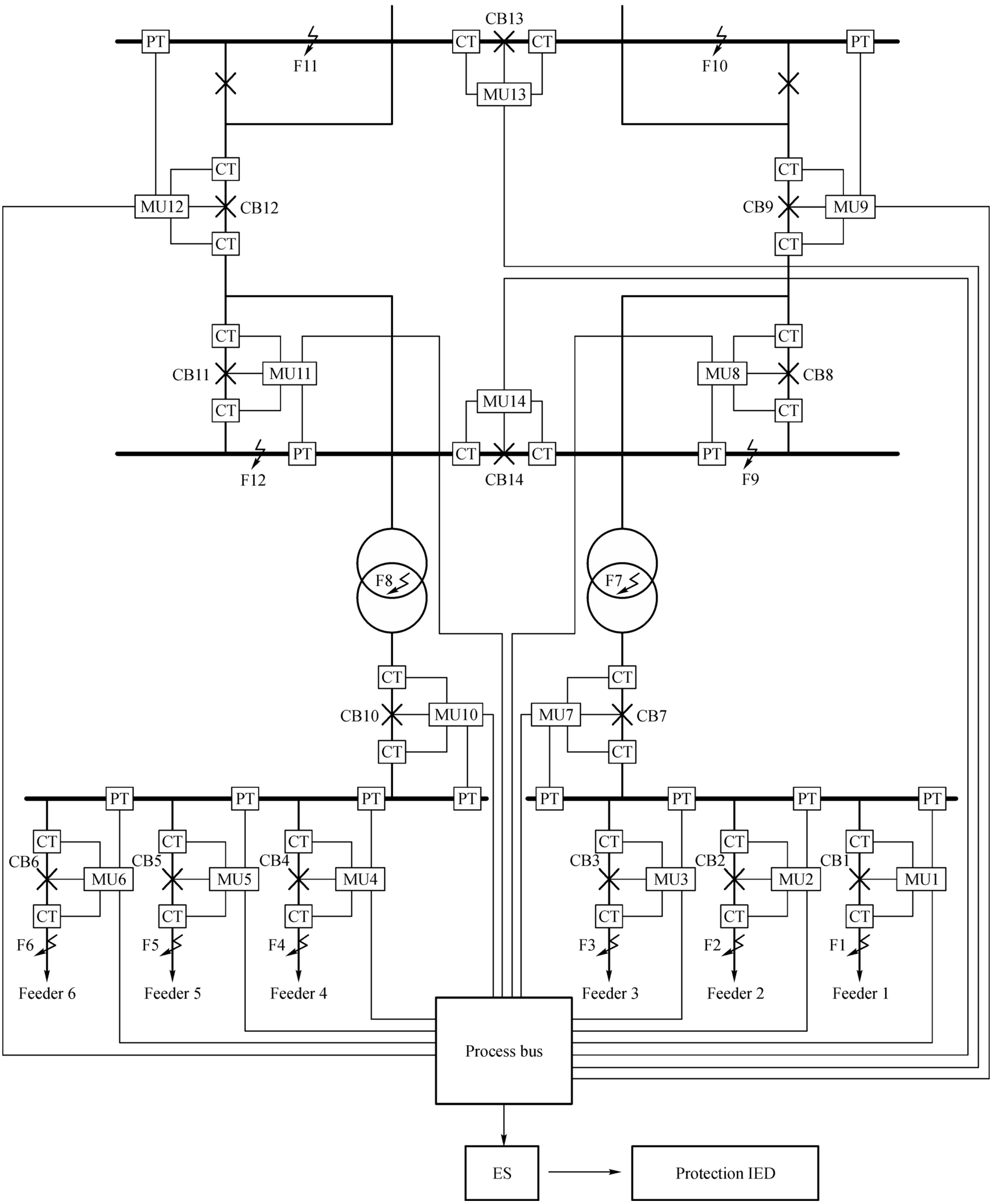


Fig. 2 Architecture of IEC 61850 for the substation

Table 2 Fault locations in IEC 61850 based distribution

Line		Bus	
Fault	Related CBs	Fault	Related CBs
F1	CB1	F5	CB1
F2	CB2	–	–
F3	CB3	–	–
F4	CB4	–	–

Table 3 Component failure rates

Component	Failure rate (times/year)	Repair rate (times/year)
CB	0.01	1095
MU	0.00667	1095
PB	0.01	1095
ES	0.02	1095
Protection IED	0.00667	1095
Communication link	0.07	876
CT	0.002	584
PT	0.002	584
Line	0.1105	1752
Transformer	0.0150	43.8
Bus	0.001	4380

$$P = 1 - \mathrm{e}^{-\lambda_{\mathrm{s}} T_{\mathrm{p1}}}, \tag{6}$$

where T_{p1} is the lifetime and λ_{s} is the standby failure rate. After assigning the probabilistic parameters of the system to all basic events, the minimal cut sets can be quantified as

$$P_{\mathrm{TOP}} = \sum_{i=1}^{n} P_{\mathrm{MCS}_i} - \sum_{i=1}^{n} P_{\mathrm{MCS}_i \cap \mathrm{MCS}_j} + \sum_{i=1}^{n} P_{\mathrm{MCS}_i \cap \mathrm{MCS}_j \cap \mathrm{MCS}_k} - \ldots + (-1)^{m-1} P \bigcap_{i=1}^{m} \mathrm{MCS}_i, \tag{7}$$

where P_{TOP} is the probability of the top event, P_{MCS_i} is the probability of occurrence of minimal cut set i (MCS_i), n is the number of minimal cut sets, and m is the number of basic events. P_{MCS_i} can be obtained as

$$P_{\mathrm{MCS}_i} = P_{B_1} \times P_{B_2} | P_{B_1} \times P_{B_3} | P_{B_1} \cap P_{B_2} \times \ldots \times P_{B_m} | P_{B_1} \cap P_{B_2} \cap \ldots \cap P_{B_{m-1}}, \tag{8}$$

where P_{B_1}, P_{B_2}, ..., P_{B_m} is the failure probabilities of basic events B_1, B_2, ..., B_m, respectively. Following this, it can be concluded that

$$P_{\mathrm{MCS}_i} = \prod_{j=1}^{m} P_{B_j}, \tag{9}$$

where P_{B_j} is the failure probability of B_j.

The failure probability of the basic events can be obtained from the probabilistic models. Assuming that B_j is the basic event, the probabilistic model can be expressed as

$$P_{B_j} \in \{\lambda_{B_j}, P_{B_j}, T_{\mathrm{i}B_j}, T_{\mathrm{t}B_j}, T_{\mathrm{m}B_j}, T_{\mathrm{r}B_j}, \eta_{B_j}\}, \tag{10}$$

where λ_{B_j} is the failure rate, $T_{\mathrm{i}B_j}$ is the test interval, $T_{\mathrm{t}B_j}$ is the test duration, $T_{\mathrm{m}B_j}$ is the mission time, $T_{\mathrm{r}B_j}$ is the repair time, and η_{B_j} is the repair rate. Thus, Eq. (7) can be written as

$$P_{\mathrm{TOP}} = \sum_{i=1}^{n} P_{\mathrm{MCS}_i} - \sum_{i<j} P_{\mathrm{MCS}_i \cap \mathrm{MCS}_j} - \sum_{i<j<k} P_{\mathrm{MCS}_i \cap \mathrm{MCS}_j \cap \mathrm{MCS}_k}. \tag{11}$$

For P_{MCS_i} less than 0.1, there is

$$P_{\mathrm{TOP}} = \sum_{i=1}^{n} P_{\mathrm{MCS}_i}. \tag{12}$$

In addition to the quantitative results, the fussell-vesely (FV) importance reveals the contribution of the basic event to the top event probability, which can be obtained from

$$\mathrm{FV}_k = 1 - \frac{P_{\mathrm{TOP}}(P_k = 0)}{P_{\mathrm{TOP}}} = 1 - \frac{1}{\mathrm{RRW}_k}, \tag{13}$$

where FV_k is the FV importance for the basic event k, P_{TOP} is the top event probability, P_{TOP} ($P_k = 0$) is the top event probability when failure probability of component modeled in basic event k is set to 0, and RRW_k is the risk reduction worth for component k.

3.3 Development of proposed reliability models of IEC 61850

Reliability analysis for the IEC 61850 structure can be conducted using the FTA concept, as shown in Figs. 4 and 5. The availability of the components working group in the IEC 61850 can be calculated by

$$A_i = \left(\prod_{j=1}^{M_i} A_i^{\mathrm{MU}} \right) \times A_i^{\mathrm{PB}} \times A_i^{\mathrm{ES}} \times A_i^{\mathrm{IED}} \times A_i^{\mathrm{link}} \times A_i^{\mathrm{CT}} \times A_i^{\mathrm{PT}} \times A_i^{\mathrm{EQ}}, \tag{14}$$

where A_i is the availability of the system; A_i^{MU} is the availability of the MU in the ith node; M_i is the number of MUs; A_i^{PB} is the availability of process bus; A_i^{ES} and A_i^{IED} are the availability of protection; A_i^{link}, A_i^{CT} and A_i^{PT} are the availability of communication link, CT, and PT, respectively; and A_i^{EQ} is the availability of each component in the system, which can be obtained as

$$A_i^{\mathrm{EQ}} = A_i^{\mathrm{CB}} \times A_i^{\mathrm{line}} \times A_i^{\mathrm{Trans}} \times A_i^{\mathrm{bus}}, \tag{15}$$

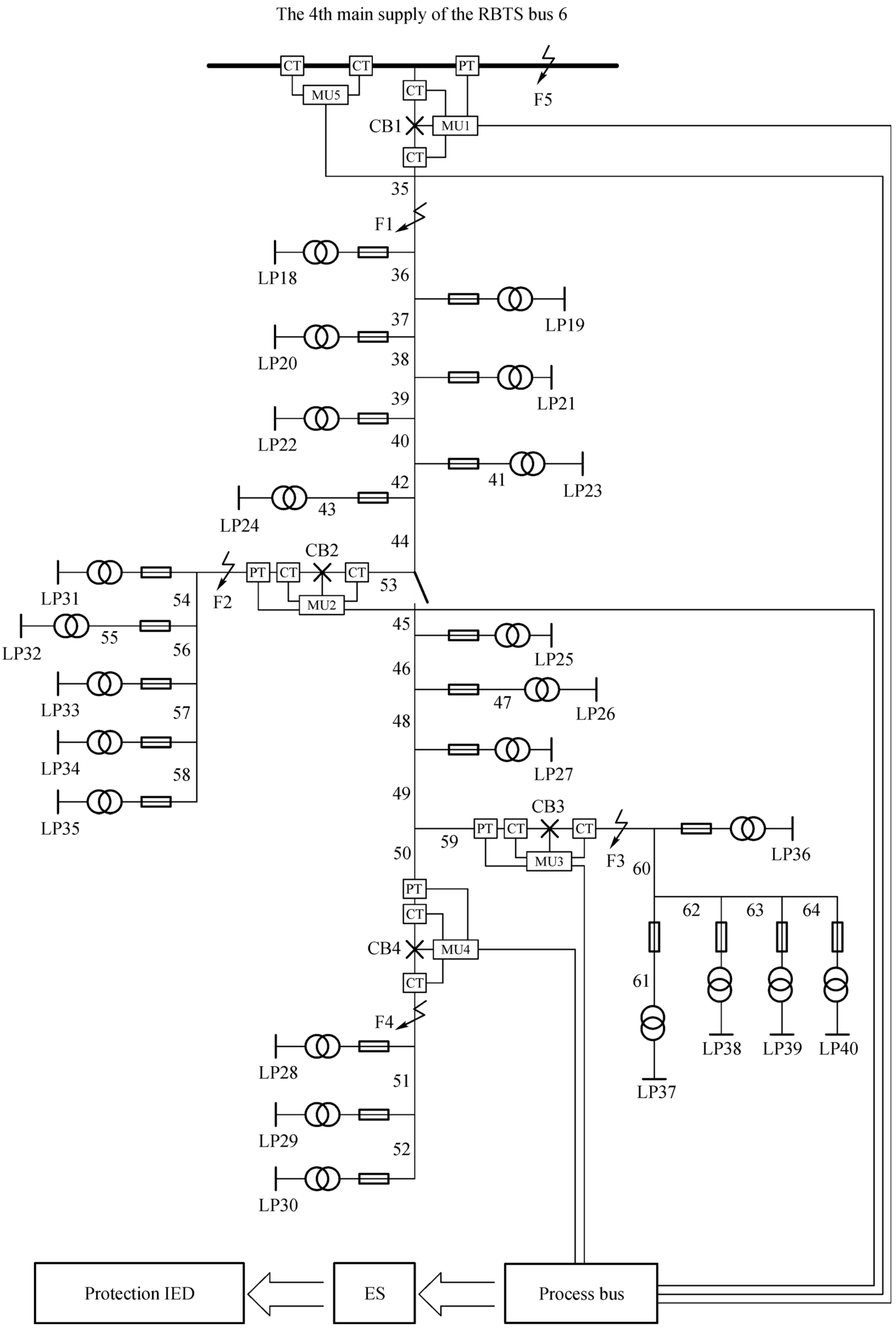


Fig. 3 Architecture of IEC 61850 for RBTS

Table 4 Availability and unavailability of components

Component	Availability	Unavailability
CB	0.999990867663309	$9.13233669098912\times10^{-6}$
MU	0.999993908712903	$6.09128709690873\times10^{-6}$
PB	0.999990867663309	$9.13233669098912\times10^{-6}$
ES	0.999981735493416	$1.82645065843546\times10^{-5}$
Protection IED	0.999993908712903	$6.09128709690873\times10^{-6}$
Communication link	0.999920097709087	$7.99022909128266\times10^{-5}$
CT	0.999996575354194	$3.42464580600751\times10^{-6}$
PT	0.999996575354194	$3.42464580600751\times10^{-6}$
Line	0.999936933201416	$6.30667985837651\times10^{-6}$
Transformer	0.999657651489216	0.000342348510783978
Bus	0.999999771689550	$2.28310450157431\times10^{-6}$

where A_i^{CB}, A_i^{line}, A_i^{Trans} and A_i^{bus} are the availability of CB, line, transformer, and bus at section i, respectively. Other reliability indices (e.g., failure rate, repair time) of each component working group in the IEC 61850 and the overall IEC 61850 can be calculated easily using the series reliability network models. For instance, the failure rates of each component in the IEC 61850 can be calculated by

$$\lambda_i = \left(\sum_{j=1}^{M_i} \lambda_i^{\mathrm{MU}}\right) + \lambda_i^{\mathrm{PB}} + \lambda_i^{\mathrm{ES}} + \lambda_i^{\mathrm{IED}} + \lambda_i^{\mathrm{link}} + \lambda_i^{\mathrm{CT}} + \lambda_i^{\mathrm{PT}}, \tag{16}$$

where λ represents the failure rate corresponding to the availability in Eq. (17). In this paper, the focus is placed on the reliability assessment technique of the IEC 61850. For clarification, the technique is explained and developed using the IEC 61850 of two test systems (i.e., RBTS, and the 400/63 kV substation with a breaker-and-a-half configuration), as shown in Figs. 2 and 3. A conditional probability of an event is the probability given that another event has occurred. To clarify the advantages of the proposed approach, a simplified fault tree based on the conditional probability of a distribution system with a probability of P_A, a protection system with a probability of P_B, restoring upstream customers with a probability of P_C, and restoring downstream customers with a probability of P_D, are given in Fig. 6. Each combination of successful and unsuccessful system responses corresponds to a path on the FTA, and the probability of any outcomes is calculated by multiplying the associated probabilities of each individual system response.

4 Study results

In this paper, the IEC 61850 based 400/63 kV substation with a breaker-and-a-half configuration and the RBTS are used to evaluate the reliability of the system. The layout of the 400/63 kV substation with a breaker-and-a-half configuration is illustrated in Fig. 2. This system has three breakers for each of 400/63 kV transformers and one breaker for each of outgoing 63 kV lines. Additionally, for the IEC 61850 based distribution system, the RBTS is considered, as demonstrated in Fig. 3. This system has 30 lines, 23 load points, 23 fuses, 23 transformers, 4 CBs and a disconnecter where the switching time is 1 hour [27,28]. The RBTS has served as a basic reference for several reliability studies in the literature. The advantage of the RBTS is existence of real reliability database for all components. The reliability data for both systems as well as the reliability data of the IEC 61850 are given in Table 3. As shown in Fig. 2, failures regarding the 63 kV lines of the substation can occur at F1, F2, F3, F4, F5 or F6. Evaluations of the reliability of the associated components are the same in all of these fault points. It is assumed that if a fault happens in F1, the voltage and current will be measured by the PT and CT and the information will be

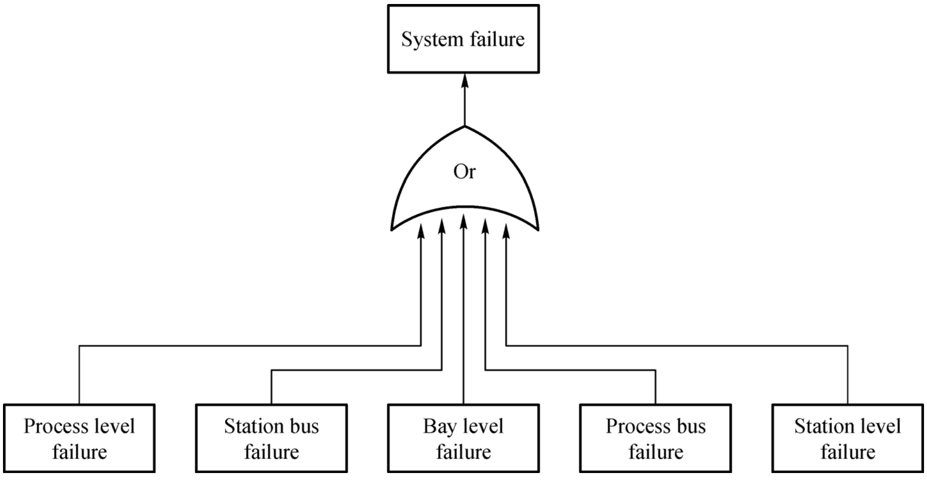


Fig. 4 FTA of IEC 61850

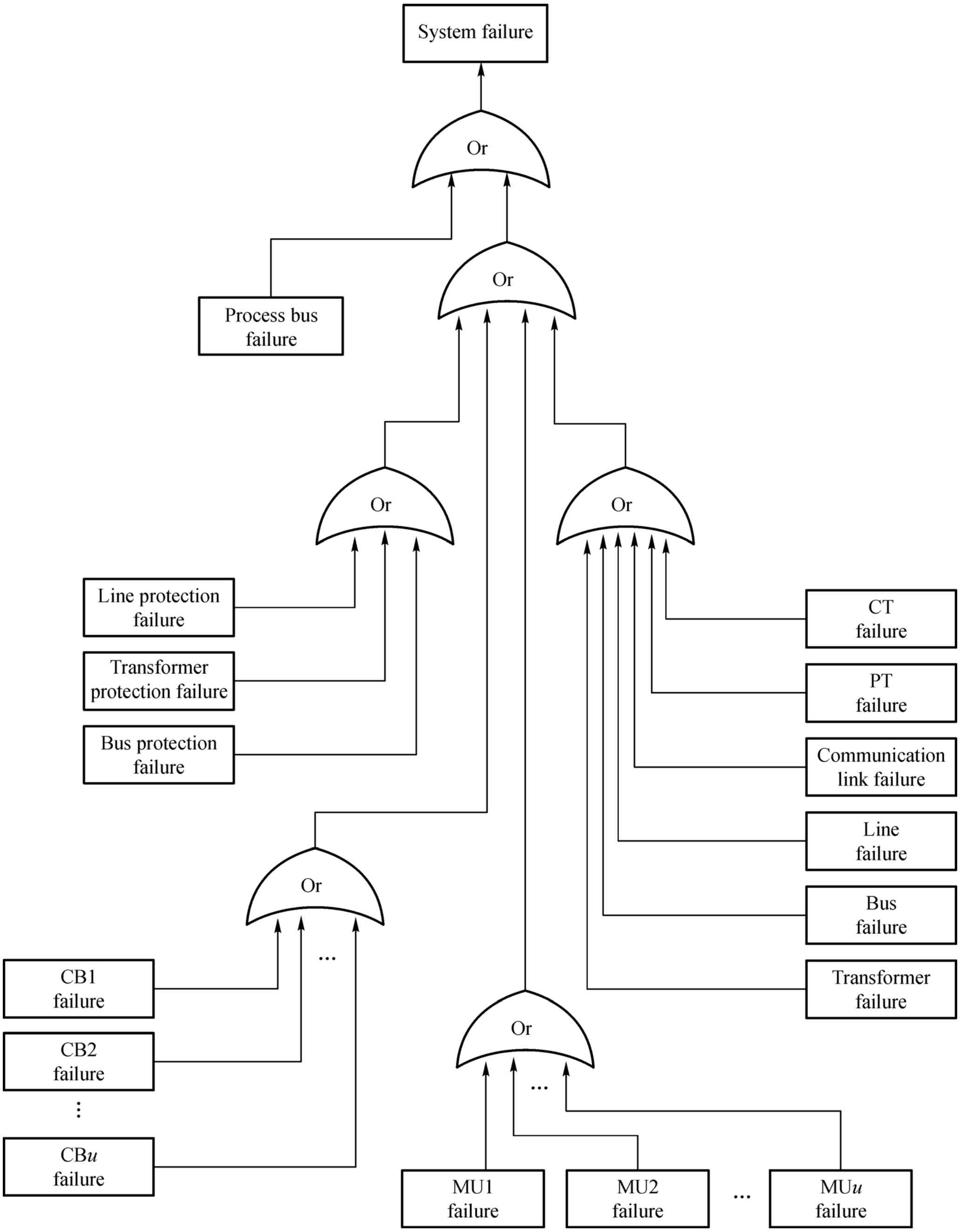


Fig. 5 FTA for IEC 61850 components

sent to the MU1 in order to be digitized. This information will be sent to the ES and then to the Protection IED by the PB. Based on the information, relay algorithms will be triggered at the Protection IED and ES and a trip signal will be sent to the CB1 by the PB. In this process, 10 components are involved which are line, two CTs, PT, MU1, communication link, PB, ES, IED and CB1. Following this, failures regarding the transformers can occur at F7 or F8, as depicted in Fig. 2. Evaluations of the reliability of the associated components are the same in all of these fault points. It is assumed that if a fault happens in F7, the voltage and current will be measured by the PT and CT and the information will be sent to the MU7, MU8 and MU9 in order to be digitized. This information will be sent to the ES and then to the Protection IED by the PB. Based on the information, relay algorithms will be triggered at the Protection IED and ES and a trip signal will be sent to the CB7, CB8, and CB9 by the PB. In this process, 20 components are involved (i.e., transformer, six CTs, three PTs, MU7, MU8, MU9, communication link, PB, ES, IED, CB7, CB8 and CB9). Moreover, failures regarding the buses can occur at F9, F10, F11 or F12, as illustrated in

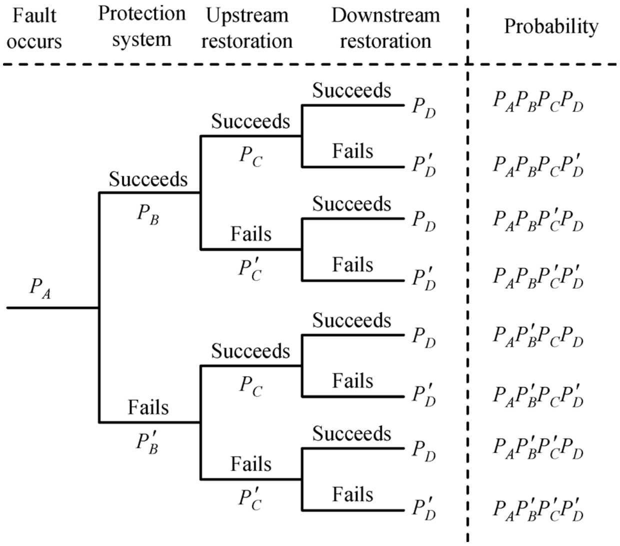


Fig. 6 Example of a probability tree based on the conditional probability

Fig. 2. Evaluations of the reliability of the associated components are the same in all of these fault points. It is assumed that if a fault happens in F9, the voltage and current will be measured by the PT and CT and the information will be sent to the MU8 and MU14 in order to be digitized. This information will be sent to the ES and then to the Protection IED by the PB. Based on the information, relay algorithms will be triggered at the Protection IED and ES and a trip signal will be sent to the CB8 and CB14 by the PB. In this process, 14 components are involved which are the bus, four CTs, PT, MU7, MU13, communication link, PB, ES, IED, CB8, and CB14. Moreover, as shown in Fig. 3, failures regarding the lines in the RBTS can occur at F1, F2, F3 or F4. Reliability evaluation of the associated components is the same in all of these fault points. It is assumed that if a fault happens at F1, the voltage and current will be measured by the PT and CT and the information will be sent to the MU1 in order to be digitized. This information will be sent to the ES and then to the Protection IED by the PB. Based on the information, relay algorithms will be triggered at the Protection IED and ES and a trip signal will be sent to the CB1 by the PB. In this process, 10 components are involved (i.e., line, two CTs, PT, MU1, communication link, PB, ES, IED and CB1). Failures regarding the bus in the RBTS can occur at F5. In case of a fault at F5, the voltage and current will be measured by the PT and CT and the information will be sent to the MU1 and MU5 in order to be digitized. This information will be sent to the ES and then to the Protection IED by the PB. Based on the information, relay algorithms will be triggered at the Protection IED and ES and a trip signal will be sent to the CB1 by the PB. In this process, 13 components are involved (i.e., bus, three CTs, PT, MU1, MU5, communication link, PB, ES, IED and CB1). The results of the following cases are presented:

1) All components work adequately.
2) The process bus is failed.
3) The components of the systems associated with the fault clearance are failed.

It is worth noting that the process bus is the hub of all the cyber links inside the system. If the process bus fails, none of the relays would receive information. Following this, all breakers would fail and the whole system will be affected by the fault. The results are shown in Tables 5 – 9. Here, the calculation of case 1 at fault point 1 in Table 5 is presented as an example. Other values in Tables 5 – 9 follow the same procedure. Case 1 indicates that all components work adequately. Taking the proposed method in use, the availability of all the components involved in fault point 1 should be multiplied. Using Eqs. (14) and (15), the probability of case 1 at fault point 1 in Table 5 can be calculated as

$$\begin{aligned} A &= A^{\mathrm{MU1}} \times A^{\mathrm{PB}} \times A^{\mathrm{ES}} \times A^{\mathrm{IED}} \times A^{\mathrm{link}} \times A^{\mathrm{CT}} \\ &\quad \times A^{\mathrm{CT}} \times A^{\mathrm{PT}} \times A^{\mathrm{CB1}} \times A^{\mathrm{line}} \\ &= 0.99979. \end{aligned} \tag{17}$$

Since all of the fault points in similar power components are similar, cyber physical components involved in sensing and removing are also similar. Given the assumption that similar components have equal repair rates and failure rates, the reliability of the system in a given case is the same for the fault points of similar power components. For this reason, in Tables 5 – 9, all of the values in a row are exactly the same. Furthermore, the FV of the IEC 61850 for the substation in terms of case 1 is presented in Fig. 7(a). The values on X axis are fault points. As it can be seen, the

Table 5 Reliability of IEC 61850 based substation automation considering line faults

Reliability	Fault at F1	Fault at F2	Fault at F3	Fault at F4	Fault at F5	Fault at F6
Case 1	0.99979	0.99979	0.99979	0.99979	0.99979	0.99979
Case 2	9.13×10^{-6}	9.13×10^{-6}	9.13×10^{-6}	9.13×10^{-6}	9.13×10^{-6}	9.13×10^{-6}
Case 3	1.14×10^{-50}	1.14×10^{-50}	1.14×10^{-50}	1.14×10^{-50}	1.14×10^{-50}	1.14×10^{-50}

Table 6 Reliability of IEC 61850 based substation automation considering transformer faults

Reliability	Fault at F7	Fault at F8
Case 1	0.99946	0.99946
Case 2	9.12×10^{-6}	9.12×10^{-6}
Case 3	3.09×10^{-103}	3.09×10^{-103}

Table 7 Reliability of IEC 61850 based substation automation considering bus faults

Reliability	Fault at F9	Fault at F10	Fault at F11	Fault at F12
Case 1	0.99983	0.99983	0.99983	0.99983
Case 2	9.13×10^{-6}	9.13×10^{-6}	9.13×10^{-6}	9.13×10^{-6}
Case 3	2.70×10^{-74}	2.70×10^{-74}	2.70×10^{-74}	2.70×10^{-74}

Table 8 Reliability of IEC 61850 based distribution automation considering line faults

Reliability	Fault at F2	Fault at F3	Fault at F4	Fault at F5
Case 1	0.99979	0.99979	0.99979	0.99979
Case 2	9.13×10^{-6}	9.13×10^{-6}	9.13×10^{-6}	9.13×10^{-6}
Case 3	1.14×10^{-50}	1.14×10^{-50}	1.14×10^{-50}	1.14×10^{-50}

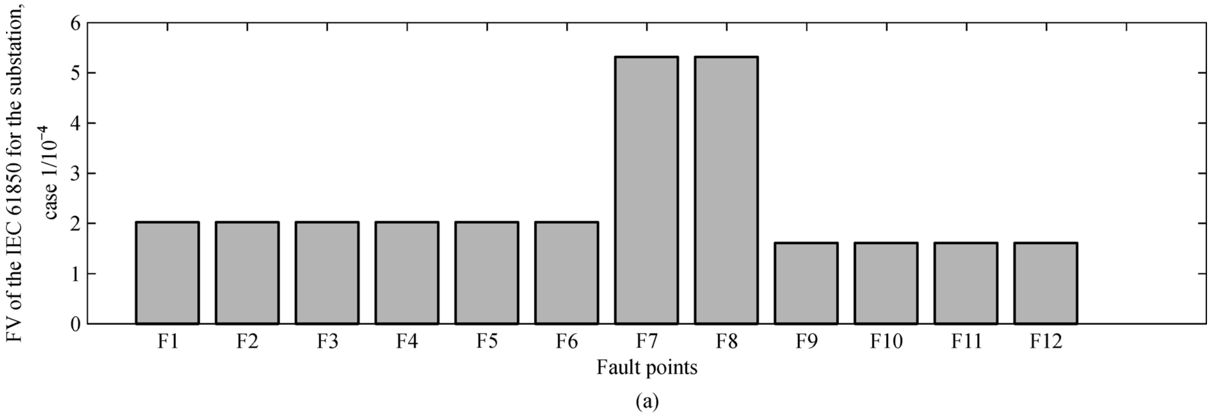
Table 9 Reliability of IEC 61850 based distribution automation considering bus faults

Reliability	Fault at F1
Case 1	0.99983
Case 2	9.13×10^{-6}
Case 3	2.70×10^{-74}

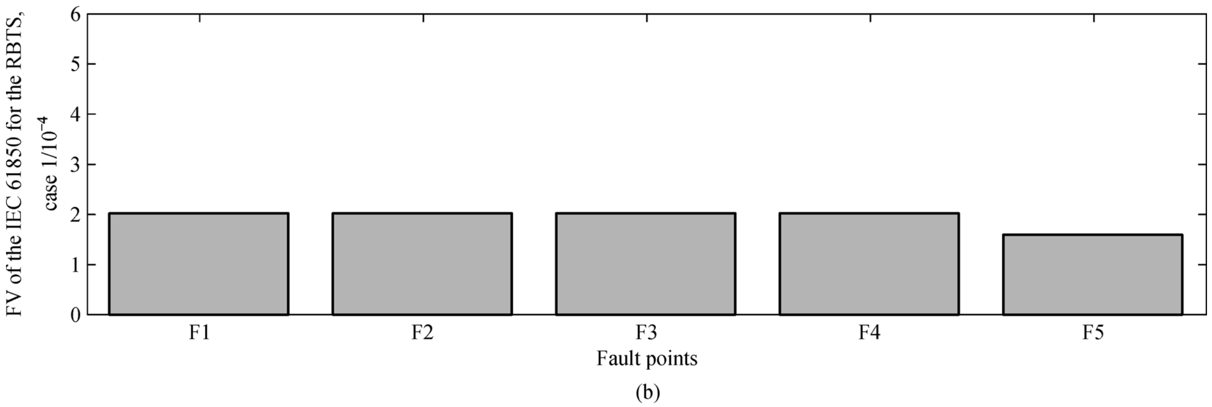
FV of fault point of similar power components are equal. Moreover, Fig. 7(b) illustrates the IEC 61850 for the RBTS in terms of case 1 for different fault points. For this grid, the first four fault points are equal because they belong to similar power component (i.e., line).

5 Conclusions

The deployment of smart grid technologies has generated considerable interests in communication and protection issues of smart grid users. The IEC 61850 plays a significant role in the automation of substation and distribution grids. The automation based on the IEC 61850 leads to several benefits such as efficiency and reliability improvement of the system. However, several issues should be taken into account in order to extend the use of IEC 61850 concepts. Similar to any other equipment of electric power distribution systems, the cyber components of the IEC 61850 may also fail due to the operational failure events or aging failures. This paper proposed a novel method based on the FTA to quantify the reliability of the IEC 61850. The technique has been demonstrated and verified using several case studies on the RBTS and 400/63 kV substation with a breaker-and-a-half configuration. The study results confirm the merits of the proposed method. The reliability evaluation of the IEC 61850 can provide both operational and annual reliability information to system operators. It is very useful for operators to take some protective actions to avoid possible system failures incorporating the components. The proposed reliability framework can serve as a useful tool for future studies on the planning of the IEC 61850. It is hoped that this paper will lead to a discussion on effect of different types of faults on the reliability of the system. Moreover, future work will focus on the development of the proposed method associated with the economical issues using different algorithms in order to optimize the reliability and costs of the IEC 61850.



(a)



(b)

Fig. 7 FV of IEC 61850
(a) For substation; (b) for RBTS

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