A reliability assessment for emergency switchgear systems improvement of LNG plant

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Abstract. The LNG plant essential load to support the operationality is taken from the emergency system. The major challenge is to ensure the reliability level of its emergency system required. The improvement of the emergency system can result in operationality of LNG production. The calculation of component or system unavailability is the essential of the emergency system reliability evaluation. This paper presents a reliability analysis for LNG plant emergency switchgear system by comparing the existing configuration and proposed new configuration. The analysis is using the software modeling with Fault Tree Diagram. Therefore, by the concept of proposed design, it can improve the reliability of emergency system by reducing the unavailability.

1. Introduction
In every LNG plant operation is backup by emergency switchgear system, besides having the main power system. The emergency switchgear system shall provide a source of electrical of required capacity, reliability and the quality to essential loads for the length of time of the operation [1]. The intended design of emergency switchgear system in LNG plant is to provide back-up power supply for two mainly process, the first for plant safe shutdown system and the second is for black-start system in case loss of main power system. The emergency switchgear system is a complete system coupled with emergency power supply, disconnecting switch and protection system, transfer switch and all control [2], also with the critical equipment installed on this switchgear. The reliability design of the emergency system affects the operationality of LNG plant. Reliability is defined the ability of the system or component to perform required functions under stated operating conditions for a period time.

The methodology of this paper is illustrated by the analysis of emergency system of LNG plant in before and after reconfiguration design model. The reliability analysis will using software with Fault Tree Diagram model. The calculation to be used is based on unavailability caused by failure of electrical component or system in emergency switchgear. Unavailability is a function of failure rate of component or system which is presented as fraction time of represents statistical probability of failure due to electrical equipment breakdown and mend down time or repair time.

2. Reliability Measures
The reliability is defined the ability of an item under combined aspects of its reliability, maintainability, and maintenance support to perform its required function at a stated instant of time or over a stated period of time. The reliability is essentially the absence of failure of the component or system.
The failure rate, repair time, maintenance downtime, mean time between failure, are the various factors indicates the reliability [4]. More of indicates used reliability are defined as follows.

Mean Time Between Failure (MTBF): The commonly used for reliability measured for repairable system. MTBF is the average time between failure of a component or system, by assuming the failed component or system is immediately repaired.

Unavailability: the unavailability is defined as the probability of component of system is out of service due failure or schedule outages

Failure rate ($\lambda$): the is the number of system or equipment per unit exposure time. The failure rate is commonly expressed in failures per hours ($f/h$) or failure per years ($f/y$)

$$\lambda(f/h) = \frac{T_f}{T_p} \quad \text{or} \quad \lambda(f/y) = \frac{T_f}{(T_p/0760)}$$

Where, $T_f$ is total number of failure and $T_p$ is Total period of calendar time over which data for the item was collected (h)

Repair Time: more often expressed as Mean Downtime (MDT) is defined as average downtime duration caused by scheduled or unscheduled maintenance, including any logistic time.

$$MDT(h) = \frac{(Rdt + Rlt + Mdt)}{Tde}$$

Where, $Rdt$ is repair downtime, whichs is the total downtime for unscheduled maintenance (exluding logistic time), $Rlt$ is repair logistic time for unscheduled maintenance. $Tde$ is total number of downtime events

3. Condition Assessment

This paper aim to propose reliability analysis that focus on the impact of unexpected events (UE). An UE is a typical system term used in the reliability domain, to identify a critical failure that could lead to catastrophic damages (human, financial, etc). In the context of electrical networks, one UE always refers to one busbar. It means the UE represent the interruption of power to busbar.

The fault tree method is developed to determine an UE. The failure tree method is the process of analyzing a component or system in such a way as to understand the lower-level fault occurrences that directly or indirectly contribute to the major or undesirable event.

In order to develop a failure tree, it is necessary to establish all possible electrical power supply paths for each of the UEs, taking into account the electrical system configuration and all of its possible mode operation. The electrical power supply unavailability is calculated for each UE, by combining the failure rates and repair times of system or component associated with the respective UE, according to the structure of the fault tree.

Each electrical component or system has several different failure modes. They represent the different kind of failure that can affect the device and result in its failure. Each failure mode has a specific probability of occurrence (failure rate), as well as a specific time to be repaired (repair time/MDT).

3.1 Risk Avoidance

The risk avoidance for the purposed configuration of emergency switchgear cab be approximated by the summation of total unavailability and repair time of existing emergency switchgear configuration with the value of amount of gas produced of the same duration with the following equation:

$$Risk \: Avoidance = \left( \frac{Total \: Unavailability(min)}{1440} \times number \: of \: Plant \: Down \times USD \: 5M \right)$$

$$+ \left(Repairtime(days) \times NumberOfPlantDown \times USD5M(\text{perday}) \right)$$
4. Switchgear Failure Mode and Repair Time
A switchgear busbar dan circuit breaker are the two main component of the MV switchgear. The other consideration is for the emergency diesel generator which connected to emergency switchgear. The most probable switchgear failure contributing causes which area exposure to moisture, exposure to dust and other contaminants, normal deterioration from age, and loose connections due to thermocycling [6]. The circuit breaker also can contribute the failure of switchgear. The mechanical failure and associated deterioration of the spring tension can result in the failure of rear disconnect assembly of circuit breaker. The other possible cause is lack of preventive maintenance.

The equipment repair time or replacement time in IEEE was not detail specified, it is possible to do initiating intuitive approach based on experience. The repair time would be the time it takes to fix the equipment and if spare part is ready. The other measures for repair time is the time is all the delays for scheduling, travel time, parts, etc all included to fix the equipment.

| Equipment Name                     | Equipment Class | Repair/Replacement Time (h) | Remarks                                                                 |
|-----------------------------------|----------------|-----------------------------|-------------------------------------------------------------------------|
| Emergency Diesel Generator (EDG)  | All            | 168                         | If one EDG breakdown, providing spare part or rent extra EDG may take a week or so, considering logistic time |
| Busbar                            | All            | 120                         | Busbar replacement after failure will take longer time in providing material and maintenance period take longer time |
| MV Circuit Breaker (CB)           | MV             | 24                          | Replacing broken CB should not take long time, since spare CB is available |

As for repair time value for components in this study, will refer to table below:

| Equipment Name                | Equipment Subclass | Failure Mode | Repair Time/ MDT (hours) | Failure Rate (λ/y) |
|------------------------------|--------------------|--------------|--------------------------|--------------------|
| Emergency Diesel Generator   | All                | M1           | 168                      | 0.00536            |
| Busbar                       | All                | M1           | 120                      | 0.001129           |
| Circuit Breaker (CB)         | All/MV             | M1/M2/M3     | 24/2/8760                | 0.0030/0.00066     |

In table above, failure mode is a type of failure associated to a given component. M1 refers to insulation fault (short circuit), M2 is a nuisance trip and M3 is total failure. Each failure mode has own designed duration. The repair time provided based on industrial practice and also considering geographical condition which may delay delivery time of components.
5. System Modeling Approach

The following assumptions are made in developing the scenario of reliability analysis:

- All the electrical loads connected in emergency switchgear were considered in good operation all condition
- The emergency switchgear system was equipped with a correctly designed and operational protection system with correctly applied protection settings
- Equipment failure rate were considered constant
- Equipment repair time were determined to included based on logistic time as well as its approach to spare parts management

In this paper, the analysis of reliability study will performed in two cases, the first is for the modeling of existing design emergency switchgear. The second study is for emergency switchgear after improvement design. Within this study, there is one bus supplying all loads for the parameter. This bus named artificial bus which categorized based on process during emergency condition. The artificial bus of this study which are: Emergency Shutdown loads, static load with mirror, static loads without mirror, and utilities. Emergency shutdown loads are loads which responsible for plant Safe Shutdown System dan Plant Re-start/Blackstart. Static loads are loads which responsible for plant Safe Shutdown System dan Plant Re-start/Blackstart. Static loads are loads which act as static load after EDG start.

On existing configuration, the link between process and electrical is relatively simple, several breakers contribute to several process, and all of them are supplied by four possible generator alternative. The existing emergency system configuration is mirrored for Utilities and Emergency System Loads, which mean one breaker out of two possible breaker to run the process. While, for process or static load, there are almost no mirror, static load which has mirror are only Platform and the rest do not have such facility.

![Figure 1. Existing Emergency Switchgear Configuration](image)

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Figure 1. Existing Emergency Switchgear Configuration
Figure 2. Proposed Emergency Switchgear Configuration

6. Result

The reliability analysis result below showed the proposed modification design of emergency switchgear configuration provides much less unavailability compared to existing configuration. It showed the advantages of proposed configuration is that it has various supply paths. Hence the emergency system has many supply paths which caused the unavailability to greatly reduce.

| No | Parameter                  | Reliability Analysis               | Total Unavailability | Emergency Shutdown | Static Loads with Mirror | Static Loads without Mirror | Utilities |
|----|----------------------------|-----------------------------------|----------------------|--------------------|--------------------------|-----------------------------|------------|
| 1  | Existing Emergency Switchgear Configuration | 166.43 min/year | 47.20 min/year | 47.21 min/year | 48.50 min/year | 552.82 min/year |
| 2  | Proposed Emergency Switchgear Configuration | 19.84 min/year | 15.55 min/year | 5.18 min/year | 53.17 min/year | 5.47 min/year |

The same Failure Rate is used in calculation of unavailability in the comparison. Therefore, the unavailability value describes the effect of Mean Down Time (MDT) improvement due to proposed emergency switchgear configuration. In reality, when the fault occur on emergency switchgear with existing configuration, MDT will be much longer than proposed configuration. In the calculation, Repair Time (which affect MDT) for existing emergency bus configuration is defined to be 120 hours (5 days). If there is failure on emergency bus, all plant cannot operate because emergency system is not available. Repair and mitigation action to supply emergency switchgear system is estimated to be 120 hours.
With proposed configuration, if failure occur on leg A or Leg B on emergency switchgear system will not stop plant operation since emergency shut down system and Plant Start is not affected. This means that the MDT will be very low in reality with proposed configuration. In the calculation of unavailability of proposed emergency switchgear system, repair time to be 24 hours (1 day). However, repair time in this case will not affect plant operation.

| Table 4. Risk Avoidance Value |
|-------------------------------|
| No | Parameter | Existing Configuration | Proposed Configuration |
|----|-----------|------------------------|------------------------|
|    |           | Total Unavailability    | Repair Time      | Investment |
|    |           |                        | (If busbar failure) |            |
| 1  | Risk Avoidance (plant not operate) | 166.43 min/year | 5 Days (1 day for total plant shutdown equal to USD 10M) | There is no total plant shutdown |
| 2  | Risk Avoidance (value) | USD 1.6M | USD 50M | USD 1.2M |

7. Conclusion
This paper has described the reliability analysis of emergency switchgear in before and after reconfiguration improvement in LNG plant. The assessment is based on the total unavailability and repair time of the component or system in emergency switchgear. The unavailability of new configuration of emergency switchgear affected plant operation is less than existing design. The plant operation maintenance of emergency bus can be performed without having stop all plant operating by redundancy of switchgear. The Risk avoidance is this paper means that the it is a risk can be avoid by the financial approach value. The total investment of proposed configuration is less than total value of existing configuration if failure occurred. Therefore, by the concept of proposed design, it can improve the reliability of emergency system by reducing the unavailability.

References
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