Analysis and improvement on reliability of 66/11 kV distribution substation and its associated feeders: A case study of Lainchour substation in Nepal

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Abstract. Electric power interruption is becoming a day to day phenomenon in our distribution system. For distribution system to be effective there should be less outage in the system and if fault occur these faults should be cleared as soon as possible. Sustained power interruption occurs several times a day from few minutes to hours. Interruptions may be due to failure of substation equipment or failure of distribution network elements. This paper attempts to identify different causes of interruption and problems that customers in Nepal have been facing due to frequent planned and unplanned sustained interruptions by evaluating various reliability indices and parameters of Lainchaur distribution substation and its associated feeders operated under Nepal Electricity Authority. First, reliability analysis of substation configuration only is done followed by analysis of reliability improvement measures like use of double bus bar, parallel distribution feeders and underground cables in DIgSILENT PowerFactory only considering sustained failures of equipment and feeders. Calculated reliability indices like System Average interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Energy Not Served (ENS) are compared for different cases so that it will be easy to make choice between options to the utility to upgrade/improve the system. Considering all feeders, result shows that main cause of interruption in the distribution system is failure of distribution lines showing 104 interruptions for total duration of 107 hours per annum in the system, followed by failure of distribution transformers indicating 19 interruptions for total duration of 47 hours per annum. Simulation result in DIgSILENT shows yearly total ENS of distribution system is high due to present configuration, and can be reduced by the use of parallel feeders and underground cables respectively. It is seen that ENS due to failure of substation components only is very low and huge revenues can be saved if auto-reclosures are used or a provision of charging feeders as soon as possible is made.

Keywords: Reliability, Interruption, Distribution Substation, Failure.
1. Introduction

Electric distribution system power quality is a growing concern in Nepal. For a system to be reliable there should be continuity of power supply. Fault statistics of the substation record shows that unplanned interruption is a major concern in Lainchour distribution system. A detailed study of the system is necessary to find out the causes of unplanned sustained interruptions so that reliability of the system can be improved and power outages due to faulty equipment are reduced. Lainchaur substation in located in middle of Kathmandu and connects the major loads. This substation can be also considered as representative substation of dense city area in Nepal. Fault statistics of the substation record shows that unplanned interruption is a major concern in Lainchaur substation and its associated feeders. Major actions are needed to improve customer based reliability indices so that frequency and duration of power interruption to its connected customer improves. Considering this fact, in this work, a comprehensive analysis of Lainchaur substation and associated feeder problem is conducted.

Robert E. Goodin [5] presents a comparative analysis of distribution reliability improvements that can be achieved by using various outdoor distribution devices. First, it discusses the application of the most common types of devices, including line reclosures, automatic sectionalizes and manual switches and analyzes to quantify the reliability improvements that can be achieved by using each (or a combination) of these devices and concludes, all devices offer an improvement in reliability. According to Oleboge K.P. Mokoka [6], Simulation can be done in DIgSILENT Power Factory and NEPLAN which has the following features: load-flow, short-circuit calculations, reliability analysis, protection coordination, stability calculation etc. He, simulated sample feeder in both NEPLAN and DIgSILENT and Mokoka compared the result of both software and made a conclusion that results are similar.

2. Methodology

Methodology starts with literature review of various related literature followed by data collection from Lainchaur substation record file. Collected data is analyzed and categorized in momentary, planned and unplanned interruptions (sustained). Frequency and duration of planned, unplanned and momentary interruption is noted. Failure rate of substation equipment like bus bar, transformers, circuit breaker, isolator etc. is determined based on data from past 12 years. For standard failure rates and repair duration, various literatures are used. Details of existing equipment in the substation are collected through Kathmandu grid division. To determine customer number in each feeder, data from different DCs is collected and analyzed. DIgSILENT power factory standard library is also used to determine some electrical parameters values for simulation

3. Description and evaluation of system under study from reliability perspective

Lainchaur substation is a 45 MVA indoor type GIS distribution substation located in the central location of Kathmandu valley. Lainchaur substation serves important and critical areas of Kathmandu like president office, office of election commission, major hotels etc. major equipment of substation are power transformer, circuit breakers, isolator, lightning arrester, current transformer, voltage transformer, bus coupler and relays.
There are two 66 kV incoming sources coming from Balaju and Chabel substation. The two 66/11 kV transformers are operated in parallel so that if one transformer fails or goes to maintenance then another transformer can supply the full demand. It consists of five radial feeders named Samakhusi, Lazimpat, Gairidhara, Kingsway and Thamel as shown in Figure 1.

Figure 2 shows hourly load variation of the substation. Single day of each month of different season is selected noting that there is no any power outage either planned or unplanned throughout the day. The reason behind selecting such day is that, if there is any sustained outage then the demand rises instantly after power is restored which might create abnormal peak.

4. Fault noticed at substation major equipment
Table 1 below shows the fault noticed at major substation equipment for twelve years. Based on the substation record files frequency and duration of outage of each major component, failure rate per annum and component repair rate is calculated. Record shows that for the last 12 years transformer62...
failed 6 times and was out of service for 127 hours 5 minutes. Once the transformer 62 fail, it will take about 21 hours to put it back in service.

Table 1. MTTR and failure rate of different components [Source: site visit record]

| Equipment            | Momentary |           | Sustained | MTTR(hr.) |
|----------------------|-----------|-----------|-----------|-----------|
|                      | Frequency | Duration  | Frequency | Duration(Hr.) | Failure rate(1/a) |          |
| Transformer 61       | 7         | 0:20      | 10        | 36:25       | 0.833            | 13:38    |
| Transformer 62       | 6         |           | 6         | 127:05      | 0.500            | 21:10    |
| 66 KV bus bar        | 1         | 2:25      | 1         | 3:15        | 0.083            | 2:15     |
| 11 kv Bus bar        | 1         | 2:17      |           |             | 0.083            | 2:17     |

Table 2 shows failure rate and average time of repair of each fault in 11 kV distribution feeders considering data of 12 months and Table 3 shows failure rate of distribution transformers connected to each feeder.

Table 2. MTTR and failure rate of different feeders [Source: site visit record]

| Feeders   | Momentary | Sustained | Sustained indices |
|-----------|-----------|-----------|-------------------|
|           | Frequency | Duration  | Frequency | Duration | Failure rate(1/a*km) | MTTR(Hr.) |
| Samakhusi | 42        | 3:30      | 18        | 18:53    | 3.025              | 1:02      |
| Lazimpat  | 49        | 4:05      | 20        | 23:57    | 6.250              | 1:11      |
| Gairidhara| 36        | 3:00      | 14        | 15:37    | 3.944              | 1:06      |
| Kingsway  | 25        | 2:05      | 31        | 27:30    | 6.392              | 0:53      |
| Thamel    | 30        | 2:30      | 21        | 22:06    | 3.750              | 1:03      |

Table 3. Failure rate of distribution transformer of each feeder [Source: site visit record]

| 11kV/400 V transformer | Sustained interruption | Indices |
|------------------------|------------------------|---------|
|                        | Frequency | Duration | Failure rate(1/a) | MTTR |
| Samakhusi              | 5         | 20:45    | 5                  | 4:09  |
| Lazimpat               | 2         | 1:04     | 2                  | 0:32  |
| Gairidhara             | 4         | 7:15     | 4                  | 1:48  |
| Kingsway               | 3         | 6:17     | 3                  | 2:05  |
| Thamel                 | 5         | 11:44    | 5                  | 2:20  |

5. Reliability evaluation of RBTS 2 bus network

The IEEE Application of Probability Methods (APM) Subcommittee published a Reliability Test System (RTS) in 1979 [1]. This has proved to be a valuable and consistent reference source for comparing alternative techniques and computer programs. It has been used extensively in reliability assessment of generation by utilities, consultants and universities [2]. RBTS Bus 2 and Bus 4 are used as test systems because they were created for educational purposes and all reliability data of components are informed. This case study is used to verify the correctness of reliability assessment tool [3].
Table 4. Result of RBTS bus 2.

| Indices | IEEE Result | Simulation result |
|---------|-------------|-------------------|
| SAIFI   | 0.602       | 0.603             |
| SAIDI   | 22.5        | 22.227            |
| CAIDI   | 37.48       | 36.82             |
| ASAI    | 0.99743     | 0.99746           |
| ASUI    | 0.00256     | 0.00253           |
| ENS     | 231.263     | 228.546           |
| AENS    | 0.121       | 0.12              |

Table 4 shows the comparison of reliability indices obtained from simulation in DIgSILENT PowerFactory and standard IEEE results. IEEE values are considered as standard and percentage deviation in results with respect to standard values is calculated. Highest deviation is seen in the value of CAIDI.

6. Simulation Results and discussion

The reliability analysis has been calculated using various reliability indices for different configurations of the existing substations. Table 5 below shows the calculations considering configuration of substation equipments 66 kV double bus bar distribution feeders of current configuration, parallel feeders and underground cables separately. Values assumed for calculations are: Out of 100 tripping circuit breaker fails to open 2 times for feeders (11 kV) and 0.1 times for 66 kV systems because opening of 66 kV circuit breaker is very rare. For substation configuration only, it is seen that energy not served due to failure of substation equipment is 5.677 MWh/a resulting major contribution to ENS is by bus bars.

Table 6 shows contribution of various substation components to reliability indices for different configuration of the substation. SAIFI value increases by about 50% considering double bus bar. SAIDI has been reduced significantly by 40%. This indicates that, after the installation of double bus bar, frequency of interruption of the system increases but the duration of interruption decreases. ENS of the system is reduced by 2.25 MWh/year. If the average cost per kWh is assumed as NRS 12[4], then there will be yearly revenue saving of NRS 26868 Per annum.

Reliability analysis is done considering existing distribution line and transformers. It is observed that distribution lines and distribution transformer are major cause poor system reliability indices. It is seen that SAIFI and SAIDI value for the study duration were 25.41 and 30.69. Due to faulty equipment, each customers of distribution system were out of power for 25.406 times for the duration of about 31 hours. Total energy that cannot be supplied to the utility was 358.14 MWh. Contribution of distribution lines to the system indices is 82.72% for SAIFI. i.e. out of 100 interruptions each customer experience 83 interruptions due to failure of distribution lines.

SAIFI, SAIDI and ENS of the improved system are 5.72, 9.86 and 116.47 respectively. When parallel line is used, reliability indices are improved significantly. Before the use of parallel lines each customers were facing a sustained interruption of about 25 times for total duration of 31 hours per year and if parallel lines are installed each customer on average will face interruption of about 6 times for duration of 10 hours per annum. ENS due to failure of distribution line is reduced to 5.575 MWh/a and after the improvement of distribution line, most revenue lost by a system is due to failure of distribution transformer which is 84.33% of total ENS i.e. 98.23 MWh/a.
Table 5. Reliability indices of different cases

| Reliability Indices | Substation configuration only | 66 kV Double Bus Bar | Distribution Feeders and transformer | Parallel Feeders | UG Cable |
|---------------------|-----------------------------|----------------------|-------------------------------------|-----------------|----------|
| SAIFI               | 0.17                        | 0.25                 | 25.41                               | 5.72            | 3.95     |
| SAIDI               | 0.47                        | 0.28                 | 30.69                               | 9.86            | 12.03    |
| CAIDI               | 2.79                        | 1.13                 | 1.21                                | 1.72            | 3.04     |
| ASAI                | 0.99                        | 0.99                 | 0.99                                | 0.99            | 0.99     |
| ENS                 | 5.68                        | 3.43                 | 358.14                              | 116.48          | 142.04   |

For underground cable, failure rate and repair duration is adopted as per IEEE Gold book 1991. SAIDI increases due to MTTR being high for underground cable. If the fast fault location and repair of faulted underground cable can be done then SAIDI and ENS of the system will be improved, for that, skilled manpower is needed.

Table 6. Contribution of components to system indices

| Case                                | Contribution of components to system indices |
|-------------------------------------|---------------------------------------------|
|                                     | Contribution to | SAIFI% | SAIDI% | ENS% |
| Substation Configuration Only       | Transformer    | 0.19   | 0.006  | 0.005|
|                                     | Bus bars       | 98.55  | 99.33  | 99.33|
|                                     | Protection system | 1.25  | 0.67   | 0.67 |
| 66 Kv Double Bus Bar                | Transformer    | 0.13   | 0.01   | 0.01 |
|                                     | Bus bars       | 98.96  | 98.95  | 98.95|
|                                     | Protection system | 0.91  | 1.04   | 1.04 |
| Distribution Feeders and transformers | Transformer | 14.16  | 27.20  | 27.61|
|                                     | Bus bars       | 0.65   | 1.53   | 1.53 |
|                                     | lines          | 82.71  | 70.18  | 69.77|
|                                     | Protection system | 2.48  | 1.09   | 1.09 |
| Parallel Feeders                    | Transformer    | 61.38  | 84.14  | 84.34|
|                                     | Bus bars       | 2.90   | 4.76   | 4.70 |
|                                     | lines          | 17.30  | 4.86   | 4.79 |
|                                     | Protection system | 18.42 | 6.23   | 6.17 |
| Underground Cables                  | Transformer    | 91.00  | 69.41  | 69.63|
|                                     | Bus bars       | 4.20   | 3.90   | 3.86 |
|                                     | cable          | 2.27   | 25.68  | 25.51|
|                                     | Protection system | 2.53  | 1.01   | 1.01 |

Table 7 shows ENS of the study period without reclosures is 36.77 MWh/a causing revenue loss of NRS 441060 per annum. When auto reclosures are used ENS will be 0.04 MWh/a with a revenue loss of NRS 480. Hence, using auto reclosures in the existing circuit breakers of distribution feeders saves the total revenue of NRS 440580. Hence it can be concluded that using auto reclosures in the system.
does not improve MAIFI but SAIDI and ENS of the system due to momentary interruption increases significantly.

Table 7. ENS using auto reclosures

| Feeder   | Average load (MW) | Interruption | Duration Hrs | ENS MWh/a | Duration Hrs | ENS |
|----------|-------------------|--------------|--------------|-----------|--------------|-----|
| Samakhusi | 2.1               | 42           | 3.5          | 7.35      | 0.004        | 0.007 |
| Lazimpat  | 3.3               | 49           | 4.08         | 13.47     | 0.004        | 0.013 |
| Gairidhara | 2.15             | 36           | 3.00         | 6.45      | 0.003        | 0.006 |
| Kingsway  | 2                 | 25           | 2.08         | 4.16      | 0.002        | 0.004 |
| Thamel    | 2.13              | 30           | 2.500        | 5.325     | 0.003        | 0.005 |
| System    |                   |              |             | 36.755    |              | 0.04 |

7. Summary of ENS and EIC

The investment decisions have been suggested for different configurations based on the ENS and revenue recovered. Table 8 shows summary of ENS and EIC for different alternatives. Table 9 shows, in the case of parallel feeders and auto reclosures, present worth of the cash flow is positive as well as benefit cost ratio is greater than 1. Hence, investment can be done. Payback period for the investment will be 10 and 9 years respectively. Whereas, in case of 66 kV double bus bar, present worth of cash flow is negative and BC ratio is less than 1. So, it is not good to invest in 66 kV double bus bar. Annual revenue savings due to use of 66 kV double bus bar is low compared to investment. Although installation cost of underground cable is 5 to 7 times higher than overhead line. Installation can be justified considering public safety and aesthetic factor of city.

Table 8. Summary of ENS and EIC

| Cases            | ENS (MWh/a) | Revenue loss To utility (RS 12/KWh) | Revenue saved to utility (NRS) | Remarks                                |
|------------------|-------------|-------------------------------------|--------------------------------|----------------------------------------|
| Substation config | 5.68        | 68,124                              |                                | Compared to single bus bar             |
| 66 kV double bus bar | 3.43       | 41,136                              | 26,988                         | Compared to radial feeder              |
| With existing feeders | 358.13     | 42,97,524                          | 26,988                         |                                        |
| Parallel feeders  | 116.48      | 13,97,700                          | 28,99,824                      | Compared to radial feeder              |
| Underground cables| 142.31      | 17,07,708                          | 25,89,816                      | Compared to radial feeder              |
| Without reclosures| 36.76       | 4,41,060                           |                                |                                        |
| With reclosures (0.3 s) | 0.04      | 480                                | 4,40,580                       | Compared to without reclosures ( 5 min) |
| Manual reclosing (3 min) | 22.06    | 2,64,720                           | 1,76,340                       | Compared to manual reclosing after 5 minutes |
Table 9. Present worth Payback period and BC ratio

| Cases                        | Present worth of cash flow (NRs) | BC ratio | Payback period (yrs.) | Investment decision |
|------------------------------|----------------------------------|----------|-----------------------|---------------------|
| Parallel feeders             | 88,55,543                        | 1.507    | 10                    | Yes                 |
| Auto reclosures              | 15,99,162                        | 1.66     | 9                     | Yes                 |
| 66 kV double bus bar         | -11,550                          | 0.174    |                       | No                  |

8. Conclusion
From simulation, it is seen that substation and its associated equipment’s are less responsible for power outage. Distribution transformers, feeders, feeder protection and switching system are more responsible for sustained unplanned power outage. SAIFI, SAIDI and ENS improve to 5.715, 9.857 and 116.475 from 25.406, 30.69 and 358.137 through the use of parallel feeders.

Using underground cables, SAIFI reduces but CAIDI increases due to fact that, underground cables take long time to identify fault and perform maintenance. Reliability indices due to substation configuration only are negligible as compared to the whole system. Using auto reclosures in the feeders does not improve MAIFI but SAIDI and ENS improves significantly. Payback period for investment in parallel feeders and auto reclosures is 10 and 9 years respectively. NEA can save yearly revenue of 2.8 million and 2.5 million through use of parallel feeders and underground cables. Although installation cost of underground cable is 5-7 times higher than overhead line, installation can be justified considering public safety and aesthetic factor of city.

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