PLANNING AND RELIABILITY ANALYSIS FOR RESTRUCTURING OF EXISTING OH LINES TO UG CABLES: A CASE STUDY

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ABSTRACT: Electrical energy in distribution system can be delivered to customers in two ways: Overhead (OH) lines and Underground (UG) cables. Most of the existing distribution systems supply power to consumers through OH lines. These lines are converted to UG cables mainly for aesthetic purpose and reduce interruption to customer. So, during restructuring of existing network, it is important to carry out reliability assessment and Load Flow Analysis (LFA) for existing network and planned network. The main objective of reliability assessment is to quantify and compare reliability indices for various reliability improvement initiatives/network configurations. Load flow analysis is carried out to find line flows, bus voltages and system voltage profile, effect of change in system configuration, possible improvements to an existing system by proposing required compensation. In this paper, study has been conducted on the existing distribution system of Jawaharlal Nehru Technological University Anantapur College of Engineering Anantapuramu (JNTUACEA), where it is planned to replace existing OH lines with UG cables. It is a miniature form of our modern day distribution system, where lighting, motor and ac load exist simultaneously, and also continuity of power supply needs to be maintained. The reliability indices for this system are evaluated using the concept of failure modes and effect analysis (FMEA) for radial distribution systems.

KEYWORDS: Load flow study, distribution system, network reconfiguration, reliability indices.

INTRODUCTION

The distribution system is a part of electric power system which delivers, electric energy from transmission to consumer demand points. In most of the utilities electricity is supplied to load points through OH lines. But, OH lines are more susceptible to outages due to varying weather conditions. So, better alternative is to replace OH lines with UG cables. For planned network it is important to carry out reliability assessment and load flow analysis; - Reliability assessment is essential to identify weaker areas which need reinforcements and understand, how changes made in one section affects performance in the remaining part of the system; - LFA reveals power flows and bus voltages for specified conditions when the system is operating under steady state.

The main purpose of the load- flow analysis is to evaluate the individual phase voltages at all buses connected to the network. The Newton-Raphson approach is the most preferred load flow method because of its various advantages. Dommel et al. (1970) has represented, that NR method has great generality and flexibility, hence enabling a wide range of representational requirements to be included easily and efficiently. For computing reliability, various probabilistic methods by Billinton (1972) have been developed. For application of these methods, the IEEE Application of Probability Methods (1979) Subcommittee published a Reliability Test System (RTS). Although it has been used extensively in recent years, but due to its large size its realistic assessment and modelling was difficult. To overcome this, Billinton et al. (1989) developed Roy Billinton Test System (RBTS), the small 6 bus distribution system. The probabilistic techniques have been easily applied on RBTS for reliability analysis educational purpose (Allan et al., 1991) and systems similar to it, to give accurate results.

In this paper, the existing distribution system of JNTUACEA has been studied to carry out the reliability assessment for various network configurations. Being a miniature form of modern distribution system, the analytical techniques (Billinton and Allan, 2007a) could be easily applied to compute its reliability. For carrying out the reliability studies, every load point is explained in terms of three reliability parameters namely: average failure rate (λ), average repair time (r) and average annual outage time (U) (Sankar, 2015). Apart from load point indices, the behaviour of system is depicted in customer based reliability indices (Billinton and Allan, 2007b).

Organization of this paper follows. In section II, Study area i.e., existing distribution system of JNTUACEA is explained in detail. In section III load flow analysis results for existing network and reconfigured network is shown. Methodology for reliability assessment, reliability indices of system with lines and cables network configurations is discussed in section IV and concluding remarks are given in section V.

STUDY AREA

The study has been carried out on the existing distribution system of JNTUACEA. The main supply for this network comes from 33/11 kV sub-station situated adjacent to campus, 0.9 km from power house of the campus. The power from sub-station to college is delivered through two distribution transformers rated (250kVA, 100kVA) 11/.415 kV, which distribute power to 10 Load Points (LP) under 250kVA - 6 load points, and under 100kVA – 4 load points. Distance of each load point from power house and department's under each load point point is shown in Table 8 and 9 respectively in Appendix-A. Distribution line joining from sub-station to power house is High Tension (HT) overhead line of 11kV, all the lines joining the primary feeders to load points are 415V Low tension (LT) overhead lines. Two transformers installed are of dry type, protection to the system includes air circuit breaker and isolators on HT lines and with Moulded Case Circuit Breaker (MCCB), High Rupture Capacity (HRC) fuses and Main Switch (MS) on LT lines. There are six capacitor banks each of 20 kVAR put at different locations as shown in Figure 1 to maintain power factor near to unity. The Single Line Diagram (SLD) of JNTUACEA, is as shown in Figure 1.

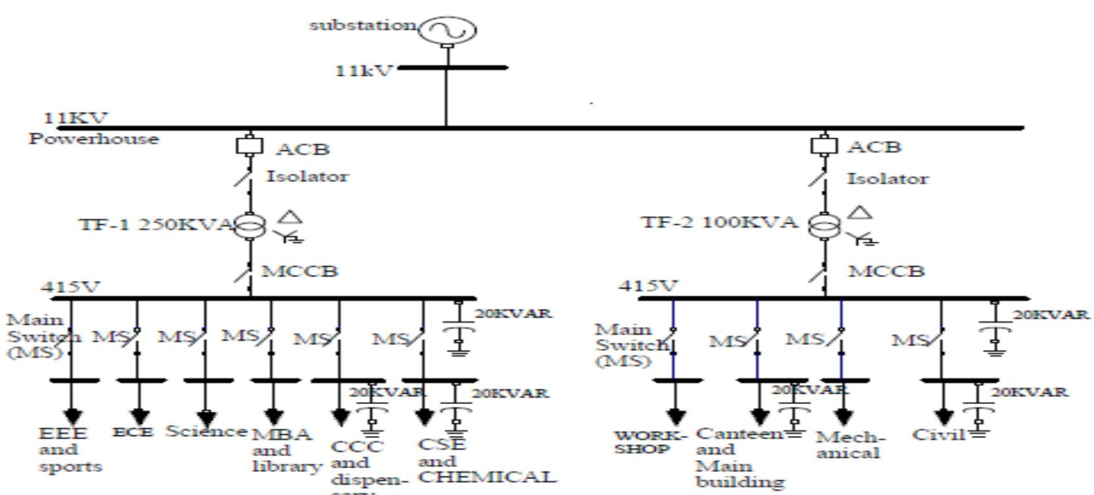

Figure 1. Single line diagram of JNTUACEA

LOAD FLOW STUDY

The study is carried out considering Maximum demand (MD), Average Demand (AD), load conditions of college and for system configuration with overhead line and underground cable through MiPower software. In existing system, there are two wings of operation, under wing - 1, 250 kVA transformer supplies power to following departments Electrical and Electronics Engineering (EEE) block, Electronics and Communication Engineering (ECE) block, SCIENCE block, Master of Business Administration (MBA) block, Centralized Computer Centre (CCC) block, Computer Science Engineering (CSE) block, CHEMICAL block, under wing - 2, 100 KVA transformer supplies power to following departments CAD block, GEO-TECH lab, CIVIL SM lab, MECHANICAL block, MAIN BUILDING, CANTEEN, WORKSHOP block. In Tables 7 and 8 in Appendix-A, shown load shared by each department of college under 250 kVA and 100 kVA transformer respectively.

Case ─ 1: Base Case (Existing System)

Voltage levels of each department for the existing system with OH lines in per unit (p.u) under 250 kVA and 100 kVA transformer during maximum demand, average demand are shown in Table 1 and 2 respectively. For all operating conditions of the existing system bus voltages should be with in limit ±5%, but under 250 kVA transformer i.e., at CSE and CHEMICAL department's voltage levels are not within limit during maximum demand condition. So, to bring voltage level with in limit a 20 kVAr capacitor bank is proposed at CHEMICAL department for the existing system. After placing 20 kVAr capacitor bank voltage level is improved (with in ±5%) at CSE and CHEMICAL, which is shown in Table 3. Comparison with and without compensation during maximum demand is also shown in Table 3. Voltage level of department's under 100 kVA transformer is within limits during both MD and AD condition.

Table 1. Voltage with OH lines under 250 kVA transformer

Department	Voltage level in p.u	
	Maximum demand	Average demand
EEE	0.953	0.974
ECE	0.95	0.972
science	0.968	0.985
MBA	0.95	0.973
CCC	0.952	0.978
CSE	0.931	0.967
chemical	0.92	0.964

Table 2. Voltage with OH lines under 100 kVA transformer

Department	Voltage level in p.u	
	Maximum demand	Average demand
workshop	0.998	1
canteen	0.954	0.98
main building	0.952	0.979
mechanical dept.	0.976	0.99
civil sm lab	0.978	0.997
geo tech lab	0.975	0.996
CAD	0.972	0.995

Table 3. Voltage with and with out compensation during maximum demand

Department	Voltage level in p.u	
	Without Compensation	With Compensation
EEE	0.953	0.9562
ECE	0.95	0.9529
science	0.968	0.9717
MBA	0.95	0.9531
CCC	0.952	0.9551
CSE	0.931	0.951
chemical	0.92	0.95

Case ─ 2: Network Reconfiguration

In this paper network reconfiguration is replacing the existing OH lines (which connect various departments in college) with UG cables. In Figure 2 reconfigured network (planned network) is shown, drawn through Mi power software with the help of college layout by considering exact length of lines, it is proposed to replace existing HT 11 kV line with HT 3 core XLPE underground cable insulated with aluminium conductor, the lines joining the primary feeders to load points with 415V LT 4 core XLPE underground cables. LFA is carried by replacing OH lines with UG cables through Mi power software. Voltage levels of each department with underground cables under 250 kVA and 100 kVA transformer during maximum demand, average demand is shown in Tables 4 and 5 respectively.

Table 4. Voltage with UG cables under 250kVA transformer

Department	Voltage level in p.u	
	Maximum demand	Average demand
EEE	0.9795	0.992
ECE	0.9787	0.991
science	0.9832	0.994
MBA	0.9788	0.991
CCC	0.979	0.992
CSE	0.9743	0.99
chemical	0.9735	0.989

Table 5. Voltage with UG cables under 100 kVA transformer

Department	Voltage level in p.u	
	Maximum demand	Average demand
workshop	1.005	1.01
canteen	0.995	1.005
main building	0.994	1.004
mechanical dept.	1	1.008
civil sm lab	1.001	1.009
geo tech lab	0.998	1.007
CAD	0.995	1.007

By comparing Tables 1 and 4, Tables 2 and 5 respectively, it can be observed that voltage level has been improved when OH lines are replaced with UG cables. Losses of the reconfigured network is less than existing network because resistance of underground cables is less than overhead lines, underground cables has capacitance effect which will support the system in improving power factor by delivering reactive power. Comparison of kW and kVAr losses with OH line and UG cables during maximum demand and average demand is shown in Table 6.

Table 6. Losses comparison with OH lines and UG cables

Losses	Maximum demand		Average demand	
	OH lines	UG cables	OH lines	UG cables
kW	12.6	5.5	6.7	2.84
kVAr absorbed	15.4	-5.64	7.66	-11.71

RELIABILITY ASSESSMENT

In this section methodology followed for evaluation of reliability indices is explained in detail, and evaluated reliability indices of the network with lines and cables compared.

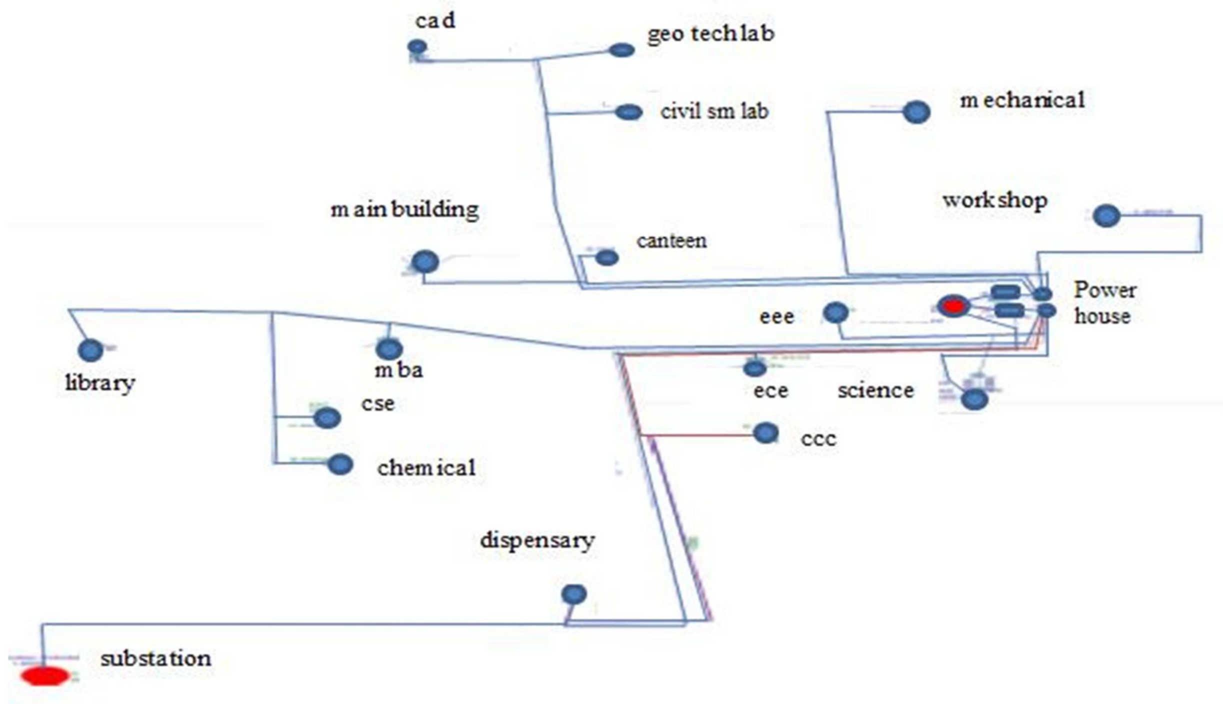

Figure 2. Reconfigured Network

Methodology

The reliability assessment of case study distribution system is carried out through failure modes and effect analysis as depicted in Figure 3. According to it, in case of failure the state of components leading to loss of load are considered. In the present analysis, only single outage events are considered. The components on 33 kV side are assumed to be 100% reliable. The effect of scheduled maintenance is not considered. Following steps are followed for estimating the reliability indices for the given system:

1. In order to estimate the failure rate of various components, the failure data of existing system is collected.
2. The repair and switching time data for every component is collected.
3. Average load and energy at each load point is estimated using data collected from college power house.
4. Data of number of departments connected at every load point is collected exactly.
5. The length of HT and LT lines is estimated, which is shown in Tables 9 and 10 respectively in Appendix-A.
6. Failure Modes and Effect Analysis (FMEA) is carried out for evaluation of load point indices.
7. From the load point indices (Sankar, 2015), the customer oriented indices (Billinton and Allan, 2007a) are evaluated.

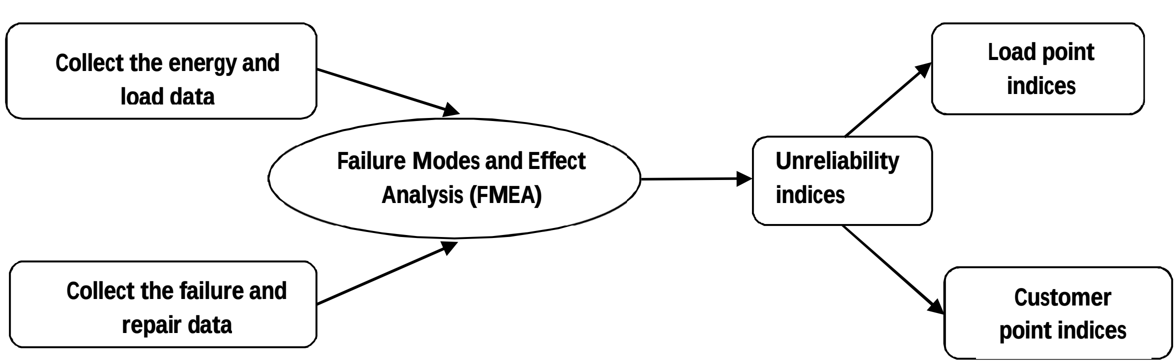

Figure 3. Philosophy of Reliability Assessment

Reliability Indices of the system with OH Lines and UG Cables

The values of reliability indices (Billinton and Allan, 2007a) for existing Allan et al., network with overhead lines and underground cables is evaluated and is shown graphically in Figure 4 and 5 respectively. In case of OH lines failure rate (λ_i), repair time (r) of feeder section and transformer is taken from (Allan et al., 1991), failure rate of college lines is 0.35failures per km-yr, which is computed by taking real time failures of college into consideration. In case of underground cables failure rate and repair time is taken from (Allan et al., 1991).
Higher value of System Average Interruption Frequency Index (SAIFI) indicates higher frequency of interruptions; its value is 0.188 interruptions per year with OH line and 0.064 interruptions per year with UG cables as shown in Figure 4. SAIFI value is less for UG cables because they are less susceptible to outages during extreme weather conditions, compared to OH line. Higher value of System Average Interruption Duration Index (SAIDI) shows large duration of load curtailment; its value is 3.75 hours per year with OH line and 4.46 hours per year with UG cables as shown in Figure 4. Even though failure frequency of UG cable is less compare to OH line, SAIDI value for UG cable is more compare to OH line because of longer repair time taken for UG cables. Repair time can be limited by optimizing the repair process. Average Service Availability Index (ASAI) value in percentage shown in Figure 5 for OH line is 99.957 and for UG cable is 99.949 which indicate high service availability of existing network and future network. Average Energy not Supplied (AENS) in Figure 5 depicts the energy not supplied to the network due to failures per year. AENS in case of UG cable is more than of OH line, this is due to higher SAIDI value of UG cable.

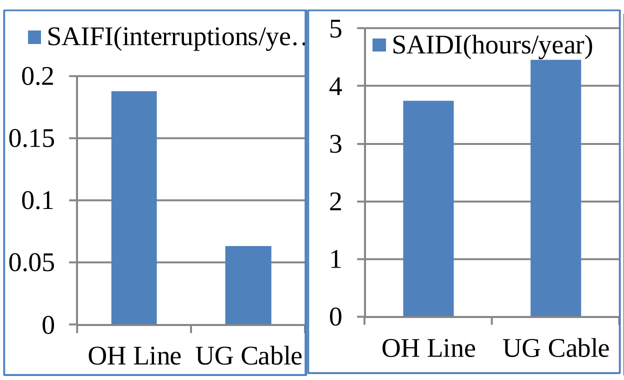

Figure 4. SAIFI and SAIDI values with OH Lines and UG cables

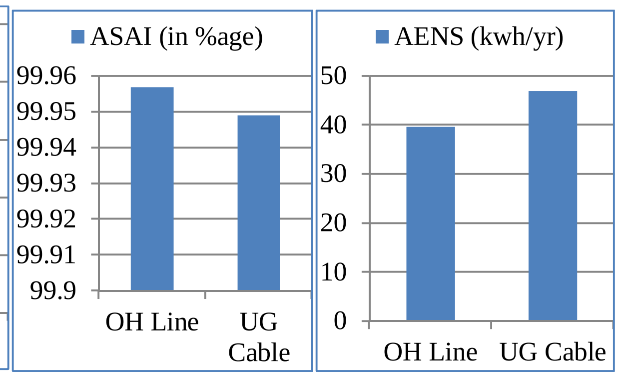

Figure 5. ASAI and AENS values with OH lines and UG cables

CONCLUSIONS

In this paper, study has been conducted on real time distribution network of JNTUACEA. It is planned to replace the existing overhead lines with underground cables. During maximum demand condition it was observed that at some buses voltage level were not with in ±5%. To bring voltage levels within limits of ±5% a 20 kVAr capacitor bank is proposed at Chemical Engineering department. Single line diagram has been developed for the system through MiPower software. Load study has been carried out for network with UG cable during MD and AD, it is observed that line loadings and voltage levels are within limits, and reactive power drawn from the substation is reduced. Reliability assessment of JNTUACEA distribution system is carried out through FMEA. Load point indices and reliability indices are calculated for the system with OH lines, UG cables. System indices indicate SAIFI value is more with OH lines compare to UG cables. Overall all indices of the system with OH line indicate that system is quiet reliable. Restructured network indices show that future network operates with satisfactory reliability.

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APPENDIX-A

Table 7. Load under 250 kVA transformer

Department	Maximum demand in kW	Average demand in kW
EEE	46	32.2
ECE	35	24.5
science	20	14
MBA	18	12.6
CCC	25	17.5
CSE	20	14
chemical	15	10.5

Table 8. Load under 100 kVA transformer

Department	Maximum demand in kW	Average demand in kW
Workshop	8	5.6
Canteen	7	4.9
Main Building	32	22.4
Mechanical	17	12
Civil SM lab	2	1.4
Geo tech	5	3.5
CAD	10	7

Table 9. Length of OH lines under 250 kVA transformer

Component	Length (in km)
Feeder	0.885
EEE Line (LP1)	0.08
ECE Line (LP2)	0.117
Science Line (LP3)	0.127
MBA Line (LP4)	0.391
CCC and Dispensary line	0.753
CSE&CHEMICAL Line (LP6)	0.445

Table 10. Length of OH lines under 100 kVA transformer

Component	Length (in km)
Workshop Line (LP7)	0.110
Canteen & Main building Line (LP8)	0.222
Mechanical (LP9)	0.230
Civil dept., CAD, geo tech lab (LP10)	0.413