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Migration from Low to High Voltage Distribution System: An Optimization of Selected Unit Transformers Using Linear Programming with Matlab

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Abstract

This paper evaluates HVDS and LVDS concepts by system performance. This is achieved by examining system losses on HV and LV distribution networks in radial AC distribution systems. Challenges associated with system losses may demand network conversion from LV to HV network. This paper addresses this issue by using HVDS optimization specifically, linear programming techniques with Matlab optimization toolbox to determine the optimal number of unit transformers in the HV network. Studies conducted on a test distribution system using CYMEDIST software show the optimized HVDS has improved voltage profile and a total system loss reduction of 29.50% as compared to the LVDS. Consequently, there is reduced operational cost and increased annual capitalized loss savings in the optimized HVDS.

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1. Introduction

LVDS and HVDS are two basic configurations of the electrical power distribution system. The LVDS is characterized by a high capacity transformer at a load centre. This transformer supplies multiple customers through long low voltage (LV) lines such as 0.415kV. In the HVDS, high voltage (HV) lines such as 11kV are the primary distributors. The HV lines terminate into a population of low capacity unit transformers with short LV lines to supply fewer customers. The main differences between the two schemes are in layouts, configurations, and applications [1]. Network limitations such as future growth, voltage drop and thermal limitations on the LV network may require voltage upgrade by migration to the HV network [2]. In support of this assertion, there are emerging projects of migration from the existing LV distribution network to the HV distribution network [2] [3] [4]. Similarly, the Electricity Company of Ghana (ECG), under Ghana Energy Development and Access Project (GEDAP) program has piloted the HVDS project in Kumasi Magazine.

A distribution system should improve voltage profile and minimizes technical losses. Usually, utilities employ various loss minimization techniques to reduce system losses in the networks. In many cases therefore, the primary objective of migration is to reduce system losses and improve voltage profile. The HVDS implementation is one of the techniques of loss minimization [5]. In [6], a simple power flow technique was used to evaluate losses on an agricultural feeder before and after migration to HVDS network. A total loss reduction of 99.89% on the feeder resulted after the migration. In certain cases, transformer losses are more in the HVDS. In spite of the increased transformer no-load losses recorded in [7], a 28.7% reduction in line loss, averagely reduced the total system losses in the HVDS.

Several authors have shown that the HVDS scheme also improves voltage profile. Amaresh et al. (2006), [6], used load flow techniques on radial networks and obtained a 20% voltage improvement as a result of migration to HVDS. By modelling and simulating a rural agricultural network, [3] recorded 24.47% improvement in tail-end voltage as a result of the proposed HVDS scheme. In a proposed restructuring of LVDS to HVDS, the backward-and-forward sweep method of iteration for load flow solutions is used to determine voltage drops in both networks [8]. The result is a reduction in voltage drop in the HVDS scheme. Reference [9] have used simulations with PSCAD software on a case study for HVDS implementation. As a result the tail-end voltage increased by 10 V. This is estimated to be about 3% voltage improvement per day.

A major challenge in the HVDS scheme is the number of transformers involved; since it represents the largest capital investment in the distribution system, and provides the best opportunity to reduce operational cost [10]. In the preceding assessments of migration schemes, there is no indication of a well-defined scientific principle used to populate the HV network with unit transformers. It follows that the HV network can suffer from some level of overpopulation or under-population with unit transformers.

Our proposed solution in this paper, overcome the challenge in selecting the right number of transformers by adopting a rigorous optimization approach. The HVDS optimization aims at determining the optimal number of unit transformers in the scheme using a linear programming approach similar to the approach used in [11]-[13]. The methodology is deployed on a modeled LV network to convert it into HV network. The two networks are modeled with CYMEDIST software and simulations are performed for load flow studies. Subsequently, an assessment of the networks is done to determine the level of enhancement on voltage profiles and system losses. A better voltage profile means improved power quality and reduction in investment in voltage improvement equipment for the utility. Furthermore, the optimal network leads to savings in operational cost due to the reduction in system losses.

The rest of the paper is structured as follow: section 2 deals with the methodology, section 3 deals with the result and discussion and section 4 presents the conclusion.

2. Methodology

The first task required a formulation of the optimization problem. In this respect, linear programming formulation for HVDS optimization was realized to select unit transformers [14]. Secondly, load flow analysis tool in

CYMEDIST was used to model and simulate the LV and HV networks using field data. Based on the load flows results, an assessment of the networks was done to determine the level of enhancement on the voltage profile and system losses.

2.1. Summary of Optimisation Technique

Table I. presents the design parameters employed in the optimization process.

Table 1. Design Parameters for the Optimisation process

Maximum Number of Poles for 16 kVA	2
Maximum Number of Poles for 25 kVA	4
Maximum System Demand	216 kVA
Number of Existing Poles	36
Maximum Average Demand /Pole	6 kVA
Bulk Transformer Capacity	315 kVA
Unit Transformers	16 kVA, 25 kVA
No-load Losses of 315 kVA Transformer (CRGO)	501 W
No-load Losses of Amorphous 16 kVA Transformer	20 W
No-load Losses of Amorphous 25 kVA Transformer	28 W

The optimisation process should be able to effectively harmonize with the network design conditions. The conceptual model is hereby considered using linear programming techniques [15].

Decision variables:

n_{16} = 6 kVA Transformers
n_{25} = 25 kVA Transformers

Linear inequality and equality constraints:

Sum of no-load losses of unit transformers ≤ sum of no-load losses of bulk transformer;

$$0.02*n_{16} + 0.028*n_{25} \leq 0.501 \qquad (1)$$

Maximum system loadings in HVDS ≤ maximum system loadings in LVDS

$$2*6*n_{16} + 4*6*n_{25} \leq 36*6*(1+r)^{i} \qquad (2)$$
$$12*n_{16} + 24*n_{25} \leq 216*(1+r)^{i} \qquad (3)$$

Non-negativity constraints:

number of 16 kVA transformer ≥ 0
number of 25 kVA transformer ≥ 0

$$n_{16} \geq 0 \qquad (4)$$

$n_{25} \geq 0$ (5)

Transformer stockings ratio:

number of 16 kVA transformer = N*number of 25 kVA transformer

$n_{16} = N*n_{25}$ (6)

Objective function:

The objective function required to give the maximum capacity of the unit transformers is given by (7).

$P = 16 *n_{16} +25 *n_{25}$ (7)

where, i = number of accumulated years
r = growth rate
N = scale factor
P = transformer capacity
In the base case, i = 0 and N = 2;

Problem modelling and solution

The generic optimization problem would be in the form given by [18]

$$\text{Minimize } C(x) \quad (8)$$
$$\text{subject to } g(x)\leq b$$

where, x is the decision variable, C(x) is the objective function and g(x)≤b is the inequality constraint.

The solution algorithm is obtained for (1) to (7) using [12].

2.2. Conversion of LV Network into Optimal HV Network

Having obtained the optimal number and sizes of unit transformers for the HV network, the next stage was to implement the HVDS scheme. The conversion was done by replacing the high capacity distribution transformer with low capacity amorphous transformers [16]. There was no significant change in the other components of the distribution system such as type of conductors, sub-station, protection equipment, operation methodology etc. Due to the voltage upgrade the conductor size for the primary distributor was changed from 50 mm2Albare to 120 mm2Albare. The high voltage line length increased due to the reduction in the length in the low voltage lines, as the transformers were taken closer to the customers. These features are shown in the modelling process as described below.

2.3. Modeling and Simulation of LV and HV Networks

The existing LVDS was modelled with field data to exhibit the characteristics of a typical network. In this design, 6 kVA was used as the demand per pole with respect to the 315 kVA transformer. As a result, 36 poles were obtained for a reasonable level of transformer loading. Hence, at each load-point the actual loading required for modelling was 6 kVA. A maximum pole span of 50 m was used. In order to ascertain its effectiveness, the proposed optimization process was tested on the network in Figure 1 to realize the network in Figure 2.

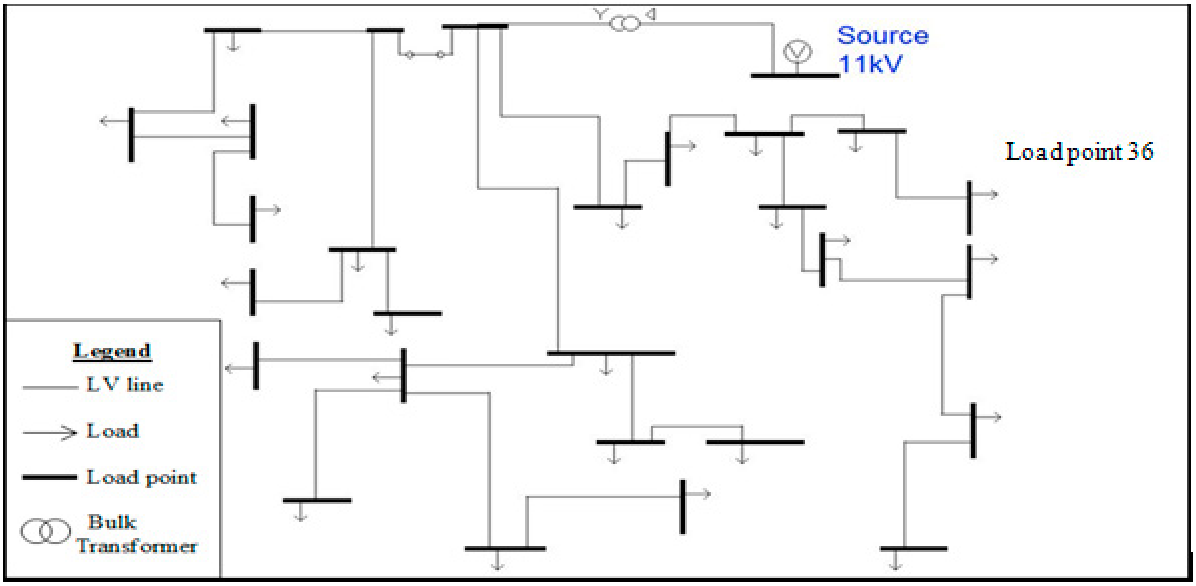

Fig. 1. Existing LV Network

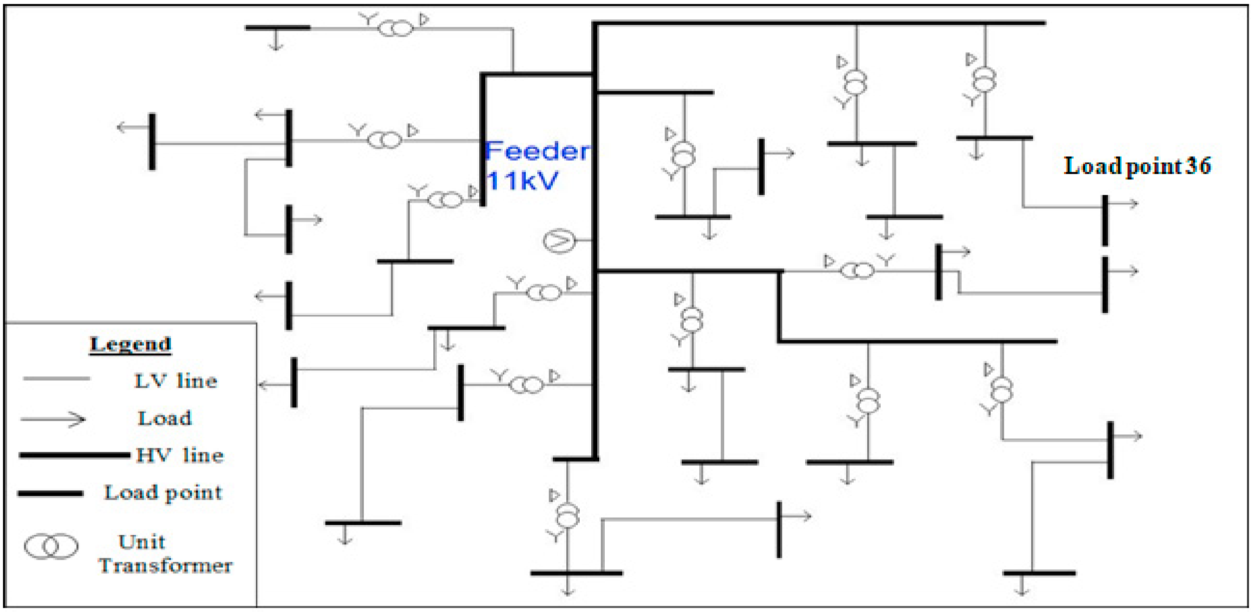

Fig. 2. Proposed Optimal HV Network

Similar networks have been modelled by other researchers on the HVDS migration scheme for loss minimization [9] [4].

3. Results and Discussion

Several studies have compared the LV and HV networks for loss minimization and voltage profile, thus obtaining similar results. Notable amongst them are the works of [3] [4] [9]. What is not so clear is the level of enhancement as a result of the optimization process on voltage profile and system losses on the HV distribution network. This discussions thus establish an understanding in this regard.

3.1. Voltage profile

The voltage profile is considered from the source to the point of utilisation of power. The drop in voltage is due to line and component impedances, and the varying loads at the load point. Technically, the final voltage drop along the line is the resultant drop due to the long line itself, and components between the source and the load. Figure 3 and Figure 4 show the drops in line voltages for load 36 in the LV and optimised HV networks respectively. In Figure 3 load 36 is 250 m away from the source of supply. It is observed that there is a steady decline in voltage along the phases due to the long LV line. However, in the case of Figure 4, there is a marginal drop in voltage along the phases due to the short LV lines.

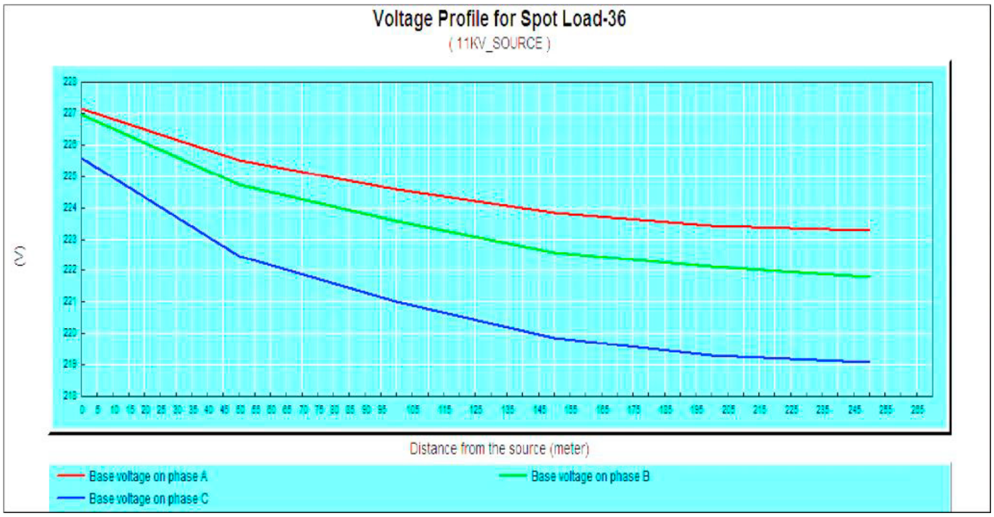

Fig. 3. Voltage Profile in LV Network

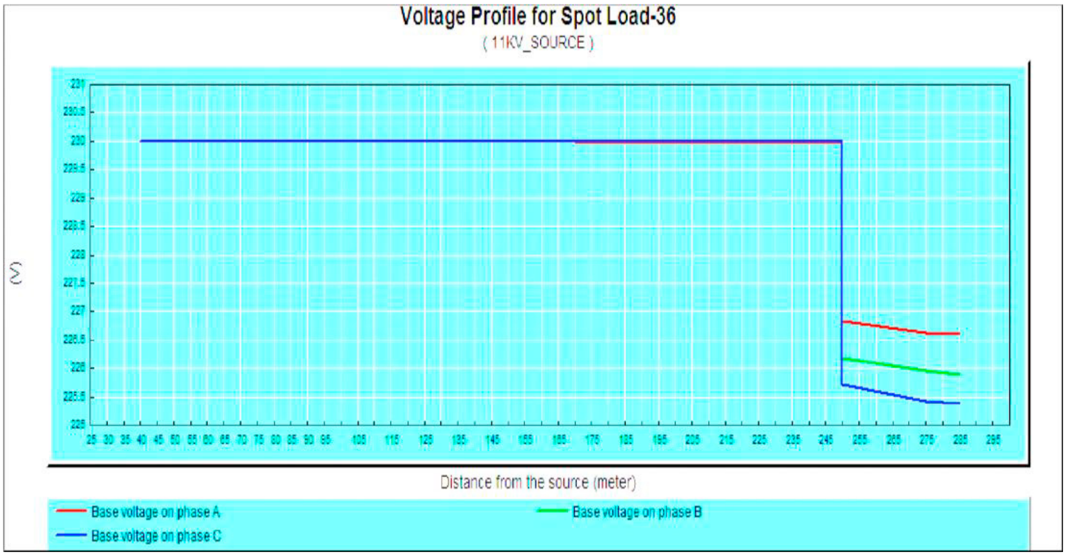

Fig. 4. Voltage Profile in Optimal HV Network

It is observed in Table II that Load 36 has a voltage drop reduction from 2.8% to 2.0% after the migration to the optimised HV network.

Table 2. Voltage Profile Results for LV and Optimal HV Networks

Network	Load Point	Source Voltage (V)	Base Voltage (V)	Voltage Drop (%)
LV	36	225.5	219.08	2.8
Optimal HV	36	230.0	225.38	2.0

Similar results have been obtained by [6] for loads on agricultural feeders after implementation of HVDS. They reported a voltage improvement of up to 20% for the running of electrical machines at their rated voltages. Under-voltages as a result of voltage drops may result in dim lights and cause damage to electric motors due to overheating of coils. Equipment lifetime may be reduced, or damage could result due to voltage violations. Therefore, a healthy distribution system should ensure that the voltage variation at the consumer's terminals is within permissible limits.

3.2. System Losses

The total system losses in the network consist of transformer no-load, transformer load and line loss. Figure 5 presents a higher loss in the LV network than the optimized HV network.

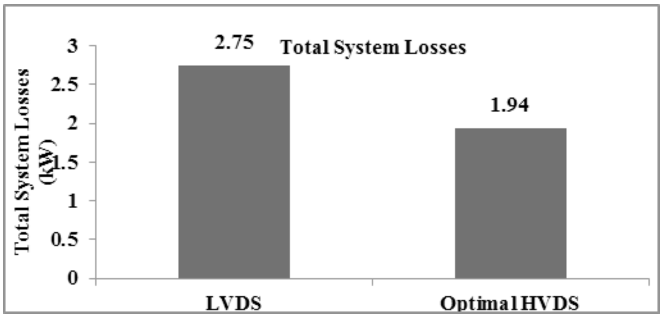

Fig. 5. Overall Losses of Networks

The difference in losses represents a reduction of 29.50% as a result of the HVDS implementation (Table 3). In a related work, [17] obtained similar results for total system losses reduction after an HVDS implementation.

Table 3. *Total System Losses*

Quantity	LVDS	Optimal HVDS	Percentage Change (%)	Effects
Line Losses (kW)	1.33	0.13	90.20	Reduction
Transformer No-Load Losses (kW)	0.50	0.29	42.00	Reduction
Transformer Load Losses (kW)	0.91	1.51	60.00	Increment
Total System Losses (kW)	2.75	1.94`	29.50	Reduction

This difference in losses is largely caused by the line losses due to the long lines in the LV network. Clearly, over 29.50% of the losses in the LVDS are saved with the implementation of optimal HVDS.

4. Conclusion

In summary, this paper presents a set of constraints in Low Voltage distribution network that explain the need for migration to a High voltage distribution network. It further presents an optimization technique to help select the appropriate number of unit transformers needed to provide equal services with minimized losses in the HV network. Based on the optimisation process, the results of the comparative analysis revealed the following: the optimized HVDS has a better voltage profile which results in improved voltage profile; system losses reduction decreases the operational cost and increases the annual capitalised loss savings in the optimal HVDS. This study is therefore an innovative approach in selecting unit transformers needed in a migration from LVDS to HVDS that will provide reliable and economical services to service providers.

References

[1] Short, T. A. (2014). Electric Power Distribution Handbook, CRC Press, Boca Raton, Florida, USA, 2nd edition, 784pp.

[2] Ward D. J. (2007). Benefits and Draw-Backs of High Voltage Distribution Networks (11/33kV) Compared to Low Voltage Systems (230/400V). Virginia, USA: Centre for Energy and Global Environment, Virginia Tech-Advanced Research Institute, pp. 49.

[3] Modi, S. B., Talati, S., Mishra, H. K., Trivedi, U. C., Singh, A. K., & Talera, S. K. (2007).“HVDS in Distribution Sector”, *Electrical Research and Development Association*, *www.indiacore.com/bulletin.* Accessed: June 15, 2014.

[4] Sarwar, M. D., Jaffery, Z. A., Siddiqui, A. S., & Quadri, I. A. (2012). TechnoEconomic Feasibility of HVDS Concepts for Distribution Feeder Power Loss Minimisation. IEEE 5th India International Conference, Delhi, India, 1 - 4.

[5] Magadum, R. B., and Timsani, T. M. (2012), “Minimisation of Power Loss in Distribution Networks by Different Techniques”, International Journal of Scientific and Engineering Research, 3(5), 1 - 5.
[6] Amaresh, K., Sivanagaraju, S., & Sankar, V. (2006). Minimisation of Losses in Radial Distribution System by using HVDS. Institute of Electrical and Electronic Engineers (IEEE) Power Electronics, Drives and Energy Systems, International Conference, PEDES ’06, New Delhi, India, 1 - 5.
[7] Agrawal, A., & Patra, A. (2011). Comparative Analysis of Reconfiguration of Existing Distribution System with HVDS Concepts. *International Journal of Data Modelling and Knowledge Management*, 1(2), 1 - 10.
[8] Spandana, K., Nikhita, L., & Varsha Reddy, A. (2013). High Voltage Distribution Systems for Better Voltage Profile. *Proceedings of the International Academy Conference of Electrical, Electronics and Computer Engineering*, Chennai, India, 37 - 41.
[9] Raju, M. M., Ramesh, L., Chowdhury, S. P., & Chowdhury, S. (2011). Restructuring Distribution Feeder through HVDS Concepts, *Latest Trends on Systems*, 1(2), 54 - 59.
[10] Daut, I., Ahmad, D. M. M., Zakaria, S., Uthman, S., & Taib, S. (2006). Comparison of Losses and Flux Distribution in Three-Phase, 100-kVA Distribution Transformer Assembled from Various Types of T-Joint Geometry. *American Journal of Applied Sciences*, 3, 1990 - 1992.
[11] A. Acakpovi, E. Ben Hagan, and F. X. Fifatin, “Cost Optimization of an Electrical Energy Supply from a Hybrid Solar, Wind and Hydropower Plant,” Int. J. Comput. Appl., vol. 114, no. 19, pp. 975–8887, 2015.
[12] A. Acakpovi, “Original Framework for Optimizing Hybrid Energy Supply,” Hindawi Publ. Corp. J. Energy, vol. 2016, pp. 1–11, 2016.
[13] A. Acakpovi, “Performance Analysis of Particle Swarm Optimization Approach for Optimizing Electricity Cost from a Hybrid Solar, Wind and Hydropower Plant,” Int. J. Renew. ENERGY Res., vol. 6, no. 1, pp. 323–334, 2016.
[14] Majeed, I. B., Acakpovi, A., & Michael, M. (2017). Optimisation of High Voltage Distribution System, *Research Journal of Applied Sciences, Engineering and Technology* 14(7): 251-255.
[15] MathWorks. (2013). *Optimization toolbox*. USA: The MathWorks, Inc., Natick, MA.
[16] López, A. P., Herrera, C. E. P., Castillo, L. R. G. and Rodríguez, G. B. (2012), “Physical Integrity Diagnostic of Amorphous Steel Core Transformer in Fault Conditions”, *International Journal of Engineering and Innovative Technology*, 1(5), 217 - 220
[17] Gupta, A., Gill, H. S., & Bansal, I. (2012). Effectiveness of High Voltage in Distribution System: High Voltage Distribution System. *IOSR Journal of Electrical and Electronic Engineering*, 1(5), 34 - 38.
[18] Seifi, H. and Sepasian, M. S. (2011), “Electric Power System Planning - Issues, Algorithms and Solutions”, Springer-Verlag, Berlin, Series 4622, 374pp.