Undergrounding the Power Distribution Network in Luang Prabang World Heritage

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Abstract— *World heritage site has a unique characteristic that needs particular attention in supplying the electric power in the area. There are two main objectives to be fulfilled, i.e. the response to the power demand increased by tourist downpour into the area and the preservation of world heritage aesthetics. Thus the design and construction of distribution system must meet such objectives. It has been widely recognized that an underground distribution line, despite its high investment cost, would offer a better reliability and quality of power supply as well as minimize an environmental impact and enhance a human safety. However, if the design and construction of an underground distribution network is not properly chosen, it may pose another deficiency. This paper proposes a systematic approach to deal with the evaluation and selection of undergrounding implementation options by taking into consideration of various governing criteria including technical, economical, social and environmental aspects. The application of the proposed approach to evaluate the undergrounding options for Luang Prabang World Heritage against the preset criteria and select the most appropriate one which coincides with the opinions of the underground system experts prove the effectiveness of the proposed methodology.*

Keywords— **AHP, power distribution, undergrounding, world heritage.**

1. INTRODUCTION

Luang Prabang, the ancient capital city of Laos, was recognized by UNESCO as world heritage site in 1995 due to its architectural and cultural richness. Since then a number of tourists have poured into the city. This pushes the city, under the tough control of world heritage representative office, to turn its traditional houses and buildings into tourist accommodations and entertainment compounds resulting in city power demand jump to such a high level. Currently, the city preserved zone is served by two overhead feeders forming an open-loop with tie switches at both receiving and far ends. These existing overhead feeders pose the reliability problems, visual pollutions as well as community conflicts due to the tree trimming. Furthermore, when new customer is to be served, it was found difficult to realize because of the problems of over ground right of way.

In order to preserve those cultural and traditional constructions to be in line with the world heritage regulations; to cope with the current power demand as well as to improve the reliability, it requires all overhead infrastructures to be converted to underground. Being the sole electricity utility of Laos PDR, it is inevitable for Electricity du Laos (EDL), to conduct a feasibility study on converting overhead lines running through Luang Prabang world heritage site into underground system. The study investigated present power availability and reliability; analyzed existing power problems; and proposed the appropriate underground cabling option for world heritage protected zone taking into consideration of all the governing factors namely technical, financial, social and environmental aspects. In this paper, the author intends to propose a systematic approach to make the best possible decision on the selection of the undergrounding methodology in order to optimize the technical, economical, social and environmental aspects of implementing the underground distribution system especially in preserved urban area. The case study of Luang Prabang World Heritage is used to show the robustness and effectiveness of the proposed approach [1].

The paper is outlined as follows; Section 2 describes the nature of underground distribution system while Section 3 details the network configuration, installation and construction, and transformer station for underground system. Section 4 explains the concept of multi-criteria decision making and the process of AHP; followed by Section 5 which discusses the study on undergrounding Luang Prabang power distribution system.

2. NATURE OF UNDERGROUND DISTRIBUTION SYSTEM

There are two types of power distribution line, i.e. overhead and underground system. The overhead construction consists of poles and wires hanging on the poles supported by electrical insulator. The underground counterparts, the wire itself is fully electrically insulated which offers less constraints in the location of installation; it can be put adjacent to one another; it can be laid underground. It has been widely recognized that an overhead network cannot provide the superior reliability and quality of power supply when comparing to an underground counterpart. The overhead system is vulnerable to external attacks such as weather conditions, natural disaster or accidents while the underground network is well protected down under the earth surface

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and out of sight. Hence, the underground system seems to be an inclusive solution to the issues of the city aesthetics, people safety and environment friendliness. However, undergrounding the distribution network may not deem excellent as it looks if the implementation is not made properly. It is found that the frequency of outages on underground systems was 50% less than overhead systems, but the average duration of an underground outage was 58% longer because those repair times are typically much longer [2]. In terms of investment, the cost of placing an overhead line underground is far more expensive. The cost to build underground distribution lines is typically four to six times the cost of underground distribution lines. For the environmental aspect, though there is some belief that placing distribution lines underground and out of sight is better for the environment, actually underground distribution lines cannot be simply plowed into the ground. They need to be encased in conduits, which are usually built with concrete. That requires large trenches and bores along the entire route of the line, which is invasive and disruptive. Construction of underground duct line can create chaos to the site of construction especially in the city where business and tourist activities are immensely taking place.

Underground distribution network has many types of designs and constructions. Different types may hold different or shared characteristics which somehow offer an advantage in some situation but a disadvantage in the others. In order to achieve the most benefit from utilizing the underground distribution network, the designs and constructions of the system has to be cautiously performed particularly by the experts in the area.

3. UNDERGROUND DISTRIBUTION NETWORK DESIGN AND CONSTRUCTION

Underground Network Configuration

The configuration of underground distribution system employed by utilities worldwide basically comprises four types namely radial, open loop, primary selective, and special spare line configuration. The radial system is the simplest and least cost option but providing poor efficiency and reliability. In this configuration, main feeder is routed out from substation and allowed to be laterally tapped to supply customers' load via distribution transformers. The failure of the main feeder especially at the portion which is close to source will result in the blackout of entire feeder.

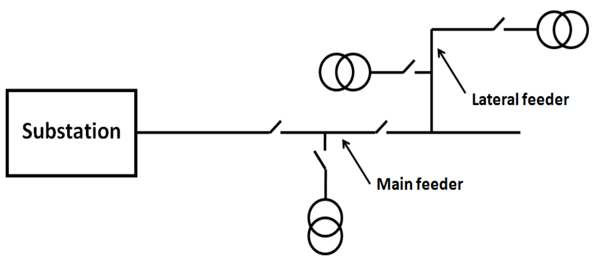


Fig. 1. Radial system.

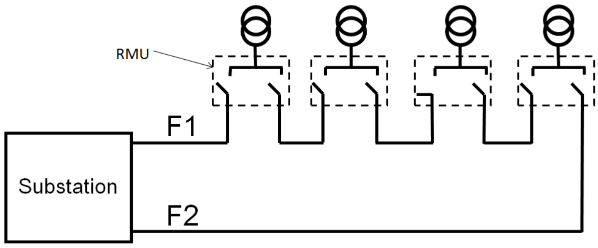


Fig. 2. Open loop system.

This deficiency caused by the radial network can be overcome by looping two feeders together where the open-loop configuration is to be formed. In the open-loop feeders, two feeders would be tied via open-switch. Ring main unit (RMU) switches are employed to deed the transformers.

In a certain circumstance when higher reliability is required, the primary selective configuration can be an option. By running two main feeders in parallel would greatly offer a flexibility to switch transformer to different sources. Furthermore, if automatic transfer switch (ATS) is incorporated into RMU, the system will be able to automatically connect the transformer to the healthy source. This will offer even higher reliable power supply to customers connected.

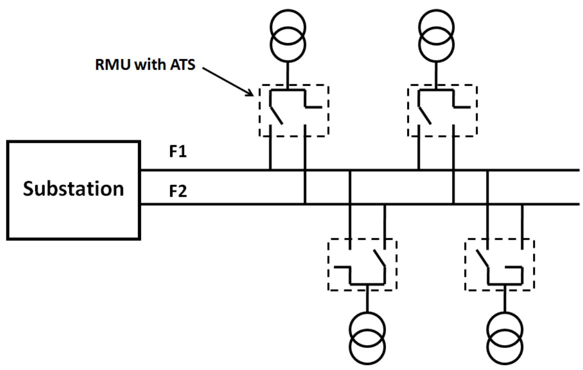


Fig. 3. Primary selective system.

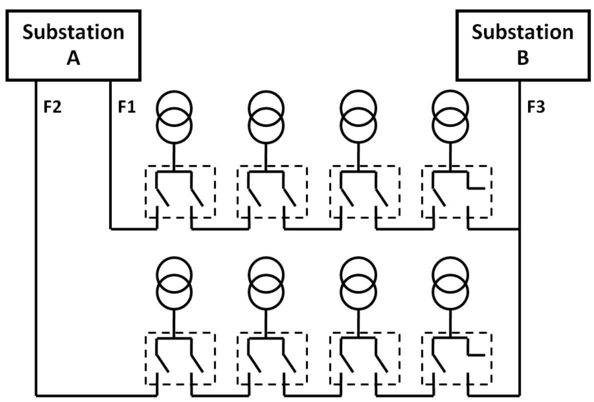


Fig.4. Special spare line system.

Table 1. Comparison of feeder configuration

Norm	Radial	Open Loop	Primary Selective	Special Spare Line
Reliability	poor	good	excellent	good
Operation flexibility	Low	fair	excellent	good
Expansion flexibility	excellent	fair	excellent	good
Fault location	fair	excellent	poor	excellent
Investment cost	low	fair	very high	high

In the open loop system, the far end of first feeder is connected to the far end of second feeder. However, if the far end of the first feeder is directly connected to the feeder specifically provided as a spare for such feeder, a system with the special spare line can be formed. In doing so, benefits could be obtained from both the open loop and the primary selective configuration. A spare feeder can serve the load of about 2-4 feeders depending on the design. Table 1 summarizes the pros and cons of each configuration type according to different implementation aspects.

Underground Network Installation and Construction

Cable installation can be done in a number of ways, depending on the criteria governed as well as the performance required. However, there seems to be only two options preferred for installing the power cable underneath public road which are direct buried laying and in-duct installation. The adoption principle lies in the level of cable protection, the simplicity of installation, the simplicity of maintenance and fault locating, and cost of installation.

Direct Burial Installation is the simplest and cheapest way to construct the underground power line. After the ground is excavated, cable will be just laid down in the groove and then backfilled with the soil. To enhance cable protection, trough and concrete slap may be put on top of the cable. Joint bays are required when two or more sections of cable are to be jointed. From the perspective of the cable mechanical protection and the cable maintenance, this method may not be a preferred choice. It is usually employed when construction is made within the utility or customer's premise. However, this method is still a preferable option in the case that earth digging activity in the public space is totally controlled.

In-Duct Installation where the ducts or pipes will be placed underground, in advance, especially during the construction of road. Then the cables will be pulled and placed in ducts anytime required afterwards. Jointing of cable sections can be made at the manhole which is dedicated for this purpose. The methods of duct construction will be described in the following paragraphs. Since the cable is installed inside ductbank, it will be protected from any external forces that may be accidentally applied to such cable. In addition, cable maintenance such as fault locating, cable repair or replacement is more convenient than direct burial method.

Fig. 5. Direct burial installation [Underground Cable Systems 2010**].**

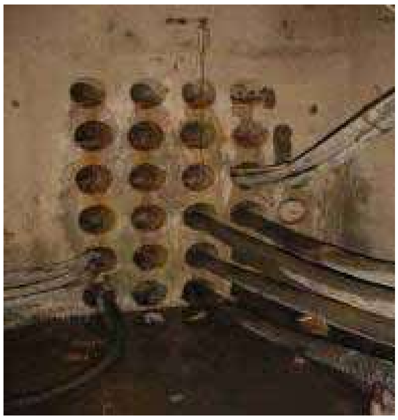
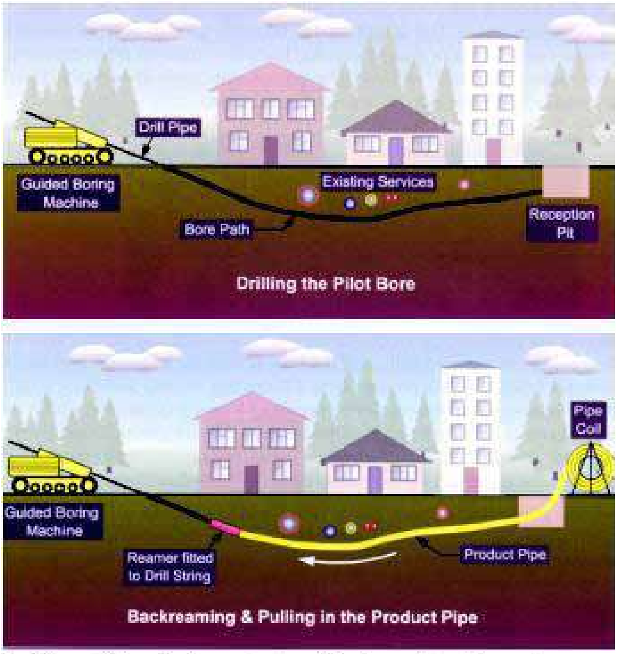


Fig. 6. Cable installed in duct and manhole.

Fig. 7. Open-cut ductbank construction.

Open-Cut Ductbank requires surface excavation, the number of ducts for installing the cables will be formed up inside a long groove and encased with concrete; joined by manhole at certain distance. As such, it is more expensive than the direct burial installation. Another disadvantage is its fragility due to a ground slide or soil movement. Since the cable is installed in the encased ducts, the cable is well-protected from the nearby digging activities. Moreover, not only this method is able to offer a spare duct for future cable installation; but it also allows utility to use the same duct in case of cable upgrade or replacement.

Horizontal Directional Drill (HDD) is the trenchless method. The construction process begins with boring a small, horizontal hole under the crossing obstacle, such as canals or roadways, with a continuous string of steel drill rod. When the bore head and rod emerge on the opposite side of the crossing, a special cutter, called a back reamer, is attached and pulled back through the pilot hole. The reamer bores out the pilot hole so that the pipe can be pulled through. The pipe is usually pulled through from the side of the crossing opposite the drill rig. A special mud, called bentonite, is used to reduce drilling torque, impart lubrication to the pipe, provide annular flushing of the freshly cut borehole soil debris, and give stability and support to the bored hole. With this method, utility can avoid the surface digging, stay away from underground obstacle, while the price is comparable to the open-cut ductbank.



Drilling of the pilot bore (top) and backreaming (bottom) to enlarge the hole and install the pipe.

Fig.8. Directional horizontal drill ductbank.

Pipe jacking is a technique for installing underground pipelines, ducts and culverts. In order to install a pipeline using this technique, thrust and reception pits are constructed, usually at manhole positions. Powerful hydraulic jacks are used to push specially designed pipes connected to tunneling machine through the ground, at the same time as excavation is taking place within the shield by machine. The method provides a flexible, structural, watertight, finished pipeline as the tunnel is excavated. Jacking and excavation are remotely controlled using techniques that require sophisticated electronic guidance systems using a combination of lasers and screen based computer techniques. After the pipe is already in place, the ductbank is placed inside and then filled the pipe with concrete. The cost of implementation is much more expensive than the abovementioned methods; using more complicated machineries. However, it offers less digging; able to avoid the underground obstacle, has less affect from ground movement, and offers supreme protection for cables. It is usually employed for crossing underneath the obstacle.

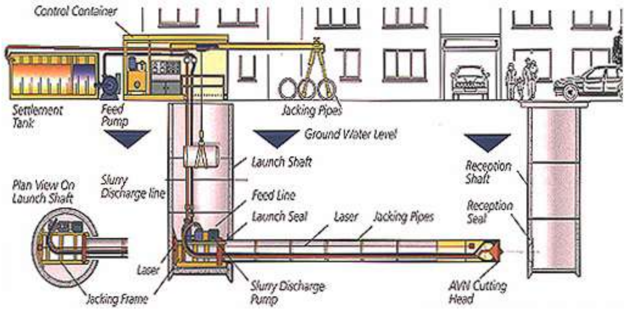


Fig. 9. Pipe jacking ductbank [Al Wardi Drilling 2010]

Distribution Transformer Substation

Typically, an underground system comprises two entities: underground cables and substation. In most case, only the cable portion is placed underground and out of sight; the substations would be located on the surface. This is due to the reason of technical constriants such as heat radiation, blockage of water ingress, staff accessibility and constructability. The substation is located right in the center of load points. This is for the benefit of power loss and voltage regulation.

The substation consists of three main parts: medium voltage switchgear, distribution transformer, and low voltage switchboard. The medium voltage switchgear is employed to take the power from the main grid at distribution voltage level and supply to the transformer. In case of feeder faut, it can be switched on and off in order to isolate the faulty part and restore the power to the remaining healthy circuit. The transformer consequently steps the distribution voltage down to the low voltage level that suits the customer eletric appliances. Such low voltage power will be conveyed to the customer premises at different location via the low voltage switchboard.

Table 2. Comparison of Conventional and Unit Substations

Norm	Conventional	Compact Unit
Installation	fair	easy
Maintenance	easy	difficult
Extension/Upgrade	easy	difficult
Environment harmony	high	fair
Reliability	fair	high
Safety	fair	high
Investment cost	fair	expensive

The construction of substation can be achieved by either **conventional** building of a small house or vault at site equipped withall electrical equipment, or **compact**

unit substation where all the equipment are placed in the metallic or concrete enclosure and completely fabricated from factory. Either of them has pros and cons as summarized in table 2.

Fig.10. Conventional Distribution Substation

Fig.11. Compact Unit Substation

4. MULTIPLE CRITERIA DECISION MAKING

Multicriteria Decision Analysis

Decision making is the study of identifying and choosing the best possible alternatives based on the values and preference of the decision maker. Making a decision implies that there are various choices to be considered, and in such a case not only identifying as many of these alternatives as possible but also choosing the one that best fits with our goals, desires, values, and so on [3]. Hence, decision making is the process of sufficiently reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made from among them. This definition stresses the information gathering function of decision making. It should be noted that uncertainty is reduced rather than eliminated. Very few decisions are made with absolute certainty because complete knowledge about all the alternatives is seldom possible. Thus, every decision involves a certain amount of risk.

Multi-criteria decision making (MCDM) is the study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process. It helps identify the ultimate goal, subgoals or criteria, and alternative choices and then systemically rank the alternatives with regards to the criteria governed. Moreover, if it is to be more than one stakeholder involved in decision making, MCDM helps compromising the preferences or expectations of stakeholders. By using knowledge elicitation techniques, it will help people form and express preferences in terms suited to the decision problem. Elicited preferences, and thus weights, would then be more stable and coherent because they have been arrived through informed and well considered value judgments [4].

Although there are a number of techniques that decision makers can select to apply in their domain problem, depending on type of problems and stakeholders' concerns; in this paper, the Analytic Hierarchy Process (AHP) technique is selected and applied for to the study presented, due to its ability to hierarchically identify the objectives and solutions.

Analytic Hierarchy Process

Analytical hierarchy process (AHP) [5] is an approach to decision making that involves structuring multiple choice criteria into a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives. The output is a ranking which is prioritized indicating the overall preference for each of the alternatives.

The AHP may be implemented in three simple consecutive steps [6]: computing the vector of objective weights, computing the matrix of option scores, and ranking the options. In addition, during formulating the matrix, the consistency check needs to be performed in order to guarantee that the comparison between each pair is made in a consistent manner. Assuming that m evaluation criteria are considered, and n options are to be evaluated, steps of AHP can be described as the followings.

Computing the Vector of Objective Weights starts by forming an $m \times m$ real matrix A. Each entry a_{jk} of the matrix **A** represents the importance of the criterion j relative to the criterion k: If $a_{jk} > 1$, then the criterion j is more important than the criterion k, while if $a_{jk} < 1$, then the criterion j is less important than the criterion k. If two criteria have the same importance, then the entry a_{jk} is 1. The entries a_{jk} and a_{kj} satisfy the following constraint:

$$a_{jk} \cdot a_{kj} = 1 \qquad (1)$$

Obviously, $a_{jj} = 1$ for all j. The relative importance between two criteria is measured according to a numerical scale from 1 to 9, as shown in table 3, where it is assumed that the criterion j is equally or more important than the criterion *k*.

Table 3. Set of Criteria of Undergrounding Project

Value of a_{jk}	Interpretation
1	*j* and *k* are equally important
3	*j* is slightly more important than *k*
5	*j* is strongly more important than *k*
7	*j* is very strongly more important than *k*
9	*j* is absolutely more important than *k*
2,4,6,8	When compromise is needed

Once the matrix **A** is built, it is possible to derive from **A** the *normalized pairwise comparison matrix* $\mathbf{A}_{norm}$ by making equal to 1 the sum of the entries on each column, *i.e.* each entry $\bar{a}_{jk}$ of the matrix $\mathbf{A}_{norm}$ is computed as:

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \quad (2)$$

Finally, the *objective weight vector* **w** (that is a *m*-dimensional column vector) is built by averaging the entries on each row of $\mathbf{A}_{norm}$, *i.e.*:

$$w_j = \frac{\sum_{l=1}^{m} \bar{a}_{jl}}{m} \quad (3)$$

Computing the Matrix of Option Scores is performed by forming an $n \times m$ real matrix **S**. Each entry s_{ij} of **S** represents the score of the option *i* with respect to the criterion *j*. In order to derive such scores, a *pairwise comparison matrix* $\mathbf{B}^{(j)}$ is first built for each criterion *j*. Each matrix $\mathbf{B}^{(j)}$ is an $n \times n$ real matrix, where *n* is the number of options evaluated. Each entry $b_{ih}^{(j)}$ of the matrix $\mathbf{B}^{(j)}$ represents the evaluation of the option *i* compared to the option *h* with respect to the criterion *j*: If $b_{ih}^{(j)} > 1$, then the option *i* is better than the option *h*, while if $b_{ih}^{(j)} < 1$, then the option *i* is worse than the option *h*. If two options are evaluated as equivalent with respect to the criterion *j*, then the entry is 1. The entries $b_{ih}^{(j)}$ and $b_{hi}^{(j)}$ satisfy the following constraint:

$$b_{ih}^{(j)} \cdot b_{hi}^{(j)} = 1 \quad (4)$$

and $b_{ii}^{(j)}$ for all *i*. An evaluation scale similar to the one introduced in table 3 may be used to translate the assessor's relative evaluations of pairs of criteria into numbers.

Second, the AHP applies to each matrix $\mathbf{B}^{(j)}$ the same two-step procedure described for the pairwise comparison matrix **A**, *i.e.* it divides each entry by the sum of the entries in the same column, and then it averages the entries on each row, thus obtaining the score vectors $s^{(j)}$. Each vector contains the scores of the evaluated options with respect to the criterion *j*.

Finally, the score matrix **S** is obtained as:

$$\mathbf{S} = [\, s^{(1)} \dots s^{(m)} \,] \quad (5)$$

i.e. the *j*-th column of **S** corresponds to $s^{(j)}$.

Ranking the Options is the final step of AHP process. Once the weight vector **w** and the score matrix **S** have been computed, the AHP obtains a vector **v** of global scores by multiplying **S** and **w**, *i.e.*:

$$\mathbf{v} = \mathbf{S} \cdot \mathbf{w} \quad (6)$$

The *i*-th entry v_i of **v** represents the global score assigned by the AHP to the option *i*. As the final step, the option ranking is accomplished by ordering the global scores in decreasing order.

Checking the Consistency during performing pairwise comparison. The AHP incorporates an effective technique for checking the consistency of the evaluations made by the assessors when building each of the pairwise comparison matrices involved in the process, namely the matrix **A** and the matrices $\mathbf{B}^{(j)}$. The technique relies on the computation of a suitable *consistency index*, and will be described only for the matrix **A**. It is straightforward to adapt it to the case of the matrices $\mathbf{B}^{(j)}$ by replacing **A** with $\mathbf{B}^{(j)}$, **w** with $s^{(j)}$, and *m* with *n*. The *Consistency Index* (*CI*) is obtained by first computing the scalar *x* as the average of the elements of the vector whose *j*-th element is the ratio of the *j*-th element of the vector $\mathbf{A} \cdot \mathbf{w}$ to the corresponding element of the vector **w**. Then:

$$CI = \frac{x - m}{m - 1} \quad (7)$$

A perfectly consistent assessors should always obtain $CI = 0$ or *Consistency Ratio* (*CR*) = 0, but small values of inconsistency may be tolerated. In particular, if:

$$CR = \frac{CI}{RI} < 0.1 \quad (8)$$

The inconsistencies are tolerable, and a reliable result may be expected from the AHP. In (8) *RI* is the *Random Index*, *i.e.* the consistency index when the entries of **A** are completely random. The values of *RI* for small problems ($m \leq 10$) are shown in table 4.

Table 4. Values of the Random Index

m	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

5. UNDERGROUNDING LUANG PRABANG POWER DISTRIBUTION SYSTEM

Development of Underground Options

As Luang Prabang is situated in the mountainous area, constraint in soil condition is observed. Among many methods, the earth excavation is suggested which means that the direct burial and open-cut ductbank methods are technically feasible for underground cable installation. The HDD with certain limitation of its bore head and back reamer which is generally designed to cut the soft soil makes this method not suitable for Luang Prabang where soil is rather hard and rocky. Furthermore, this method also has the disadvantage of less protection for the cable as compared to concrete encased ductbank because the ducts in use are of polymer type and no additional protection is applied around the ducts and being clogged by accumulated seeping mud due to its sagging. In light of the pipe jacking, it is not recommended because of its construction high cost. For the transformer station, both conventional and compact unit substation are technically feasible. Hence, four alternate options are proposed for Luang Prabang underground network which are:

- Direct buried cable with conventional substation (DR-CS)
- Direct buried cable with compact unit substation (DR-US)
- Cable in ductbank with conventional substation (DB-CS)
- Cable in ductbank with compact unit substation (DB-US)

Each option has pros and cons depending on the assessment criteria.

Formulation of Assessment Criteria

For Overhead to Underground Conversion Project in Luang Prabang World Heritage, the criteria taken into account for evaluation are shown in Table 5. These criteria will also be used for evaluating the implementation options of this project.

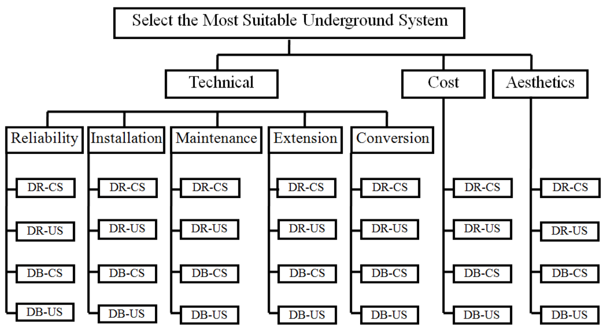


Fig. 12. Undergrounding methodology decision hierarchy.

Evaluation and Selection of Underground Project

The evaluation of the various options mentioned above falls into the MCDA process which is the most appropriate method when there are various options to consider, and at the same time many criteria or objectives of those options. Thus the AHP was employed to evaluate various implementation options for the undergrounding project. The decision hierarchy for Luang Prabang power distribution system undergrounding was formed as illustrated in Fig. 12 below.

Table 5. Set of criteria of undergrounding project

Criteria	Subcriteria	Description
Technical	Reliability	Well protection and well performance of network equipment
	Construction	Simplicity of construction and installation of duct, cable, switchgear and transformer; Less adverse impact to public sector
	Maintenance	Convenience of underground network maintenance (inspection, repair, replacement) and operation
	Extension	Network expansion (new substation connected) and new customer connection can be achieved with ease.
	Conversion process	Simplicity of conversion steps from existing overhead to underground Less adverse impact to customers.
Aesthetics		The network shall be in harmony with the cityscape and existing construction.
Safety		Safety to employees and public community
Cost		Cost of implementation which will eventually be borne by every stakeholder

In order to evaluate the undergrounding options comprehensively, the meeting was called among representatives from various relevant utilities and authorities in Luang Prabang, the attendees were then asked to compare underground implementation options against governing criteria by expressing their preference on one over another. In addition, they were also invited to express their views on the significance of each criterion in the context of Luang Prabang network undergrounding. Such opinions were numerically represented and accordingly analyzed using AHP. The results obtained from the study, as shown in table 6, evidently showed that by taking all the governing criteria into consideration, the option of cable in ductbank and conventional substation is the most preferable one. This is in conformity with the opinions of various underground system experts at the Metropolitan Electricity Authority recognized as the most proficient personnel in distribution network undergrounding profession. It is worth noting that the safety criterion was not taken into the AHP evaluation process since, according to utility experts, all the four options offer the same level of safety.

Table 6. Assessment of undergrounding options

Criteria	Weight	DR-CS	DR-US	DB-CS	DB-US
Reliability	.1183	.0477	.1080	.2588	.5854
Construction	.0453	.0732	.1969	.1969	.5330
Maintenance	.0534	.0569	.1219	.5579	.2633
Extension	.0159	.3750	.1250	.3750	.1250
Conversion	.0275	.1250	.1250	.3750	.3750
Aesthetic	.6333	.3750	.1250	.3750	.1250
Cost	.1062	.5579	.2633	.1219	.0569
Overall marks (%)		31.81	14.08	33.61	20.50

Discussion and Recommendation

Feeder Configuration was selected by expert team upon the careful study and discussion with EDL staff**.** The open loop system offers an effective utilization of the underground cables to supply the demand in Luang Prabang protection zone. It is not necessary to run the parallel lines to feeder transformers as proposed by the primary selective configuration or to adopt the special spare line since there are only two feeders serving the area. Furthermore, when the RMU is equipped with fault indicator, the open loop configuration will offer the best alternative for fault locating and segregation which in turn increase the reliability of the system.

Cable Laying Method affects all walks of life in Luang Prabang; the design and construction must be implemented cautiously. That is why it needs to be considered by relevant authorities. Although both direct burial and cable-in-duct installation are technically feasible, it is suggested that the latter be employed for Luang Prabang undergrounding. Despite its high cost, this option is recommended based on the followings:

- Excellent cable protection from any digging activities
- Easy to repair/replace the faulted cables
- Flexible to upgrade the capacity of feeder by just replacing the old cables with the new ones without any digging.
- Usage of ductbank could be shared among utilities which in turn reducing the costs and avoiding multiple excavation on public road.

Substation is visible to public eyes whereas the principal requirement of undergrounding in Luang Prabang is to preserve the aesthetic of world heritage site. As such, the visible construction of the project shall be made in harmony with the existing construction and landscape. For this reason, the indoor conventional substation is more favorable than the compact unit substation since the design of substation building can be specially designed to blend with the local environment. Furthermore, the inspection, repair or replacement of substation equipment can be done easier when compared with unit substation. In term of cost effectiveness, the construction or repair of conventional substation is cheaper than the unit substation. The only disadvantage of this option is that it requires a little more time consuming for construction and installation.

Cost-Benefit Analysis indicates that the selected option is economically feasible. With the project life of 30 years and sunk cost discarded, the investment on new underground network facility produces the profit from energy sale of 5.09 cent/kWh while the energy is purchased at 3.28 cent/kWh. The energy consumption is calculated based on the current demand with expected growth of 10% each year for 5 year period and 5% onwards. The operation and maintenance cost of the facility is 0.2% of its investment cost. The project gives the internal rate of return (IRR) of 13.01%. This implies that the investment on the project gives favorable return.

6. CONCLUSION

From the study of undergrounding the power distribution network in Luang Prabang World Heritage, it can be concluded that the underground cable network is the most appropriate electric distribution system for Luang Prabang since it can optimize the network technical aspects; preserve the city aesthetics; enhance public safety and manage cost concerns. When comes to the selection of the most suitable undergrounding option which is by nature complicated and attributed with various criteria and objectives, the result of selection has shown that the AHP is the most systematic and effective approach in managing this kind of situation.

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