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Deployment of Lifetime Cost Analysis to Reassess Economic Current Density in the Presence of Vietnam's Market Economy

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Abstract: - A decent choice of conductor size for overhead power transmission lines can provide economic advantages throughout the project's lifetime. One of the crucial criteria for sizing conductors is economic current density. In Vietnam, the electricity industry has extensively utilized the 1950s-era economic current density that ignores the value of cash flow at diverse points in time and applies the assumption of the constant electricity tariff and wire cost. These costs, nonetheless, are likely to greatly impact the figures of economic current density; as a result, these figures must be modified. This paper puts forward novel figures of economic current density that are systematically determined on the basis of lifetime cost (LTC) analysis in the presence of Vietnam's market economy. The LTC is made up of the initial capital expenditure (ICE) and the overall operating cost (OPC), which includes the expense incurred for maintenance and electricity energy loss. An analytical formulation of ICE related to conductor size and system voltage is established based on information from recently built overhead transmission lines and a regression-based method. The electricity energy loss is computed based on equivalent hours of maximum power loss contingent upon equivalent hours of maximum power usage throughout an analytical expression obtained on the basis of the regression technique from load consumption patterns in the past. Finally, the feasibility and efficacy of the proposed economic current density values are validated by practical case studies of overhead transmission lines in Vietnam. The deployment of the suggested strategy demonstrates a decrease in lifetime cost ranging from approximately 5% to around 20% in comparison to the methodology prescribed by the existing Vietnam standard.

Keywords: Economic Current Density, Overhead Transmission Lines, Lifetime Cost (LTC) Analysis, Conductor Cross-Sectional Area, Regression Analysis.

I. INTRODUCTION

Because of responsibility for the electricity transmission and contribution of a sizeable amount to the overall cost, the conductor of an overhead power line is often regarded as being one of the components that contribute the most significantly to the line's overall efficacy. It is noted that conductor expenses associated with the initial capital investment in a new overhead transmission line might make up roughly forty per cent of the overall expenditure of the line [1]. As a result, a significant number of researchers focus their attention on choosing the best size of the conductor with the intention of satisfying both the demand needs of the present and those that are anticipated for the future [2]-[3].

In Vietnam, when designing power line assets, the conductor cross-sectional area is mostly determined by the economic current density. Table 1 provides the figures of the economic current density according to the Vietnamese national standard for power transmission lines equipped with Aluminium Conductor Steel Reinforced (ACSR). Nonetheless, the figures of economic current density that are depicted in Table 1 were proposed in the 1950s. Those values failed to address the value of cash flow at diverse points in time and presumed that the tariff of electricity and conductor remained unchanged. In addition, these estimated figures of economic current density were derived using load consumption patterns from the 1950s in the post-Soviet states. As a result, the economic current density has to be updated with the aim of accurately representing both the condition of the market economy and the current load consumption patterns.

Table 1: Economic current density figures according to Vietnamese national standard (A/mm^2)

Wire substance	The equivalent hours of maximum power usage (h)		
	1000 ÷ 3000	3000 ÷ 5000	> 5000
ACSR	1.3	1.1	1.0

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Furthermore, the adoption of the lifetime cost (LTC) has been prevalent within the energy sector as a means of optimally sizing the conductor in transmission line schemes [4],[5]. The lifetime cost is composed of two primary elements, namely, the initial capital expenditure (ICE) and the overall operating cost (OPC) [6]. The overall operational expenditure includes both the expenses related to maintenance and the costs incurred due to the energy loss [7]. The determination of energy loss cost is carried out on the basis of the term of the equivalent hours of maximal power loss (τ), which is contingent upon the equivalent hours of maximal power usage ($T_{\max}$). In the context of Vietnam, there exists a well-known formula that is deployed to establish the relationship between the equivalent hours of maximum power loss and the equivalent hours of maximum power usage:

$$\tau = \left(0.124 + T_{\max} \times 10^{-4}\right)^2 \times 8760 \left(\mathrm{h}\right) \tag{1}$$

Nevertheless, the aforementioned equation was proposed based on demand patterns from the 1950s and data statistics from the former Soviet republics. Therefore, this formula may not be the most suitable choice for implementation inside the electricity system of Vietnam.

The aim of this study is to formulate two novel analytical equations: (1) the initial capital expenditure (ICE) equation, which relates the system voltage as well as conductor size, and (2) the equation for calculating the equivalent hours of maximum power loss based on the equivalent hours of maximum power consumption. The two analytic formulae are derived by regression method utilizing recent historical information within the context of the power system in Vietnam. Subsequently, a proposition is made about the revised figures of economic current density, taking into account the prevailing market economy circumstance and the present operational characteristics of Vietnam's electricity system.

The paper is organized into five sections. In Section 2, the lifetime cost calculation for electricity lines is presented. Section 3 presents the mathematical equation that is deployed to calculate the economic current density, taking into account the lifetime cost. Section 4 presents the numerical findings and discussions pertaining to overhead power lines operating at system voltages of 110 kV and 220 kV. In Section 5, the conclusions drawn from these findings are presented.

II. LIFETIME COST (LTC) FOR OVERHEAD TRANSMISSION LINES

The primary aim of optimally selecting the conductor cross-sectional area for overhead transmission lines is to reduce the lifetime cost (LTC). This cost function has two primary elements: the initial capital expenditure (ICE) and the overall operating cost (OPC). Both of these components are calculated throughout the whole lifespan of the lines in the following expression:

$$\mathrm{LTC} = \mathrm{ICE} + \sum_{t=1}^{N} \mathrm{OPC}_t \frac{1}{\left(1+r\right)^t} \quad \left(\mathrm{VND}\right) \tag{2}$$

where

- N represents the line lifespan in years, with a chosen value of 30 years;
- r denotes the interest rate;
- OPC_t signifies the overall operational expenses in the t^{th} year.

A. Initial Capital Expenditure (ICE)

In this work, we represent the term ICE as the initial capital expenditure per kilometre for the overhead power lines. Furthermore, the currency used in Vietnam is the Vietnamese Dong (VND).

The primary factor contributing to the initial capital expenditure encompasses the voltage-dependent component, the element associated with the size of the conductor, and the autonomous component [8]:

$$\mathrm{ICE} = a + bqU + c\sqrt[4]{n}mqF \quad \left(\mathrm{VND/km}\right) \tag{3}$$

where:

- a, b and c represent coefficients pertaining to cost;
- q represents the velocity pressure, measured in daN/m^2;
- U_{n} represents the system voltage, measured in kV;
- n denotes the quantity of conductors per phase;
- m represents the quantity of overhead line circuits;
- F denotes the cross-sectional area of the conductor, measured in square millimetres (mm^2).

The regression analysis is applied to calculate the cost factors in (3) by using the input dataset obtained from previously erected electricity lines.

B. Overall Operating Cost (OPC)

The overall operational expenditure per kilometre of power transmission lines in the t^{th} year consists of two primary components, namely the cost of maintenance and the cost of energy loss, which may be delineated as follows:

$$\mathrm{OPC} = \mathrm{OPC_{MC}} + \mathrm{OPC_{\Delta A}} \quad (\mathrm{VND/km/year}) \tag{4}$$

1) Maintenance cost (OPC$_{MC}$)

The estimation of the yearly maintenance cost is often based on a percentage of the original cost of erecting the electrical line. Consequently, the cost per kilometre for maintaining the electrical line may be calculated as follows:

$$\mathrm{OPC_{MC}} = a_{\mathrm{MC}} \times \mathrm{ICE} \quad (\mathrm{VND/km/year}) \tag{5}$$

where a_{MC} denotes a given value related to the maintenance cost (in this research, $a_{\mathrm{MC}} = 7\%$).

2) Energy loss cost (OPC$_{\Delta A}$)

The calculation of the yearly energy loss cost resulting from the line resistance may be derived below [9], [10]:

$$\mathrm{OPC_{\Delta A}} = \Delta A \times c_{\Delta A} = 3 \times m \times I_{\max}^2 \times r_{0,\theta} \times \tau \times c_{\Delta A} \quad (\mathrm{VND/km/year}) \tag{6}$$

where

- ΔA represents the aggregate amount of energy loss, measured in kilowatt-hours (kWh);
- $c_{\Delta \mathrm{A}}$ represents the electricity tariff (VND/kWh);
- $I_{\max}$ denotes the phase current (A);
- $r_{0,\theta}$ represents the conductor resistance at operational temperature θ (Ω/km);
- τ denotes the equivalent hours of maximum power loss.

Determining the resistance of the conductor at operational temperature θ involves using that obtained at the temperature of 20 degrees Celcius as follows:

$$r_{0,\theta} = \frac{r_{0,20^{\circ}\mathrm{C}} \left[1 + \alpha\left(\theta - 20\right)\right]}{n} \quad (\Omega/\mathrm{km}) \tag{7}$$

where α denotes a coefficient associated with the conductor substance.

The calculation of the equivalent hours of maximum power loss may be attained on the basis of the approximate formula proposed by Kezevich, a researcher from the post-Soviet states in 1948. This formula has been extensively used in Vietnam [9]:

$$\tau = \left(e + f \times T_{\max} \times 10^{-4}\right)^2 8760 \quad (\mathrm{h}) \tag{8}$$

where:

- e and f denote coefficients derived from statistical figures;
- $T_{\max}$ represents the equivalent hours of maximum power use.

In addition, we conduct regression analysis using the input dataset obtained from daily, monthly, and annual load curves to estimate the coefficients outlined in the equation (8). The determination of the equivalent hours of maximum power utilization and the equivalent hours of maximum power loss is derived from the analysis of these load patterns below:

$$T_{\max} = \frac{\int_0^T S(t)\,\mathrm{d}t}{S_{\max}} \tag{9}$$

$$\tau = \frac{\int_0^T \left[S(t)\right]^2 \mathrm{d}t}{S_{\max}^2} \tag{10}$$

where $S_{\max}$ denotes the maximal apparent power of the overall load; T represents the number of time intervals of the computation horizon.

C. Lifetime Cost

By applying equations (3) through (6), the lifetime cost per kilometre for overhead power lines may be determined below:

$$\text{LTC} = \text{ICE} + \sum_{t=1}^{N} \left(a_{\text{MC}} \times \text{ICE} + \Delta A \times c_{\Delta A} \right) \frac{1}{(1+r)^t} \; (\text{VND/km})$$
$$\text{LTC} = \text{ICE} + \sum_{t=1}^{N} \left(a_{\text{MC}} \times \text{ICE} + 3 \times m \times I_{\max}^2 \times r_{0,\theta} \times \tau \times c_{\Delta A} \right) \frac{1}{(1+r)^t} \; (\text{VND/km}) \tag{11}$$

It is postulated that the yearly operational expenses stay constant. Hence, the mathematical statement denoted by (11) may be reformulated in the following manner:

$$\text{LTC} = \text{ICE} + \left(a_{\text{MC}} \times \text{ICE} + 3 \times m \times I_{\max}^2 \times r_{0,\theta} \times \tau \times c_{\Delta A} \right) \frac{(1+r)^N - 1}{r(1+r)^N} \; (\text{VND/km}) \tag{12}$$

III. PROPOSED ECONOMIC CURRENT DENSITY

The initial capital expenditure of power lines may be determined based on the size of the conductor, the system voltage and velocity pressure. This relationship can be obtained using the equation (3).

$$\text{ICE}(F) = a' + c' \times F \quad (\text{VND/km}) \tag{13}$$

where:

$$a' = a + bqU$$
$$c' = c\sqrt[4]{n}mq \tag{14}$$

Let

$$p = \frac{(1+r)^N - 1}{r(1+r)^N} \tag{15}$$

Furthermore, the resistance of the conductor at a temperature of 20 degrees Celsius may be estimated as follows:

$$r_{0,20^\circ\text{C}} = \frac{\rho}{F} \quad (\Omega/\text{km}) \tag{16}$$

where ρ denotes the specific resistivity value of the conductor substance at a temperature of 20 degree Celsius ($\Omega.\text{mm}^2/\text{km}$).

By putting together (12)-(16), the lifetime cost may be expressed as follows:

$$\text{LTC}(I_{\max}, F) = \text{ICE}(F) + \left[a_{\text{MC}} \times \text{ICE}(F) + 3mI_{\max}^2 \frac{\rho}{F} \frac{\left[1 + \alpha(\theta - 20)\right]}{n} \tau c_{\Delta A} \right] p \quad (\text{VND/km}) \tag{17}$$

In order to determine the economic current density, the first step involves computing the derivative of the lifetime cost in relation to the cross-sectional area of the conductor:

$$\begin{aligned} \frac{\partial \text{LTC}(I_{\max}, F)}{\partial F} &= \frac{\partial \text{ICE}(F)}{\partial F} \\ &+ \left[a_{\text{MC}} \times \frac{\partial \text{ICE}(F)}{\partial F} - 3mI_{\max}^2 \frac{\rho}{F^2} \frac{\left[1 + \alpha(\theta - 20)\right]}{n} \tau c_{\Delta A} \right] p \\ &= c' + \left[a_{\text{MC}} \times c' - 3mI_{\max}^2 \frac{\rho}{F^2} \frac{\left[1 + \alpha(\theta - 20)\right]}{n} \tau c_{\Delta A} \right] p \end{aligned} \tag{18}$$

Subsequently, when the derivative of the function reaches a value of zero, we achieve the optimal cross-sectional area of the conductor:

$$\begin{aligned} &\frac{\partial \text{LTC}(I_{\max}, F)}{\partial F} = 0 \\ \Leftrightarrow &\frac{c'}{p} + a_{\text{MC}} \times c' - 3mI_{\max}^2 \rho \frac{\left[1 + \alpha(\theta - 20)\right]}{n} \tau c_{\Delta A} \frac{1}{F_{\text{opt}}^2} = 0 \end{aligned} \tag{19}$$

$$F_{\text{opt}} = I_{\max} \sqrt{\frac{3m\tau c_{\Delta A} \rho \left[1 + \alpha(\theta - 20)\right]}{\left(\frac{1}{p} + a_{\text{MC}}\right) c\sqrt[4]{n^5} mq}} \quad (\text{mm}^2) \tag{20}$$

The economic current density can be established as follows:

$$j = \frac{I_{\max}}{F_{\text{opt}}} = \sqrt{\frac{\left(\frac{1}{p} + a_{\text{MC}}\right) c\sqrt[4]{n^5}\, mq}{3m\tau c_{\Delta A}\rho\left[1+\alpha\left(\theta-20\right)\right]}} \quad \left(\text{A/mm}^2\right) \tag{21}$$

Equation (21) demonstrates that the economic current density is influenced by several factors, with particular emphasis on the parameter c associated with the construction cost and the electricity tariff $c_{\Delta\text{A}}$. Hence, when alterations are made to these parameters, it becomes necessary to reevaluate the economic current density in order to accurately represent the prevailing market economy conditions.

The average values of the economic current density corresponding to the equivalent hours of maximal power use from $T_{\max1}$ to $T_{\max2}$ are expressed as follows:

$$j_{\text{average}} = \frac{1}{T_{\max2} - T_{\max1}} \int_{T_{\max1}}^{T_{\max2}} j\,\text{d}t \quad \left(\text{A/mm}^2\right)$$

$$j_{\text{average}} = \frac{1}{T_{\max 2} - T_{\max 1}} \sqrt{\frac{\left(\frac{1}{p} + a_{\text{MC}}\right) c\sqrt[4]{n^5}\, q}{3\times 8760 \times c_{\Delta A}\rho\left[1+\alpha\left(\theta-20\right)\right]\left(1,0824\times10^{-4}\right)^2}} \times \ln\left|\frac{0,0494 + 1,0824\times T_{\max 2}\times10^{-4}}{0,0494 + 1,0824\times T_{\max 1}\times10^{-4}}\right| \tag{22}$$

IV. A Case Study in Vietnam

In this section, the data collected in Vietnam's power system is used. The first dataset pertains to the cost of erecting overhead power lines, as reported by Vietnam Electricity (EVN) group in the year 2018 [11]. The subsequent dataset comprises the daily patterns of aggregate electricity consumption within the power grid of Vietnam, spanning the years 2016 to 2020. The daily load consumption patterns are gathered at hourly intervals. Hence, the quantities of yearly, monthly, and daily consumption curves are 5, 60, and 1825, respectively.

In addition, the performance of the formula used for regression is assessed by the use of certain error indexes [12], such as the mean absolute percentage error (MAPE) and root-mean-squared error (RMSE):

$$\text{MAPE} = \frac{100}{n} \sum_{i=1}^{n} \left|\frac{\hat{y}_i - y_i}{y_i}\right| \tag{23}$$

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left(\hat{y}_i - y_i\right)} \tag{24}$$

where:

- n indicates the number of data points used in the regression analysis;
- $\hat{y}_i$ refers the regressed values of data item i;
- y_i specifies the real figures of data item i.

Through the implementation of regression analysis, a mathematical function is derived to depict the relationship between the original investment cost and several characteristics, including the system voltage, the pressure of the wind and the conductor size:

$$\text{ICE} = \left(309.9403 + 0.1639\times qU + 0.0138\times\sqrt[4]{n}mqF\right)\times10^6 \ \left(\text{VND/km}\right) \tag{25}$$

Furthermore, the mean absolute percentage error (MAPE) and root-mean-squared error (RMSE) values obtained from the regression analysis (25) are 23.088 and 34.711, respectively. These findings indicate that the regression model used in the analysis is appropriate.

The regression method for calculating the equivalent hours of maximum power loss is shown as follows:

$$\tau = \left(0.0494 + 1.0824\times T_{\max}\times10^{-4}\right)^2 \times 8760 \ \left(\text{h}\right) \tag{26}$$

Moreover, the values of MAPE as well as RMSE for the regression model (26) are 0.805566 and 0.00894, respectively. These outcomes suggest that the regression formula is extremely appropriate.

Subsequently, the economic current density approach that has been established is implemented in two case studies, outlined as follows.

Case study 1: Choose the size of the Aluminium Conductor Steel Reinforced (ACSR) for a power transmission line with dual circuits operating at the 110 kV system voltage. Furthermore, the active power of the load is equal to 50 MW, and the load's power factor is chosen as 0.9. Simultaneously, the velocity pressure inside the vicinity where the power line is constructed is taken as 95 daN/mm^2.

Case study 2: Choose the size of the Aluminium Conductor Steel Reinforced (ACSR) for a power transmission line that consists of dual circuits and operates at a system voltage of 220 kV. Furthermore, the active power of the load equals 180 MW, and the load's power factor is chosen as 0.9. Simultaneously, the velocity pressure inside the vicinity where the power line is constructed is taken as 95 daN/mm^2.

In addition, the interest rate as well as the operational temperature of the power line are established at 7% and 50 degrees Celsius, respectively. Three situations of the equivalent hours of maximum power usage ($T_{\max}$) are investigated below:

- $T_{\max} = 4500$ h;
- $T_{\max} = 5100$ h;
- $T_{\max} = 6000$ h.

In relation to each instance of equivalent hours of maximum power usage, we take into account different electricity tariff values, particularly 1500, 1866.44, 2200, 2500, and 3000 VND/kWh. It is noticeable that the figure of 1866.44 VND/kWh represents the mean electricity tariff in Vietnam in the year 2021.

In the meanwhile, we have also determined the size of the conductor by deploying the economic current density figures in line with the requirement for the Vietnam standard. After that, an analysis and comparison of the two different values of lifetime cost are carried out utilizing the cross-sectional area of the conductor selected from the existing Vietnamese national standard as well as the suggested approach.

A. *Case Study 1: An Overhead Power Line of 110 kV*

The following description is conducted based on the equivalent hours of maximum power usage of 5100 hours and an electricity tariff of 1500 Vietnamese Dong per kilowatt-hour. The computation outcomes for all situations are shown in Table 2.

The current per phase is calculated as follows:

$$I_{\max} = \frac{\sqrt{50^2 + 24.216^2}}{\sqrt{3} \times 110 \times 2} = 145.79 \text{ A}$$

and

$$p = \frac{(1+r)^N - 1}{r(1+r)^N} = \frac{(1+0.07)^{30} - 1}{0.07(1+0.07)^{30}} = 12.409$$

1) *Deployment of the existing Vietnamese national standard*

The determination of the cross-sectional area of the conductor, in line with the economic current density specified by the current Vietnamese national standard, is achieved by the following procedure:

$$F_{\text{opt}} = \frac{I_{\max}}{j} = \frac{145.79}{1} = 145.79 \text{ mm}^2$$

The nominal value of the selected conductor size is 150 mm^2.

The calculation of the initial capital expenditure is derived by applying (25) in the following manner:

$$\text{ICE} = 309.9403 + 0.1639 \times 95 \times 110 + 0.0138 \times 2 \times 95 \times 150$$

$$\text{ICE} = 2415.99 \times 10^6 \text{ VND/km}$$

The lifetime cost associated with the optimal cross-sectional area of 150 mm^2 is calculated in the following form:

$$\mathrm{LTC}\left(I_{\max}, F_{\mathrm{opt}}\right) = 2415.99 + \begin{pmatrix} 0.07 \times 2415.99 + \\ 3 \times 2 \times 145.79^2 \times \dfrac{28}{150} \times 1.12 \times 3168.586 \times 1.5 \times 10^{-6} \end{pmatrix}$$

$$\times 12.409$$

$$\mathrm{LTC}\left(I_{\max}, F_{\mathrm{opt}}\right) = 6087.071 \times 10^6 \ \text{VND/km}$$

2) Deployment of the proposed method

The equivalent hours of maximum power loss is determined according to (26) as follows:

$$\tau = \left(0.0494 + 1.0824 \times T_{\max} \times 10^{-4}\right)^2 \times 8760 \ = 3168.586 \ \text{h}$$

The proposed economic current density is described on the basis of (21) below:

$$j = \sqrt{\frac{\left(\dfrac{1}{12.409} + 0.07\right) \times 0.0138 \times \sqrt[4]{1^5} \times 2 \times 95}{3 \times 2 \times 3168.589 \times 0.0015 \times 28 \times \left[1 + 0.004 \times (50 - 20)\right]}} = 0.664 \ \text{A/mm}^2$$

Fig. 1 illustrates the correlation between the proposed economic current density, denoted by j and the equivalent hours of maximal power utilization, indicated by $T_{\max}$.

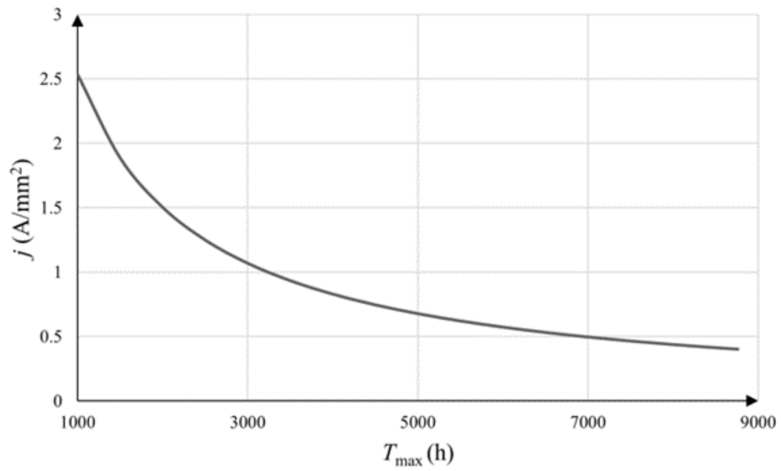

Fig. 1: The dependency of the developed economic current density on the equivalent hours of maximal power usage for the electricity tariff of 1500 VND/kWh

The attainment of the most suitable conductor size, in alignment with the suggested economic current density, is realized below:

$$F'_{\mathrm{opt}} = \frac{I_{\max}}{j} = \frac{145.79}{0.664} = 219.56 \ \text{mm}^2$$

The nominal figure of the conductor size is selected as 240 mm^2.

By deploying (25), we obtain the initial capital expenditure below:

$$\mathrm{ICE}\left(F'_{\mathrm{opt}}\right) = 309.9403 + 0.1639 \times 95 \times 110 + 0.0138 \times 2 \times 95 \times 240$$

$$= 2651.97 \times 10^6 \ \text{VND/km}$$

The computation of the lifetime cost associated with the optimal cross-sectional area of 240 mm^2 is implemented in accordance with (17) below:

$$\mathrm{LTC}\left(I_{\max}, F'_{\mathrm{opt}}\right) = 2651.97 +$$

$$\begin{pmatrix} 0.07 \times 2651.97 + \\ 3 \times 2 \times 145.79^2 \times \dfrac{28}{240} \times 1.12 \times 3168.586 \times 1.5 \times 10^{-6} \end{pmatrix} \times 12.409$$

$$\mathrm{LTC}\left(I_{\max}, F'_{\mathrm{opt}}\right) = 5938.359 \times 10^6 \ \text{VND/km}$$

The results presented here allow us to draw the following findings:

$$\frac{\mathrm{LTC}\left(I_{\max}, F'_{\mathrm{opt}}\right)}{\mathrm{LTC}\left(I_{\max}, F_{\mathrm{opt}}\right)} = 0.975$$

Hence, the lifetime cost, as determined by the economic current density put forward in this study, exhibits a lower value in comparison to the one prescribed by the Vietnam standard. The extent to which the lifetime cost is reduced is significantly influenced by the electricity tariff and the equivalent hours of maximum power usage. Specifically, a decrease of 16.4% is seen when the electricity tariff and the equivalent hours of maximum power usage are 3000 VND/kWh and 6000 h, respectively, as depicted in Table 2.

Table 2: Comparison of lifetime cost for case study 1

$T_{\max}$ (h)	$c_{\Delta A}$ (VND /kWh)	F'_{opt} (mm²)	$\mathrm{LTC}\left(I_{\max}, F'_{\mathrm{opt}}\right)$ (10^6VND/km)	F_{opt} (mm²)	$\mathrm{LTC}\left(I_{\max}, F_{\mathrm{opt}}\right)$ (10^6 VND/km)	$\frac{\mathrm{LTC}\left(I_{\max}, F'_{\mathrm{opt}}\right)}{\mathrm{LTC}\left(I_{\max}, F_{\mathrm{opt}}\right)}$
4500	1500	185	5700.582	120	5931.630	0.961
	1866.44	240	5928.607	120	6313.708	0.939
	2200	240	6102.505	120	6661.503	0.916
	2500	240	6258.906	120	6974.306	0.897
	3000	300	6500.745	120	7495.644	0.867
5100	1500	240	5938.36	150	6087.081	0.976
	1866.44	240	6178.452	150	6471.227	0.955
	2200	240	6397.000	150	6820.905	0.938
	2500	300	6559.933	150	7135.401	0.919
	3000	300	6822.013	150	7659.561	0.891
6000	1500	240	6282.525	150	6637.744	0.946
	1866.44	300	6570.439	150	7156.413	0.918
	2200	300	6806.505	150	7628.543	0.892
	2500	330	7004.961	150	8053.172	0.870
	3000	330	7326.649	150	8760.886	0.836

B. Case Study 2: An Overhead Power Line of 220 kV

Similarly, Table 3 depicts the comparison between the lifetime cost determined by the proposed approach and that from the current Vietnam standard. This comparison is conducted for various scenarios, including the equivalent hours of maximal power usage and the electricity rate.

The calculation results show that the optimal conductor size calculated by the developed approach is higher than that of the current Vietnam standard. Moreover, the lifetime cost of the suggested method is lower than that of the existing Vietnam standard. In particular, there is a decline of approximately 20% in the lifetime cost when the electricity tariff and the equivalent hours of maximum power usage are set at 3000 VND/kWh and 6000 h, respectively.

Table 3: Comparison of lifetime cost for case study 2

T_{max} (h)	$c_{\Delta A}$ (VND /kWh)	F'_{opt} (mm^2)	$\text{LTC}(I_{max}, F'_{opt})$ (10^6VND/km)	F_{opt} (mm^2)	$\text{LTC}(I_{max}, F_{opt})$ (10^6 VND/km)	$\frac{\text{LTC}(I_{max}, F'_{opt})}{\text{LTC}(I_{max}, F_{opt})}$
4500	1500	330	10360.594	240	10580.973	0.979
	1866.44	400	10750.371	240	11173.362	0.962
	2200	400	11073.912	240	11712.596	0.945
	2500	400	11364.901	240	12197.578	0.932
	3000	500	11757.859	240	13005.880	0.904
5100	1500	400	10768.517	240	11203.605	0.961
	1866.44	400	11215.213	240	11948.099	0.939
	2200	500	11575.416	240	12625.790	0.917
	2500	500	11867.980	240	13235.298	0.897
	3000	500	12355.586	240	14251.145	0.867
6000	1500	400	11408.843	240	12270.815	0.930
	1866.44	500	11887.527	240	13276.021	0.895
	2200	500	12326.732	240	14191.032	0.869
	2500	630	12679.429	240	15013.981	0.845
	3000	630	13201.937	240	16385.564	0.806

C. Proposed Values of Economic Current Density

Table 4 represents the figures for economic current density determined by the proposed methodology in this paper. The determination of these figures is implemented according to (22). The comparison between Table 1 and Table 4 reveals that the proposed values of economic current density are markedly different from those of the existing Vietnam standard.

Table 4: Proposed values of economic current density

Electricity tariff (VND/kWh)	The equivalent hours of maximum power use (h)		
	1000 ÷ 3000	3000 ÷ 5000	> 5000
1500	1.595	0.842	0.514
1866.44	1.430	0.755	0.461
2200	1.317	0.695	0.425
2500	1.235	0.652	0.398
3000	1.128	0.595	0.363

Specifically, when the equivalent hours of maximum power usage is higher than 5000, the figures of economic current density for the suggested method and the Vietnam standard are 1.0 A/mm^2 and 0.461 A/mm^2 (at the electricity tariff of 1866.44 VND/kWh). In addition, it is noted that the proposed economic current density depends on the electricity tariff and wire price, while these factors do not influence the existing Vietnam standard values.

V. CONCLUSION

This research presents an innovative method that utilizes lifetime cost analysis to determine the figures of economic current density that align with Vietnam's prevailing market economy circumstances in a scientific and thorough manner. The lifetime cost refers to the aggregate of the initial investment expenditure and the overall operational cost, which includes expenses related to maintenance and electricity energy loss. The analytical equation of the initial investment expenditure, which takes into account conductor size and system voltage, is determined via the use of historical information obtained from built overhead lines as well as the regression technique. The regression approach is also used to quantify the energy loss cost by using historical demand patterns. This method allows for the determination of the analytical formula of the equivalent hours of maximum power loss in relation to the equivalent hours of maximal power usage. The implementation of the suggested methodology for Vietnam's overhead power lines with system voltages of 110 kV and 220 kV ultimately demonstrates its superior cost-effectiveness in comparison with the strategy issued by the current Vietnam standard.

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