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# EVALUATION OF ELECTRICAL SUBMERSIBLE PUMP (ESP) BASED ON ENERGY LOSS ANALYSIS AT SOUTH-EAST SUMATRA (SES) BLOCK

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**ABSTRACT**

The production wells in the South-East Sumatra (SES) Block are characterized as a mature field with a high water cut, requiring significant energy to lift fluids to the surface. The main challenge faced is the high energy inefficiency of the Electrical Submersible Pump (ESP). Therefore, this study aims to evaluate ESP performance based on energy loss analysis, determine the best optimization scenario to reduce energy requirements, and analyze potential operational cost savings. The research method involves evaluating the distribution of energy losses in hydraulic components (friction, backpressure, and pumps) and electrical components (motor, cables, and surface equipment). Based on this evaluation, three optimization scenarios were conducted: backpressure loss, frictional loss, and pump loss. Furthermore, a cost savings analysis is carried out by comparing the costs before and after optimization. The results indicate that energy inefficiency in high flow rates wells is dominated by backpressure and friction, while in relatively small flow rates wells is caused by low pump efficiency and backpressure. The application of the best optimization scenario in the five wells can reduce the total energy requirement from 768.83 kW to 568.21 kW. This resulted in a cost reduction from US$512,641 to US$378,869.

**Keywords:** Cost saving, energy loss, Electrical Submersible Pump, inefficiency energy, operational cost, optimization.

## I. INTRODUCTION

Oil and gas production is an industrial sector that relies heavily on the performance of production equipment. Equipment performance is significantly influenced by efficiency. Addressing efficiency issues requires sound production system design, one example of which is the design of an Electrical Submersible Pump (ESP) artificial lift system. ESPs play a crucial role in increasing oil production rates in wells that lack sufficient energy to naturally lift fluids to the surface. This artificial lift method is often used due to its advantages: it can operate in wells with relatively deep depths (approximately 15,000 ft) and high fluid flow rates (approximately 60,000 bpd)

With increasing demands for energy sustainability analyzing energy losses in ESP systems is crucial, not only from a technical but also an environmental perspective. Inefficient ESP systems result in increased energy consumption, which in turn increases carbon emissions and the ecological footprint of oil and gas field operations. Energy losses in ESP systems can be caused by various factors, such as equipment specifications and operational parameters. The interaction of these factors results in energy losses that directly impact ESP performance and increase operational costs.

The South-East Sumatra (SES) Block, which utilizes the ESP artificial lift method in various fields, faces challenges such as high water cut and energy consumption. There are indications that some wells using the ESP system are not yet operating at their Best Efficiency Point (BEP), either due to well characteristics or possibly outdated initial designs (oversized/ undersized). This has the potential to cause high energy losses, which can increase operational costs.

Therefore, an in-depth evaluation of the distribution of energy losses occurring in the ESP system in wells at the South-East Sumatra (SES) Block is necessary to identify inefficiencies in hydraulic and electrical components. This study combines energy loss analysis (frictional loss, backpressure loss, pump loss, motor loss, cable loss, and surface facility loss) with simulations of three optimization scenarios to find the best optimization scenario for each well. This study not only analyzes the technical aspects but also analyzes cost savings by comparing costs before and after optimization.

As oil reserves in mature fields deplete, the energy required to produce oil becomes increasingly critical. Inefficient energy management can significantly exacerbate carbon emissions and operational costs. Therefore, this research is highly relevant as part of innovation efforts in the energy sector that not only focus on improving pump technology, but also on

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Vol. 7 No. 1 2026

a systematic approach to lower costs and increase the sustainability of environmentally friendly operations in the oil and gas industry.

## II. METHODS

The study was conducted by evaluating the distribution of energy losses in five production wells spread across several fields in the South-East Sumatra (SES) Block. Data analysis was performed by calculating energy losses in each component of the Electrical Submersible Pump (ESP). Using the conservation of energy concept, input energy from the generator is distributed into useful work (uplift) and energy losses. The following are the stages of this research:

1. Existing Design Evaluation: This initial stage involves calculating an energy balance under current operating conditions or before optimization to map the distribution of energy consumption. This analysis is conducted by separating energy losses into two categories:
   - Hydraulic Components: Calculating energy loss due to fluid friction in the tubing (frictional loss), energy loss due to backpressure from the surface (backpressure loss), and internal pump inefficiency (pump loss).
   - Electrical Components: Calculating energy loss in the motor due to load efficiency (motor loss), energy loss in the cable due to resistance and well temperature (cable loss), and losses in surface equipment such as transformers (surface facility loss).
2. Energy Loss Optimization Analysis: Based on the evaluation results under existing conditions, optimization is conducted to minimize energy loss by implementing three scenarios:
   - Backpressure Loss Optimization: This scenario focuses on reducing wellhead pressure by opening the choke, followed by adjusting the number of pump stages and motor size to match the new head.
   - Frictional Loss Optimization: This scenario focuses on reducing fluid friction within tubing by replacing the production tubing with a larger diameter. Optimization is only performed on ESP-2 and ESP-3, which have high flow rates.
   - Pump Loss Optimization: This scenario focuses on increasing pump efficiency by replacing the pump model so the pump can operate at its Best Efficiency Point (BEP) according to the production flow rate. Optimization is only performed on ESP-1, ESP-4, and ESP-5, which have low pump efficiency.
3. Cost Savings Analysis: This stage calculates estimated costs before and after optimization. Energy requirements are converted to gas fuel volume (MMBtu) using the Specific Fuel Consumption (SFC) factor, then multiplied by the prevailing gas price or US$ 7 to obtain the annual electricity cost (US$/year).

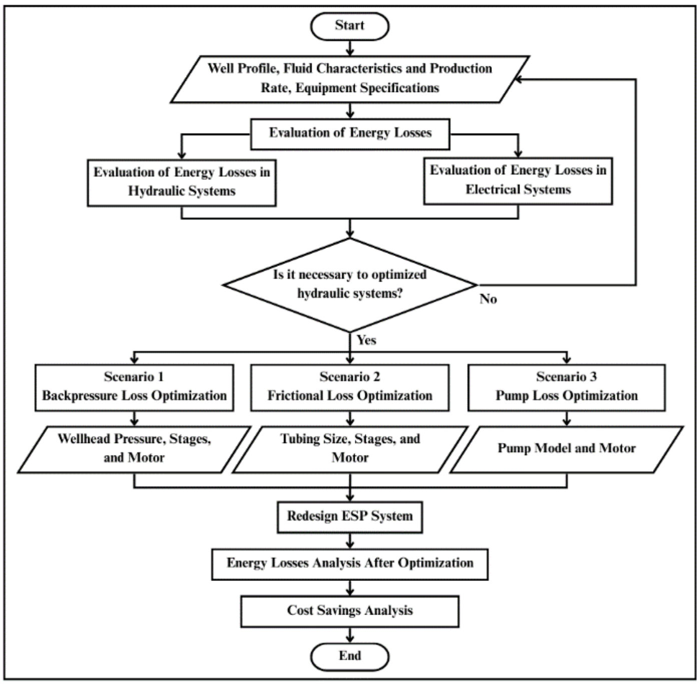


**Figure 1. Research Methodology Flowchart.**

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## III. RESULTS AND DISCUSSION

### 3.1. Existing Design Evaluation

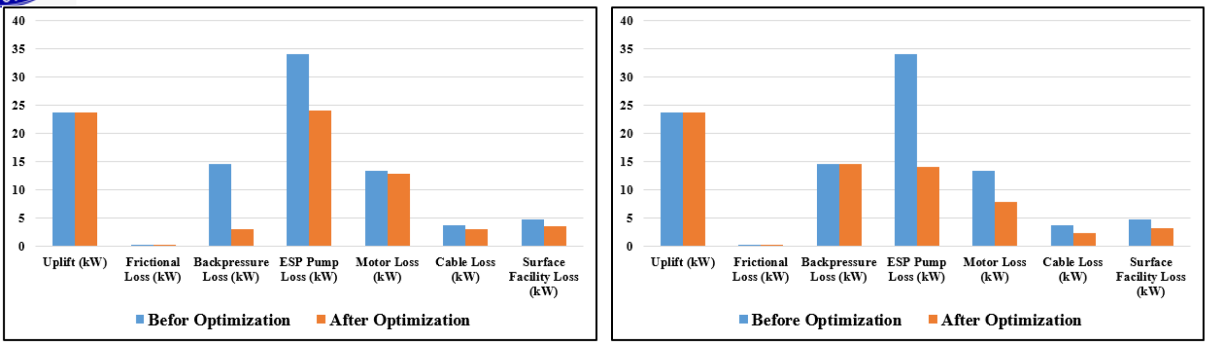
**Table 1. Energy Losses in Each Well.**

| ESP Well Number | ESP-1 | ESP-2 | ESP-3 | ESP-4 | ESP-5 |
|---|---|---|---|---|---|
| Uplift (kW) | 23,81 | 93,21 | 97,27 | 5,88 | 5,74 |
| Frictional Loss (kW) | 0,39 | 9,35 | 35,67 | 0,02 | 0,04 |
| Backpressure Loss (kW) | 14,72 | 94,95 | 57,19 | 4,29 | 2,93 |
| Pump Loss (kW) | 34,13 | 56,19 | 54,82 | 13,14 | 8,79 |
| Motor Loss (kW) | 13,47 | 36,74 | 35,54 | 6,15 | 4,95 |
| Cable Loss (kW) | 3,74 | 6,80 | 8,36 | 0,96 | 1,17 |
| Surface FacilityLoss (kW) | 4,75 | 15,64 | 15,20 | 1,60 | 1,24 |
| From Generator (kW) | 95,00 | 312,87 | 304,05 | 32,05 | 24,86 |
| Electrical Efficiency | 77% | 81% | 81% | 73% | 70% |
| Hydraulic Efficiency | 53% | 78% | 78% | 44% | 50% |
| Overal Efficiency | 41% | 63% | 63% | 32% | 35% |

Energy balance calculations under existing conditions show that the overall efficiency of the system varies significantly. Under existing conditions, ESP-1 operates with a low overall efficiency of 41%. Based on the energy balance analysis, the largest inefficiency comes from the pump component (pump loss), wich reaches 34.13 kW, but the energy used to lift the fluid (uplift) is only 23.81 kW. This indicates that the installed pump is not operating at its Best Efficiency Point (BEP). In ESP-2, despite an overall efficiency of 62%, this well requires significant energy to overcome backpressure. Backpressure loss in this well reached 94.95 kW, exceeding the energy used for uplift (93.21 kW). This high energy loss is due to the wellhead pressure being maintained at 500 psi. The main problem with ESP-3 was the high frictional resistance within the tubing. Under existing conditions, the frictional loss was 35.67 kW, significantly higher than that of other wells. This was due to the tubing being too small (2.992 inches) to accommodate the high flow rate, resulting in significant pressure loss. ESP-4 had the lowest overall efficiency of all the wells, at only 33%. Analysis showed that the inefficiency was caused by both pump and backpressure losses. Although pump loss was quite dominant, comparing the results of the pump loss optimization and backpressure loss optimization showed that backpressure loss optimization provided a more effective energy reduction impact. As with ESP-4, ESP-5 faced the challenge of low system efficiency (36%). Based on a comparison of pump loss optimization and backpressure loss optimization results, the backpressure loss optimization method performed better than the pump loss optimization method.

### 3.2. ESP-1 Performance Analysis After Optimization

Two optimizations were performed on this well: backpressure loss optimization and pump loss optimization. Backpressure loss optimization reduced the wellhead pressure from 700 psi to 150 psi. This reduction in wellhead pressure reduced the total head the pump had to support, necessitating adjustments to the number of pump stages. As a result, energy requirements decreased from 95.1 kW to 70.96 kW, resulting in a 24.14 kW energy savings. Pump loss optimization replaced the Q32 pump model with the QH20, whose capacity better matched the well's production rate. This replacement enabled the pump to operate at its Best Efficiency Point (BEP). Pump loss increased hydraulic efficiency from 53% to 73% and reduced energy requirements to 66.68 kW, resulting in a 28.42 energy savings.

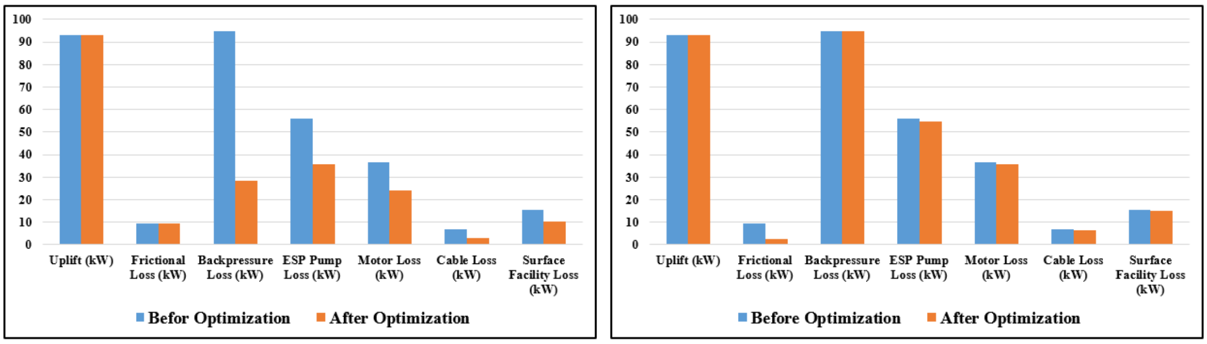



(a) (b)

**Figure 2. Comparison Before and After Optimization in ESP-1. (a) After Backpressure Loss Optimization. (b) After Pump Loss Optimization.**

### 3.3. ESP-2 Performance Analysis After Optimization

Two optimizations were performed on this well: backpressure loss optimization and frictional loss optimization. Backpressure loss optimization reduced the wellhead pressure from 500 psi to 150 psi. This reduction in wellhead pressure allowed for a reduction in the number of pump stages from 35 to 23 and the replacement of the motor with appropriate capacities. The impact was significant, with total energy requirements decreasing from 312.87 kW to 204.71 kW, resulting in an energy savings of 108.17 kW. Frictional loss optimization, on the other hand, reduced the tubing size from 4 inches to 6.456 inches to reduce fluid friction within the tubing. The optimization results showed a reduction in frictional loss, which reduced energy requirements to 302.72 kW. Although this provided an energy savings of 10.15 kW, its impact was smaller than the backpressure loss.

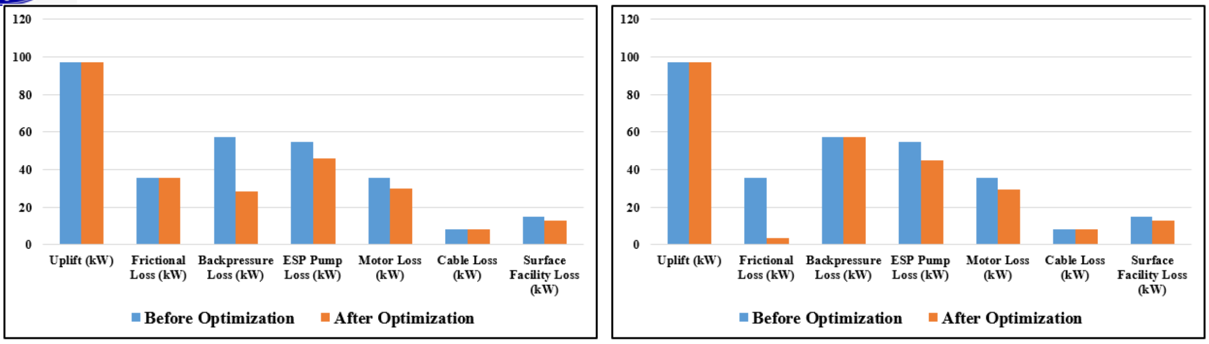



(a) (b)

**Figure 3. Comparison Before and After Optimization in ESP-2. (a) After Backpressure Loss Optimization. (b) After Frictional Loss Optimization.**

### 3.4. ESP-3 Performance Analysis After Optimization

Two optimizations were performed on this well: backpressure loss optimization and frictional loss optimization. Backpressure loss optimization reduced the wellhead pressure from 300 psi to 150 psi, resulting in significant savings. Energy requirements dropped from 304.05 kW to 259.06 kW, resulting in a 45 kW energy savings. Frictional loss optimization, on the other hand, changed the tubing size from 2.992 inches to 6.456 inches. This effectively reduced frictional resistance, and energy requirements were reduced to 253.4 kW.

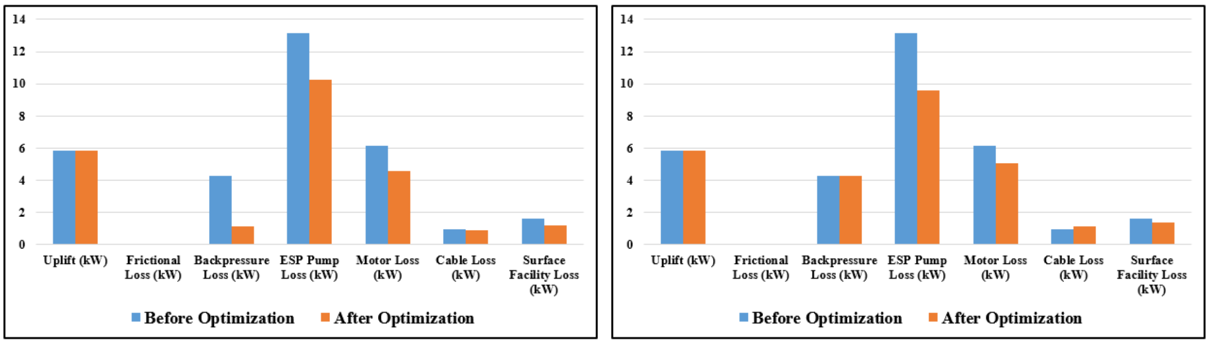



(a) (b)

**Figure 4. Comparison Before and After Optimization in ESP-3. (a) After Backpressure Loss Optimization. (b) After Frictional Loss Optimization.**

### 3.5. ESP-4 Performance Analysis After Optimization

Two optimizations were performed on this well: backpressure loss optimization and pump loss optimization. Backpressure loss optimization reduced the wellhead pressure from 550 psi to 150 psi, reducing the pump load. This reduced the number of stages from 122 to 85. Energy requirements decreased from 32.05 kW to 24.03 kW, resulting in an energy savings of 8.02 kW. Pump loss optimization, on the other hand, replaced the QH10 pump model with the Q10. Although pump loss was reduced, energy requirements only decreased to 27.34 kW. Therefore, backpressure loss optimization was superior to pump loss optimization.

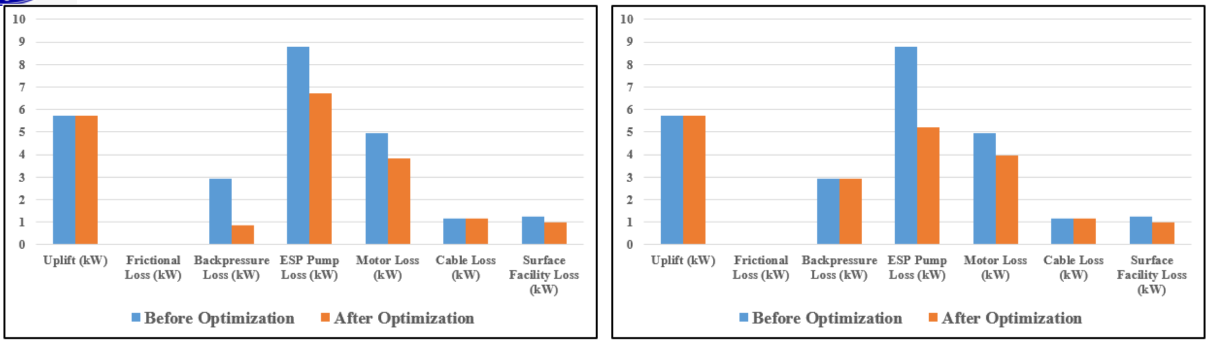



(a) (b)

**Figure 5. Comparison Before and After Optimization in ESP-4. (a) After Backpressure Loss Optimization. (b) After Pump Loss Optimization.**

### 3.6. ESP-5 Performance Analysis After Optimization

In this well, two optimizations were performed: backpressure loss optimization and pump loss optimization. In backpressure loss optimization, the wellhead pressure was reduced from 500 psi to 150 psi, where the number of pump stages could be reduced from 24.86 kW to 19.39kW, providing energy savings of 5.47 kW. Meanwhile, in pump loss optimization, replacing the QH10 pump model with the DN675 successfully reduced pump loss, with energy requirements of 20.07 kW. This result almost equals the results of backpressure loss optimization.




(a) (b)

**Figure 6. Comparison Before and After Optimization in ESP-5. (a) After Backpressure Loss Optimization. (b) After Pump Loss Optimization.**

### 3.7. Energy Savings

**Table 2. Energy Requirements Before Optimization for Each Well.**

| Wells Name | Energy Requirements (kW) |
|---|---|
| ESP-1 | 95 |
| ESP-2 | 312.87 |
| ESP-3 | 304.05 |
| ESP-4 | 32.05 |
| ESP-5 | 24.86 |
| Total | 768.83 |

**Table 3. Energy Requirements Based on the Best Optimization for Each Well.**

| Well Name | Best Optimization | Energy Requirements (kW) |
|---|---|---|
| ESP-1 | Optimasi Pump Loss | 66.68 |
| ESP-2 | Optimasi Backpressure Loss | 204.71 |
| ESP-3 | Optimasi Frictional Loss | 253.40 |
| ESP-4 | Optimasi Backpressure Loss | 24.03 |
| ESP-5 | Optimasi Backpressure Loss | 19.39 |
| | Total | 568.21 |

After conducting the three energy loss optimization scenarios, the best scenario was selected for each well. Applying the best optimization scenario to all five wells had a positive impact, reducing the total power requirement for all five wells from 768.83 kW to 568.21 kW.

### 3.8. Costs Savings

Based on the best-case scenario for each well, a comparison was made of the electricity costs required to cover the useful work (uplift) and energy losses before and after optimization. The comparison showed a reduction in total costs from US$ 512,641 to US$ 378,869. Therefore, selecting the best optimization for each well resulted in savings of US$ 133,772 in electricity costs.

**Table 4. Cost Comparison Before and After Optimization.**

| Well Name | Annual Costs Before Optimization (USD/year) | Annual Costs After Optimization (USD/year) |
|---|---|---|
| ESP-1 | 63,345 | 44,462 |
| ESP-2 | 208,617 | 136,494 |
| ESP-3 | 202,736 | 168,964 |
| ESP-4 | 21,368 | 16,021 |
| ESP-5 | 16,575 | 12,927 |
| Total | 512,641 | 378,869 |

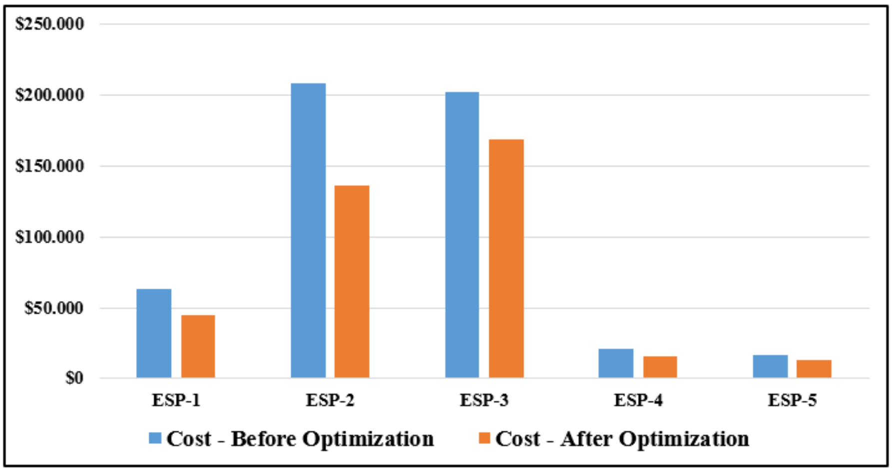



**Figure 7. Cost Comparison Before and After Optimization.**

## IV. CONCLUSION

Based on the evaluation and optimization of energy losses occurring in the Electrical Submersible Pump (ESP) system, the following conclusions can be drawn:

1. Energy losses in ESP-1, ESP-4, and ESP-5 are dominated by backpressure loss and pump loss. Meanwhile, energy losses in ESP-2 and ESP-3 are dominated by backpressure loss and frictional loss.
2. Optimizing backpressure loss is the best scenario for ESP-2, ESP-4, and ESP-5. Optimizing frictional loss is the best scenario for ESP-3. Optimizing pump loss is the best scenario for ESP-1.
3. Integrating the best optimization methods for each well can reduce total energy requirements from 768.83 kW to 568.21 kW (energy savings by 200.62 kW).
4. This reduction in energy consumption is equivalent to a reduction in electricity costs from US$ 512.641 to US$ 378.869 (cost savings of US$ 133.772).

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# ATTACHMENT

$$\text{Uplift} = 1{,}7 \times 10^{-5} \cdot Q_l\left(0{,}433 \cdot \gamma_l \cdot h_{pump} - PIP\right)0{,}746 \quad (1)$$

where:

Uplift = working output of the ESP system (kW);
$Q_l$ = Fluid flow rate (bpd);
$\gamma_l$ = Specific gravity of the mixture;
$h_{pump}$ = Pump setting depth (ft);
PIP = Pump intake pressure (psi);
0,746 = HP to kW conversion factor.

**Energy Loss in Hydraulic Components**

1. Frictional Loss

$$\Delta H_{fr} = \Delta h_{fr} \frac{h_{pump}}{1000} \quad (2)$$

where:

$\Delta H_{fr}$ = Total frictional head loss in the tubing (ft);
$\Delta h_{fr}$ = Frictional head loss (ft/1000ft);
$h_{pump}$ = Pump setting depth (ft).

$$E_{fr} = (7{,}368 \times 10^{-6} Q_l \Delta H_{fr} \gamma_l)0{,}746 \quad (3)$$

where:

$E_{fr}$ = Energy loss due to friction in the tubing (kW);
$Q_l$ = Fluid flow rate (bpd);
$\Delta H_{fr}$ = Frictional head loss in the tubing (ft/100ft);
$\gamma_l$ = Specific gravity of the mixture;
0,746 = HP to kW conversion factor.

2. Backpressure Loss

$$E_{bp} = (1{,}7 \times 10^{-5} Q_l WHP)\ 0{,}746 \quad (4)$$

where:

$E_{bp}$ = Energy loss due to backpressure (kW);
$Q_l$ = Fluid flow rate (bpd);
WHP = Wellhead pressure (psi);
0,746 = HP to kW conversion factor.

3. Pump Loss

$$E_p = BHP_{pump}\left(1 - \eta_p\right) 0{,}746 \quad (5)$$

where:

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Vol. 7 No. 1 2026

| | | |
|---|---|---|
| $E_p$ | = | Energy loss in the pump (kW); |
| $BHP_{pump}$ | = | Energy required to drive the pump (HP); |
| $\eta_p$ | = | Pump efficiency; |
| 0,746 | = | HP to kW conversion factor. |

**Energy Loss in Electrical Components**

1. Motor Loss

$$E_m = (Uplift + E_{fr} + E_{bp} + E_p)\frac{(1-\eta_m)}{\eta_m} \quad (6)$$

where:

| | | |
|---|---|---|
| $E_m$ | = | Energy loss in the motor (kW); |
| Uplift | = | Work output of the ESP system (kW); |
| $E_{fr}$ | = | Energy loss due to friction in the tubing (kW); |
| $E_{bp}$ | = | Energy loss due to backpressure (kW); |
| $E_p$ | = | Energy loss due to the pump (kW); |
| $\eta_m$ | = | Motor efficiency. |

2. Cable Loss

$$\Delta U_{cable} = h_{cable} \times V_{drop} \times T_c \quad (7)$$

where:

| | | |
|---|---|---|
| $\Delta U_{cable}$ | = | Total voltage drop (V); |
| $h_{cable}$ | = | Cable length (ft); |
| $V_{drop}$ | = | Voltage drop per 1000 ft (V/1000 ft); |
| $T_c$ | = | Temperature correction. |

$$R_T = \frac{\Delta U_{cable}}{1{,}732 \times I} \quad (8)$$

where:

| | | |
|---|---|---|
| $R_T$ | = | Cable resistance at well temperature (Ohm); |
| I | = | Current required by motor (amps); |
| $\Delta U_{cable}$ | = | Total voltage drop (V). |

$$E_c = \frac{3I^2R_T}{1000} \quad (9)$$

where:

| | | |
|---|---|---|
| $E_c$ | = | Energy loss in the cable (kW); |
| I | = | Current required by motor (amps); |
| $R_T$ | = | Cable resistance at well temperature (Ohm). |

3. Surface Facility Loss

$$E_{sf} = P\,\frac{(1-\eta_{sf})}{\eta_{sf}} \qquad (10)$$

where:

$E_{sf}$ = Energy loss in surface equipment (kW);

P = Hydraulic lift and total energy loss (kW);

$\eta_{sf}$ = Surface equipment power factor (assumed to be 0,95).

4. Energi Generator

$$E_{Generator} = \frac{E_{sf}}{(1-\eta_{sf})} \qquad (11)$$

where:

$E_{Generator}$ = Energy required by the generator (kW);

$E_{sf}$ = Energy loss in surface equipment (kW);

$\eta_{sf}$ = Surface equipment power factor (assumed to be 0,95).

**Energy Efficiency in ESP Systems**

1. Hydraulic Efficiency

$$\eta_{hydraulic} = \frac{Uplift+E_{fr}+E_{bp}}{Uplift+E_{fr}+E_{bp}+E_p} \qquad (12)$$

where:

$\eta_{hydraulic}$ = Hidraulic efficiency;

Uplift = Work output of the ESP system (kW);

$E_{fr}$ = Energy loss due to friction in the tubing (kW);

$E_{bp}$ = Energy loss due to backpressure (kW);

$E_p$ = Energy loss due to the pump (kW).

2. Electrical Efficiency

$$\eta_{electrical} = \frac{Uplift+E_{fr}+E_{bp}+E_p}{E_{Generator}} \qquad (13)$$

where:

$\eta_{electrical}$ = Electrical efficiency;

Uplift = Work output of the ESP system (kW);

$E_{fr}$ = Energy loss due to friction in the tubing (kW);

$E_{bp}$ = Energy loss due to backpressure (kW);

$E_p$ = Energy loss due to the pump (kW);

$E_{Generator}$ = Energy required by the generator (kW).

3. Overall Efficiency

$$\eta_{overall} = \eta_{hydraulic} \times \eta_{electrical} \qquad (14)$$

where:

$\eta_{overall}$ = Overall efficiency;

$\eta_{hydraulic}$ = Hidraulic efficiency;

$\eta_{electrical}$ = Electrical efficiency.

**Cost Savings**

$$Q_{gas} = E_{Generator} \times 24 \times SFC \quad (15)$$

where:

$Q_{gas}$ = Gas demand (scf);

$E_{Generator}$ = Energy required by the generator (kW) (kW);

SFC = Specific fuel consumption (scf/kWh).

$$C_{saving} = \left(\frac{Q_{gas} \times 365}{1000} \times T_{gas}\right) \quad (16)$$

where:

$C_{saving}$ = Annual cost (USD);

$Q_{gas}$ = Gas demand (scf);

$T_{gas}$ = Gas price, assumed to be US$ 7 (USD/MMBtu).