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Examining the Utilization Various Types of Electric Submersible Pump (ESP) Motors for Energy Efficiency in the Mature Offshore Oil Field Indonesia

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Abstract **- The dwindling non-associated natural gas production in offshore Field X mandates a thorough investigation into optimizing energy usage. This study scrutinizes various Electric Submersible Pump (ESP) motors for energy efficiency in Indonesia's mature offshore Field X, focusing on crude oil extraction. An efficiency analysis of Induction Motors, High-Efficiency Induction Motors, and Permanent Magnet Motors was executed across Field X wells. The key aim was *identifying and comparing* energy losses, particularly in ESP motors, constituting 13% of total losses. Implementing Permanent Magnet Motors in all Field X wells is projected to slash total electrical energy consumption by a significant 15 MW, elevating ESP system efficiency to 33.1%. This shift is anticipated to curtail emissions by 196 *tons of CO_2 per day* for every 15 MW saved, offering a promising solution to the declining natural gas challenge. Sensitivity to Net Present Value (NPV) and Internal Rate of Return (IRR) emphasizes economic viability, urging decision-makers to assess this transition's feasibility for widespread adoption and highlighting potential natural gas savings of 3.3 MMSCFD or 15755 USD/day.**

Keywords: **Electric submersible pump (ESP), Energy efficiency, Natural gas savings, Permanent magnet motors, Emission.**

INTRODUCTION

Oil and gas are limited and non-renewable energy sources(Flamos & Begg, 2010). If this energy source is produced, the amount will decrease, so an energy efficiency effort is needed in oil and gas production. Energy efficiency saves energy by utilizing new technology and equipment to do the same work with less energy(Olughu, 2021).

Offshore Field X has 328 oil wells, consisting of 210 producing oil wells and 109 shut-in oil wells as of January 6th, ranking it as the biggest oil producer in Indonesia(SKK Migas, 2022). All oil wells in the field are produced using an artificial lift method, namely the Electric Submersible Pump (ESP)(Waskito et al., 2020). Electricity needs for ESP oil wells are obtained from gas electricity generators, which require natural gas around 16.4 MMSCFD, which produces 50.8 MW/day of electricity. 48% of total gas production or 84% of non-associated gas production is used for the electricity needs of the oil well. Non-associated gas production in the field is declining yearly, where gas production in 2019 was 58 MMSCFD, and currently, in 2023 amounted to 19.5 MMSCFD (PHE OSES, 2023). It can threaten the sustainability of oil well production using ESP. Therefore, ESP energy efficiency is required to maintain the electricity supply's adequacy.

ESP is one type of artificial lift method in oil wells that is very familiar and widely used worldwide, where more than 100,000 oil wells use ESP. ESP is an excellent artificial lift method that can beapplied offshore(Sayed, 2020). ESP is widely used because it can lift large amounts of fluid from the reservoir, requires little equipment at the surface, and can be used in wells with significant dips and doglegs. It has enormous efficiency (about 50%) if it produces more than 1000 barrels/day of fluid, has corrosion resistance in oil wells, and has low maintenance costs(Takacs, 2009). ESP can be used in oil wells where reservoir pressure is still high or if reservoir pressure is already low, and ESP can have a wide range of fluid production rates ranging from 150 BFPD to 150,000 BFPD(Clegg, 2007).

ESP components include two major sections, namely downhole equipment components and surface equipment components. Downhole equipment consists of pumps, protectors, motors, sensors, and power cables, while surface equipment components consist of junction boxes, transformers, and VSDs. In general, ESP motors use the Induction Motor (IM) type. Still, other motor technologies can increase the efficiency of ESP systems by 10-30%(Hamzah et al., 2017) and 10.5% - 40% increase in efficiency compared to Induction Motors(Leon et al., 2021), namely by using Permanent Magnet Motors (PMM), which have motor efficiency 90-93%(Ballarini et al., 2017) and high-efficiency induction motor (HEIM) technology where a minimum increase of 3.5% efficiency compared to ordinary induction motors(Schlumberger, 2021). This study discusses the energy efficiency analysis in Field X by comparing ESP induction motor technology, high-efficiency induction motor, and Permanent Magnet Motor. Then, electricity savings are obtained as the basis for calculating gas volume savings.

METHODS

The following is a flowchart of study on energy efficiency in ESP motors in Figure 1:

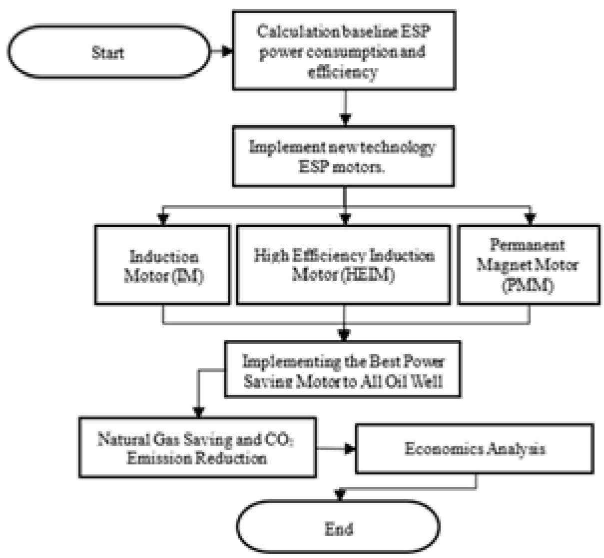

FIGURE 1 RESEARCH FLOW CHART

1. Calculation Baseline ESP Power Consumption Field X

The calculation of ESP power consumption in Field X using existing induction motors was carried out for baseline data before implementing new motor technology. Theoretically, ESP absorbs 39% of the energy, and energy loss occurs in the ESP system (61%), specifically in the pump (29%), motor (13%), power cable (10%), tubing (4%), VSD (3%), and transformer (2%)(Refai et al., 2013). Power flow in the ESP system is presented in Figure 2.

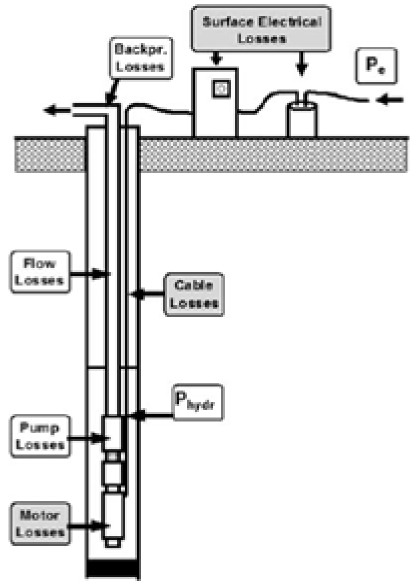

FIGURE 2 POWER FLOW IN ESP SYSTEM (TAKACS, 2009)

Power flow in ESP system (P_e) was calculated using Equations (1-8) below(Takacs, 2009):

$$P_{hydr} = 1.7\ 10^{-5} q_l\ (0.433\ SG\ PSD - PIP) \quad (1)$$

$$\Delta P_{fr} = 7.368\ \ 10^{-6} q_l \Delta H_{fr}\ SG \quad (2)$$

$$\Delta P_{bp} = 1.7\ 10^{-5} q_l \text{WHP} \quad (3)$$

$$\Delta P_p = BHP_p\ (1 - \eta_{pump}) \quad (4)$$

$$\Delta P_m = BHP_m\ (1 - \eta_{mtr}) \quad (5)$$

$$\Delta P_c = \frac{3\ \ I^2\ R_T}{1000} \quad (6)$$

$$\Delta P_s = P\,\frac{(1 - \eta_{surf})}{\eta_{surf}} \quad (7)$$

$$P_e = (0.746\left(P_{hydr} + \Delta P_{fr} + \Delta P_{bp} + \Delta P_{pump} + \Delta P_{mtr}\right)) + \Delta P_c + \Delta P_{surf} \quad (8)$$

Meanwhile, the ESP system efficiency (η_{sistem}) can be calculated by(Takacs, 2009):

$$\eta_{fr} = \frac{P_{hydr}}{P_{hydr} + \Delta P_{fr}} \quad (9)$$

$$\eta_{bp} = \frac{P_{hydr} + \Delta P_{fr}}{P_{hydr} + \Delta P_{fr} + \Delta P_{bp}} \quad (10)$$

$$\eta_{pump} = from\ pump\ perfomance\ curve \quad (11)$$

$$\eta_{sep} = \frac{BHP_p}{BHP_p + P_{sep}} \quad (12)$$

$$\eta_{mtr} = from\ motor\ curved\ base\ on\ motor\ load \quad (13)$$

$$\eta_c = \frac{P_{mtr\,e}}{P_{mtr\,e} + \Delta P_c} \quad (14)$$

$$\eta_{surf} = around\ 97\% \quad (15)$$

$$\eta_{sistem} = \eta_{fr}\eta_{bp}\eta_{pump}\eta_{sep}\eta_{mtr}\eta_c\eta_{surf} \quad (16)$$

2. *Implement New Technology ESP Motor and Economics Analysis*

New technology ESP motors, such as high-efficiency induction motors (HEIM) and permanent magnet motors (PMM) were applied in several wells.

Table 1 presents more details about the comparison of the technologies. Then, calculations will be conducted for each sub-system ESP's power consumption and efficiency using those new motors. After that, the most efficient motor was chosen to calculate all wells' projection power consumption and efficiency. Finally, natural gas savings and economic calculations were performed.

TABLE 1
COMPARISON NEW TECHNOLOGIES ESP MOTOR

Features	Induction Motor(IM)	High Efficiency Induction Motor (HEIM)	Permanent Magnet Motor (PMM)	References
Rotor Type	Squirrel Cage	Squirrel Cage	Permanent Magnet	(Leon et al., 2021)
Principal operation	Interaction of rotor and stator (rotating) magnetic fields. Magnetic fields generate rotor torque and slip		Interaction of rotor and stator magnetic fieldsmagnetic field generates rotortorque	(Leon et al., 2021), (Simmons, 2019)
Magnetic source	Stator	Stator	Permanent Magnet	(Leon et al., 2021)
Efficiency	80-83%	min 3.5% more efficient than IM	90-93%	(Leon et al., 2021)(Ballarini et al., 2017)(Schlumberger, 2021)
Power Density	Medium	Medium	Higher	(Leon et al., 2021)
Power Factor	0.75 - 0.85	0.75- 0.85	> 90%	(Leon et al., 2021), (Schlumberger, 2021), (Schlumberger, 2020), (Schlumberger, 2022), (Tiofiolo et al., 2018)
Winding operating temperature	baseline	2-5% cooler than IM	5% cooler than IM	(PHE OSES, 2023), (Leon et al., 2021), (Schlumberger, 2021).
Motor length	baseline	40% shorter than IM	30-60% shorter than IM	(PHE OSES, 2023), (Leon et al., 2021), (Schlumberger, 2021), (Xiao & Lastra, 2019)
Drive	Switchboard or VSD	Switchboard or VSD	VSD	(Tiofiolo et al., 2018)
Frequency	30-90 Hz	50-60 Hz	10-750 Hz	(Schlumberger, 2021), (Schlumberger, 2020), (Xiao & Lastra, 2019)
Price	Low-Medium	Low-Medium	High	(PHE OSES, 2023)

Results And Discussion

1. *Baseline ESP Power Consumption*

Based on the results of the calculation of energy consumption for each ESP subsystem Field X in Figure3, the energy consumption of lift power (P_{hyd}) at 35%, pump (ΔP_{pump}) at 27%, system back pressure at the wellhead (ΔP_{bp}) at 15%, and motor (ΔP_{motor}) at 13% are the four major contributors to energy loss in the ESP system.

It is because the efficiency of the four ESP subsystems is the smallest among other ESP subsystem efficiencies, ΔP_{fr}, ΔP_c, and ΔP_{surf}, following the results of research by Mazzola(Mazzola et al., 2015). Based on Table 2, the most significant electrical power consumption is in the ESP class "Hi Moderate" of 34.3% or 17.4 MW, and the class contributes the most considerable production contribution of 41.6% or 608,646 BFPD, following the research of Hamzah(Hamzah et al., 2017) where the higher the flow rate produced by ESP, the higher the electrical power needed.

TABLE 2
DETAILS POWER CONSUMPTION ESP FIELD X

Well Class	BFPD	ESP Setting Depth (ft)	Well	Power Consumption (kW)							
				P_{hyd}	ΛP_{fr}	ΛP_{bp}	ΛP_{p}	ΛP_{m}	ΛP_{c}	ΛP_{r}	P_{e}
Low Shallow	0-1500	0-4000	30	401	2	198	806	276	34	40	1.3
Low Moderate	0-1500	4001-7000	87	1666	37	618	2646	845	159	139	4.6
Low Deep	0-1500	7001-20000	30	516	3	143	1043	246	101	48	1.6
MediumLow Shallow	1501-3500	0-4000	22	838	31	349	1082	381	49	63	2.1
MediumLow Moderate	1501-3500	4001-7000	33	1283	43	643	1552	649	119	100	3.3
MediumLow Deep	1501-3500	7001-20000	2	85	1	15	60	28	6	5	0.2
MediumHi Shallow	3501-10000	0-4000	26	2297	411	938	2092	893	163	158	5.3
MediumHi Moderate	3501-10000	4001-7000	28	3281	729	1123	2373	1112	244	206	6.9
MediumHi Deep	3501-10000	7001-20000	4	464	149	126	358	204	36	31	1
Hi Shallow	10001-30000	0-4000	16	3111	586	1601	1536	962	176	185	6.2
Hi Moderate	10001-30000	4001-7000	47	8963	1701	3886	4551	2746	597	523	17.4
Hi Deep	10001-30000	7001-20000	3	401	69	220	225	108	27	24	0.8
Total			328	23306	3763	9860	18324	8449	1711	1523	50.8

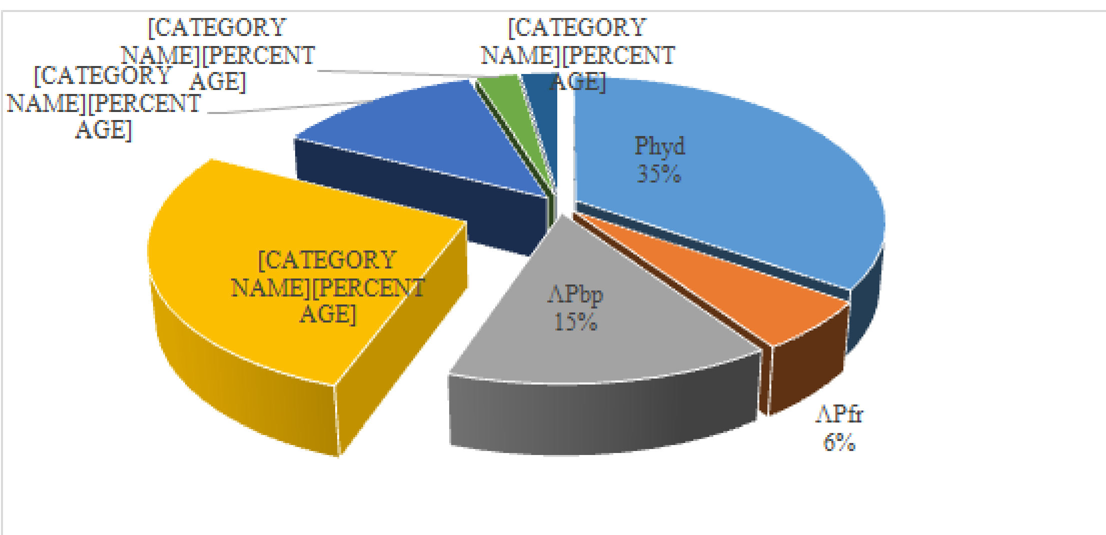

FIGURE 3 SUMMARY POWER CONSUMPTION ESP FIELD X

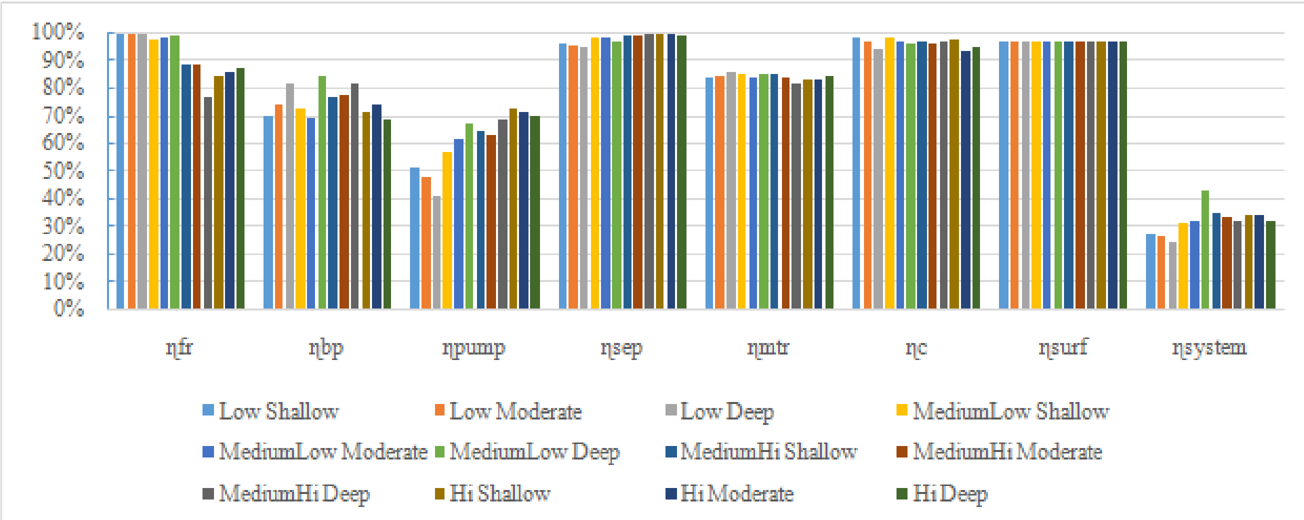

FIGURE 4 EFFICIENCY SUB SYSTEM ESP FIELD X

Figure4 shows that the highest efficiency in the ESP sub-system of Field X is η_c (96.2%), η_{surf}(97%), and η_{sep} (97.8%). Meanwhile, the lowest efficiency is in η_{pump} (61.2%), η_{bp} (75%), and η_{motor} (84%), and the average efficiency of the ESP system is 31.8%. The pump's flow rate and recommended operating range (ROR) impact pump efficiency. The flow rate must also be at the peak of the ROR to achieve the best efficiency point (BEP) on the pump. With the current pump technology in Field X, the highest efficiency ranges from 75–80%. Motor efficiency is strongly influenced by the motor load, as represented by the comparison of running amperes with nameplate motor amperes. The more the running ampere approaches the nameplate motor ampere, the higher the motor efficiency. For induction motors, the motor efficiency ranges from 80–83%(Leon et al., 2021). However, in this study, the motor efficiency ranges from 81.9–85.8% due to different types of induction motors compared to other studies. The maximum ESP system efficiency is up to 43%, which aligns with Clegg's study(Clegg et al., 1993). More efforts are needed to increase the efficiency, for example, by changing to larger tubing to reduce energy loss due to friction in the tubing or by adding surface pumps on each offshore oil platform to reduce wellhead pressure to obtain energy loss due to minor system backpressure.

2. Implement New Technology ESP Motor in Field X

To increase the motor's efficiency, new ESP motor technologies, namely high-efficiency induction motors (HEIM) and Permanent Magnet Motors (PMM), werecarried out in field X.

All of the subsystems in the KTA-05 well that use the PMM motor are using less energy.The total amount of electricity needed (P*e*) has decreased by 25.6 kW, as shown in Table 3.The total electrical power has been reduced due to the increase in motor efficiency and the efficiency of other subsystems, such as the back pressure, separator, and cable, as seen in Table 4. The efficiency of the new pump has decreased because the new flow rate is lower than the initial flow rate. For energy use, kW/BFPD KTA-05 fell from 0.0364 to 0.0323, which can be concluded to have decreased electricity consumption in installing this PMM motor, as seen in Table3. For other ESP wells (FRC-01, CNH-13, and WDE-10) installed with PMM motors, the ΔP_{motor} and total electrical power consumption decreased. Therefore, it can be concluded that using PMM motors increases motor efficiency and total efficiency and reduces the consumption of motor electric power and total electric power in these wells.

For wells using high-efficiency induction motors (HEIM), the energy consumption of the motor ΔPmotor only decreased in the ZLE-10 well. However, in the other two wells, ZLE-03 and FRC-11, the motor's energy consumption increased. The total energy consumption of the ESP system using high-induction motors has decreased in two wells, FRC-11 and ZLE-10, while in well ZLE-03, the total energy consumption has increased. The highest increase in HEIM efficiency is 0.2% in the ZLE-03 well, which means that the increase in motor efficiency has not increased significantly. At the same time, the system efficiency ranges from 2.6% to 8.3%.

TABLE 3
ENERGY CONSUMPTION OF ESP SUB-SYSTEMS WITH NEW MOTOR TECHNOLOGY

			Power Consumption (kW)								
Oil Well	Motor	BFPD	P_{hyd}	ΔP_{fr}	ΔP_{bp}	ΔP_{pump}	ΔP_{motor}	ΔP_{c}	ΔP_{surf}	P_{e}	kW/BFPD
FRC-01	IM	624	23.2	0.04	3.4	38.8	9.9	2.8	1.8	60.8	0.0974
	PMM	569	21.6	0.031	3.5	14.2	4.3	1.3	1	34.9	0.0614
KTA-05	IM	4196	69	5.641	49.9	51	18.9	3.1	4.6	152.9	0.0364
	PMM	3936	65.8	4.713	23.4	53	17.2	0.9	3.8	127.2	0.0323
CNH-13	IM	820	14.9	0.06	2.9	44.1	10.2	2.8	1.7	58.3	0.0711
	PMM	922	17.2	0.083	11.8	15.2	4.4	2	1.2	39.4	0.0427
WDE-10	IM	8612	133.2	37.328	76.1	106.7	66.4	13.2	10.1	336.5	0.0391
	PMM	8544	101	26.308	61	60.3	25.2	2.2	6.4	212.9	0.0249
ZLE-03	IM	576	25.4	0.038	7.4	31.2	10.7	1.5	1.8	59.1	0.1025
	HEIM	849	36	0.114	11.7	28.7	12.5	5.3	2.2	73.9	0.0871
FRC-11	IM	545	20.1	0.089	5	28.7	5.9	2	1.4	48	0.0881
	HEIM	336	12.7	0.023	2.4	26	6.4	2	1.2	38.6	0.1148
ZLE-10	IM	216	9.7	0.003	2.1	47.2	10.1	7.6	1.8	61	0.2823
	HEIM	233	10.4	0.004	2.2	30.2	7.5	6.1	1.3	45	0.1931

TABLE 4
EFFICIENCY OF ESP SUB-SYSTEMS WITH NEW MOTOR TECHNOLOGY

Oil Well	Motor	η_{fr}	η_{bp}	η_{pump}	η_{sep}	η_{mtr}	η_{c}	η_{surf}	η_{system}	$\Delta\eta_{system}$
FRC-01	IM	99.8%	87.2%	41.5%	94.3%	85.1%	95.4%	97%	26.8%	11.9%
	PMM	99.9%	86.1%	60.9%	90.1%	88.1%	95.9%	97%	38.7%	
KTA-05	IM	92.4%	59.9%	67.1%	98.7%	87.8%	97.7%	97%	30.5%	7.8%
	PMM	93.3%	75.1%	64.9%	98.7%	88.6%	99.3%	97%	38.3%	
CNH-13	IM	99.6%	83.6%	28.3%	96.9%	83.4%	95.2%	97%	17.6%	10.9%
	PMM	99.5%	59.4%	62.0%	95.2%	89.1%	94.4%	97%	28.5%	
WDE-10	IM	78.1%	69.1%	70.5%	99.5%	81.7%	96.2%	97%	28.8%	6.4%
	PMM	79.3%	67.6%	76.4%	99.2%	90.2%	99.0%	97%	35.2%	
ZLE-03	IM	99.9%	77.4%	56.2%	97.3%	85.0%	97.7%	97%	34.0%	3.5%
	HEIM	99.7%	75.6%	66.1%	97.7%	85.2%	93.3%	97%	37.5%	
FRC-11	IM	99.6%	80.1%	27.7%	90.8%	85.1%	94.6%	97%	15.7%	8.3%
	HEIM	99.8%	84.2%	39.7%	91.5%	85.2%	95.0%	97%	24.0%	
ZLE-10	IM	100.0%	82.1%	27.8%	97.0%	84.6%	88.4%	97%	16.0%	2.6%
	HEIM	100.0%	82.4%	33.6%	95.8%	83.5%	86.9%	97%	18.7%	

As presented in Table 3 and Table 4, it can be concluded that the use of PMM motors provides better motor efficiency values than high-efficiency induction motors (HEIM), PMM motor energy consumption is better than high-efficiency induction motors (HEIM), and kW/BFPD PMM motors are better than high induction motors. The PMM motor gives a power saving ΔkW/BFPD range from 11.3% to 40%, with an average power saving of 31.1% that will be used for calculating power saving and natural gas savings. Therefore, this research chose a PMM motor to be applied in other ESP wells in field X.

3. *TheEstimated Natural Gas Savings and CO_2 Emission ReductionUsing ESP PMM Motor in All Oil Well Field X.*

Using the ESP motor with the best efficiency, namely PMM, then calculating the estimated natural gas savings and CO_2 emission reductions.The electricity generated by the Gas Turbine is assumed to be 1 MMSCFD, generating 4.5 MW(Ojijiagwo et al., 2018), and the price of natural gas is 6 USD/MMBTU(Kementrian ESDM, 2022). Using the GHV of the non-associated gas source in Field X is 787 BTU/SCF, the natural gas price is 6 USD/MMBTU x 787 MMBTU/MMSCF = 4722 USD/MMSCFD. Therefore, the electricity price is 4726 USD/MMSCFD x 1 MMSCFD/4.5 MW = 1050 USD/MW.

Calculation of gas savings due to the use of PMM Motor in Field X, which has an average value of electricity savings of 31.1%. The total electrical energy can be projected to decrease by 15 MW from 50.8 MW to 35 MW due to the replacement of the ESP PMM system, and gas savings are = 15 MW x 1050 USD / MW = 15755 USD / day. CO_2 emission from open cycle gas turbine generator was 547 $kgCO_2$/MWh(Steen, 2011), soimplementingESP PMM in all oil well Field X can reduce emission196 $TonCO_2$/day every 15 MW electricity saving.

4. *Economic* Analysis

The Gross Split Oil and Gas Field X contract parameters are used for the economic analysis. The rental cost of the PMM ESP + VSD is USD 650/day, the cost of replacing the ESP with a workover rig is USD 450,000/job, and the cost of lifting is USD 28/day. The results of PMM motor usage have an average value of total electricity savings obtained ΔkW / BFPD of 11.3%–40% with an average of 31.1%.

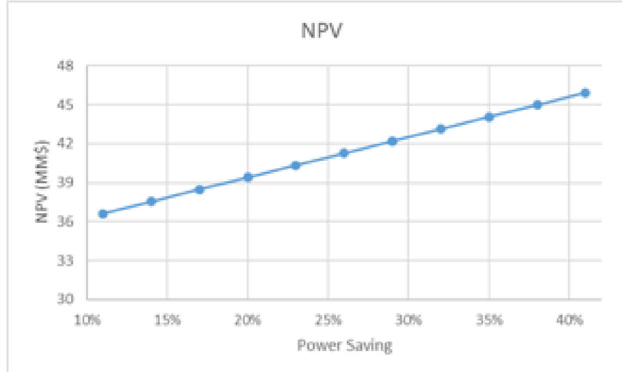

FIGURE 5 SENSITIVITY ANALYSIS POWER SAVING TO NPV USING PMM MOTOR

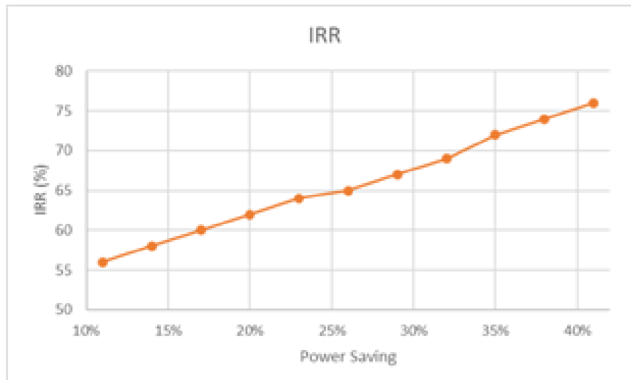

FIGURE 6 SENSITIVITY ANALYSIS POWER SAVING TO IRR USING PMM MOTOR

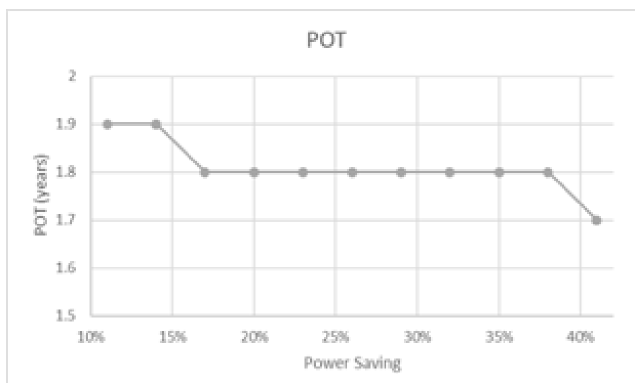

FIGURE 7 SENSITIVITY ANALYSIS POWER SAVING TO POT USING PMM MOTOR

The economic sensitivity analysis of Net Present Value (NPV), Internal Rate of Return (IRR), andPay Out Time(POT) compared to power savings can be seen in Figures5, 6, and 7. The increased power savings from using ESP PMM in an oil well lead to reduced operating costs, resulting in higher positive cash flows, which, in turn, contribute to a higher NPV and IRR. However, the effect of changes in power savings on the impact of POT is not very significant.

CONCLUSION

Using PMM motors for ESP is the best way to keep the X Field's electricity supply adequate. Tests in four oil wells (FRC-01, KTA-05, CNH-13, and WDE-10) showed that this increased motor efficiency by as much as 8.5% and decreased the total amount of electricity needed by ESP by at least 19 kW in the CNH-13 oil well and 123.6 kW in the WDE-10 oil well, which was the most significant reduction. The projected use of PMM motors in all oil wells in Field X can decrease energy consumption in ESP motors by 11.3% - 40 %, with an average value of electricity savings of 31.1%. The total electrical energy can be projected to decrease by 15 MW from 50.8 MW to 35 MW if the ESP PMM system is used and the emission of 192 tons of CO2 per day for every 15 MW of electricity saving is reduced. Natural gas savings due to PMM motor usage in Field X amounted to 3.3 MMSCFD, or 15755 USD/day. Power savings using ESP PMM are sensitive to NPV and IRR and less sensitive to POT.

NOMENCLATURES

η_{sistem}	ESP system efficiency, %.
q_l	Liquid flow rate, STB/day
SG	Liquid specific gravity, dimensionless
PSD	ESP setting depth, ft
PIP	Pump intake pressure, psi
P_{hydr}	Hydrostatic energy to lift fluid, HP
P_e	Total power electricity ESP, kW
ΔP_{fr}	Energy loss due to tubing friction, HP
ΔH_{fr}	Head loss tubing friction, ft
η_{fr}	Efficiency tubing friction, %
ΔP_{bp}	Energy loss due to system back pressure, HP
WHP	Wellhead pressure, psi
η_{bp}	Efficiency system back pressure, %
ΔP_{pump}	Energy loss in pump, HP
BHP_p	Brake horsepower required by pump, HP
η_{pump}	Efficiency pump, %
η_{sep}	Efficiency gas separator, %
P_{sep}	Brake horsepower required by separator, HP
ΔP_{mtr}	Energy loss in motor, HP
BHP_m	Brake horsepower required by motor, HP
η_{mtr}	Efficiency motor, %
P_{mtre}	Electricity energy in motor, kW
ΔP_c	Energy loss in power cable, kW
I	Electricity current required by motor, A
R_T	Power cable resistance, Ohms
η_c	Efficiency power cable, %
ΔP_{surf}	Energy loss in surface equipment, kW
P	Total energy loss, kW
η_{surf}	Efficiency surface equipment, %

REFERENCES

[1] Ballarini, M., Bruni, M., Muñoz, H., Colla, M., Teves, R., Cruz Pirez, J., Russo, M., Oyarzun, R., & Fleitas, D. (2017, April 24). High Efficiency ESP Applications for Slim Wells. Day 4 Thu, April 27, 2017. https://doi.org/10.2118/185137-MS

[2] Clegg, J. (2007). Petroleum Engineering Handbook, Volume IV: Production Operations Engineering. Society of Petroleum Engineering. https://store.spe.org/Petroleum-Engineering-Handbook-Volume-IV-Production-Operations-Engineering-P61.aspx

[3] Clegg, J., Bucaram, S. M., & Hein, N. W. (1993). Recommendations and Comparisons for Selecting Artificial-Lift Methods(includes associated papers 28645 and 29092). Journal of Petroleum Technology, 45(12), 1128–1167. https://doi.org/10.2118/24834-PA

[4] Flamos, A., & Begg, K. (2010). Technology transfer insights for new climate regime. Environment, Development and Sustainability, 12(1), 19–33. https://doi.org/10.1007/s10668-008-9177-9

[5] Hamzah, K., Prakoso, N. F., Dwitiya, D., Kusuma, H., Amijaya, W., Yudhanto, G., Bong, F., Hidayat, T., & Wirasupena, H. (2017, November 7). Extensive Application of ESP with Permanent Magnet Motor: Continuous Improvement for Energy Saving and Cost Reduction. Day 1 Tue, November 07, 2017. https://doi.org/10.2118/189211-MS

[6] Kementrian ESDM. (2022). Peraturan Menteri ESDM No.15 Tahun 2022. https://peraturan.bpk.go.id/Download/314221/Peraturan Menteri ESDM Nomor 15 Tahun 2022.pdf

[7] Leon, J. L. V., Ruales, F., Miranda, S., Godin, F., Velasquez, E., Shirikov, D., Anaya, O., Forero, N., Estupiñan, D., Peña, L., & Gonzalez, L. (2021, September 27). Permanent Magnet Motors: The Future of ESP Applications? Day 4 Thu, October 07, 2021. https://doi.org/10.2118/204485-MS

[8] Mazzola, R., Colla, M., Teodoulou, M., Ballarini, M., Pereyra, M., Muñoz, H., Bruni, M., Teves, R., & Oyarzun, R. (2015, May 27). Study To Improve Energy Efficiency Using ESP. All Days. https://doi.org/10.2118/173978-MS

[9] Ojijiagwo, E. N., Oduoza, C. F., & Emekwuru, N. (2018). Technological and economic evaluation of conversion of potential flare gas to electricity in Nigeria. Procedia Manufacturing, 17, 444–451. https://doi.org/10.1016/j.promfg.2018.10.068

[10] Olughu, O. U. (2021). Energy Efficiency and Conservation. IOP Conference Series: Earth and Environmental Science, 730(1), 012026. https://doi.org/10.1088/1755-1315/730/1/012026

[11] PHE OSES. (2023). Data Produksi Lapangan Pertamina Hulu Energi Offshore Southeast Sumatera Januari 2023.

[12] Refai, A., Abdou, H. A. M., Seleim, A., Biasin, G., Reda, W., & Letunov, D. (2013, April 15). Permanent Magnet Motor application for ESP Artificial Lift. All Days. https://doi.org/10.2118/164666-MS

[13] Sayed, G. (2020). Electrical Submersible Pump Design in Vertical Oil Wells. Petroleum & Petrochemical Engineering Journal, 4(4), 1–7. https://doi.org/10.23880/ppej-16000237

[14] Schlumberger. (2020). Reda Maximus Motor.

[15] Schlumberger. (2021). Reda Maximus EON Motor.

[16] Schlumberger. (2022). Reda Permanent Magnet Motor.

[17] Simmons, L. (2019). Permanent Magnet Motors for ESP Applications-Updating the Track Record of Performance.

[18] SKK Migas. (2022). Laporan Tahunan 2022 SKK Migas.

[19] Steen, M. (2011). Greenhouse Gas Emissions From Fossil Fuel Fired Power Generation Systems. http://www.jrc.nl

[20] Takacs, G. (2009). Electrical Submersible Pumps Manual Design Operations and Maintenance: Vol. 2nd Edition.

[21] Tiofiolo, A. L., Dotta, J. J., & Teves, R. . (2018, August 28). Efficiency Study in Vizcacheras Field and Implementation of PMM Motors to Increase Production Capability. Day 1 Tue, August 28, 2018. https://doi.org/10.2118/190951-MS

[22] Waskito, L. B., Vidrianto, M., & Cahyoniarso, B. (2020, October 25). Initiate Digital Oil Field Application at Mature Offshore Oil Field in South East Sumatera, Indonesia. Day 3 Thu, October 31, 2019. https://doi.org/10.2118/196398-MS

[23] Xiao, J. J., & Lastra, R. . (2019). Induction vs. Permanent-Magnet Motors for ESP Applications. SPE Production & Operations, 34(02), 385–393. https://doi.org/10.2118/192177-PA