OIL FIELD ELECTRICAL EFFICIENCY IMPROVEMENT AND COST SAVINGS RESULTS FROM FIELD IMPLEMENTATIONS

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Abstract:

There are approximately 600,000 producing crude oil wells in the United States, the majority of which use electricity to meet their production needs. Of these wells, approximately 75% are classified as "Stripper Wells", producing an average of 2.34 barrels per day [1]. Many of these wells are only marginally economic, and an efficiency improvement project may make the difference between continuing to extract oil from a well and having to shut it in. In addition to the pump jacks, electric motors are used for water injection, pipeline pumping, steam production, and other operational necessities. In all, roughly 95% of all electricity used in an oil field operation goes into operating electric motors.

The University of Wyoming Electric Motor Training and Testing Center (WEMTTC) has conducted an extensive study of electric motor efficiency at the DOE's Naval Petroleum Reserve #3 in Casper, Wyoming. Approximately 500 motors were tested for operating efficiency, many of which were determined to be oversized and operating inefficiently. This paper discusses the test method and instrumentation developed by WEMTTC, estimated results for energy-efficient motor retrofits, and actual results of several retrofits. The economic benefits of the retrofits are discussed, as well as a protocol for improving electrical energy efficiency in the oil field.

Introduction:

Electrical energy consumption has been increasing at an average annual rate of 2.4% for the past 20 years, while the nonelectric growth rate has been a negative 0.9% [2]. This has occurred for many different reasons including the flexibility of electricity and the modernization of many industrial users, including oil fields. In the past, electricity has been relatively inexpensive and the efficiency of an electricity-consuming product was not a big factor. With today's rising energy costs, however, many industries that once saw electricity bills as a minor portion of their operating cost, now see a much larger percentage of their operating cost going towards electricity.

Electric motors consume two-thirds of all electricity produced in the United States as well as many other countries. In an industrial setting such as an oil field or other manufacturing plant, however, electric motors may account for well over 90% of all electricity consumed [3]. It stands to reason, then, that motors provide the best opportunity for efficiency improvement. This is the case as new-generation, high efficiency motors have become available to users in the past 10 years.

In a study of oil field electrical use performed by the University of Wyoming, 81% of respondents indicated that electricity was their major source of operating energy, while 31% said all of their energy needs were met by electricity. This high use of electricity is surprising considering that most of these fields have a surplus of natural gas. Many oil fields have gone electric after starting with a majority of gas motors as prime movers. Some of the reasons we have been given for this is because of the high reliability of electric motors, the higher maintenance cost of gas motors, and in some regions, concerns about air pollution from gas motors.

Of the nearly 600,000 oil wells in operation in the United States, 75% can be classified as stripper wells. These wells produce an average of 2.34 barrels of oil a day, and electrical costs for the electric motor can be a large portion of the total production cost. Increasing a well's electrical efficiency can make the difference between a marginally economic well being shut in, or continuing to produce oil. This was the goal of our study.

Super-Efficient Industrial Motors:

New-generation, high efficiency motors are actually not new at all; they operate on the same designs and principles that electric induction motors have been using all along. The efficiency improvement is generated through better manufacturing techniques which involve more exacting tolerances for motors, better materials used in construction, more copper being wound onto the motors, and the use of computers to aid in the design of motors to minimize operational losses. Through a combination of more precise design and manufacturing, new-generation, high efficiency motors may be up to 5% more efficient than their standard efficiency counterparts. In addition, they are more reliable than standard efficiency motors because of the better materials and manufacturing processes used [4]. Figure 1 shows a comparison of the efficiency of an energy efficient and a standard efficiency electric motor. Despite all of the benefits, there are still some roadblocks to implementing energy-efficient motors.

Roadblocks to Implementing Energy-Efficient Motors:

Because of the significant increase in efficiency obtained through the use of an energy efficient motor (EEM), they are being widely used in new applications. The difference in initial cost between an EEM and a standard efficiency motor is usually repaid within a year in new applications, which make it easy to justify the slightly higher cost paid for the premium-efficiency motor. In a retrofit application, however, the benefits are not as readily calculated, therefore the retrofit is not often performed. The lack of a test method to quickly and accurately determine operating efficiency has been a prime reason for the failure of industries to perform the money saving retrofits. Test methods developed by WEMTTC have solved this problem. The method and instrumentation require no interruption of the production process, and accurately determine a motor's operating characteristics.

Perhaps one of the greatest blocks to implementing energy-efficient motor retrofits is the inherent reliability of electric motors. Motors will operate for many years in a harsh environment without complaint, so why fix it if it's not broken? This attitude may be costing industrial users millions of dollars a year in potential electric bill savings. A motor may be operating fine, but may be doing so inefficiently either due to inherent inefficiencies of that particular motor, rewinds, or an improperly sized motor. Replacing a fully functional motor with a new generation, high efficiency motor has been shown to be cost effective in numerous studies.

Another obstruction to energy-efficient motors found most often in the oil field is the common belief that pump jack motors must be design D. At the present time, energy efficient motors are only available in design B, so many operators don't think they are applicable to pump jacks. While it has not been proven for all wells, our studies show that the properly sized design B motors operate pump jacks satisfactorily, and with a lower energy use than the less efficient design D motors. In the following sections the results of several of these retrofits are presented.

Energy Consumption By Naval Petroleum Reserve #3:

The U.S. Department of Energy operates the Naval Petroleum Reserve oil field near Casper, Wyoming. Oil was first discovered there in 1922. The production history and 1990 production are shown in Tables 1 and 2, respectively.

Operating Electric Motors at NPR #3:

NPR #3 uses electric motors to drive all of its pump jacks, water and steam injection pumps, and many other loads. Approximately 500 motors have been tested at the field, with the distribution given in Table 3. The distribution of motors by horsepower is shown in Figure 2.

From Figure 2, it is clear that the majority of the motors at NPR-3 are below 10 hp. Approximately 75% of the motors are smaller than 10 hp, yet they account for only 21 % of the total horsepower. Motors between 10 and 100 hp account for 22 % of the total number of motors and account for 43 % of the total horsepower. There are only 9 motors larger than 100 hp at the field, but they account for 35% of the total horsepower. Large industrial motors are normally very efficient however, so the best potential for savings lies in the medium industrial motor region, between 10 and 75 hp.

Analyzing Electric Motor Efficiency:

The standard method for determining a motor's efficiency is to measure the input and output power and divide the two:

$$\text{Efficiency (\%)} = \text{Output / Input} \times 100\%.$$

In the lab, this is simple to perform. A torque transducer is installed between the motor and load, and measurements are taken directly. In the field, however, this process is more difficult.

In many industrial environments, it may be difficult or impossible to install a torque transducer due to the physical configuration of the motor-load system. In cases where installing the transducer is possible, the production process must be shut down for a period of time to allow the mechanical work to be performed. When faced with this prospect, many users will choose to allow a motor to continue to run, efficiently or not.

WEMTTC has developed a test method and instrumentation which allows a motor's efficiency to be accurately tested without interrupting the production process. The instrument measures the input electrical characteristics of the motor, then, based on manufacturer's efficiency curves or standardized curves for that particular size and design motor, estimates the operating load and efficiency for that motor. A properly sized energy efficient replacement motor is then determined, as well as the efficiency improvement gained through the use of the new motor. Based on electricity costs and the operating time of the motor, provided by the user, the economics of the retrofit are then calculated. The user can then decide for himself what criteria will be used for determining when a motor will be replaced.

Another important feature of the WEMTTC method is the archival of existing motor data. One of the benefits of testing every motor in an operation using WEMTTC instrumentation is the creation of a computerized database containing all of the information. Once created, the database can be used in the future for maintenance information. If a motor that was not practical for replacement at the time of the test fails, the database can be consulted to determine the correct sized motor for that location, to prevent future oversizing of motors. In addition, if a motor's operating characteristics change, with no corresponding change in production, it may indicate either an impending motor failure or possible mechanical problems with the pump. In this manner, the instrumentation provides a useful tool for oil field maintenance.

Results of Motor Testing and Retrofits at NPR #3:

Of the 500 motors tested, 77 proved to be good candidates for an EEM retrofit. In many facilities this percentage would be higher, but due to the large number of wells which operate infrequently on time clocks at NPR #3, the paybacks on many was not sufficient to meet the DOE's specification for payback on a project of this type. Replacing these motors will cost a total of approximately $55,000, and save an estimated $14,000 per year, giving a simple payback of 3.9 years for the entire project.

Approximately 30 motors have been retrofitted to date, and the results of these will now be presented.

One of the important by-products of testing each individual well in a detailed analysis of this nature is that many problems other than those of an electrical nature are discovered. Of the thirty wells targeted for the initial retrofit, 18 had mechanical problems which were fixed during the retrofit, in keeping with the project's goal of overall efficiency improvement. These problems ranged from improper well balancing to buildup of paraffin downhole. Fixing mechanical problems will reduce the electrical use of a well by a certain fraction, in addition to the reductions made by the installation of an EEM. This mechanical improvement was not separated from the electrical improvement in this test, so only those motors which had just the motor retrofit performed will now be examined.

Table 4 shows the information from the twelve motor retrofits which were performed with no other modifications.

As shown, the average reduction in motor size was almost 6.5 hp, a significant reduction in the overall connected horsepower of the system. It should be noted that the new motor sizes calculated by WEMTTC for oil field applications leave at least a 30% margin for load increases. This means the load can increase by 30% or more before the motor may start experiencing overheating problems. If this occurs, there is most likely a mechanical problem with the well that should be corrected.

The total power input to these motors was reduced by 27%, a considerable savings. Another aspect demonstrated by Table 4 is that the WEMTTC method for efficiency and load estimation provided conservative results for all retrofit cases. This is important because in no case did a recommended retrofit produce less than expected savings, so the payback on each of these motors will either meet or exceed expected values. This allows the user to make retrofit decisions with confidence.

There are several possible reasons for the errors seen in the replacement calculations. The first reason is that in all cases the actual operational efficiency was less than that specified by the manufacturer for the motor when it was new; a reasonable assumption. The second possible reason, especially for the two cases where significant differences exist between expected and actual values, was that some mechanical problem such as a belt tension or alignment problem was inadvertently corrected during the motor changeout.

Future Motor Retrofits at NPR #3:

At the present time, motors are being ordered to carry out the remainder of the targeted motor retrofits. Replacing all of the recommended motors should further reduce power consumption at NPR #3 by amounts similar to those seen in the initial project. In all, an estimated 5% of the total annual cost of electricity at NPR #3 will be saved, with a total project payback of under 5 years. For other fields, where pumps operate a higher percent of the time, the payback periods will be proportionally lower, and the benefits proportionally higher.

Conclusion:

The results of the energy efficient motor retrofits at NPR #3 were even better than expected. Of the twelve motors replaced, all either met or exceeded expected savings. While it is possible that in the future, cases may be found where the typical design D motor may be necessary to operate a very large or unbalanced well, the limited number of wells tested in this study indicate that the correctly sized energy-efficient design B motor is suitable for oil field pump jack applications.

Increasing the electrical efficiency of oil wells in the U.S. can serve to make the oil more economical to produce, thereby lowering the American dependence on oil imports. In addition, marginally economic wells can be used longer, ensuring maximum benefit from each drilled well. The test methods developed by WEMTTC make it easy for all to benefit from energy-efficient motors without interrupting the production process during the energy audit and testing phase.

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Acknowledgments:

We would like to thank all of the people who worked on this project with us at NPR #3, but especially Dennis Climer; for all his help from beginning to end.

Table 1 - Naval Petroleum Reserve #3
Production History

Year Of First Production:	1922
Cumulative Production (Mbbls):	23
Production Since 1976 (Mbbls):	15
Remaining Reserves (Mbbls):	3.4
Added Reserves Through Steam Flooding (Mbbls):	11.4

Table 2 - Naval Petroleum Reserve #3
1990 Production

Crude Oil (BBLS):	829,492
Natural Gas (MCF):	3,042,560*
Propane (Gallons):	812,161
Butane (Gallons):	2,406,607
Total Revenue:	$18.6 Million
Total Costs:	$15.1 Million
Net Cash Flow:	$3.5 Million

* No natural gas sold due to operational requirements.

Table 3 - Motor Distribution at NPR #3

Pump-Jacks:	410
Shut-Ins (Repairs or Economics):	20
Injection/Disposal:	70
Total:	500

Table 4 - Results of the Twelve Motor Retrofits Performed at NPR #3

WELL LOCATION	ORIGINAL MOTOR SIZE	NEW MOTOR SIZE	OLD POWER CONSUMED	NEW POWER CONSUMED	ACTUAL SAVINGS (KW)	ACTUAL SAVINGS (%)	CALC. SAVINGS (KW)	CALC. SAVINGS (%)	DIFFERENCE (KW)	DIFFERENCE (%)
24-15-STX-2	7.5	3	2.13	1.76	0.37	17.37%	0.28	13.15%	0.09	4.23%
85-55-SX-3	3	2	1.32	1.1	0.22	16.67%	0.16	12.12%	0.06	4.55%
22-STX-3	7.5	5	4.07	3.44	0.63	15.48%	0.34	8.35%	0.29	7.13%
18-AX-34	15	5	4.49	2.51	1.98	44.10%	1.06	23.61%	0.92	20.49%
38-1-AX-34	20	7.5	5.2	3.52	1.68	32.31%	0.99	19.04%	0.69	13.27%
15-S-2	3	1	1.1	0.65	0.45	40.91%	0.17	15.45%	0.28	25.45%
85-S-3	2	1	0.85	0.67	0.18	21.18%	0.11	12.94%	0.07	8.24%
85-24-SX-3	3	1.5	1.06	0.75	0.31	29.25%	0.17	16.04%	0.14	13.21%
85-1-SX-3	7.5	5	2.81	2.18	0.63	22.42%	0.3	10.68%	0.33	11.74%
84-AX-3	20	15	8.41	6.14	2.27	26.99%	1.35	16.05%	0.92	10.94%
85-AX-3	25	7.5	7.2	5.68	1.52	21.11%	1.34	18.61%	0.18	2.50%
14-AX-2	25	7.5	6.2	4.29	1.91	30.81%	1.42	22.90%	0.49	7.90%

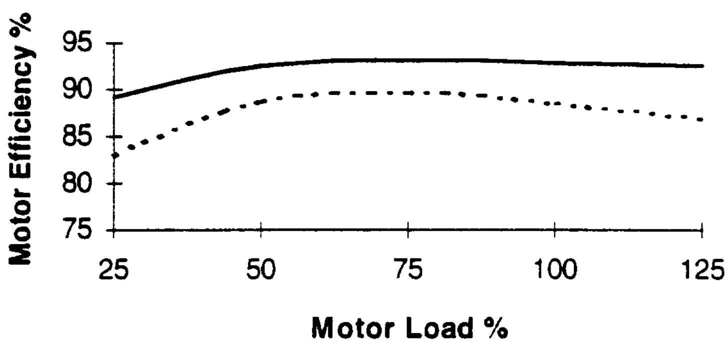

Figure 1 - Comparison of Super- and Standard-Efficiency Motors

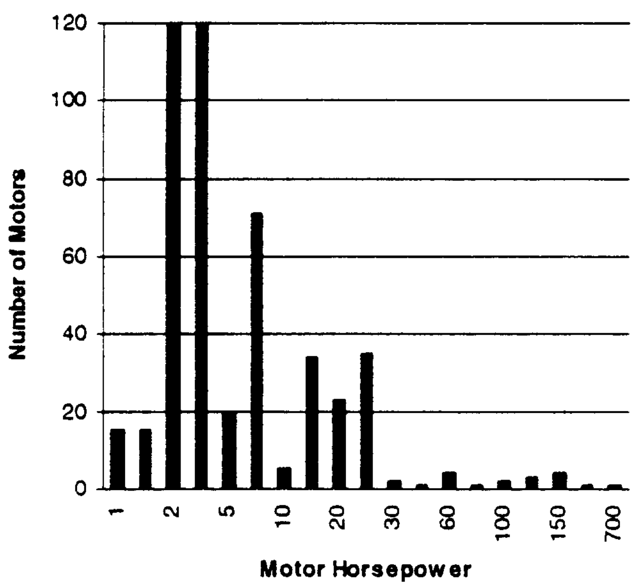

Figure 2 - Distribution of Motors by Horsepower at NPR #3