An Electric Pumping System from the Power Source to the Bottom of the Hole

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There have been written many papers, reports, and engineering studies regarding the problems and the solutions to the problems with respect to pumping oil electrically. Some have been broad in scope while others have been more specific; and they have all been of some value to the industry because a great measure of success is contributed to that which we glean from the experiences and thinking of others. This presentation will by no means be a revelation of a sure "cure-all" to the age-old problems. Instead it will be a different view of the problem.

In pumping oil electrically, the goal or aim is basic: to get oil out of the ground at the least cost per barrel. The enormity of the problem depends largely upon the approach to it. The intent here is to put forth a realistic approach, that of determining what is required to do the job rather than what can be used to do the job. The title of this presentation is indicative of the approach: the source or the bottom of the hole. The oil is down there and it is there that one gets his first clues to the actual pumping requirements.

RESERVOIR ANALYSIS

A realistic reservoir analysis is the first need and from it should be determined: (1) the amount of oil available with water cut; (2) the life expectancy of the conditions now existing, and; (3) at what rate, in barrels per day, is the well to be produced. With today's modern methods and techniques, availability and life expectancy of oil can be fairly realistic; no longer is the halo of lustre and optimism orbiting around the oil industry. The oil industry has changed to a hard-nosed, highly competitive, penny-saving business, and the geological people probe, with more skepticism than optimism, into the earth's depth. Now, they are looking for a good dollar investment, so, it is not a hard matter to determine items (1) and (2). From this information is determined the economic aspects of pumping the well. When it is determined that the well is to be pumped, then item (3) plays the feature role in this analysis. The rate of production will govern many equipment applications; each costs money, and collectively they represent a substantial investment.

There are many installations that will fall into the category of the following example. A well will produce only 30 or 40 bbl of fluid per day; yet the pumping equipment applied is capable of producing 150 to 200 BPD which represent a safety margin of some 400 per cent. A safety margin is good insurance, but like all good insurance, it costs money. In this case, not only did the equipment initially cost more money, but operating expenses were skyrocketed because of losses in efficiency. Here is another thought to consider, especially here in Texas. It matters not what the well will produce because of regulatory authority that allows a certain number of barrels to be produced -- and at a prescribed number of days. A 30 bbl allowable per day on an 8-day producing month amounts to 240 bbl per month. It would take an extreme emergency for this same allowable to be increased to 30 days which would amount to 900 barrels per month and an increase of 275 per cent. Yet the job could be done with equipment designed for 30 BPD production, and any emergency beyond this scope cannot be economically considered. In view of the above considerations, one should resolve exactly what is needed and proceed accordingly.

PUMPING EQUIPMENT

The pump, rods and unit, though not electrical in function, have a direct bearing upon the application and the efficient operation of the electrical system. The unit, the pump size, length of stroke and SPM should be determined on the basis of the requirements necessary to handle the extreme conditions of the well analysis.

MOTOR APPLICATION

Motor application should not be a subject of controversy in beam pumping. The pumping unit and the well analysis data by which it was selected determines the horsepower input, in kilowatts, required to bring oil to the top. No longer can one apply pumping equipment and electric motors as others in the same field are doing. Just because an operator is pumping with a 25 hp motor does not mean that the same job could not be done with a 15 hp or even a 10 hp motor, and with sufficient safety margin. Again one is faced with sound economics that should prevent overpowering and overspending. When a pumping system is designed to adequately handle the well and its forseeable possibilities, then the motor can be sized accordingly, with an assurance that it will perform efficiently. To illustrate: suppose that a well is 5000 ft deep and 240 bbl total fluid per day is considered maximum recovery. The proper unit is selected and a 1-1/2 in. pump is installed. With a pump efficiency of 80 per cent, a 56 in. stroke at the rate of 20 SPM, according to most production calculators, would produce 240 bbl of total fluid in 24 hr. According to experience, this situation would require 18 input hp to the motor, and depending upon the motor design, this application would require a 20, 25 or 30 hp motor. If the length of stroke were established, for no specific reason, at 72 in., the pump capacity would become 300 BPD and would represent a 40 per cent increase in pump capacity, or 60 bbl of fluid over maximum design. The input requirement would now be 22 hp plus, and the motor application would become 25, 30 or 40 hp for the same 240 bbl well. By not designing to these realistic requirements, the initial investment in motor size will increase, and this investment pyramids as one goes further into the electrical system by adding proper controls, distribution lines and transformers. Hence, one must consider the sound economics of applying the equipment to a realistic probelm.

TYPES OF MOTORS

The types of motors available for application to beam pumping fall into three basic designs: (1) the standard nema "C" which is high torque, normal slip; (2) the standard nema "D" which is high torque, medium slip; (3) and a "special" motor produced by a few manufacturers as being specifically designed for oilfield beam pumping. In the past, the nema "C" motor was the best motor available for beam pumping because it was more readily available and it cost considerable less money than did the nema "D" motor. It had high starting torque characteristics, an important requisite for beam pumping. The nema "D" motor had even higher torque and slip characteristics; and, although, many tests proved that it was the most desirable motor, it was a premium price motor.

Today, some electric motor manufacturers, recognize beam pumping as a peculiar application, unlike that of any other industry. Extremely high starting torque is required; higher slip is desirable; the load condition varies from no load to overload; and the climatic conditions under which they must operate vary more than does the weather in Texas. Too, there are many other conditions with which to cope when pumping oil electrically; consequently, there is now available a motor to suit the special requirement of beam pumping. No longer is it necessary to buy a larger horsepower motor to meet the torque requirements of starting under semi-stall conditions. No longer is it necessary to buy a larger horsepower motor to overcome the high thermal heating resultant from the extreme peak load requirement of lifting the weights and, in the next half cycle, of lifting the rods. A motor designed specifically for beam pumping will have sufficient starting torque at design voltage as compared to the 200 to 235 per cent rating of the nema "C" motor or the 275 to 285 per cent rating of the nema "D" motor. Under full load, it will develop 8 to 10 per cent slip at design voltage, as compared to the 3 to 5 ver cent slip of the normal slip, nema "C" motor or the 5 to 8 per cent slip of the medium slip nema "D" motor. A motor designed for beam pumping will pay dividends, horsepower wise, in savings on initial installation, and in more efficient and economical operation: the latter is results, primarily, from a higher slip motor that slows down when peak loads are applied and results in a flatter peak current demand. It necessarily follows, then, that the nearer this motor is applied to actual and realistic load requirements, the greater benefits will be reaped from its design slip characteristics. These benefits are utilized from this point throughout the overall design of the electric system.

MOTOR PROTECTION

Actual motor cost is very small in the overall system design; but, in the function of the system, it plays the feature role, getting oil to the top. Therefore, maximum protection of the motor is a "must" consideration. Primarily, operators are concerned with overload and lightning protection, but this motor is part of a system, so one must also consider system problems, mainly, low unbalanced voltage and single phasing. Recently methods have been developed for inherently protecting oil field pumping motors, and these methods of protection sense the heat inside the motor windings, regardless of the cause. Three common causes of motor heating are overload, stalls and low unbalanced voltage, the latter the villain of this overheating trio. The frequency of it happening is hard to predict; it is much harder to pin-point its cause; and it is the most difficult type of heating to protect against. For years overload relays, of one type or another, have been used for protection. But in doing so, the motor is automatically derated, for rëlays with heaters that will trip fast enough to protect under abnormal conditions will of necessity trip prematurely under normal conditions as the load applied nears the upper range of the motor. The idea of inherently protecting the motor is feasible, for that is where the heat is generated. And the protection would allow the motor to be run at full design capacity without sacrificing the necessary protection against the quick, high heating evidence with single phases and stalls.

Recently, an operator reported at an AIEE conference its findings on the use of inherently protected motors. During the last two months of 1960 and the first two months of 1961, 32 inherently protected motors were installed in a particular field. After eight months, and at the time of the report, there had been no failures reported on the 32 installations. However, in the same field and during the same eight month period, 37 regular motors, protected by conventional overload relays, failed and required rewinds. These failures were broken down as follows: 17 burned out because of bearing failures and 20 burned out because of apparent overload or single phase. In all cases, the resultant heating was not sensed properly or in sufficient time by the overload relays. In the report other instances were cited of motors not staying on the line when protected with overload relays, but when inherent protection was utilized, the motors performed without any trip-off. On these installations, the inherent protective devices removed the motors from the line when overload and single phase conditions were simulated. Therefore, this means of protection should definitely be considered as an economic factor -- from the standpoint of more usable horsepower for initial application as well as dependability for service and low cost, maintenance free, operation.

CONTROL APPLICATION

There are many different situations and conditions under which the motor must be controlled. First, one should determine the control functions required, those designed and their availability. The motor control is the brain of the motor: it starts and stops it at pre-determined intervals; it even skips certain days; it provides time delay restarting. High pick-up/high drop-out voltage control is available (on larger motors, particularly on larger distribution systems, definite consideration should be given to a maintained restarting sequence and rigid voltage control). Control panels also are available to easily re-connect to either operating voltage of the motor. In all cases, consideration should be given to reliability and durability of the components that make up the control. Furthermore, special emphasis should be given to the circuit itself: it should be completely fail safe in design and afford positive lock-out features should motor over-heating occur.

MOTOR AND CONTROL UNIT

The utilizing, or packaging of the motor and control into one unit is an idea that is rapidly being accepted throughout the oil patch. The same sound reasons that call for tailoring a motor to a specific job hold true for fitting a control function to a motor, and there is merit in the idea, regardless of the place to which the motor goes and of its proper control and protection.

Considerable savings in installation material and labor is evident with this type of installation, while another aspect which appeals to the operators is the bonding together in one common mass and the connecting to one common ground of everything with which the pumper comes in contact with--the unit, the motor and control and the brake. The lightning arrester is also part of this unit and its effectiveness is enhanced by the improved grounding conditions. Operators' experiences over the last two years reflect less coil burnouts and lightning arrester failures when using the motor and control package approach. New standards of efficiency and economy can be obtained by lower maintenance cost and less operating time or production losses.

THE DISTRIBUTION SYSTEM

There is sound economy in designing each electrical system to suit the particular needs of the lease, instead of designing from general standards, charts, and tables. In service are many conventional distribution systems whose yearly losses amount up to 10 and sometimes 15 per cent of the installed cost of the system. A system properly designed to keep losses to a minimum should, within a reasonable length of time, pay out any increase in initial installation costs and make money thereafter. In systems thus installed, the following can generally be noted: (1) the transformer installations are smaller in capacity and greater in number; (2) capacitors are used to improve the overall system efficiency and reduce transformer KVA requirements; and (3) the conductor sizes remain about the same even though the length of the secondary run is much shorter.

A system so designed offers many advantages. It is not necessary to invest money in large transformer banks and associated secondary systems to cover possible future loads; thus, the initial investment in transformers and distribution systems are kept to a minimum. Furthermore, the system is versatile and can be enlarged easily as future wells come on. Line losses are minimized because of shorter runs and the reduction of exposure to lightning is reduced. These features collectively represent a bonus of operating advantages and optimum overall economy of the complete electrical system.

TRANSFORMERS

The most important phase of the distribution system design is the selection of the transformers. Their type, size and location in relation to the well to be pumped will depend upon the following factors: (1) the power factor correction by use of capacitors at the motor terminals; (2) the actual loading of the motors which, in this instance, should be the nameplate rating of the motor; and (3) the number of motors per transformer installation. Actual installed distribution system costs capitalized over a 3 yr period, plus system losses, have been plotted against connected transformer capacity in KVA. This was done with a typical 16 well, 40 acre spacing lease and a curve was plotted for each of the horsepower sizes -- 5 thru 30 hp. Five systems for each horsepower size were compared as follows: (1) a system with a single transformer installation for 16 wells, (2) a system with 2 transformer installations for 8 wells each, (3) a system with 4 transformer installations with 4 wells each, (4) a system with 8 transformer installations with 2 wells each, and (5) a system with 16 transformer installations, 1 for each well. Based on the findings of this study, the optimum system for each motor size is as follows:

MOTOR SIZE IN HORSEPOWER	NUMBER OF WELLS PER TRANSFORMER INSTALLATION	QUANTITY	TRANSFORMER INSTALLATION SIZE	INDIVIDUAL MOTOR CAPACITORS, SWITCHED WITH MOTOR
5	8	2	30 KVA	YES
7.5	8	2	45 KVA	YES
10	4	4	30 KVA	YES
15	4	4	45 KVA	YES
20	2	8	30 KVA	YES
25	2	8	45 KVA	YES
30	2	8	45 KVA	YES

(Refer to "economic design of 440-volt lease distribution systems" -- General Electric Company Publication No. GER-1122A)

Notice here that only 30 and 45 KVA transformer installations are used and that capacitors are applied in every case.

In recent years more operators have been using the three-phase self-protected transformer for oilfield electric distribution systems. The popular sizes for this type transformer are 15, 30, 45 and 75 KVA. This type of transformer fits well into the optimum systems outlined above and there are several other advantages to consider. (1) The initial cost of a 3-phase self-protected transformer is less than 3 single phase transformers of equal capacity when considering the extra cost of separate lightning arresters and extra structure required. (2) Installation costs of the 3 phase transformer are not as great as are those of conventional banks of single phase transformers. (3) The secondary windings of the 3 phase transformer are protected from overloads by a 3-pole low voltage circuit breaker that is installed in the transformer tank and that can easily be reset by an external operating handle. In conventional banks of single phase transformers, the overcurrent protection is in the primary buss. If the fuse is large enough to eliminate nuisance fuse blowing, often caused by lightning or switching surges, then the overcurrent protection is sacrificed. The proper fuse for overcurrent protection will blow when subjected to most switching and lightning surges and will result in a low unbalanced voltage, rather than a single phase, on the secondary. (4) Lightning arresters are mounted on the tank and offer the best possible protection. (5) Primary fuses are mounted inside the high voltage bushings of 3-phase, self-protected transformers and provide short circuit protection caused by system faults.

CAPACITORS

Capacitors are not a must in an electric system, but they contribute heavily to high efficiency operation and an economic initial investment. A capacitor, when properly applied, simply serves as a magnetizing current generator for the motor which requires magnetizing current in order to run. This current is stacked upon the actual work current as a burden upon the distribution system lines and the transformer. The capacitor draws a current nearly equal to the magnetizing current and voids it and, thereby, releases some system capacity either to be utilized or to be shaved off the initial design by a reduction of wire size or transformer capacity. In either case, it means dollars to use capacitors. One should consider the following general effects:

(1) Up to 25 per cent reduction in transformer investment
(2) Up to 44 per cent reduction in cost of secondary losses
(3) An approximate 25 per cent reduction in secondary voltage drop because of reduced current
(4) Definite savings in power bills if a power factor clause is involved and enforced

CONDUCTORS

After the transformers and capacitors have been sized and their location established, it is not a difficult matter to select the proper conductor size. The main objective is to maintain adequate voltage with minimum losses at the well farthest from the transformer installation. The extreme condition is the starting of the motor at the farthest well with all other motors running. For calculating the proper conductor size, there are several formulas: some are rather detailed but they all reach relatively the same end result. A good rule-of-the-thumb method for properly sizing conductor is to use a conductor that will maintain, with all motors running, a 3 to 5 per cent maximum voltage drop at the farthest well. In this method, the nameplate full load current of the motor should be considered, and a conductor thus sized will be large enough to start the farthest well with all others running.

INSTALLATION

Once the motor, control, transformers, capacitors and conductor have been determined, there remains the consideration of construction standards, lightning protection and installation of the system. Construction standards such as hardware, insulators, poles, guys, spacing and sagging of conductors, etc., are fairly standard and vary only slightly from area to area. These variations are governed mainly by climatic and terrain conditions, and any qualified electrical contractor should be familiar with these conditions and the construction practices required. However, there is one phase of the installation that should be called to everyone's attention: the installation of lightning arresters and the proper grounding of the arrester and other equipments. The types of arresters are varied and so are the opinions as to which type is superior to the others. One common denominator to all arresters is that maximum effect (protection) is dependent upon the nearness of the arrester to the device to be protected and the ground system to which it is connected.

In a recent report a considerable percentage of the total motor failures over a one year period were attributed to lightning. Experience has taught that one can't whip lightning 100 per cent of the time, but with a little extra effort in protective measures, the odds can be kept in our favor. An example of ideal location of lightning arresters can be seen on the 3-phase transformer in which the arrester is mounted right at the primary bushing terminal; but with the motor and control package, the arrester is mounted and connected at the motor terminals. These are ideal mounting arrangements, provided the ground connection is satisfactory, and a good, low resistance ground insures lowest voltage spill-over level of the arrester material. Suitable grounds have been attained by driving several ground rods around an area and inter-connecting them, by clamping onto the well casing, and often by making a ground bed by digging a hole. Installing a copper electrode, pouring in softener salt, and providing a means to periodically water tne bed. Some operators are extremely careful to insure a good ground for their equipment; and these are operators who, everytime a cloud passes over, are not losing equipment.

At the well installation, the best possible ground is onto the well casing or well head. The ground wire should be solidly attached to the casing or well head, the unit, the motor and the control panel; with the motor and controls units these physical connections are minimized to two. Another grounding advantage inherent with this type of installation is that the operator is not entirely dependent upon the physical ground connection, for the unit, motor, control and lightning arrester sit solidly upon a natural moisture bed.

SUMMATION

There are many other methods, devices, and approaches to this problem of producing oil electrically, but there is no absolute or definite pattern to follow, and each electric system should be considered on its own merit. However, there are some basic ground rules to follow in equipment application. Today, initial installed costs, operating costs, and maintenance costs are more important to management whose prime concern is "How long will it take to pay out?" With these thoughts in mind, the following should be seriously considered:

(1) A true picture, a well analysis, of what is to be done, and its use as a basis of design throughout the entire system;
(2) Care with motor application (one may be buying certain advantages that he is not using; thus the motor should be sized to the load);
(3) The best possible means of protecting the motor and the purchase of those means;
(4) The fact that the control is more than just a "starter-box" and that there are definite types to suit particular situations;
(4) Avoidance of "short-dollaring" the company on distribution system design (there are measurable advantages to a system properly designed);
(6) If necessary, the "bird-dogging" of the system and the of proper installation and grounding methods.

The pump, rods, and unit that one selects for a given job form a "package unit" for that job. The motor and its control are a unit; the motor is the workhorse and the control, its brain. The distribution system is a package of basic units fitted together to furnish adequate power, with economy and dependability.

Pumping oil electrically, with optimum efficiency and economy, is the product of properly combining these packages into one complete and functioning system.