LIGHTNING PROTECTION FOR AN OILFIELD AUTOMATION AND INSTRUMENTATION SYSTEM

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INTRODUCTION

For many years, the problem of protecting electrical systems from lightning discharges has plagued power and communications engineers. Only within the past few decades has lightning been a problem to engineers dealing with electrical power systems in oilfields. The problem of lightning protection in West Texas oilfields is unique due to the high concentration of elevated high-voltage lines above flat plains that attract lightning discharges.

Most modern, electrically operated oilfields have power-distribution systems that are well protected from lightning discharges; in many cases, the systems are isolated by sectionalizers and other devices. Even if a portion of a field is disabled by lightning damage, the remainder of the field continues to function normally. This paper, therefore, concentrates on protecting the low-voltage electronic-instrument systems that are very susceptible to even minor voltage surges caused by lightning.

In the last several years, the tremendous expansion of oilfield automation and electronic-surveillance equipment has required increased emphasis on protecting low-voltage instrument systems from lightning discharges. These systems use direct-current voltages of 1 to 50 volts with 120 volt alternating-current power sources. This paper deals with methods used in a major oilfield automation project to protect various parts of the system from lightning damage. The lightning protection devices discussed are used to protect two computer-monitored oilfield automation projects located on the South high plains of West Texas near Levelland, Texas.

Figure 1 shows schematically the automation project operating in one of the locations. This is a secondary waterflood unit with almost 700 wells. The unit is under the surveillance of a computer-monitored oilfield production-automation system which utilizes about 1500 status, control, and measurement devices and has about 150 miles of buried multiconductor cables ranging from 6-pair to 50-pair cables. In this project, "pump-off" controllers are used in local mode to control the producing wells and have dry contacts indicating satisfactory controller operation and motor status. Water injection wells are controlled by mechanical pressure-regulating valves. The injection rates are monitored by the computer "reading" amplified signals from turbine meters.

At satellite tank batteries, the status of tank levels, fire indicators, temperature, and other conditions are monitored with each end device having a set of dry contacts. Producing-well tests are obtained by automatically switching individual flow lines to fired heater-treaters or separators using electrically operated ball valves. Dry contact meter pulses from these vessels are accumulated by the computer system to determine producing volumes and rates.

The telemetry system consists of master and remote telemetry units. Communications between telemetry units is accomplished by frequency modulated signals transmitted through buried copper conductors. The communication circuits, as well as status, accumulator, and analog circuits, are very easily damaged by transients and must be protected from lightning. The field and area mini-computers must also be protected.

Figure 2 schematically shows the automation project operating in the second location since early

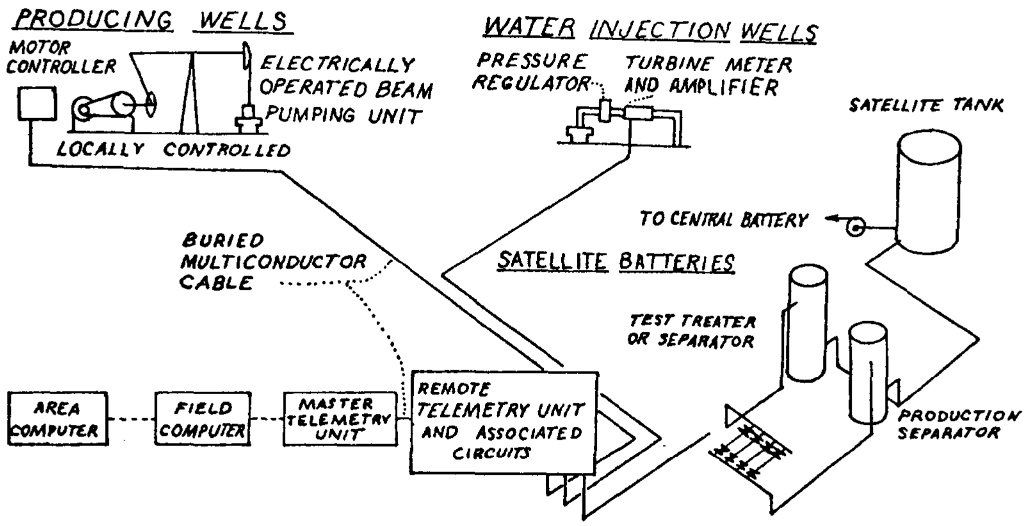

FIGURE 1

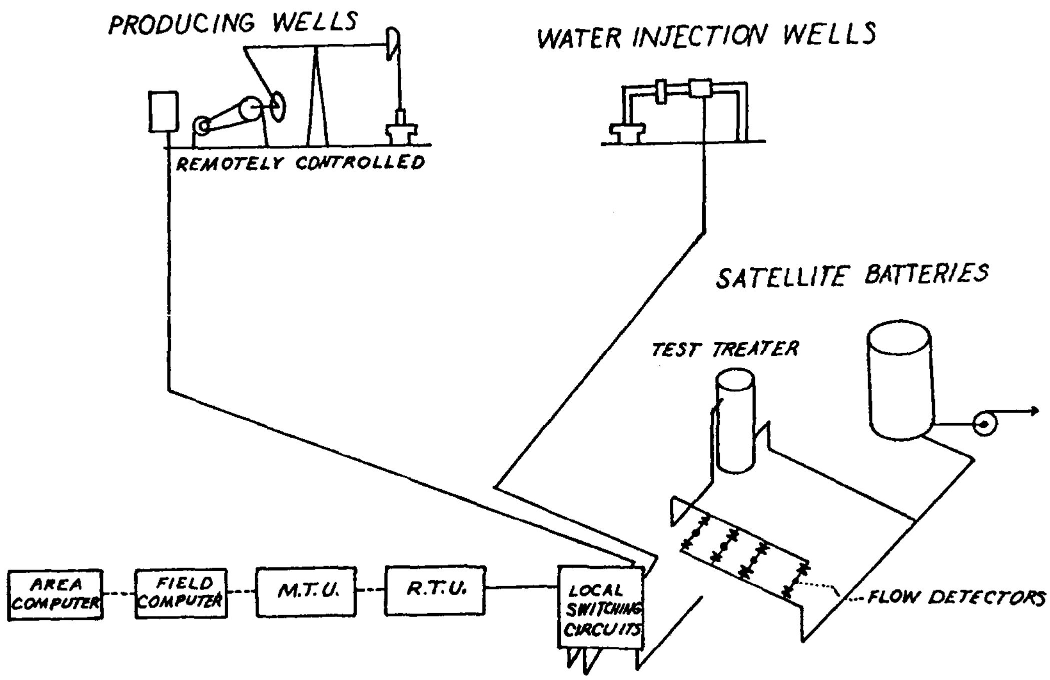

FIGURE 2

1975. In this project, producing wells are remotely controlled by the computer system based on data from flow detectors located at satellite batteries. The remainder of this project is essentially identical to the previous project, although there are some minor differences in mechanical construction and in the lightning-protection system.

LIGHTNING PROTECTION SYSTEMS

In an electrically operated oilfield, power is generally delivered by a network of primary transmission and secondary-distribution lines. Often, these are overhead lines. These overhead lines and pumping units, process facilities, buildings, and service equipment are elevated above the landscape, and they attract lightning.

In a field where instrument voltages are transmitted from one location to another, single or multiconductor cables are often severely affected or damaged by lightning strokes. Overhead lines and equipment are hit directly by strokes of lightning. A less serious but more prevalent condition occurs when lightning induces a damaging transient current on underground cables in much the same way that current in the primary winding of a transformer induces current in the secondary winding.

During a thunderstorm, a high voltage is present between the clouds and the surface of the earth and objects on the surface. This high potential difference can create a path of ionized air that allows large-magnitude currents to flow between the clouds and objects on the earth, generally, the tallest object in an area. For a period of several milliseconds, one or several strokes (or bursts of current) will flow. The tallest object or a point on the surface may have a current flow ranging from several hundred to several hundred thousand amperes. The current flowing to this point flows along the earth's surface, radially, from a relatively large surface area. In the case of overhead lines, this current also flows in both directions along the lines. Lightning protection equipment must protect equipment connected to these lines and must protect equipment connected to underground cables which will carry transient currents induced by the current flow in the earth's surface. Also, grounded equipment at each end of a line must be protected because the ground potential at one end of the line is shifted with respect to that at the other end by current flow in the earth's surface.

The induced current in cables can cause a voltage pulse of 500 to 1500 volts on low-voltage systems for a period of several-hundred micro-seconds.

In oilfield automation projects, the signals transmitted from one point to another are either analog signals or digital signals. A device transmitting current or not transmitting current, to indicate a motor running or not running, generates a digital signal (discrete signal) because the value of the signal depends only on presence or absence but not on current magnitude. A device transmitting a current proportional to a variable such as temperature or pressure transmits an analog signal (a continuous signal). Regardless of signal classification or whether overhead or underground cable is used, the cable must be protected on each end because a lightning transient travels in both directions along the cable.

Protection of digital signals from lightning transients is a relatively simple task because it is only necessary to preserve the presence or absence of a current at the telemetry unit, not necessarily to preserve the current flowing through the contacts of the end device. At the end device, a low voltage (90 volt) surge voltage protector is installed parallel to the contacts. This surge voltage protector is commonly called a 90-volt spark gap or gas tube. At the telemetry-equipment end of the cable, a circuit as shown in Figure 3 is installed. The relay shown is used to electrically isolate the signal cable from the telemetry system, thereby protecting the telemetry sytem (or other instrument system) from lightning transients. Another spark gap is used to protect the relay.

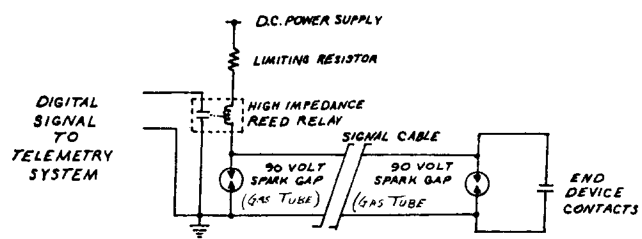

FIGURE 3

The lightning-protection system in Figure 3 has proved to be an excellent system. In some cases a transient may destroy the relay but in most cases the two spark gaps dissipate the transient. When only the gas tube is affected, the tube normally returns to the nonconducting mode without affecting the signal This has proved to be an advantage because the system is fully operational as soon as the transient is over. Systems using fuses, diodes, or both are generally inoperative after a transient until maintenance personnel can replace components.

Analog signals require more complex lightning-protection circuits because the current at the end device must be transmitted (intact) to the telemetry system. At each end of a cable carrying an analog signal, a circuit as shown in Figure 4 is installed. One circuit protects the end device and another circuit protects the telemetry system (or instrument system). This same type circuit is used to protect the sinusoidal signal from water injection-well turbine meters.

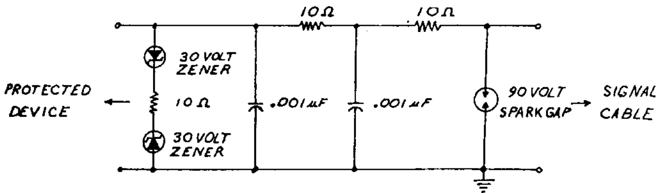

FIGURE 4

Again, a spark gap is used as the primary protective device. However, during the several microseconds required for the spark gap to operate, a high voltage may be present across its terminals. Therefore, the R-C network and the zener diodes are used to "slow down" and limit the high voltage pulse until the spark gap operates.

As in the case of digital systems, the protection system for analog signals is a nondestructive system. The spark gap dissipates most of the power carried by the high voltage pulse. Once the pulse has ended, the spark gap is an open circuit and the protection circuit no longer has an effect on the analog signal.

Most of the equipment in the automation project in which the above circuit is used operates with frequencies of less than 1000 Hertz. At this frequency, the R-C circuit shows no tendency to alter the normal waveshape of the signal passing through it.

The automation system at the second location is an expansion of a pilot automation project. The original system used high impedance carbon resistors (shown below in Figure 7) from every incoming signal conductor. These resistors were left intact, but the previously described lightning protection systems were also installed on each conductor as if the carbon resistors were not present. Thus far, this protection scheme has been no more effective than the systems where no carbon resistors are used. This indicates that the carbon resistors contribute very little to protection against lightning in the circuit shown in Figures 3 and 4.

One other type of lightning protection is used in data communication between telemetry units. This device must be transmitted (intact) to the elemetry equivalent circuit is shown in Figure 5. Since this device is hermetically sealed, it is not possible to replace any damaged components. The device is also much more costly than is the circuit shown in Figure 4. The circuit in Figure 5 is primarily used for a pair of wires in which neither is grounded. This situation generally applies to telemetry-system communication lines, but it has been found to be more practical to use the circuit of Figure 4 for wire pairs where one of the conductors is grounded.

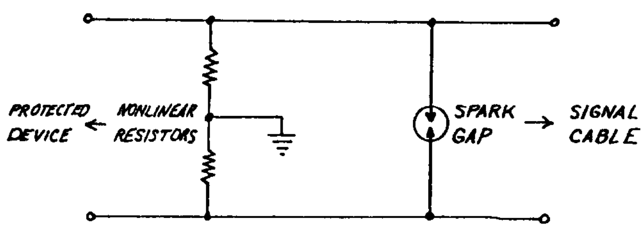

FIGURE 5

Another part of the automation system that requires protection is the computer system. At each major project, a field computer communicates with the telemetry system. The field computers communicate with a second computer referred to as an area computer. The field computers are protected from lightning transients coming from the fields by the telemetry system and its lightning protection. The computers are connected together by telephone lines and data sets furnished by the telephone company. Thus the computers are protected from lightning on telephone lines by telephone-company data sets and an extensive lightning protection system.

The other major component of an oilfield automation system is the power-distribution system. Most instrument systems depend on the direct-current power supplies which are powered by 120 or 480 VAC.distribution lines. The lightning protection used on this system is shown in Figure 6.

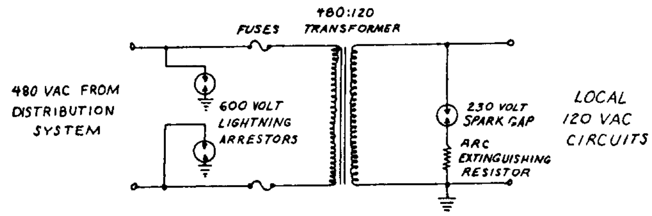

FIGURE 6

FIELD RESULTS OF LIGHTNING PROTECTION SYSTEMS

The only method by which the effectiveness of the lightning-protection system can be measured is to compare the number of status, control, or measurement devices which were made inoperable by lightning damage to the total number of devices and operating time during a thunderstrom. This is then compared to the values observed for the initial pilot automation project.

The circuit in Figure 7 was the lightning-protection circuit for the pilot automation project. This circuit offered adequate protection in that few end devices were ever damaged in the five year duration of the pilot project. However, after each moderate or heavy thunderstorm, about 25% of the approximately 400 status, control, and measurement devices were rendered inoperable when lightning damaged the fuse and/or diodes. For a period of about 16 hours (8 hours before personnel reported to work and 8 hours to repair the damage) these devices were inoperative and useless for the function they were intended to perform.

The effectiveness of the lightning protection in the original pilot project was based on the estimated number of device-hours of downtime during thunderstorm periods compared to the total number

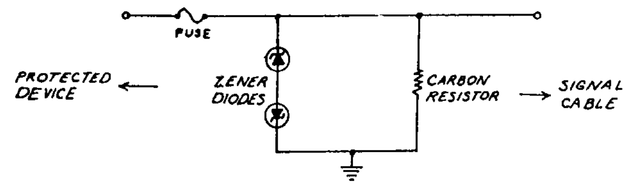

FIGURE 7

of connected device-hours during the thunderstorm period. A device-hour is defined as one device or control in operation for one hour. During the year 1970, an estimated 20 thunderstorms occurred and of a possible 240,000 device-hours of operation, a total of 40,000 device-hours (16.6 percent) were lost due to lightning damages.

The effectiveness of the present lightning protection system is shown in Table 1, a tabulation of the lightning damage experienced in one of the two automation projects during 1974. The table shows the lightning damage classified according to type of circuit and according to whether damage was suffered by the lightning protection circuit or by the protected device.

The table lists only nine thunderstorms in a 1-year period. Levelland, Texas, is in an area of the country where thunderstorm activity occurs an average of 20 to 50 days per year. It is possible that on some occasions, defective devices and circuits were repaired without diagnosing these failures as lightning damage. However, there were about 15 moderate-to-heavy thunderstorms that caused no damage at all according to repair records. It should be noted that during the nine thunderstorms, a total of 1132 device-hours of downtime was experienced during a total of 864,000 device-hours of operating time including these storms that caused no damage. Thus, a toal of 0.13-percent downtime during

TABLE 1—RECORD OF LIGHTNING PROTECTION DEVICES

		Figure 3		Figure 4		Figure 5		Figure 6				
Date (1974)	Intensity of Storm	Circuit	End Device	Circuit	End Device	Circuit	End Device	Circuit	End Device	Downtime* (Hours)	(Device-Hours)	% Downtime
3-09	Light	8	-	-	-	-	-	2	1	12	132	0.4
4-28	Heavy	1	-	-	-	-	-	-	3	12	48	0.1
4-30	Heavy	1	1	-	-	-	-	-	3	12	60	0.2
5-04	Heavy	10	4	-	-	-	1	-	9	16	384	1.1
6-13	Heavy	2	-	-	-	1	1	1	6	12	132	0.4
8-21	Moderate	-	-	-	-	-	1	-	3	12	48	0.1
8-24	Light	-	-	-	-	-	-	-	2	10	20	0.1
8-25	Moderate	-	-	-	-	-	1	2	4	12	84	0.2
8-26	Heavy	-	-	-	-	1	1	3	9	16	224	0.6
											1132	

*The downtime includes an estimated 8 hours before personnel are aware of the problem and begin to repair damage.

thunderstorms was experienced during 1974.

Recently, the previously mentioned pilot project was rebuilt and modernized as shown on Figure 2. The lightning-protection systems of Figures 3 through 6 were installed in place of an earlier circuit, except that the carbon resistors were left intact. Sufficient data has not been obtained to fully evaluate the effectiveness of the lightning protection system. However, at this time several severe and moderate thunderstorms have struck the area and caused no damage.

Based on the above data, the lightning protection systems have been performing satisfactorily in limiting lightning damage, associated downtime, and expense to acceptable levels. The downtime caused by lightning damage is negligible when compared to the operating time during thunderstorms.

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