Application of Fiber Optics for the Protection and Control of Power Systems

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1 Introduction

Electrical power systems, when viewed as being organized in hierarchical form, can be seen to have become complex in recent years due to their range of structural, status, and relevant technical issues. Such complexity, implemented in order to provide safer, cheaper, and more reliable power to the consumer, requires better control, monitoring, protection, measurement, and information transmission [1].

A prerequisite for the safe and stable operation of an electrical power system is the accurate and reliable measurement of the major system parameters, in particular current and voltage. In the Traditional power system, it is achieved by using a high-voltage current transformer and voltage transformers. But these transformers are very bulky in size and also very costly. Both these devices are increasingly coming under review in modem power systems due to their cost, and the safety implications for personnel, and the surrounding plants if a failure occurs. In the urban area cost of land and the cost of installation of a plant is high and also installation process is time-consuming. The main interests have been in producing devices to replace conventional equipment and CTs, utilizing the non-conductive nature of the optical components. Other important functions for measurements in the industry are those for diagnostic and metering tasks.

The main equipment used for the measurement of the quantities helps to solve the problems directly or indirectly arising in the power system. When a circuit breaker is used to break the current of the transmission line, due to the presence of the inductance and capacitance in the transmission line high-frequency surges can be induced. Managing the level of frequency and voltage is very important, in the power system for stable and safe operation.

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Since the power system required stable and efficient operation hence the transmission of data is very complex. For the stable operation and control of the power system, the centralized control system was used which required high bandwidth of the communication system. But the traditional control and communication system has many limitations in respect of frequency allocations and channel availability [2].

The classical control systems are also very difficult to handle and operate because of their complex nature and installation cost and place requirement is very high. Since a power system uses high voltage and current for transmission so its needs a reliable control system. And the control system depends on the signals it received from various parts of the operating area of the power system. If they received information very fast then they can take quick action and operate the system and hence the system will be safe and operated as per desired operations.

Old communication channels used metallic circuits, which can be affected by external causes like interference of voltage and current from other circuits. Hence the effectiveness and reliability of such a metallic-based control system are reduced. Mostly pilot circuits are used for communication of the signal which is purchased or rented by telecommunication authorities. Such kind of communication circuits used electronic signal repeaters which are unable to send the signals long distances. Since the power system used a large network for long-distance its need a suitable system that can send the signal in all operating area at high speed without any interference [3].

The main objective of the use of the pilot wire is to trip the circuit when any unwanted operation arises in the power system. Since the operation of the pilot wire depends on the signal of CT and PT, so it can help to protect the system if received correct and fast signals from CT and PT.

Continuous monitoring and maintenance are required for the equipment and systems used for measurements and control of the electrical power systems because they are sensitive and very costly. Now we are required to use online monitoring approach which is effective, accurate, and less costly as compared to traditional systems. Such online monitoring helps to operate the system with stable voltage, frequency, and power factor and also helps to protect the whole power system from unwanted hazards. Since the traditional monitoring and control systems are not much efficient so cannot perform effectively the expected tasks.

For the support of the monitoring and control system, the required to stabilize a set of locations (monitoring point) in the electrical power system, so the system can measure the accurate value and also communicate with high speed the same exact values. Such kind of development of system improves the working efficiency of the control system. Integration and coordination of the operation of a utility system based on a hierarchical control superimposed on a distributed local control structure require local microcomputer networks linked together and installed in key control areas such as power plants, substations, and load centers, for example.

Modern power systems use SCADA (supervisory control and data acquisition) monitoring and control system which is operated by the local network system. Vibration monitoring, control of large remote heat systems, remote control of transformers, temperature monitoring of high-voltage cables, and lightning observations

from other functions of monitoring and control are also important. The fault is a common problem in transmission lines, especially in rainy sessions, which interrupt the supply of power for a long time [4].

Optical fiber transmission systems are very fast and free from external interference used in the electrical power system for control and operation. In these respects optical Fiber thermometer can offer a new perspective. OFC transmission system is used between substation for transmission line safety, monitoring between point-to-point working systems with connection to the SCADA system, and transmitting voice or video messages for supervision and control. What is more, to support the complicated system management and improved protection algorithms of complex structures of substation protection and control systems, integrated digital protection and control systems have been employed.

Electrical equipment that fulfills responsible functions in high voltage, high power systems should be supervised continuously in the real–time of operation. This equipment includes power lines, transformers, switches, current transformers, etc. The supervision functions and system redundancy is needed to assure the desired level of reliability in the system [5].

The protection system mainly divided in two-level, higher level, and low level. The higher level consists of the diagnosis of the technical problems arises in the system and lower level included buzzer/alarms and operating switches. Technical diagnostics sub–system gives the possibility of early or nearing fault detection to the user of the whole system. The build feature enabling an early detection in the system protects it directly against any fatal breakdown stage. Here system used for supervision and control is distinguished in four following reliability stages:

- Normal work under nominal conditions,
- Early fault stage of work,
- Disturbed stage of work,
- Break down stage.

The electrical power system is supervised continuously so that power can be transmitted and distributed at all stages of the system without any interruptions. During the breakdown of power, information received by the supervision system is very important. This information is shared in many high and down-level systems to overcome the breakdown problem as soon as possible. The optical fiber communication system here helps to transmit the information very quickly to supervision control units as well as other stages without any change in signals.

This chapter focused on the fiber optic supervision network system connected with SCADA supervisory system and protects the whole power system. The supervision system mainly depends on the signal received in terms of voltage, current, frequency, temperature, power factor, and change in lodging at receiving end side. Also using many electrical switches and equipment which is used to trace a double in the electrical power system and also trip the circuit when any unwanted state arises with the help of a supervisory system [6].

2 Optical Fiber System

Glass or fiber is used to make the optical fiber. Optical fiber is a very thin wire and its diameter is near to diameter of a human hair. It is a very long wire where the signal is transmitted at almost the speed of light using the principle of total refraction from the center of the wire from one end to another end [7]. For many applications, it performs better than metallic conductors because it's had higher bandwidth and transmits speeds. A comparative analysis between copper conductor communication and OFC is shown in Table 1.

Table 1 Comparison between OFC and copper conductor communication

Properties	OFC	Copper conductor
Speed	OFC can transmit signal with speed of light	Its speed is less than OFC
Electrical Isolation	Free from ground loop problem	Ground compulsory required
Sparking	No sparking	Maybe sparking arises
Interference	No electromagnetic interference	electromagnetic interference arises
Power loss	Very low	High
Handling	Its weight is very light so easily can be handled	Its weight is high so transportation and handling are not easy

2.1 Construction of Optical Fiber

A Fiber Optic Cable consists of the following parts shown in Fig. 1.

A. **Core**: It is in cylindrical form made of plastic used to cover the fiber cable along with the length of the cable. The core provides protection for the cable. The length and diameter of the core design are as per the applications used.
B. **Cladding**: It is used for the protection of the core. It covers the core outer part. It helps the light to reflect back into the core. Generally, when light enters from dense medium (core) to low dense medium (cladding), it changes its angle in such a way that it can reflect back to the core.
C. **Buffer**: Since the fibers are arranged in thousands of optical fibers so its required mechanical support and protection, such mechanical support, and protection are provided by the buffer.
D. **Jacket:** It is the outer part of the fiber cable used for the protection of the cables from outside hazards and environmental problems.

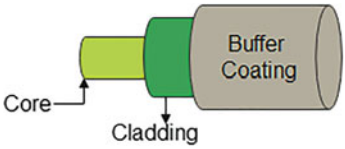

Fig. 1 Main part used in optical fiber

2.2 OFC Operating Principal

Characteristic of any Optical materials depends on the index of refraction as they are reflected in the medium of propagation changed. The optical fiber is working on the principle of total internal reflections as shown in Fig. 2. The reflection index is defined as

$$\text{Refraction index} = \frac{\text{speed of light in a vacuum}}{\text{speed of light in the material}}$$

Law of refraction given by Eq. (1)

$$n_I sinI = n_r sinR \tag{1}$$

where I-The angle of incidence, R-angle of reflection, n_I -medium of incidence of the light, and n_R–medium of reflection of light.

For the total internal reflection, it is required to angle of incidence is always greater than the critical angle. In the optical fiber, about 82° incidence angle is used for internal reflection. At such an angle, light is reflected without any loss as shown in Fig. 3.

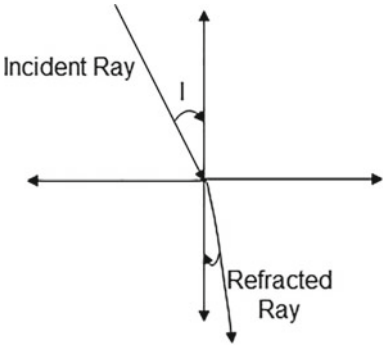

Fig. 2 Principle of interference used in optical fiber

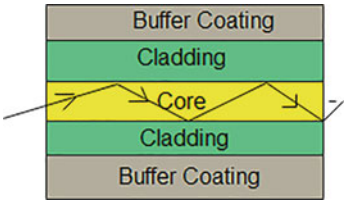

Fig. 3 Total internal reflection of light inside of the core of the fiber optics

2.3 Classifications of Optical Fibers

As per the construction and used material composition for core optical fiber cables are categorized as shown in Fig. 4.

1. **Step-index fiber**—In this case of the cabal, the core has a uniform refractive index throughout the length and it is suddenly changed when reached the cladding boundary.
2. **Graded-index fiber**—In this case of the cabal, the core has a variable refractive index from the center of the cable.

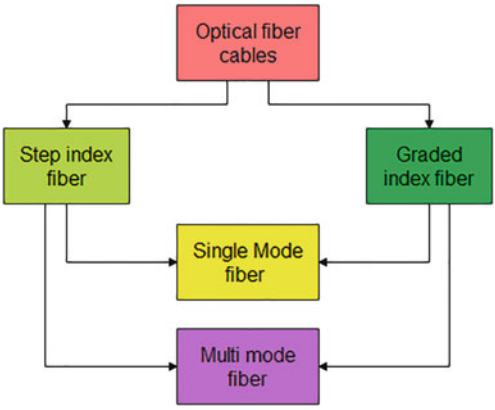

Fig. 4 Classifications of the optical fiber cables

Now these two types of cables are classified into two forms.

A. **Single-mode fiber**

- It is suitable for long-distance communication only.
- Small diameter of the glass used for the construction of single-mode fiber.
- Minor signal strength reduced due to small diameter
- Signal light of beam used which can travel for long distance.
- High bandwidth used to transmit the signal
- In this mode laser is used as a source of light

B. **Multi-mode fiber**

- It is used for a short-distance of communication.
- It required a large core diameter for the reflection of the signals.
- Multi signals can be transmitted
- Signal loss is possible in multi-mode fiber
- LED used as a source of light

2.4 Advantages of Fiber Optics

OFC has the following advantages

- OFC can support higher bandwidth communication.
- Signals travel for long distances so need for any signal booster.
- OFC signal cannot affect by electromagnetic interference.
- It can be used in water also.
- OFC has light in weight; mechanical strength can be used for long life, and easy in handling.
- It is free from maintenance.

2.5 Disadvantages of OFC

- It is costly compared to copper wire.
- Since optical fiber uses glass so it required higher protection compared to copper wire.
- New Installation required much labor and hence needs much cost.
- If the cable bend or curved around a radius of a few centimeters due to its fragile nature it can be broken or the signal can be lost.

2.6 Fiber Optic Communication

It is a technology used to transmit the data from one end to another end of the circuit. In this system, infrared light pulses are used as signals to transmit the data. Light is used as a signal carrier and it is converted into data. Where long distance, high bandwidth, and high-speed data transfer are required optical fiber cable is preferred instead of copper cable [8].

For the transmission of audio, video, and large data Fiber-optic communication is the most suitable system. Optical fiber communication is also used for telephone and television signals. Currently in India Jio and Airtel companies mostly use fiber optical systems for internet and TV signal communication.

2.6.1 Working of Fiber Optic Communication System

In an optical fiber, the light signal is transmitted from one point to another end. As shown in Fig. 5 it has a transmitter that transmits the electrical signal to the light of the source and such electrical is converted into a light signal. After that using fiber and optical cables light source signal send to the receiver, and here again, it is converted into a digital signal for further use [9].

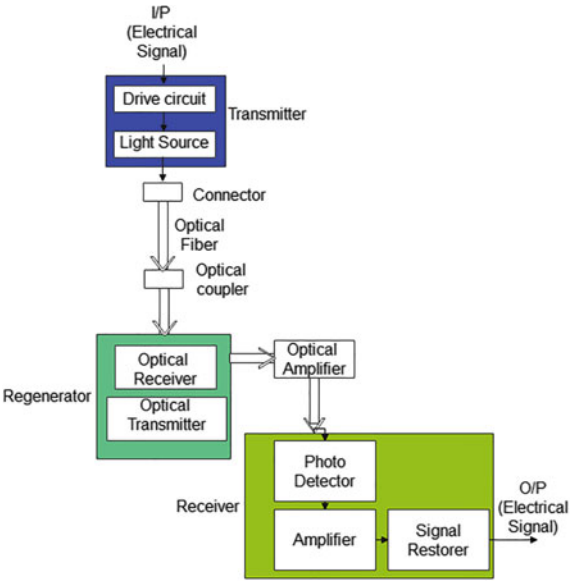

Fig. 5 Main part used in communication

2.6.2 Elements of a Fiber Optic Communication System

Figure 5 shows the basic major elements used for the optical fiber communication system.

Transmitter—It consists of a drive circuit and light sources. A drive circuit is generally used to convert the electrical signal into a digital signal. And a light source has an LED and laser diode for the generation of the light beam. The difference between LED and laser light diodes is given in Table 2. Generally, the light source value depends on the network area and size of the network.

LED is an important element used as a light source In an optical fiber communication system. It can convert the electrical signal into an equivalent light signal which is used as an input signal for optical fiber. The LED has some good characteristics like it induces less heat when converting an electrical signal into a light

Table 2 Comparison of characteristics of laser diode and LED

Quantity	Characteristic of laser	Characteristic of LED
Speed	Very fast	Slow
Handling	Difficult compared to LED	Easy in operation
Output power	High	Low
Cost	High	Low
Spectral width	Narrow	High

source so it improves the overall efficiency of communication. LED has the following advantages:-

- Size is small so it easily fits in the circuit.
- LED has a high radiance.
- LED has small emitting regions like optical fiber dimensions so it is suitable for use.
- LED is a highly reliable element.
- They can be changed at high speeds.

Optical fiber cables: it is used to transmit electrical signal in terms of the light beam from one circuit to another circuit. The main characteristic of such optical fiber is high bandwidth, Low power losses, and high speed of transmitting the data.

Regenerator: It consists of an optical receiver and optical transmitter. The optical receiver receives the optical signal coming from the optical fiber and the optical transmitter transmits the optical signal to the receiver via an optical amplifier.

Receiver: It consists of the photodetector, which identifies the signal that came from the regenerator. A signal restorer is also present in the receiver, which converts the light signal into an electrical signal.

2.6.3 Characteristics of Optical Fiber

Optical fiber has many characteristics as shown in Fig. 6.

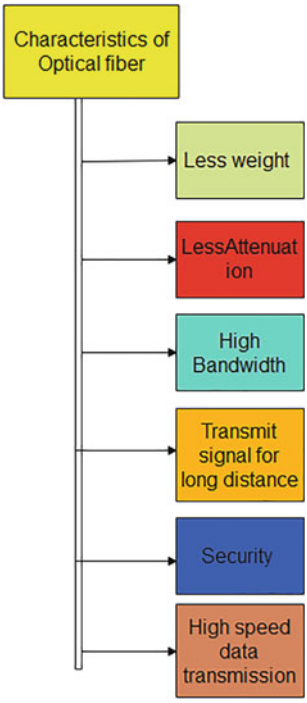

Fig. 6 Characteristic of optical fiber

2.6.4 Fiber Optics Applications

Optical fibers have many applications, and Fig. 7 shows various sectors where optical fiber is highly recommended [10].

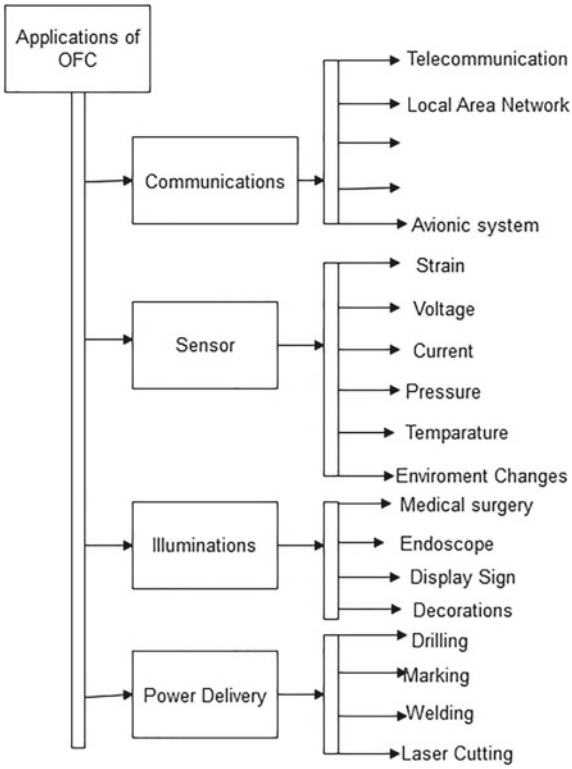

Fig. 7 Applications of OFC

2.6.5 Fiber Optic and Satellite Communication

In the present day, Optic fiber and satellite communications are used mostly all over the world. Both technologies have some advantages and limitations. The main differences between these methods are shown in Table 3.

Table 3 Difference between fiber optical and satellite communication

S.no	Fiber optic communication	Satellite communication
1	It is more suitable for urban areas	It is suitable for anywhere in the country
2	This type of communication used light signals for the medium of propagation	Electromagnetic signals are used for the medium of propagation
3	For this communication optical fiber is required	In this communication relay station used
4	Bandwidth of the fiber optical communication is very high and low interference with	Bandwidth is less and interference is always flat
5	For fiber communication antennas are not required	Special antennas required
6	Medium of transmission is fiber	Medium of transmission is air
7	It is more suitable for point-to-point and short-distance communication	It is suitable for long-distance communication only
8	Rate of data flow is very high and propagation delays are very low	Flow of data rate is slow and since data is transferred from satellites to earth, propagation delay is high
9	Its cost is less	It is very costly
10	It is used for stationary communication	It can be used for movable communication as the mobile
11	It is reliable and chances of error are very less	It is also reliable but the chances of error are more

Advantages

The advantages of optical fiber communication include the following.

- Communication is secured
- Speed
- Electromagnetic compatibility
- Distance
- Bandwidth
- No Power loss
- Interference
- Size
- Less Weight
- Security

3 Electrical Power System Protection and Control System

3.1 Power System Protection

The electrical power system is designed in such a way that it can generate and transmit power to all consumers. Power systems ensure operation economically and provide full safety to the consumers. The huge capital investments in the generation, transmission, and distribution of power with proper precautions are taken to ensure that the equipment operates at peak efficiency and must be protected from accidents. The electrical current is normally transferred from the generator to the transformer, transformer to transmission lines, transmission lines to the distribution line, and distribution line to different loads using suitable insulators [1].

Total protection depends on the insulation provided in the power system, so if due to environmental effects or aging or any physical accident insulator is damaged then the current follows an abnormal path generally known as a short circuit (fault). Generally, we can say fault means the abnormal operation of the power system. Faults may arise in two ways, first open circuits and second short circuits. Various faults occurred in the transmission line shown in Fig. 8. In most cases, short circuit faults arise more compared to open circuit faults [11].

During the fault occurs in the power system, an automatic protective device is required to isolate the faulty element as quickly as possible to keep the healthy section of the system in normal operation. When any short circuit fault occurs in any section of the power system, a very high short circuit current will start to flow in the circuit this high current is very dangerous for the human as well as equipment connected with the power system. In such conditions, it is required to clear the fault within a fraction of a second. If the short circuit is present in the circuit for a long time it can damage the system mostly and sometimes it catches the fire and damages the surrounding areas. So it is required to eliminate short circuits as quickly as possible using protective elements like relays and circuit breakers. Also required

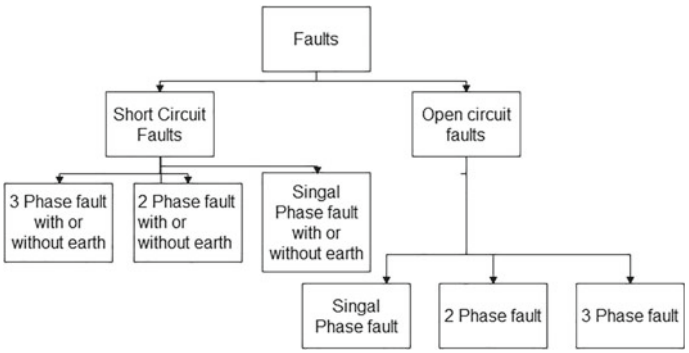

Fig. 8 various faults occurred in transmission line

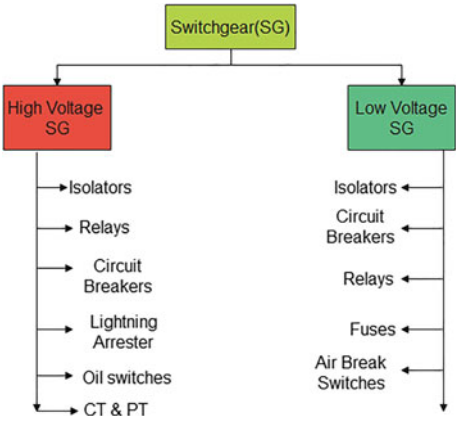

Fig. 9 Switchgears used for protection of power system

is an automatic protection system that isolates the healthy part of the system from a short circuit [12].

The design of a protection system required two types of devices, the first type of device is used to sense the value of current and voltage in the normal situation as well as abnormal situation, the second type of device is used to break the faulty section of the line from the healthy line. CT (Current transformer) and VT (Voltage transformer) are used as primary devices; they can sense the value of current and voltage. Relay is also used as a sensor that senses the value of CT current and accordingly sends information to the circuit breaker. Circuit breakers and switchgears are used as secondary devices which can break the circuit during abnormal condition. Figure 9 shows the different types of switchgears Fig. 10 shows the various relays and Fig. 11 shows various circuit breakers used for the protection of the power system [13].

The general layout of the protection system used for the electrical power system is shown in Fig. 12. CT and PT are used for the measurement of current and voltage from the power system using step down the principle of the transformer. Relay is connected with CT & PT and reads the current and voltage values and according to the value of CT and PT it takes the decision whether it is a normal operation going on or any abnormal situation arises. If an abnormal situation arises it sends a signal to the trip connector. The trip connector activated and magnetized the trip coil so that it can operate the circuit breaker. So using a trip coil circuit breaker opens the faulty parts of the system. In this way protection system protects the whole power system.

But in the classical protection and control system has many problems. Most common problem is to transfer the signal in high speed without any interference. Since classical system are using copper wire as a communication line. So in this communication system has chances of magnetic interference and loss of signals. Since copper wire is using so losses also arises [14]. For the protection of failure of system and avoid cut of power need new technology-based automatic protection

Fig. 10 Different types of relays used in power system

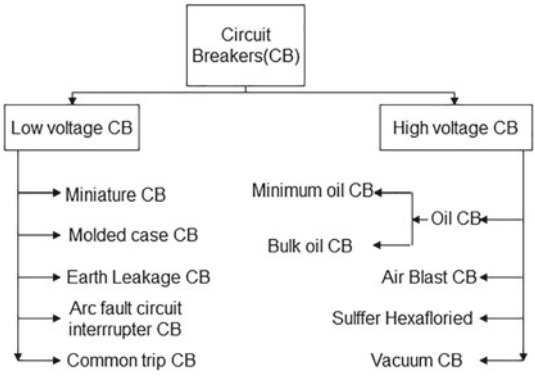

Fig. 11 Different types of CB used in power system

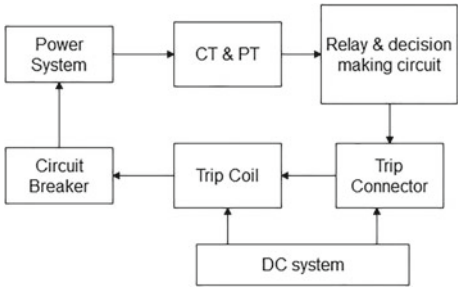

Fig. 12 Layout diagram of power system protection

system. Such an Automatic system accurately monitors, control, and protect the power system and improve the efficiency and reliability of the system.

3.2 Qualities Required of a Protection System

The protection system has the following qualities:

- Reliability
- Stability
- Selectivity or discrimination
- Sensitivity
- Adequateness
- Speed and time
- Simplicity and economy

4 Automation Power System Protection System with Fiber Optics

Automation system has an effective impact in all sectors of industries which can make them more suitable for human daily life. The automation system also increases the productivity of work, improves manufacturing quality, and decreases total costs. The use of Automation in the power system provides effective and efficient monitoring and control.

SCADA systems recently started to use in the power systems as supervisory and control units. As the signal is received from the power system switchgear accordingly SCADA system takes action and provides control and protection. In the power system for the communication of signals, a copper conductor is used. As already discussed in this chapter copper conductor communication suffers from electromagnetic interference and hence communication signal is not clear for some time. The speed of the signal is also not good. So If the signal is not clear and also not reached in time by the protective elements, how they can take proper action, and how to provide protection at the correct time?

To overcome the problem of copper conductor communication systems fiber optics can be used in place of copper conductors. As already discussed fiber optics can transmit the signal with high speed for long distances and high bandwidth without any interference. So there is no chance to lose the signal. If the protection system received the correct signal it can take corrective action in time and provide safe operation of the power system.

The optical fiber is the most important communication part between the field data interface, control units, and the SCADA system for transferring the data signal. Fiber optic communication is free from electromagnetic and radio frequency interference,

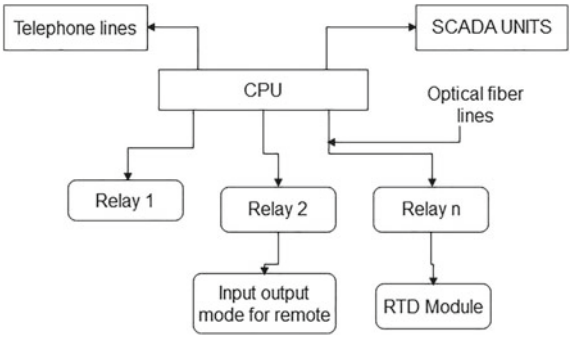

Fig. 13 SCADA system with fiber optics communication

sparking does not arise like in copper conductor, data is transited securely and very low attenuation coefficient, loss of data is very less and suitable for long communication at very low cost. The structure of SCADA with fiber optics communication system is shown in Fig. 13.

CPU is the central processing unit used to monitor all processes and send signals to different relays to trip the circuit under abnormal conditions. All relays are connected with fiber optic cables with CPU units. As with any abnormal situation observed by CPU units its send message to the SCADA system as well as different connected relays. As the SCADA system received a signal from the CPU unit it sends a signal to different protective devices by fiber optics and protective units operate and turns off the power as soon as possible. Optical technology applications in electrical power systems have in the main included the following major aspects shown in Table 4 and (Figs. 14 and 15).

Table 4 Application of optical fiber system in electrical power system measurements and communications

S. no	Application area	Measurement (%)	Communication (%)
1	Control & monitoring	40	55
2	Substations	30	70
3	Fault location	45	50
4	Unser ground cables	30	80
5	Overhead lines	10	95
6	Distribution system	45	55
7	Relay and protection	15	90

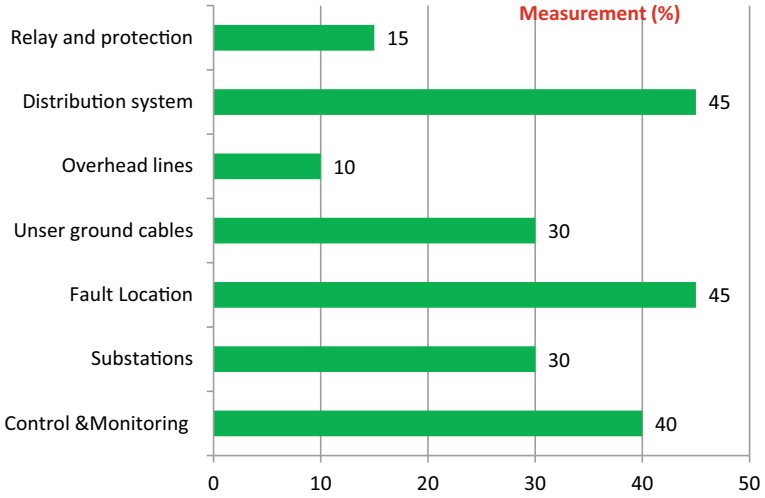

Fig. 14 Use of measurement in percentage in different power system areas

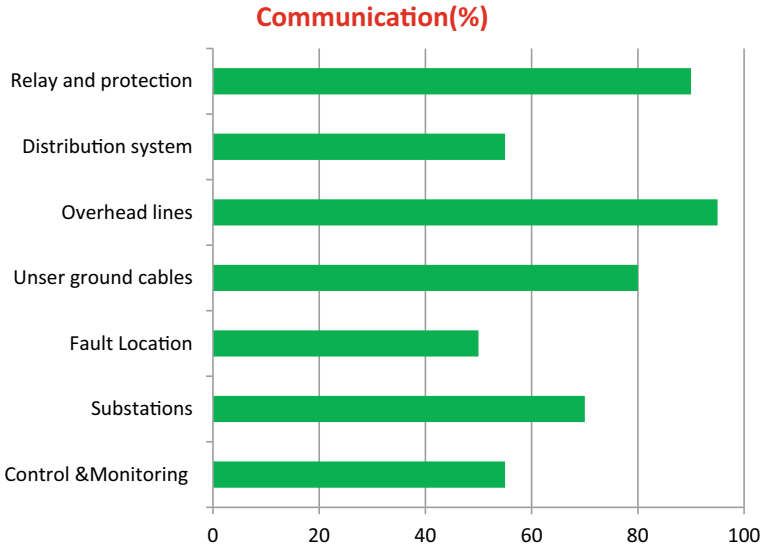

Fig. 15 Use of communication in percentage in different power system areas

5 Conclusions

The electrical power system has a very large network and continuously works for the supply of power for different consumers. A huge of capital is invested in the generation, transmission, and distribution of power. But safety is the most important phenomenon in the power system. From time to time protection and control system is updated by the electricity companies. But that is not enough as the demand and utilization are increasing continuously. The switchgear and protection system work together using communication copper conductor signals. The copper conductor communication system has many issues so the protection system also does not work accurately.

Now the time has come to update the communication system using fiber optics which has so many great advantages which make it suitable for communications. For power system protection and control, optical fiber can play a big role in providing accurate signals which high speed. So using a SCADA system with fiber optics can provide great control and protection of the power system.

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