# • 7 • *Relay Technology*

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## 7.1 INTRODUCTION

The last thirty years have seen enormous changes in relay technology. The electromechanical relay in all of its different forms has been replaced successively by static, digital and numerical relays, each change bringing with it reductions and size and improvements in functionality. At the same time, reliability levels have been maintained or even improved and availability significantly increased due to techniques not available with older relay types. This represents a tremendous achievement for all those involved in relay design and manufacture.

This chapter charts the course of relay technology through the years. As the purpose of the book is to describe modern protection relay practice, it is natural therefore to concentrate on digital and numerical relay technology. The vast number of electromechanical and static relays are still giving dependable service, but descriptions on the technology used must necessarily be somewhat brief. For those interested in the technology of electromechanical and static technology, more detailed descriptions can be found in reference [7.1].

## 7.2 ELECTROMECHANICAL RELAYS

These relays were the earliest forms of relay used for the protection of power systems, and they date back nearly 100 years. They work on the principle of a mechanical force causing operation of a relay contact in response to a stimulus. The mechanical force is generated through current flow in one or more windings on a magnetic core or cores, hence the term electromechanical relay. The principle advantage of such relays is that they provide galvanic isolation between the inputs and outputs in a simple, cheap and reliable form – therefore for simple on/off switching functions where the output contacts have to carry substantial currents, they are still used.

Electromechanical relays can be classified into several different types as follows:

**a.** attracted armature
**b.** moving coil
**c.** induction
**d.** thermal
**e.** motor operated
**f.** mechanical

However, only attracted armature types have significant application at this time, all other types having been superseded by more modern equivalents.

### 7.2.1 Attracted Armature Relays

These generally consist of an iron-cored electromagnet that attracts a hinged armature when energised. A restoring force is provided by means of a spring or gravity so that the armature will return to its original position when the electromagnet is de-energised. Typical forms of an attracted armature relay are shown in Figure 7.1. Movement of the armature causes contact closure or opening, the armature either carrying a moving contact that engages with a fixed one, or causes a rod to move that brings two contacts together. It is very easy to mount multiple contacts in rows or stacks, and hence cause a single input to actuate a number of outputs. The contacts can be made quite robust and hence able to make, carry and break relatively large currents under quite onerous conditions (highly inductive circuits). This is still a significant advantage of this type of relay that ensures its continued use.

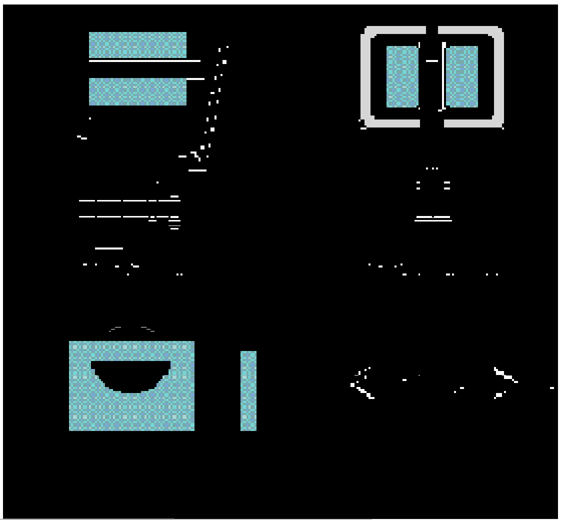

*Figure 7.1: Typical attracted armature relays*

The energising quantity can be either an a.c. or a d.c. current. If an a.c. current is used, means must be provided to prevent the chatter that would occur from the flux passing through zero every half cycle. A common solution to the problem is to split the magnetic pole and provide a copper loop round one half. The flux change is now phase-shifted in this pole, so that at no time is the total flux equal to zero. Conversely, for relays energised using a d.c. current, remanent flux may prevent the relay from releasing when the actuating current is removed. This can be avoided by preventing the armature from contacting the electromagnet by a non-magnetic stop, or constructing the electromagnet using a material with very low remanent flux properties.

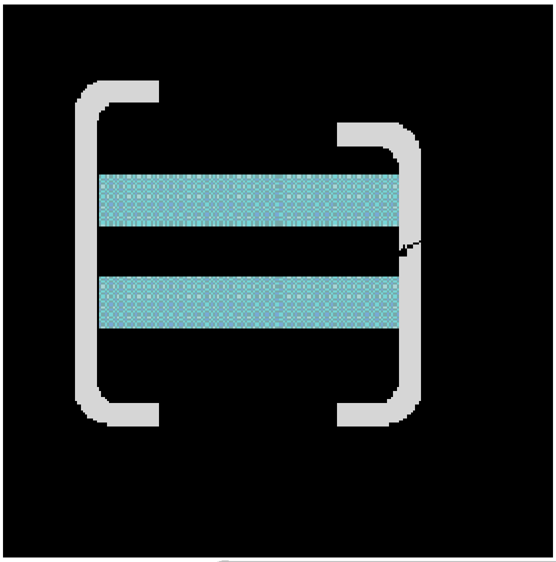

*Figure 7.2: Typical polarised relay*

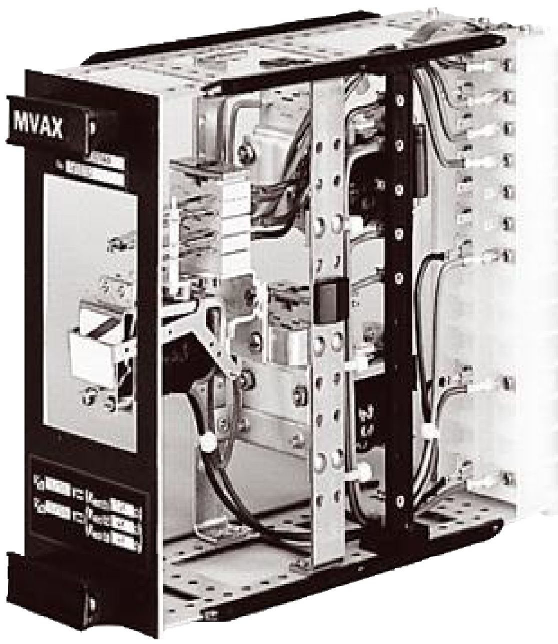


*Figure 7.3: Typical attracted armature relay mounted in case*

Operating speed, power consumption and the number and type of contacts required are a function of the design. The typical attracted armature relay has an operating speed of between 100ms and 400ms, but reed relays (whose use spanned a relatively short period in the history of protection relays) with light current contacts can be designed to have an operating time of as little as 1msec. Operating power is typically 0.05-0.2 watts, but could be as large as 80 watts for a relay with several heavy-duty contacts and a high degree of resistance to mechanical shock.

Some applications require the use of a polarised relay. This can be simply achieved by adding a permanent magnet to the basic electromagnet. Both self-reset and bi-stable forms can be achieved. Figure 7.2 shows the basic construction. One possible example of use is to provide very fast operating times for a single contact, speeds of less than 1ms being possible. Figure 7.3 illustrates a typical example of an attracted armature relay.

## 7.3 STATIC RELAYS

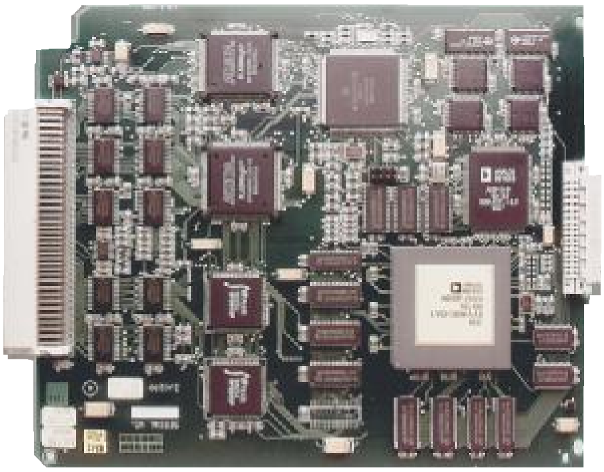

*Figure 7.4: Circuit board of static relay*

The term 'static' implies that the relay has no moving parts. This is not strictly the case for a static relay, as the output contacts are still generally attracted armature relays. In a protection relay, the term 'static' refers to the absence of moving parts to create the relay characteristic.

Introduction of static relays began in the early 1960's. Their design is based on the use of analogue electronic devices instead of coils and magnets to create the relay characteristic. Early versions used discrete devices such as transistors and diodes in conjunction with resistors, capacitors, inductors, etc., but advances in electronics enabled the use of linear and digital integrated circuits in later versions for signal processing and implementation of logic functions. While basic circuits may be common to a number of relays, the packaging was still essentially restricted to a single protection function per case, while complex functions required several cases of hardware suitably interconnected. User programming was restricted to the basic functions of adjustment of relay characteristic curves. They therefore can be viewed in simple terms as an analogue electronic replacement for electromechanical relays, with some additional flexibility in settings and some saving in space requirements. In some cases, relay burden is reduced, making for reduced CT/VT output requirements.

A number of design problems had to be solved with static relays. In particular, the relays generally require a reliable source of d.c. power and measures to prevent damage to vulnerable electronic circuits had to be devised. Substation environments are particularly hostile to electronic circuits due to electrical interference of various forms that are commonly found (e.g. switching operations and the effect of faults). While it is possible to arrange for the d.c. supply to be generated from the measured quantities of the relay, this has the disadvantage of increasing the burden on the CT's or VT's, and there will be a minimum primary current or voltage below which the relay will not operate. This directly affects the possible sensitivity of the relay. So provision of an independent, highly reliable and secure source of relay power supply was an important consideration. To prevent maloperation or destruction of electronic devices during faults or switching operations, sensitive circuitry is housed in a shielded case to exclude common mode and radiated interference. The devices may also be sensitive to static charge, requiring special precautions during handling, as damage from this cause may not be immediately apparent, but become apparent later in the form of premature failure of the relay. Therefore, radically different relay manufacturing facilities are required compared to electromechanical relays. Calibration and repair is no longer a task performed in the field without specialised equipment. Figure 7.4 shows the circuit board for a simple static relay and Figure 7.5 shows examples of simple and complex static relays.


*Figure 7.5: Selection of static relays*

## 7.4 DIGITAL RELAYS

Digital protection relays introduced a step change in technology. Microprocessors and microcontrollers replaced analogue circuits used in static relays to implement relay functions. Early examples began to be introduced into service around 1980, and, with improvements in processing capacity, can still be regarded as current technology for many relay applications. However, such technology will be completely superseded within the next five years by numerical relays.

Compared to static relays, digital relays introduce A/D conversion of all measured analogue quantities and use a microprocessor to implement the protection algorithm. The microprocessor may use some kind of counting technique, or use the Discrete Fourier Transform (DFT) to implement the algorithm. However, the typical microprocessors used have limited processing capacity and memory compared to that provided in numerical relays. The functionality tends therefore to be limited and restricted largely to the protection function itself. Additional functionality compared to that provided by an electromechanical or static relay is usually available, typically taking the form of a wider range of settings, and greater accuracy. A communications link to a remote computer may also be provided.

The limited power of the microprocessors used in digital relays restricts the number of samples of the waveform that can be measured per cycle. This, in turn, limits the speed of operation of the relay in certain applications. Therefore, a digital relay for a particular protection function may have a longer operation time than the static relay equivalent. However, the extra time is not significant in terms of overall tripping time and possible effects of power system stability. Examples of digital relays are shown in Figure 7.6.

*Figure 7.6: Selection of digital relays*

## 7.5 NUMERICAL RELAYS

The distinction between digital and numerical relay rests on points of fine technical detail, and is rarely found in areas other than Protection. They can be viewed as natural developments of digital relays as a result of advances in technology. Typically, they use a specialised digital signal processor (DSP) as the computational hardware, together with the associated software tools. The input analogue signals are converted into a digital representation and processed according to the appropriate mathematical algorithm. Processing is carried out using a specialised microprocessor that is optimised for signal processing applications, known as a digital signal processor or DSP for short. Digital processing of signals in real time requires a very high power microprocessor.

In addition, the continuing reduction in the cost of microprocessors and related digital devices (memory, I/O, etc.) naturally leads to an approach where a single item of hardware is used to provide a range of functions ('one-box solution' approach). By using multiple microprocessors to provide the necessary computational performance, a large number of functions previously implemented in separate items of hardware can now be included within a single item. Table 7.1 provides a list of typical functions available, while Table 7.2 summarises the advantages of a modern numerical relay over the static equivalent of only 10-15 years ago. Figure 7.7 shows typical numerical relays, and a circuit board is shown in Figure 7.8. Figure 7.9 provides an illustration of the savings in space possible on a HV feeder showing the space requirement for relays with electromechanical and numerical relay technology to provide the same functionality.

| |
|---|
| Distance Protection- several schemes including user definable) |
| Overcurrent Protection (directional/non-directional) |
| Several Setting Groups for protection values |
| Switch-on-to-Fault Protection |
| Power Swing Blocking |
| Voltage Transformer Supervision |
| Negative Sequence Current Protection |
| Undervoltage Protection |
| Overvoltage Protection |
| CB Fail Protection |
| Fault Location |
| CT Supervision |
| VT Supervision |
| Check Synchronisation |
| Autoreclose |
| CB Condition Monitoring |
| CB State Monitoring |
| User-Definable Logic |
| Broken Conductor Detection |
| Measurement of Power System Quantities (Current, Voltage, etc.) |
| Fault/Event/Disturbance recorder |

*Table 7.1: Numerical distance relay features*

Figure 7.7: Typical numerical relays

| |
|---|
| Several setting groups |
| Wider range of parameter adjustment |
| Remote communications built in |
| Internal Fault diagnosis |
| Power system measurements available |
| Distance to fault locator |
| Disturbance recorder |
| Auxiliary protection functions ( broken conductor, negative sequence, etc.) |
| CB monitoring (state, condition) |
| User-definable logic |
| Backup protection functions in-built |
| Consistency of operation times - reduced grading margin |

Table 7.2: Advantages of numerical protection relays over static

Because a numerical relay may implement the functionality that used to require several discrete relays, the relay functions (overcurrent, earth fault, etc.) are now referred to as being 'relay elements', so that a single relay (i.e. an item of hardware housed in a single case) may implement several functions using several relay elements. Each relay element will typically be a software routine or routines.

The argument against putting many features into one piece of hardware centres on the issues of reliability and availability. A failure of a numerical relay may cause many more functions to be lost, compared to applications where different functions are implemented by separate hardware items. Comparison of reliability and availability between the two methods is complex as inter-dependency of elements of an application provided by separate relay elements needs to be taken into account.

With the experience gained with static and digital relays, most hardware failure mechanisms are now well understood and suitable precautions taken at the design stage. Software problems are minimised by rigorous use of software design techniques, extensive prototype testing (see Chapter 21) and the ability to download amended software into memory (possibly using a remote telephone link for download). Practical experience indicates that numerical relays are at least as reliable and have at least as good a record of availability as relays of earlier technologies.

As the technology of numerical relays has only become available in recent years, a presentation of the concepts behind a numerical relay is presented in the following sections.

### 7.5.1 Hardware Architecture

The typical architecture of a numerical relay is shown in Figure 7.10. It consists of one or more DSP microprocessors, some memory, digital and analogue input/output (I/O), and a power supply. Where multiple processors are provided, it is usual for one of them to be dedicated to executing the protection relay algorithms, while the remainder implements any associated logic and handles the Human Machine Interface (HMI) interfaces. By organising the I/O on a set of plug-in printed circuit boards (PCB's), additional I/O up to the limits of the hardware/software can be easily added. The internal communications bus links the hardware and therefore is critical component in

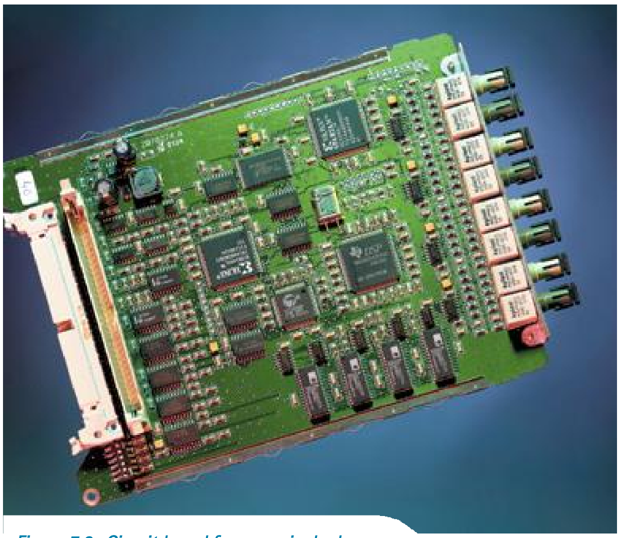

Figure 7.8: Circuit board for numerical relay

the design. It must work at high speed, use low voltage levels and yet be immune to conducted and radiated interference from the electrically noisy substation environment. Excellent shielding of the relevant areas is therefore required. Digital inputs are optically isolated to prevent transients being transmitted to the internal circuitry. Analogue inputs are isolated using precision transformers to maintain measurement accuracy while removing harmful

Figure 7.9: Space requirements of different relay technologies for same functionality