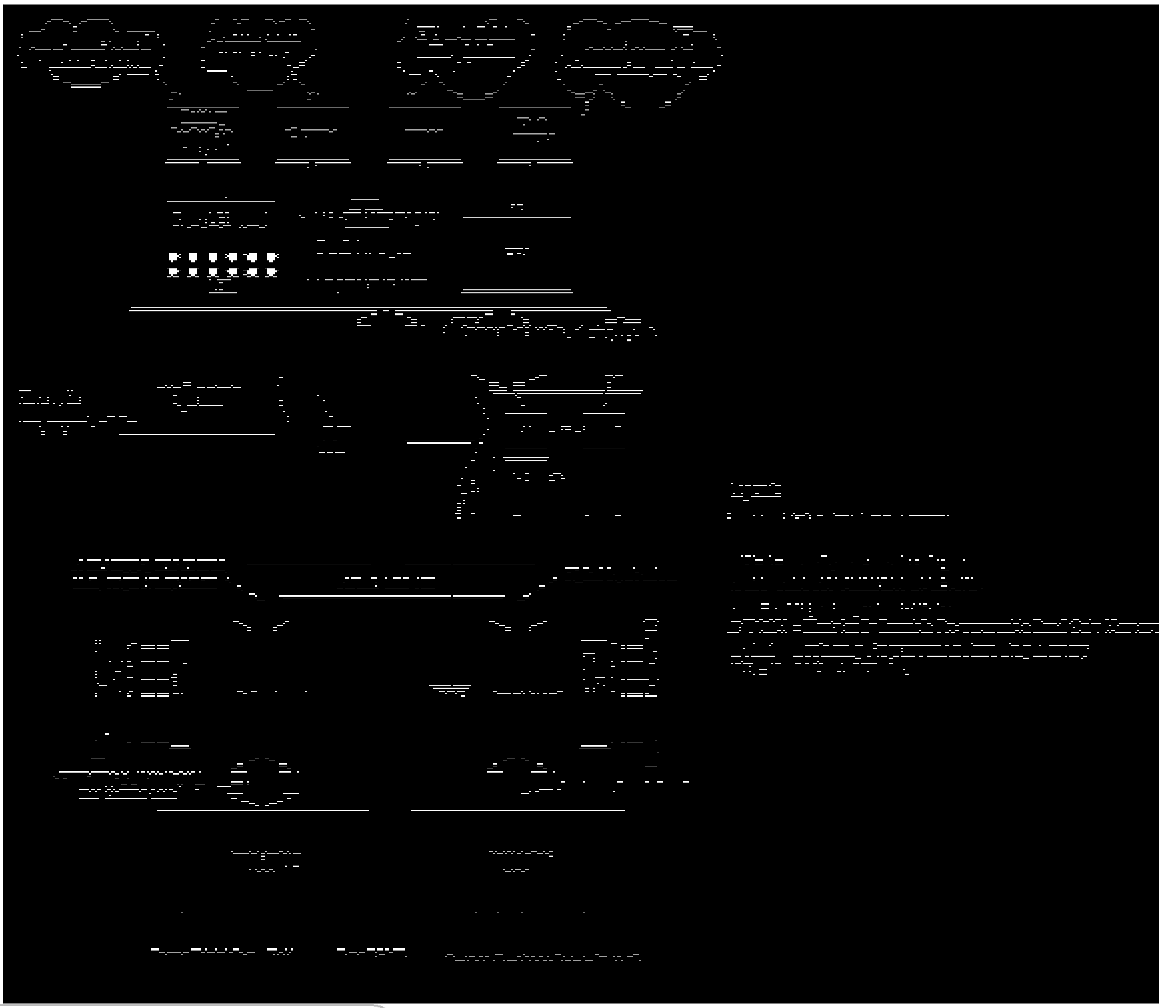

Figure 7.10: Relay modules and information flow

transients. Additionally, the input signals must be amplitude limited to avoid them exceeding the power supply voltages, as otherwise the waveform will appear distorted, as shown in Figure 7.11.

Analogue signals are converted to digital form using an A/D converter. The cheapest method is to use a single A/D converter, preceded by a multiplexer to connect each of the input signals in turn to the converter. The signals may be initially input to a number of simultaneous sample-and-hold circuits prior to multiplexing, or the time relationship between successive samples must be known if the phase relationship between signals is important. The alternative is to provide each input with a dedicated A/D converter, and logic to ensure that all converters perform the measurement simultaneously.

The frequency of sampling must be carefully considered, as the Nyquist criterion applies:

$$f_s \quad 2 \times f_h$$

where:

f_s = sampling frequency

f_h = highest frequency of interest

If too low a sampling frequency is chosen, aliasing of the input signal can occur (Figure 7.12), resulting in high frequencies appearing as part of signal in the frequency range of interest. Incorrect results will then be obtained. The solution is to apply an anti-aliasing filter, coupled with an appropriate choice of sampling frequency, to the analogue signal, so those frequency components that could cause aliasing are filtered out. Digital sine and cosine filters are used (Figure 7.13), with a frequency response shown in Figure 7.14, to extract the real and imaginary components of the signal. Frequency tracking of the input signals is applied to adjust the sampling frequency so that the desired number of samples/cycle is always obtained. A modern numerical relay may sample each analogue input quantity at between 16 and 24 samples per cycle.

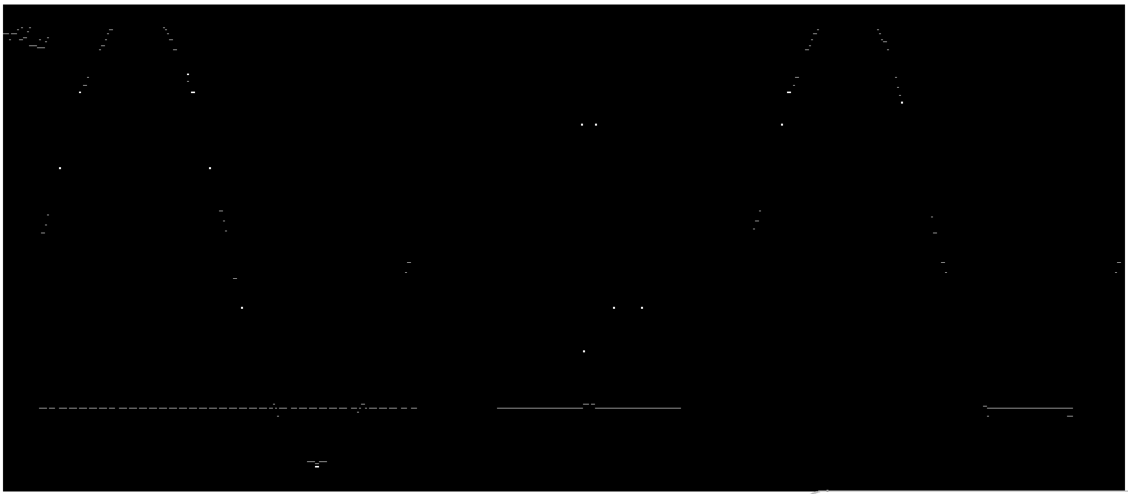

Figure 7.11: Signal distortion due to excessive amplitude

All subsequent signal processing is carried out digitally in software, final digital outputs use relays to provide isolation or are sent via an external communications bus to other devices.

7.5.2 Relay Software

The software provided is commonly organised into a series of tasks, operating in real time. An essential component is the Real Time Operating System (RTOS), whose function is to ensure that the other tasks are executed as and when required, on a priority basis.

Other task software provided will naturally vary according to the function of the specific relay, but can be generalised as follows:

a. system services software – this is akin to the BIOS of an ordinary PC, and controls the low-level I/O for the relay (i.e. drivers for the relay hardware, boot-up sequence, etc.)

b. HMI interface software – the high level software for communicating with a user, via the front panel controls or through a data link to another computer running suitable software, storage of setting data, etc.

c. application software – this is the software that defines the protection function of the relay

d. auxiliary functions – software to implement other features offered in the relay – often structured as a series of modules to reflect the options offered to a user by the manufacturer

7.5.3 Application Software

The relevant software algorithm is then applied. Firstly, the values of the quantities of interest have to be determined from the available information contained in the data samples. This is conveniently done by the application of the Discrete Fourier Transform (DFT), and

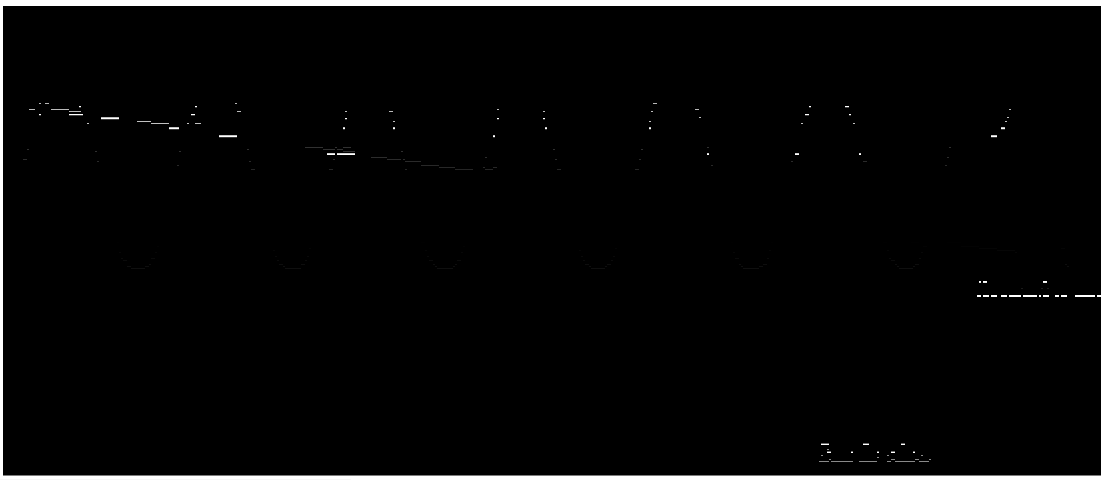

Figure 7.12: Signal aliasing problem

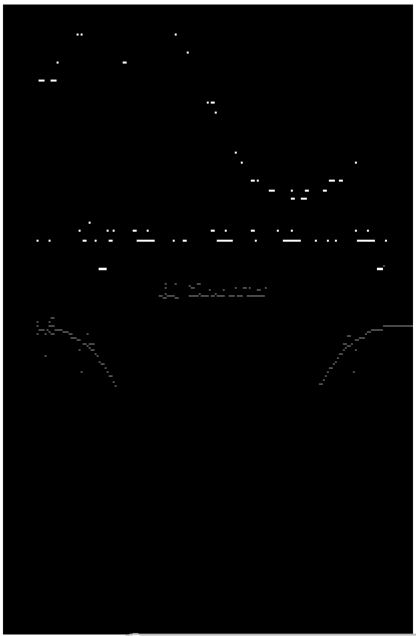

Figure 7.13: Digital filters

the result is magnitude and phase information for the selected quantity. This calculation is repeated for all of the quantities of interest. The quantities can then be compared with the relay characteristic, and a decision made in terms of the following:

a. value above setting – start timers, etc.

b. timer expired – action alarm/trip

c. value returned below setting – reset timers, etc.

d. value below setting – do nothing

e. value still above setting – increment timer, etc.

Since the overall cycle time for the software is known, timers are generally implemented as counters.

7.6 ADDITIONAL FEATURES OF NUMERICAL RELAYS

The DSP chip in a numerical relay is normally of sufficient processing capacity that calculation of the relay protection function only occupies part of the processing capacity. The excess capacity is therefore available to perform other functions. Of course, care must be taken never to load the processor beyond capacity, for if this happens, the protection algorithm will not complete its calculation in the required time and the protection function will be compromised.

Typical functions that may be found in a numerical relay besides protection functions are described in this section. Note that not all functions may be found in a particular relay. In common with earlier generations of relays, manufacturers, in accordance with their perceived market segmentation, will offer different versions offering a different set of functions. Function parameters will generally be available for display on the front panel of the relay and also via an external

Figure 7.14: Filter frequency response

communications port, but some by their nature may only be available at one output interface.

7.6.1 Measured Values Display

This is perhaps the most obvious and simple function to implement, as it involves the least additional processor time. The values that the relay must measure to perform its protection function have already been acquired and processed. It is therefore a simple task to display them on the front panel, and/or transmit as required to a remote computer/HMI station. Less obvious is that a number of extra quantities may be able to be derived from the measured quantities, depending on the input signals available. These might include:

a. sequence quantities (positive, negative, zero)

b. power, reactive power and power factor

c. energy (kWh, kvarh)

d. max. demand in a period (kW, kvar; average and peak values)

e. harmonic quantities

f. frequency

g. temperatures/RTD status

h. motor start information (start time, total no. of starts/reaccelerations, total running time

i. distance to fault

The accuracy of the measured values can only be as good as the accuracy of the transducers used (VT's CT's, A/D converter, etc.). As CT's and VT's for protection functions may have a different accuracy specification to those for metering functions, such data may not be sufficiently accurate for tariff purposes. However, it will be sufficiently accurate for an operator to assess system conditions and make appropriate decisions.

7.6.2 VT/CT Supervision

If suitable VT's are used, supervision of the VT/CT supplies can be made available. VT supervision is made more complicated by the different conditions under which there may be no VT signal – some of which indicate VT failure and some occur because of a power system fault having occurred.

CT supervision is carried out more easily, the general principle being the calculation of a level of negative sequence current that is inconsistent with the calculated value of negative sequence voltage.

7.6.3 CB Control/State Indication /Condition Monitoring

System operators will normally require knowledge of the state of all circuit breakers under their control. The CB position-switch outputs can be connected to the relay digital inputs and hence provide the indication of state via the communications bus to a remote control centre.

Circuit breakers also require periodic maintenance of their operating mechanisms and contacts to ensure they will operate when required and that the fault capacity is not affected adversely. The requirement for maintenance is a function of the number of trip operations, the cumulative current broken and the type of breaker. A numerical relay can record all of these parameters and hence be configured to send an alarm when maintenance is due. If maintenance is not carried out within defined criteria (such as a pre-defined time or number of trips) after maintenance is required, the CB can be arranged to trip and lockout, or inhibit certain functions such as auto-reclose.

Finally, as well as tripping the CB as required under fault conditions, it can also be arranged for a digital output to be used for CB closure, so that separate CB close control circuits can be eliminated.

7.6.4 Disturbance Recorder

The relay memory requires a certain minimum number of cycles of measured data to be stored for correct signal processing and detection of events. The memory can easily be expanded to allow storage of a greater time period of input data, both analogue and digital, plus the state of the relay outputs. It then has the capability to act as a disturbance recorder for the circuit being monitored, so that by freezing the memory at the instant of fault detection or trip, a record of the disturbance is available for later download and analysis. It may be inconvenient to download the record immediately, so facilities may be provided to capture and store a number of disturbances. In industrial and small distribution networks, this may be all that is required. In transmission networks, it may be necessary to provide a single recorder to monitor a number of circuits simultaneously, and in this case, a separate disturbance recorder will still be required.

7.6.5 Time Synchronisation

Disturbance records and data relating to energy consumption requires time tagging to serve any useful purpose. Although an internal clock will normally be present, this is of limited accuracy and use of this clock to provide time information may cause problems if the disturbance record has to be correlated with similar records from other sources to obtain a complete picture of an event. Many numerical relays have the facility for time synchronisation from an external clock. The standard normally used is an IRIG-B signal, which may be derived from a number of sources, the latest being from a GPS satellite system.

7.6.6 Programmable Logic

Logic functions are well suited to implementation using microprocessors. The implementation of logic in a relay is not new, as functions such as intertripping and auto-reclose require a certain amount of logic. However, by providing a substantial number of digital I/O and making the logic capable of being programmed using suitable off-line software, the functionality of such schemes can be enhanced and/or additional features provided. For instance, an overcurrent relay at the receiving end of a transformer feeder could use the temperature inputs provided to monitor transformer winding temperature and provide alarm/trip facilities to the operator/upstream relay, eliminating the need for a separate winding temperature relay. This is an elementary example, but other advantages are evident to the relay manufacturer – different logic schemes required by different Utilities, etc., no longer need separate relay versions or some hard-wired logic to implement, reducing the cost of manufacture. It is also easier to customise a relay for a specific application, and eliminate other devices that would otherwise be required.

7.6.7 Provision of Setting Groups

Historically, electromechanical and static relays have been provided with only one group of settings to be applied to the relay. Unfortunately, power systems change their topology due to operational reasons on a regular basis. (e.g. supply from normal/emergency generation). The different configurations may require different relay settings to maintain the desired level of network protection (since, for the above example, the fault levels will be significantly different on parts of the network that remain energised under both conditions).

This problem can be overcome by the provision within the relay of a number of setting groups, only one of which is in use at any one time. Changeover between groups can be achieved from a remote command from the operator, or possibly through the programmable logic system. This may obviate the need for duplicate relays to be fitted with some form of switching arrangement of the inputs and outputs depending on network configuration. The operator will also have the ability to remotely program the relay with a group of settings if required.

7.6.8 Conclusions

The provision of extra facilities in numerical relays may avoid the need for other measurement/control devices to be fitted in a substation. A trend can therefore be discerned in which protection relays are provided with functionality that in the past has been provided using separate equipment. The protection relay no longer performs a basic protection function; but is becoming an integral and major part of a substation automation scheme. The choice of a protection relay rather than some other device is logical, as the protection relay is probably the only device that is virtually mandatory on circuits of any significant rating. Thus, the functions previously carried out by separate devices such as bay controllers, discrete metering transducers and similar devices are now found in a protection relay. It is now possible to implement a substation automation scheme using numerical relays as the principal or indeed only hardware provided at bay level. As the power of microprocessors continues to grow and pressure on operators to reduce costs continues, this trend will probably continue, one obvious development being the provision of RTU facilities in designated relays that act as local concentrators of information within the overall network automation scheme.

7.7 NUMERICAL RELAY ISSUES

The introduction of numerical relays replaces some of the issues of previous generations of relays with new ones. Some of the new issues that must be addressed are as follows:

a. software version control
b. relay data management
c. testing and commissioning

7.7.1 Software Version Control

Numerical relays perform their functions by means of software. The process used for software generation is no different in principle to that for any other device using real-time software, and includes the difficulties of developing code that is error-free. Manufacturers must therefore pay particular attention to the methodology used for software generation and testing to ensure that as far as possible, the code contains no errors. However, it is virtually impossible to perform internal tests that cover all possible combinations of external effects, etc., and therefore it must be accepted that errors may exist. In this respect, software used in relays is no different to any other software, where users accept that field use may uncover errors that may require changes to the software. Obviously, type testing can be expected to prove that the protection functions implemented by the relay are carried out properly, but it has been known for failures of rarely used auxiliary functions to occur under some conditions.

Where problems are discovered in software subsequent to the release of a numerical relay for sale, a new version of the software may be considered necessary. This process then requires some form of software version control to be implemented to keep track of:

a. the different software versions in existence
b. the differences between each version
c. the reasons for the change
d. relays fitted with each of the versions

With an effective version control system, manufacturers are able to advise users in the event of reported problems if the problem is a known software related problem and what remedial action is required. With the aid of suitable software held by a user, it may be possible to download the new software version instead of requiring a visit from a service engineer.

7.7.2 Relay Data Management

A numerical relay usually provides many more features than a relay using static or electromechanical technology. To use these features, the appropriate data must be entered into the memory of the relay. Users must also keep a record of all of the data, in case of data loss within the relay, or for use in system studies, etc. The amount of data per numerical relay may be 10-50 times that of an equivalent electromechanical relay, to which must be added the possibility of user-defined logic functions. The task of entering the data correctly into a numerical relay becomes a much more complex task than previously, which adds to the possibility of a mistake being made. Similarly, the amount of data that must be recorded is much larger, giving rise potentially to problems of storage.

The problems have been addressed by the provision of software to automate the preparation and download of relay setting data from a portable computer connected to a communications port of the relay. As part of the process, the setting data can be read back from the relay and compared with the desired settings to ensure that the download has been error-free. A copy of the setting data (including user defined logic schemes where used) can also be stored on the computer, for later printout and/or upload to the users database facilities.

More advanced software is available to perform the above functions from an Engineering Computer in a substation automation scheme – see Chapter 24 for details of such schemes).

7.7.3 Relay Testing and Commissioning

The testing of relays based on software is of necessity radically different from earlier generations of relays. The topic is dealt with in detail in Chapter 21, but it can be mentioned here that site commissioning is usually restricted to the in-built software self-check and verification that currents and voltages measured by the relay are correct. Problems revealed by such tests require specialist equipment to resolve, and hence field policy is usually on a repair-by-replacement basis.

7.8 REFERENCES

7.1 *Protective Relays Application Guide*, 3rd edition. AREVA T&D Protection and Control, 1987.