

AN6145

Fault Finding in Thyristor Equipment

Application Note

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19. Fault Finding in Thyristor Equipment

There is no doubt that one of the big advantages of static control equipment is that it continues to work for long periods of time without maintenance. It is also true that its biggest problem is finding the fault when the equipment stops working. The long periods of satisfactory operation mean that those entrusted with the job of keeping it running have little opportunity of learning to understand it. Fault finding often provides one of the few chances of finding out how equipment works, but it usually has to take place urgently so that the equipment can be put back into operation as quickly as possible. It is not therefore surprising that some users resort to exchange of subassemblies as a means of reducing downtime, nor that an increasing number of static equipment designs are based on removable, interchangeable functional assemblies.

However, this does not pinpoint the specific fault, and the only sure method of doing this is to understand the basic principles of operation of the particular equipment. It is a main aim of this book to help the users understand their equipment so that they may readily be able to find those faults which occasionally occur.

In this chapter, the most common faults which occur in thyristor equipment will be explained along with the fault symptoms which can be observed or measured. The content has been restricted to considering those faults which occur either in the thyristor power circuit (with its auxiliary and protective components), or in the gate firing system (as defined in Chapter 8). Electronic control-system faults are not included in any detail except where they have a specific bearing on the thyristor circuit fault or its symptoms. In the following section, the “golden rules” of fault finding are stated and although these are basically common sense, and hardly touch on the technical operation of the equipment, they are fundamental to quick fault-location in all electrical equipment. This chapter has been written to follow on from those dealing with measurement and testing of thyristor equipment. It is assumed that these have already been read and understood.

The most difficult fault finding occurs during the testing period in the manufacturer's works because the tester has to assume initially that anything could be wrong. Fortunately, he will usually have more sophisticated measuring and testing facilities available to him to check all parameters under a variety of operating conditions. Faults which occur after the equipment has operated correctly are relatively easier to assess as it is reasonable to assume that only one fault has occurred and it is possible to compare operating conditions with those which occurred during normal, correct operation. In practice, however, the lack of measuring and loading facilities on site make even simple faults hard to find.

If components just failed completely, fault location would be much easier as the fault would be obvious after only a few simple tests. Unfortunately, components also deteriorate and initially fail only under extreme operating conditions which may be difficult to reproduce. This chapter should help in the location of most faults and does explain the methods which can produce the quickest results. However, there will always be faults which are very difficult to find and no amount of written information will overcome this. Intermittent faults are in this category and these can usually be found over a relatively long period of time by systematic substitution. In these difficult cases, the solution will only be found by observation of symptoms and simple tests, and, most important, technical deduction.

19.1 The Important Principles of Fault Finding

In general, the process of fault location is the application of common sense to a technical understanding of the principles of operation. It is the method of approaching the problem which is all-important.

The following points define the common-sense method which gives quick and efficient results:

1. *Understand the operation of the equipment* and then fault finding will be considerably simplified. Most reputable manufacturers provide instruction books explaining the operation and circuitry of the equipment; they may even include some fault-location advice. Study these and particularly refer to them when a fault occurs. Any time spent working out how the unit works will be amply recovered when a fault occurs.
2. *Do not hurry - think.* Whenever an important or expensive piece of equipment fails to work it is invariably necessary to repair it as quickly as possible. The quickest way is always to observe and think; action can follow later. No problem will be solved by furious action; this usually results in more damage which may be much more difficult to repair.
3. *Record the symptoms.* Fault finding is a technical form of detective work. The clues to the fault are often there to see. Make full use of any fault-indication alarms and lamps. Find out when the fault occurred and under what equipment conditions. Note the location of any obviously failed items.
4. *Prove any potential fault explanation* before accepting it as a true statement of what occurred. Having decided what may have happened, find a way of proving that it is correct. Only the true explanation of the fault will fully satisfy *all* the symptoms.
5. *Study any recent changes first.* Faults often show up when some change in operational conditions has been made or after a routine maintenance check, etc. Always study the recent history; it may be a clue to the fault and it may even be the change which has caused the fault to occur. For example, a change in the load process may result in additional current loading on the control equipment.
6. *Failed components may be the result* of the fault rather than its cause. Many faulty conditions following a failed or incorrectly working component will result in excessive stresses being placed on other components. The original fault may not be obvious until these stressed components fail. When failed components are located, it is essential to investigate the possible cause of their failure before operating the equipment further, to avoid repeated failures.

7. *Check the electrical parameters* of the circuit under a safe operating condition to obtain more clues to the fault. Often auxiliary circuits, e.g. power supplies, electronics, fans, relays, etc., can be measured without the main power circuit being in operation.

8. *Try to reproduce the faulty condition* if the cause of the fault cannot be readily located. This should be done under as safe an operating condition as possible, preferably by temporarily disconnecting the load system from the equipment.

9. *Locate the area of the fault* by studying the equipment in sections. Most systems will naturally split themselves into electrical functions, each having a simply defined role and relatively few input and output connections. The initial aim should be to locate the faulty function.

10. *Faults do not go away.* If the fault has not been found and corrected it will return some time.

19.2 Naturally Commutated Equipment

Any of the following faults can occur in a thyristor power circuit and each will result in different symptoms:

- a. A thyristor short-circuit.
- b. Thyristor forward break-over.
- c. A non-conducting thyristor.
- d. Diode or thyristor reverse blocking failure.
- e. Snubber circuit failure.
- f. Surge suppression circuit failure.

A short-circuit thyristor will invariably result in a high fault current and the protection fuses or circuit breaker will operate. These fault currents can flow even if the load circuit is disconnected.

A thyristor or diode reverse blocking failure will have a similar effect.

Thyristor forward break-over will cause the maximum circuit voltage to be applied to the load. If the load is a low-impedance one, such as a motor, this can cause high fault currents which will blow fuses or trip protective circuit breakers. In an antiparallel circuit, it will cause internal fault currents within the equipment which will probably blow circuit fuses. If it happens while an equipment is inverting, it will initiate an inversion failure, again causing fault currents to flow.

It may be caused by thyristor deterioration, the application of excessive voltage or rate of change of voltage (dv/dt), over-temperature, or it can result from misfiring. Any of these faults will produce the same result as above. If a single thyristor in a parallel set breaks-over, then the full circuit current will flow through the faulty thyristor. If it is one of a series string, then its share of the circuit voltage will have to be accepted by the other thyristors. If thyristor break-over occurs in a circuit with a high-impedance load, then it will show up only as instability or lack of control.

A non-conducting thyristor will only result in a reduced output if the circuit is rectifying. If, however, it is inverting, the result will be an inversion failure and a high fault current which will operate protective fuses or circuit breakers. The condition can be due to an internal fault in the thyristor, a lack of firing pulses, or failure of the thyristor to pick up current.

A non-conducting thyristor in a parallel set will cause its current to be shared among the remaining healthy thyristors in that arm of the circuit. If it is one of a series string, it will probably break-over when the others are fired and it would eventually fail.

An open-circuit snubber circuit will cause high peak voltages and dv/dt to be applied to the appropriate thyristor, causing it to break-over. A short-circuit in the snubber will often be followed by an open-circuit due to the high current which would temporarily flow through it.

Surge suppression circuit failure resulting in loss of overvoltage protection will be followed by thyristor break-over or failure.

Similar symptoms can also result from faults within the firing circuit.

Complete loss of pulses will result in no output from the thyristor circuit; if it occurs during rectifying operation, no fault currents will be produced, but if the circuit was inverting, a short-circuit inversion failure will occur, causing operation of over-current protection devices.

Loss of pulses to one arm of the circuit will produce exactly the same symptoms as a non-conducting thyristor arm.

Extra firing pulses occurring during normally non-conducting periods will usually have the same effect as thyristor or thyristor arm break-over.

Pulses of insufficient magnitude may not fire the thyristors. If they do manage to fire them, there is a possibility of di/dt failure of the thyristors.

If a sudden jump in the firing pulse phase position occurs, it will cause a rise or fall in the output voltage. Depending on its severity, it may cause an over-current fault and operation of the protection or it may cause control-system instability if the current control is able to prevent excessive current use.

Incorrect setting of the front stops in the firing circuit, for any reason, will only cause a problem with short firing pulses. If the firing pulse occurs before the forward voltage, the thyristor will not fire; if it occurs when the forward voltage is too low, the thyristor may not pick up.

Incorrect setting of back stops in the firing circuit can have more significant consequences. If the firing pulses occur too early, it may not be possible to maintain satisfactory control; if they are too late, inversion failure may occur.

Incorrect phase rotation of the firing-circuit reference voltage waveforms will result in completely erratic firing of the thyristors and closed-loop control circuits will complicate the symptoms even further. The usual results will be lack of control and high over-current faults, causing operation of fuses or circuit breakers.

Fault-finding Procedure

When faced with a fault situation on thyristor equipment which is normally working, the basic symptoms are likely to be that no output is available (possibly due to the supply switches having tripped), the control of the output is erratic, or full output is continuously available. This latter case is only likely on a high-impedance load as with others, for example a motor load, high output will normally cause the over-current protection devices to trip.

In all cases, the sensible initial procedure is to check all available alarms, indicating lamps, fuses, and protective relays, etc. If this does not enable the fault to be identified, then the equipment should be operated in such a way that high fault load currents cannot flow by:

- a. Disconnecting low-impedance loads.
- b. Removing the interconnection between anti-parallel circuits or removing the firing pulses from one of the circuits.
- c. Connecting a low current resistance load to the equipment to enable good thyristor pick-up to occur (say 10 per cent rated load at full voltage).

If these tests do not reveal the cause of the fault, the next stage is to try to reproduce the faulty condition. The fault may exhibit one of the above symptoms, perhaps after running under load conditions, in which case the guidance of Table 19.1 should be followed.

If the fault conditions result in immediate blowing of fuses or the operation of over-current protection circuit breakers, then Table 19.2 will be of assistance.

Study of the operation of the equipment under these test conditions, with the help of Table 19.1, should enable the fault to be located and corrected. It is often a help to be able to set the level of input control signal directly to the firing circuits during these tests.

Table 19.1 Fault finding

Symptom	Possible fault	Action recommended
<i>No output</i> although control signal to the firing circuit is sufficient	No power supply No firing pulses	Check main power supply, fuses, circuit breakers, etc. 1. Check firing pulses. If none: 2. Check any inhibit or pulse suppression system 3. Check power supply to firing circuit 4. Check reference waveforms are present
<i>Equipment trips out due to over-current or fuse blowing</i> although the low-impedance load has been disconnected	Thyristor or diode reverse voltage failure	1. Check thyristor associated with blown fuses, if any doubt, replace them 2. Check overvoltage protection circuits before switching on again
<i>Erratic control</i> at low output	Erratic firing pulses	1. Check firing pulses with a constant input signal to the firing circuit 2. Check reference waveforms 3. Check inhibit signals
	Thyristor forward break-over	1. Output should still be erratic even with firing pulses disconnected or inhibited 2. Study output voltage waveforms to decide faulty thyristor 3. Check overvoltage protection circuits and snubbers
<i>Erratic control</i> at a specific point in the control range	Firing circuit mal-operation	1. Check firing pulses 2. Check reference waveforms
<i>Erratic control</i> near to full output	With short pulse firing circuits this may be caused by incorrect front stop settings	1. Check firing pulses 2. Check front stop settings
<i>Insufficient output</i> although control signal is sufficient	Thyristor(s) not being fired Open-circuit thyristor	1. Check firing pulses 2. Check reference waveforms Study output voltage waveforms to find which arm is not conducting

Table 19.2 Over-current fault conditions

Condition under which fuses or circuit breakers operate	Possible faults
While feeding power to the load at low output	1. Thyristor break-over 2. Erratic firing pulses
During acceleration or high load current	Current-limit failure
During regeneration of power from the load	1. Thyristor break-over 2. Erratic or lost firing pulses
During regeneration at high load current	Incorrect firing circuit backstop settings
On anti-parallel changeover to the opposite polarity	1. Anti-parallel changeover logic fault 2. Zero-current detection fault
At low output in half-controlled bridge circuit	Incorrect firing circuit backstop settings

19.3 Forced-commutated Equipment

Fault finding in forced-commutated thyristor circuits is dominated by one very important factor: all significant faults will result in a failure to commute, a short circuit, and usually operation of the over-current protective fuses, circuit breakers, or static switches.

Excessive currents. All forced-commutated circuits have a definite limit to the level of current which can be switched: if this level is exceeded, a commutation failure will occur. In all inverter circuits this will cause a short-circuit current to flow as soon as another thyristor is turned on. This current will quickly increase the thyristor junction temperatures above the controllable limit and they will remain in the ON-state.

The situation is nearly as bad in chopper circuits in that commutation failure will result in the unit giving full output voltage, which, with low impedance loads, will result in uncontrollable high currents.

Thyristor break-over or misfiring will have the same result and this can be directly caused by many faults in the thyristor circuit and the firing system. Snubber or voltage protection circuit failures, excessive thyristor temperature, faulty firing pulses (for any of the many possible reasons), as well as thyristor deterioration itself all come within this category resulting in commutation failure.

Loss of supply. In addition, most circuits depend on the presence of the input power supply for correct operation. Even temporary loss of the input supply can lead to insufficient commutating ability because the commutating capacitors may not fully charge. Supply difficulties can therefore also be a reason for commutation failure and the equipment consequently tripping out.

Control faults. In some designs it is also possible for failures within the control system, which is instructing the firing circuit, to have the same consequence of incorrectly firing the thyristors or causing excessive currents. The better designs, however, contain electronic circuitry to prevent incorrect firing of the thyristors by control system changes or faults. In addition, a fast and accurate current-limiting control can prevent over-currents being caused by the load, the supply system, or the control electronics.

The majority of faults will therefore result in the same overall effect and some further investigation will always be necessary to locate the prime cause.

Fault-finding Procedure

When approaching a fault, it is first necessary to accept the fact that the cause of the unit having blown its fuses or tripped its protection switches may be:

- a. A load fault causing excessive current.
- b. An input power supply failure.
- c. An internal fault in the thyristor equipment.

It is most unwise to delve into the complicated thyristor and control circuitry until some initial external checks have been made:

1. Study the load system to find out if any load faults have occurred, i.e. fuses blown, circuit breakers tripped, overloading, etc.
2. Investigate the power supply system to make sure, as far as possible, that a fault has not occurred causing temporary or permanent loss of supply to the equipment. Check line fuses and circuit breaker trip relays, etc.

If no fault has been located then:

3. Disconnect the load from the equipment and try to operate the equipment under this condition.

If the unit is unable to operate under this no-load condition either because it gives no output or because it results in a commutation failure, then the following detailed investigations will be necessary:

4. Note the condition of all alarms, indicating lamps, protective relays and switches, the operation of cooling fans and pumps.
5. Switch off and visually inspect all significant components, particularly looking for:
 - a. Blown fuses.
 - b. Wire, cables, or busbars disconnected.
 - c. Mechanical damage.
 - d. Failed commutating capacitors (usually observed by their leaking, bulging, or exploding).
 - e. Overheated resistors.

6. Switch on the auxiliary power supplies, preferably without the main power thyristor circuit being energized. Operate the electronic controls and firing circuits, etc. under this condition and check all possible auxiliary circuits including:

- a. Auxiliary power packs.
- b. The firing pulses to the thyristors.
- c. The frequency of the firing pulses.
- d. The correct timing between the firing of the various thyristors.
- e. The end stop limits of the control range.

7. Inhibit or disconnect firing pulses to the thyristors and switch on the main power supply. All thyristors should remain in the OFF-state and all snubber and voltage protection circuits should be working. If any fault occurs under this condition, it can only be a component in the power circuit, e.g. a thyristor.

If the unit will work, apparently satisfactorily, on no load but not when load is applied, it is recommended that tests 6 and 7 above are carried out, followed by:

8. A light-load test as detailed in Section 18.3 so that circuit turn-off times and thyristor firing could be positively confirmed. If the unit still fails on load, the following points may help:

9. If the unit fails on starting or stopping, the necessary logic circuitry which controls the sequence of starting or stopping should be checked.

10. If the unit fails after a period of time, then those components which significantly heat up should be suspected. This will include power semiconductors in the firing circuits as well as the main power thyristors.

11. If the unit fails only at high load, then either the current limit system is not holding the current low enough or a thyristor turn-off time is too high.

In the unlikely event of the fault still not being found, then selective replacement of specific sub-assemblies and components will usually solve the problem in the quickest way. Replacement of the thyristors, which are difficult to test and prove, should be followed by full testing of them by the manufacturer, particularly if there is doubt as to which one is faulty.

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