SYSTEM-LEVEL HYBRID FAULT DIAGNOSABILITY WITH GENERAL TEST INVALIDATION

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Abstract

On the basis of a self-checking system model with general test invalidation the problem of diagnosability in the case of permanent and intermittent faults known as hybrid fault situation is discussed. Two hybrid fault models have been introduced that take into consideration the behaviour of the faulty tester. On the basis of the relationship that exists between the permanent and hybrid fault models, given the number of all units in a system, the upper bound of the number of diagnosable faulty units is defined without restriction on the test connection assignment.

Keywords: self-checking system, intermittent faults, general test invalidation, hybrid fault diagnosability.

Introduction

The study of diagnosable systems with different models received considerable attention in the last 20 years. The models that have been proposed in the literature assign different interpretation to the test outcomes. The most extensively studied one is the PMC model known also as symmetrical invalidation model, introduced by PREPARATA, METZE and CHIEN (1967). Very often is used the asymmetrical invalidation of the BGM model recommended by BARSI, GRANDONI and MAESTRINI (1976). In both invalidation models the system consists of intelligent units which are able to test each other individually and completely. A unit can be either fault-free or faulty and may be testing another fault-free or faulty unit. The general test invalidation table (*Table 1*) represents all possible test invalidations that may occur in different models.

Nine different test invalidations can come into consideration that may be referred to as special cases of the symmetrical invalidation model. Primarily the various models have been used for the case in which the faulty units can only be permanently faulty. In general, a faulty unit can be either permanently or intermittently faulty. An intermittently faulty unit can behave either as a fault-free or as a faulty unit in its different tests.

Table 1
General test invalidation table

Tester	Unit under test	Test outcome
fault-free	fault-free	$a=0$
fault-free	faulty	$b=1$
faulty	fault-free	$c=0$ or 1 or X
faulty	faulty	$d=0$ or 1 or X

Fault diagnosis using PMC models has been studied recently by MALLELA and MASSON (1978 and 1980) and DAHBURA and MASSON (1983) for the case in which some or all of the faulty units can be intermittently faulty. In general, the explicitly bounded combinations of permanently faulty and intermittently faulty units in the system are referred to as hybrid fault situations. The complete set of test outcomes is called a syndrome. The diagnosis of hybrid fault situations in a system can be described as the identification of faulty units on the basis of the syndromes produced by the test applications. Because of the great variety of syndromes that may be produced in a given fault situation, difficulties can arise in the diagnosability of the faulty units. It is supposed that in a system the units do not go faulty all at the same time. Therefore a restriction of the fault situation is applied, for a system of n units the number of faulty ones is assumed not to exceed t. If all faulty units can be identified based on a given syndrome produced by a faulty set, then the diagnosis is said to be complete. If no fault-free units are identified as faulty, the diagnosis is correct. However, if intermittent faults are present, the incomplete diagnosis is the best one achievable, because an intermittently faulty unit can remain undetected for many test applications. MALLELA and MASSON (1980) and YANG and MASSON (1985 and 1987) have dealt with the diagnosis of hybrid fault situations.

The diagnosis of hybrid faults discussed in this paper uses some elements of the approach compatible with the diagnosis of permanent fault situations proposed by MALLELA and MASSON (1980). A syndrome is defined to be permanent fault (pf) compatible if it may be produced by a set of permanently faulty units. In order to obtain a pf-compatible syndrome in a hybrid fault situation, a repeated application of the test set is required. After each test application an updated syndrome is formed, in which $a_{ij}=1$ if and only if unit u_i evaluates unit u_j to be faulty in any of the test set applications; otherwise $a_{ij}=0$. The diagnosis of the faulty units is made on the basis of the updated syndrome if it is pf-compatible.

Models of Hybrid Faults

A fault-free tester correctly qualifies the unit under test. When the tester is faulty the test result produced during the repeated test applications may give different qualifications of the tested unit. The behaviour of the faulty tester depends on its internal structure.

Sometimes a permanently faulty tester can give deterministic qualifications of the tested unit throughout the repeated testing (e.g. when the error is in the compare function). It is possible also that the faulty tester qualifies the tested unit with an unpredictable result throughout the repeated testing.

This kind of different behaviour does not play any role in the case of permanent faults, because it is enough to test only once in order to get a syndrome for the diagnosis.

Let us suppose that in a self-checking system there are both permanently and intermittently faulty units. Test connections exist between the units and the testing strategy is the repeated application of the test set as a result of which binary sequences are formed.

I. Fixed Hybrid Fault Model

Let us suppose that in a system the behaviour of the permanently faulty tester is such that the test outcome of the unit under test is always one and the same independently of the valid test invalidation. Because of this deterministic behaviour the test sequence formed during the repeated testing would contain either only zeros or only ones (*Fig. 1*).

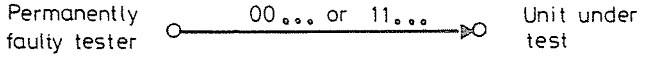

Fig. 1. Test sequence of a permanently faulty tester in the case of PMC test invalidation

A unit can be defined to be intermittently faulty if during the repeated testing in one test at least it has behaved like a faulty unit and in a test at least it has behaved like a fault-free one. Because of its character the test sequence would contain both zeros and ones. (*Fig. 2*).

Fig. 2. Test sequence of an intermittently faulty in the case of PMC test invalidation

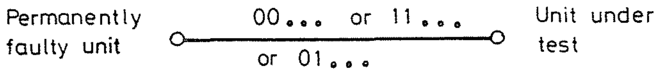

Fig. 3. Test invalidation in the case of the general hybrid fault model

II. General Hybrid Fault Model

Let the behaviour of a permanently faulty tester be such that test outcomes in the test sequence are unpredictable and contain both zeros and ones (*Fig. 3*).

The intermittently faulty unit can behave as a faulty as well as a fault-free one in its tests and also may form a test sequence like the one shown (*Fig. 3*).

Compression of the Syndrome for the Case of Hybrid Fault Diagnosability

The test sequences that come into account as a result of the repeated application of the test set may be denoted in the following manner:

- the sequence containing only zeros (that means that every test result is 'GO') will be denoted by '00';
- the sequence containing only ones (that means that every test result is 'NO GO') will be denoted by '11';
- the case when zeros and ones occur in the test sequence will be denoted by '01'.

As a result of the testing in the case when permanent and intermittent faults are present in a system the syndrome produced will be represented by '00', '01' and '11'. The distinction of these three kinds of sequences is a compression that contains all the necessary information for the diagnosability of the examined system.

Similarly to the case of the pf-compatible syndrome that has been applied for XX and X1 test invalidation and taking into consideration the above presented, an intermittently fault compatible syndrome will be defined on the basis of which the hybrid fault diagnosability can be examined. A syndrome is considered to be intermittently fault compatible (if-compatible) when an intermittently faulty unit has behaved at least once as a fault-free and at least once as a faulty one during the repeated testing.

Relations for the Case of General Test Invalidations

SELÉNYI (1985) stated that a relationship exists between all possible models of test invalidation for a given diagnosable system consisting of n units in which the faulty ones are at most t. This relationship is represented in *Fig. 4* using all possible values of c and d in *Table 1*. For example, all possible test outcomes in the BGM invalidation model can be produced also under the PMC invalidation model. For a given system all test outcomes behave as a special case of the PMC model. It is easy to note that each of the models of test invalidation is a restricted version of some other model. The following information about the necessary and sufficient conditions for t-diagnosability of a system can be derived from the following relationship: the sufficient conditions are transitive downwards, while the necessary ones are transitive upwards. Some conditions are common for all the models, others are different and depend on the model itself.

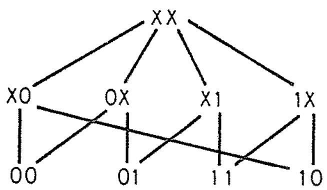

Fig. 4. The relationship between the test invalidation models for a given system

The sufficient and necessary conditions for the diagnosability of a system supposing the symmetric invalidation model for the permanent fault situation are given by HAKIMI and AMIN (1974). The condition representing the dependence between the number of the units of the system (n) and upper bound of the faulty units (t), $n \geq 2t+1$, is sufficient for the case in which no restriction is applied on the test connection assignment of the system. This condition is also sufficient for the case of BGM invalidation model and for all other models beneath it. The condition for the BGM model $n \geq t+2$, is a necessary one for all other models above it and a sufficient one for the models beneath.

The diagnosis of hybrid fault situations includes as special cases the permanent fault case and the intermittent fault case. As the permanent fault case is a special case of the hybrid fault case and the fixed hybrid fault model is a special case of the general hybrid fault model a relationship exists between these models represented in *Fig. 5*.

On the basis of the considerations that *Fig. 4* and *Fig. 5* contain the assertion shown in *Fig. 6* is introduced. It expresses the relationship that holds between the general hybrid fault model and the permanent fault

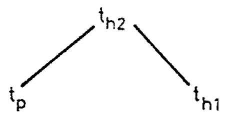

Fig. 5. The relation between the permanent and the hybrid fault models

model for all possible test invalidations in a system. Under every test invalidation the dependence $n \geq f(t)$ is shown, in which tp assigns the upper bound of the permanent faults and th assigns the upper bound of the hybrid faults in the system.

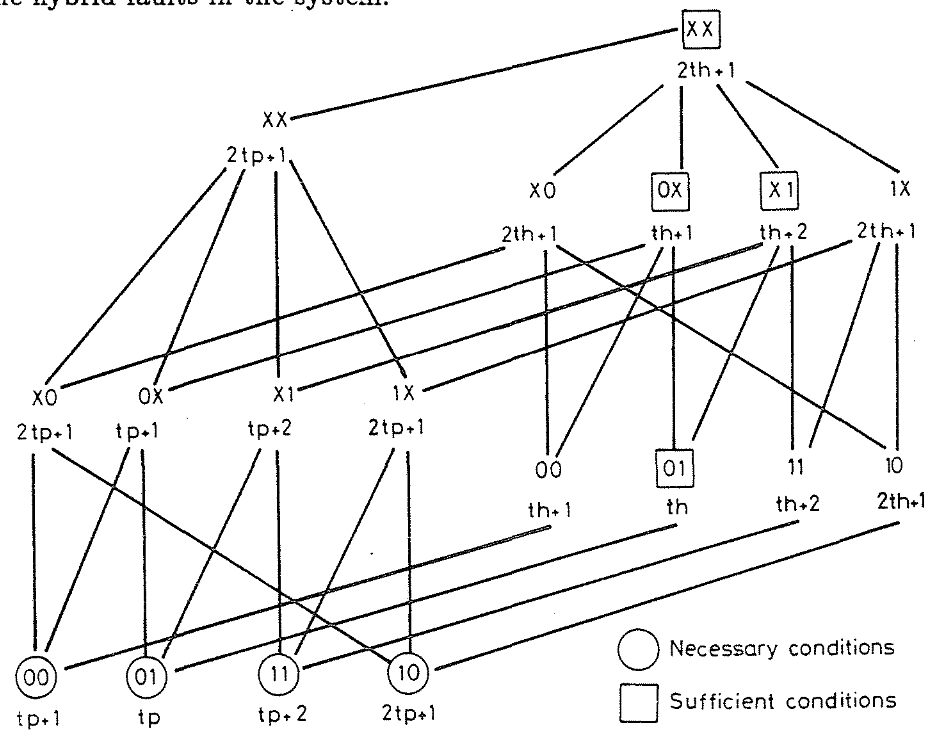

Fig. 6. The relationship between hybrid fault situations and permanent fault situations for all models of test invalidations representing the $n = f/t$ conditions in the case of the general hybrid fault model

To prove the statements for all test invalidations it is sufficient to prove the necessity of the conditions that stand in the lowest part of the relation and the sufficiency of the conditions at the top of it.

The statements for the dependence of $n \geq f(t)$ are valid for a diagnosable system without restrictions on the test connection assignment. Such a system can be represented by a complete directed graph, in which the vertices correspond to the units and the edges to the testing links. In this complete graph each unit tests every other one.

Proof of the Necessity

– 00 test invalidation model: $n \geq tp+1$

In a system of n units the diagnosability of permanent faults is assured if at least one fault-free unit exists, because it can correctly evaluate faulty units as being faulty. Otherwise, only 0-test outcomes can be obtained in the syndrome on the basis of which it is impossible to diagnose whether the units are faulty or fault-free.

– 01 test invalidation model: $n \geq tp$

The upper bound of the faulty units is restricted only by the number of all units in the system. Every faulty unit under test is correctly evaluated as being faulty independently of the tester's state because of the test invalidation model.

– 10 test invalidation model: $n \geq 2tp+1$

Let us suppose that the condition does not hold and there are only tp fault-free units in the system. In this case it is possible to decompose the units of the system into two sets of tp units in the following manner: the units in each of the sets test one another with 0-test outcomes and both sets test each other with 1-test outcomes (see *Fig. 3*). The identification of the faulty and the fault-free units is not possible on the basis of this syndrome. Therefore, the existence of $tp+1$ fault-free units is a necessary condition for the diagnosability of the system.

– 11 test invalidation model: $n \geq tp+2$

Let us suppose that there is only one fault-free unit in a diagnosable system in which every two units test each other. The syndrome obtained in this case consists of only 1-test outcomes that makes impossible the recognition of the fault-free unit. If there are two fault-free units in the system they test each other with 0-test outcomes. Units that test each other with 0-test outcomes can be identified as fault-free ones.

Proof of the Sufficiency

– 0X test invalidation model: $n \geq th+1$

If there is at least one fault-free unit, all other units will test it with 00-test outcomes and the faulty ones will be tested with one 11 or 01-test outcome at least, because of the test invalidation $c=0$. Therefore:

– All units tested with 00-test outcomes will be diagnosed as fault-free. They form the set of fault-free units.

– The diagnosed fault-free units evaluate correctly the faulty ones, i.e., every unit which has been tested with at least 11-test outcome belongs to the set of faulty units.

The existence of one fault-free unit at least is sufficient for the *th*-diagnosability of a system with 0X test invalidation.

– X1 test invalidation model: $n \geq th+2$

Let us suppose that the condition holds and there are at least two fault-free units in the system. If between two units that have been separately tested with 00-test outcomes there is a 01-test outcome, it is impossible to diagnose correctly which one of the two units is the faulty one. Repeated testing has to be performed until similar cases in the system disappear and an if-compatible syndrome is formed. Every two fault-free units in an if-compatible syndrome always test each other with 00-test outcomes. Therefore:

– The units that test each other with 00-test outcomes in an if-compatible syndrome can form only one and unambiguous maximum 00-test subgraph. This subgraph contains all fault-free units in the system.

– The set of fault-free units evaluates correctly the faulty ones, That is, it is possible to unambiguously decompose the units into two sets: a set of fault-free units and a set of faulty ones.

The presence of at least two fault-free units is a sufficient condition for the existence of the 00-test subgraph on the basis of which the above-mentioned decomposition can be performed.

– 01 test invalidation model: $n \geq th$

The number of the units in the system defines the upper bound of the faulty units. Obviously, the units tested with only 00-test outcomes in an if-compatible syndrome can be evaluated as fault-free, the units tested with only 11-test outcomes belong to the set of faulty ones.

– XX test invalidation model: $n \geq 2th+1$

The proof of the sufficiency of the condition for the diagnosability of a system represented by a complete digraph follows directly from the sufficient and necessary conditions for the *th*-diagnosability of a system supposing a PMC model which has already been discussed by MALLELA and MASSON (1980).

Statements for the Fixed Hybrid Fault Model

Let us suppose that the statements already proved are also valid for the case of the fixed hybrid fault model. As there is no difference between the deterministic and the unpredictable behaviour of the tester in the case when 00, 01, 11 and 10 test invalidations stand, the two hybrid fault models coincide.

The relationship between the two hybrid fault models is represented in *Fig. 7.*

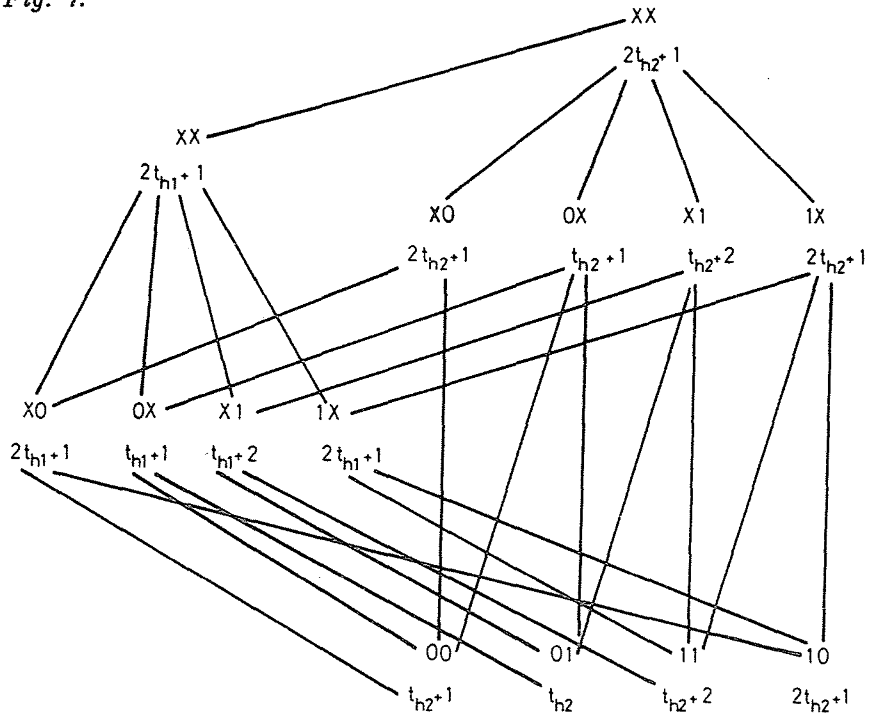

Fig. 7. The relationship between the fix (h1) hybrid fault model and the general (h2) hybrid fault model for all cases of test invalidations

In the case of XX, X1, X0, 1X and 0X test invalidations the proof of the $n \geq f(t_{h1})$ statements follows as a result of the upper and lower limits in the figure unambiguously.

Conclusions

In this paper the generalization of test invalidations for the case of permanent and hybrid fault situations has been developed. For a given system in which the units test one another, a relationship exists between the different possible test invalidations. The necessary and sufficient conditions for the *th*-diagnosability of such kinds of systems have been described and proved using the presented relationship. The proof of the conditions can be given in the form of fault diagnosis algorithms and can be used successfully for the identification of the faulty units over if-compatible syndrome sets. The diagnosis achieved will never be incorrect, but might be incomplete. The conditions hold for diagnosable systems represented by complete directed graphs.

The main conclusion that follows is that the maximum number of the hybrid fault units in such systems is just the same as in the case of permanent faults. The occurrence of intermittent faults does not deteriorate the properties of the diagnosable system but the diagnosis is achievable with the help of repeated testing. The relationship between the different models of test invalidation that has been presented and the hybrid fault models introduced can be particularly useful and have further impact on the solution of characterization problems of system diagnosability.

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