SPECIFIC SYMPTOMS OF SINGLE-PHASE INVERTERS FAULTS THAT ARE REQUIRED FOR AN EXPERT SYSTEM DESIGN

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The paper presents an expert system for the control, monitoring and diagnosis of digitally controlled single-phase inverters (DCSI). As a result, the system is capable to both detect faults and correctly identify the cause of each fault.

The work is based on DCSIs designing and manufacturing (technology implementation) experience of the authors and it starts with the main symptoms during permanent operation of DCSIs. There are 14 main symptoms and for each there are presented their triggering causes. The analysis is performed for an IMD 30kVA DCSI, 230V, 50Hz manufactured by Electrotehnica Echipamente Electrice SRL from Bucureşti.

Keywords: inverter, faults, diagnosis, expert system, UPS, power source

1. Introduction

The inverters are electronic converters that input a DC voltage and output a customized alternative voltage of desired RMS and frequency values [1], [2]. The inverters are generally used as backup power source in case of grid blackout or various events featuring abnormal parameters (RMS voltage range – under voltage and overvoltage, voltage distortion – high harmonic content and electrical noise) [3], [4]. As a backup power source, the inverter becomes the key device for all the powering and safety systems [5 - 7], [6], [7]. For this reason, the possible faults analysis that can occur during operation is a critical task for the designing of a DCSI expert diagnosing system [8], [9].

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Expert systems are based on the already existing knowledge of expert people and are an integrated component of informatics, namely the artificial intelligence. They can be applied for all the systems no matter the field. A monitoring system that automatically detects and diagnoses the events increases the reliability and the autonomy of electrical equipment [10]. This great advantage has brought to these systems a highly success rate especially in the industrial field.

In the paper are presented the main faults of a DCSI that can occur during the operation as the output block of an Uninterruptable Power Supply unit (UPS). The remedies for each fault are also presented so that the task of designing an expert system is fully defined [11 - 14].

2. Equipment configuration

The analyzed inverter is 30kVA with an output rated voltage of 230V RMS and 50 Hz [15]. The inverter is part of a UPS. This inverter (UPS) is designed and manufactured at Electrotehnica Echipamente Electrice SRL from Bucureşti. The power stations which supply critical consumers who need continuous electricity constitute its application area.–For example, hospitals require continuous energy supply because they operate with life support equipment. For hospitals another key equipment are the patient transportation elevators especially the ones servicing the emergency and rescue department.

The power part of the inverter (UPS) is shown in Fig. 2. The stabilized AC output voltage of 230V RMS and 50 Hz is measured after the contactor *K5*. The inverter itself is supplied from a battery accumulator pack that is parallel connected at the output of a rectifier with an output constant voltage U_0 of 220V DC. The DC voltage is denoted *Source 2* in Fig. 2. During normal operation, the following contactors are closed: *K1, K2, K4* and *K5*. When a fault is present and the inverter output it is not possible to be set by the circuits linked with *Source 2* or even *Source* 2 suffers a fault the inverter's control assembly switches the inverter's input to grid connection (400V/50Hz), denominated as *Source 1*. The switching is performed as fast as possible, namely 5 ms. This amount of time is large enough so that even the most sensible load of the inverter does not suffer operating modifications. The switching is practically performed by opening the electronic switch *CS2* and closing the electronic switch *CS1*.

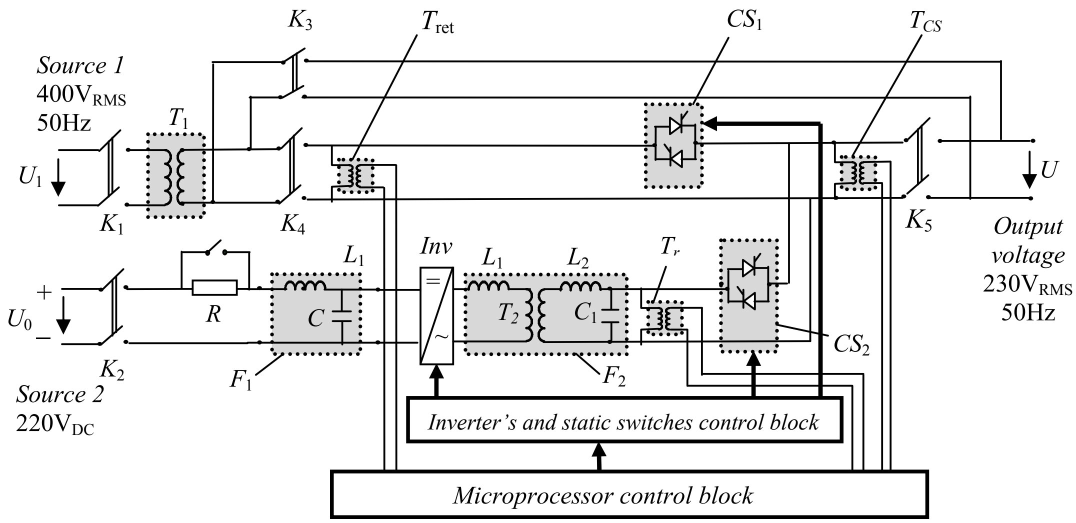

Fig. 2. The inverter's (UPS) power part schematic

The main components of the power part schematic are the following:

- The grid transformer *T1* that adapts the electrical grid voltage from 400 V to 230 V. This adapted voltage is supplied at the UPS's output. The advantage is that the input and the output are galvanically insulated. Thus, a possible DC component (e.g. short-circuit) is not transferred from one electric circuit to another one [16];
- The resistor *R* has the role to limit the sudden charging of the capacitor *C1* when the inverter is connected to the grid line. When capacitor *C1* is charged, the resistor *R* is short-circuited;
- The input filter *F1* encloses the inductance *L1* and the capacitor *C1*; it filters the rectifier's output voltage U_0 which is also one of the inverter's input voltage. Practically it is a low-pass filter that ideally allows only the passage of the DC component [17].
- The inverter's output filter *F2* eliminates the high order harmonics (ideally, it allows only the passage of the 50 Hz fundamental). A second role is to adapt the inverter's output voltage to 230V RMS level. This value is required by the inverter's load. The low pass filter *F2* encloses inductances *L1* and *L2*, the capacitor *C2* and the transformer T2. An additional role of the transformer is to physically isolate the electric circuits but also to cancel the inverter's output DC component [18];
- The static switches *CS1* and *CS2* switch the inverter's *Inv* input voltage between the main source (*Source 1*) and back-up one (*Source 2*). They operate as follows: when the UPS is set to operate with the inverter *Inv* as the main

power source, after the start-up, static switch *CS1* is turned off for at least 5 seconds. Meanwhile the inverter *Inv* is turned on and is brought to the desired output parameters by the UPS control block. The state of the inverter *Inv* output is monitored with the transformer *Tr*. As soon as this transformer (*Tr*) measures a correct output voltage, the static switch *CS2* is turned on and the UPS starts to supply a correct output voltage. This step is required because otherwise the UPS's loads are supplied with ramp-up RMS voltage. When the transformer *Tcs* signals to the UPS's control block a correct voltage, the static switch *CS1* is left off. If a fault occurs, and after 5 seconds the transformer *Tcs* still measures an incorrect voltage, the static switch *CS1* is turned on in less than 3 ms and the load is supplied directly from the grid. The same behaviour is observed if the fault occurs later than the 5 seconds from the UPS's start-up, i.e. the inverter *Inv* starts to operate correctly and then a fault occurs;

- The inverter block *Inv* is made of four IGBT modules mounted in a H-bridge that is PWM controlled by the microprocessor [19][20];
- The *microprocessor control block* is a critical part of the UPS because it provides its correct operation. The microprocessor regulates the output voltage to a constant level and its frequency to a fixed value. It also protects all the modules against overloading, short-circuit and other similar troubles. The link between the PWM control signals generated by the microprocessor and the IGBT modules and the static switches (*CS1* and *CS2*) is represented by the driving circuits. These drivers not only interface the microprocessor with the semiconductor devices but also monitor and protect the IGBTs against malfunction. The total harmonic distortion (THD) parameter of the inverter's output voltage is less than 3%;
- The transformer *Tret,* measures the value of the grid voltage. The grid voltage represents the reference for the inverter's output voltage. This is required in order to be able to switch between the grid and the inverter at any instant without any disturbance for the UPS loads.
- For the in-phase regulation of the inverter's output voltage and the grid's voltage, a closed loop is required. The feedback is performed by the *Tr* transformer that measures the inverter's output voltage.

The schematic depicted in Fig. 2 includes only the main components and modules of the UPS system. The electric and thermal signal monitoring, acquiring and visualization modules and operating mode modules are missing.

3. Diagnosing basics for power inverters

A diagnose system does not replace an expert person but it helps. It helps the users by decreasing the time required for maintenance and service and never the less the exploitation cost. Such a system is capable to diagnose the great majority of the possible faults. It is also capable to point out the fault causes and sometimes the steps to be performed in order to cancel that fault. In this way an expert system increases for sure the number of operating hours and the equipment's life time.

The presented power inverters are the key component of alternative voltage uninterruptable power supplying systems for vital consumers. The diagnosing operations are performed mostly in an on-line fashion based on a setup controlled by the process computer that receives signals from all the sensors, transducers and measurement transformers within the inverter. A sudden fault or a drift one influence the already good known operation parameters of the inverter. Any change of these values detected by the process computer triggers software routines or even hardware elements, such as relays (e.g. temperature, short-circuit, overload, under voltage, overvoltage). The specific objective of the diagnosing process is to identify the possible faults and to point out the cause for already occurred faults or the possible cause for inherent ones.

4. Symptoms, faults and causes

In order to be able to identify the causes of a fault and to indicate the steps required to cancel that fault, it should be started from the fault's specific features. In the same time, the schematics of the equipment (both power and control parts) must be thoroughly known.

In principle, the rated data of the analyzed inverter are required only for usual measurements and check-outs. As long as the power and control schematics of another inverter are similar to the analyzed ones, the symptoms would be similar. The difference would be just for the measured values. In other words, the symptoms, faults and their causes are identical for both of the inverters and, in fact, are the same for all the inverters with the same electric circuit, control type and protection methods.

For the analyzed inverter the presented symptoms are known based on the long time (more than 40 years [21]) practical experience of the engineers and technicians from Electrotehnica Echipamente Electrice SRL from Bucureşti in the development, manufacturing ,servicing and maintenance of such inverters.

The analysis encloses 14 specific symptoms of the analyzed inverter type. They are denoted as S0, S1 … S13. Theirs significance is the following: S0 – Faults during commissioning the inverter; S1 – No output voltage due to faults within the intermediate DC link circuit (*Source 2*); S2 – No output voltage due to AC grid faults (*Source 1*); S3 – No output voltage due to maintenance bypass; S4 – Non-sinusoidal output voltage; S5 – Output under voltage; S6 – Output overvoltage; S7 – Over currents within power circuits; S8 – Under currents within power circuits; S9 – At rated load the efficiency and power factor are lower than rated values; S10 – Overheating of static, electric, magnetic and other components; S11 – Noises and vibrations during inverter's operation; S12 – The switch between the two input sources (*Source 1* and *Source 2*) does not take place; S13 – Inverter's possible diagnosed symptoms.

For increased clarity of the performed analysis the following notations are introduced: S – symptom, D – fault (defect), C – fault's causes. These follow a direct and successive logical link of the specified items. For example the symptom S1 is specific to faults D1.1, D1.2, D1.3 … D1.20. The causes notation that triggered a fault contain the fault's specific number. For example, the fault D1.3 can be triggered by the causes C1.3.1, C1.3.2, C1.3.3 and C1.3.4. In this manner, using this rule for notations the links between symptoms, faults and causes are easier to identify. Further the main inverter symptoms, faults and causes are described in a natural sequence.

S0 – Faults during inverter commissioning

D0.1 – Broken power supply cable: C0.1.1 – The temperature within the cable channel is too high.
D0.2 – Loose connections between the battery accumulator pack and intermediate DC link circuit: C0.2.1 – Loose terminals; C0.2.2 – Oxidized terminals or dirty contacts; C0.2.3 – Battery faulty terminals or broken wires;
D0.3 - Broken grid power supply cable: C0.3.1 – Broken cable insulation; C0.3.2 – Faulty socket.
D0.4 – High cables voltages drop: C0.3.1 – Cables small cross-section; C0.3.2 – Faulty contact at terminals.

S1 – No output voltage due to faults within the intermediate DC link circuit

D1.1 – No input DC voltage: C1.1.1 – Broken battery accumulator pack; C1.1.2 – Broken input fuses or faulty circuit breaker; C0.1.3 – Broken wire;
D1.2 – Broken input fuses / switched-off circuit breaker: C1.2.1 – Inappropriate designed fuses; C1.2.2 – Short-circuit within IGBT module; C1.2.3 – Broken/Short-circuited electrolytic capacitor; C1.2.4 – Short-circuited capacitors within the harmonic filter.
D1.3 – Short-circuit within the device: C1.3.1– High humidity inside the equipment; C1.3.2 – Hovering or laid-down dust particles; C1.3.3 – Overheating of circuit components; C1.3.4 – Switching over voltages.
D1.4 – DC under voltage: C1.4.1 – Inappropriate designed power supply cable; C1.4.2 – Discharged battery; C1.4.3 – Not equally charged battery elements; C1.4.4 – Rectifier outputs under voltage.

D1.5 – DC over voltage: C1.5.1 – Battery accumulator pack has more elements; C1.5.2 - Rectifier outputs over voltage.

D1.6. Faulty input contactor: C1.6.1 – Contactor's coil does not energize; C1.6.2 – Mechanically locked contactor; C1.6.3 – High-resistance contactor's main contacts.

D1.7 – Faulty sequential startup circuit: C1.7.1 – Open automated circuit breaker or faulty; C1.7.2 – Wrong connections, loose terminals or broken cables; C1.7.3 – Not energized or faulty relay; C1.7.4 – Faulty start/stop switch; C1.7.5 – Loosen connections or broken cables.

D1.8 – *L1* broken inductance: C1.8.1 – Local winding overheating; C1.8.2 – Loosen connections; C1.8.3 – Loosen/faulty terminals.

D1.9. Short-circuited *C1* capacitor: C1.9.1 – DC circuit over voltage; C1.9.2 – Capacitor capacity out of tolerance bounds; C1.9.3 – Unused for long periods of time.

D1.10 – IGBT modules operate at no-load or short-circuit: C1.10.1 – Aged IGBT modules; C1.10.2 – Over voltage between the gate and the cathode; C1.10.3 – Short-circuit between bridge diagonals; C1.10.4 Over voltage between the cathode and the anode; C1.10.5 – Faulty IGBT control block; C1.10.6 – Faulty regulation and control block.

D1.11 – Faulty static contactor *CS1*: C1.11.1 – Short-circuited components due to impurities lay-down; C1.11.2 – Components overheating due to impurities lay-down; C1.11.3 – Aged components.

D1.12 – Faulty regulation and control block: C1.12.1 – Faulty 5VDC source; C1.12.2 – Faulty 15VDC source; C1.12.3 – Faulty 24VDC sources; C1.12.4 - Short-circuited components due to impurities lay-down; C1.12.5 - Components overheating due to impurities lay-down; C1.12.6 – Aged components.

D1.13 – Faulty transducers, sensors or relays: C1.13.1 – Voltage transducer has broken coil; C1.13.2 – Voltage transducer has short-circuited coil; C1.13.3- Current transducer has short-circuited coil; C1.13.4 – Broken temperature sensor; C1.13.5 – Control relay with broken coil; C1.13.6 – Control relays locked in switched-on state; C1.13.7 – Control relays faulty contacts.

D1.14 – Loosen connections/broken wires between electronic blocks: C1.14.1 – Too much screwed contacts; C1.14.2 – Loosen contacts; C1.14.3 – Cold end formation; C1.14.4 – Contact detachment due to vibrations.

D1.15 – Broken inductance *L1* within filter *F2*: C1.15.1 – Detached connections; C1.15.2 – Broken turns; C1.15.3 – Short-circuited turns; C1.15.4 – Overheated coil; C1.15.5 – Loosen cross tie rods and bolts; C1.15.6 – Saturated inductance.

D1.16 – Faulty transformer T2 within filter F2: C1.16.1 - Detached connections; C1.16.2 – Broken turns; C1.16.3 – Short-circuited turns; C1.16.4 – Overheated coil; C1.16.5 - Loosen cross tie rods and bolts; C1.16.6 – Transformer is saturated.

D1.17 - Faulty *C2* capacitor within the F2 filter: C1.17.1 – Short-circuited terminals; C1.17.2 – Dried capacitor; C1.17.3 – Terminals overvoltage; C1.17.4 – Detached connections, broken wires or unsoldered terminals.
D1.18 – Faulty *L2* inductance within the *F2* filter: C1.18.1, C1.18.2, ..., C1.18.6 – similarly defined as causes for the fault D1.15.
D1.19 - Faulty static contactor *CS2*: C1.19.1 – Broken static contactor *CS2*; C1.19.2 – Faulty microprocessor regulation and control blocks; C1.19.3 – Loosen connections and/or broken conductors.
D1.20 – Output contactor *K5* has high-resistance contacts: C1.20.1- Electric arc formation when switched on and switched off; C1.20.2- Contacts low force; C1.20.3 – Contacts overheating; C1.20.4 – Mechanically deformed contacts.

S2 – No output voltage due to AC grid faults

D2.1 – AC grid no voltage: C2.1.1 – The grid AC voltage is cut.
D2.2 – Output contactor *K*1 is switched off: C2.2.1 – The switching on of the contactor has not been checked-out.
D2.3 – Contactor *K1* has mechanical faults: C2.3.1 – Locked lever; C2.3.2 – Lever not remaining in on position.
D2.4 – Contactor *K1* contacts have high-resistance: C2.4.1, C2.4.2, ... , C2.4.4 - similarly defined as causes for the fault D1.20.
D2.5 – Faulty by-pass transformer *T1*: C2.5.1, C2.5.2, ... , C2.5.6 – similarly defined as causes for the fault D1.16
D2.6 – Output contactor *K4* is switched off: C2.6.1 – Contactor state has not been checked-out.
D2.7 – Contactor *K4* has mechanical faults: C2.7.1 – Locked lever; C2.7.2 - Lever not remaining in on position.
D2.8 – Contactor *K4* contacts have high-resistance: C2.8.1, C2.8.2, ... , C2.8.4 - similarly defined as causes for the fault D1.20.
D2.9 – Faulty static contactor *CS2*: C2.9.1 **–** Broken static contactor *CS2*; C2.9.2 - Faulty microprocessor regulation and control blocks; C2.9.3 **–** Loosen connections and/or broken conductors.
D2.10 – Output contactor *K5* is switched off: C2.10.1 **–** Contactor state has not been checked-out.
D2.11 – Contactor *K5* has mechanical faults: C2.11.1, C2.11.2 – similarly defined as causes for the fault D2.7.
D2.12 – Contactor *K5* contacts have high-resistance: C2.12.1, C12.2, ..., C12.4 - similarly defined as causes for the fault D1.20.

S3 – No output voltage due to maintenance bypass

D3.1 – AC grid no voltage: C3.1.1 – The grid AC voltage is cut.
D3.2 – Output contactor *K*1 is switched off: C3.2.1 – similarly defined as causes of the fault C2.6.1.
D3.3 – Contactor *K1* has mechanical faults: C3.3.1, C3.3.2 – similarly defined as causes for the fault D2.7.
D3.4 – Contactor *K1* contacts have high-resistance: C3.4.1, C3.4.2, ... , C3.4.4 - similarly defined as causes for the fault D1.20.
D3.5 – Faulty bypass supplying transformer *T1*: C3.5.1, C3.5.2, ... ,C3.5.6– similarly defined as causes for the fault D1.16.

S4 – Non-sinusoidal output voltage

D4.1 – Broken input filtering capacitor: C4.1.1 – Broken capacitor bank *C1* within input filter; C4.1.2 – Loosen connections or broken wire.
D4.2 – Faulty inverter bridge *Inv*: C4.2.1 – IGBT modules overheating; C4.2.2 – No control signals for IGBT module; C4.2.3 – IGBT module high voltage drop.
D4.3 – Faulty transformer *T2* within filter *F2*: similarly defined as causes for the fault C4.3.1, C4.3.2, ... , C4.3.6 – similarly defined as causes for the fault D1.16.
D4.4 – Faulty capacitor *C1* within filter *F2*: similarly defined as causes for the fault D1.17.
D4.5 – Faulty IGBT within IGBT module: C4.5.1 – Broken or short-circuited IGBT; C4.5.2 – IGBTs have no control signal; C4.5.3 – Loosen connections and/or broke wires.
D4.6 – Highly non-linear load or power factor less than 0.8 (lagging or leading): C4.6.1 – Inductive or capacitive loads are present and are inappropriate.

S5 – Low output voltage

D5.1 – DC voltage thresholds are set below correct values: C5.1.1 – Discharged battery accumulator pack; C5.1.2 – DC min/max voltage relay incorrectly set; C5.1.3 – Faulty DC min/max voltage relay.
D5.2 - IGBT module high voltage drop: C5.2.1 – Aged IGBT modules; C5.2.2 – Oscillatory DC voltage; C5.2.3 – Oscillatory AC voltage; C5.2.4 – Feedback voltage wrong polarity.
D5.3 – Faulty electronic components: C5.3.1 – Electronic components out of tolerance limits; C5.3.2 – Short-circuited or broken electronic components; C5.3.3 – Unsoldered electronic components; C5.3.4 – Faulty contacts.
D5.4 – Faulty voltage transducer: C5.4.1 – Too high voltage transducer output voltage.

D5.5 – Faulty adaptation transformer *T2* within filter *F2:* similarly defined as causes for the fault D4.3.
D5.6 – Broken static contactor *CS2*: C5.6.1 – Faulty thyristor within static contactor; C5.6.2 – Faulty control block.
D5.7 – Faulty microprocessor regulation and control blocks: C5.7.1 – Electronic components out of tolerance limits; C5.7.2 – Short-circuited or broken electronic components.
D5.8 – Oxidized contacts and/or with corrosion: C5.8.1 – Increased resistivity contacts.
D5.9 – UPS operates on *Source 1* (grid voltage) or on the maintenance bypass: C5.9.1 – Faulty inverter *Inv*; C5.9.2 – Inverter *Inv* not supplied.

S6 – Output overvoltage

D6.1 – Faulty regulation and control blocks: C6.1.1 – Electronic components out of tolerance limits; C6.1.2 – Short-circuited or broken electronic components.
D6.2 – Faulty adaptation transformer *T2* within filter *F2*: C6.2.1 – Primary winding with short-circuited turns.
D6.3 – UPS operates on *Source 1* (grid voltage) or on the maintenance bypass: C6.3.1 – Faulty inverter *Inv*; C6.3.2 – Switched off inverter.

S7 – Over loading within power circuits

D7.1 – Very high DC current drawn from battery: C7.1.1 – Low DC voltage supply; C7.1.2 – Capacitor *C1* within the input filter not connected or short-circuited; C7.1.3 – Faulty inverter *Inv*; C7.1.4 – Faulty transformer *T2*; C7.1.5 – Non-linear inverter load mainly inductive or capacitive; C7.1.6 – Inverter low output voltage; C7.1.7 – Broken static contactor *CS2*.
D7.2 – Increased primary current of *T2* transformer: C7.2.1 – Faulty inverter *Inv*; C7.2.2 – *T2* transformer with short-circuited turns for primary winding; C7.2.3 – Non-linear inverter load mainly capacitive; C7.2.4 – Inverter low output voltage; C7.2.5 – Broken static contactor *CS2*.
D7.3 – Increased load current: C7.3.1 – Inverter load is an overload or a short-circuit; C7.3.2 – Inverter low output voltage; C7.3.3 – Broken static contactor *CS2*.

S8 – Low load within power circuits

D8.1 – Very low drawn DC current: C8.1.1 – Increased DC supply voltage; C8.1.2 – *T2* transformer with short-circuited turns for secondary winding; C8.1.3 – Increased voltage between inverter terminals.

D8.2 – Decreased primary current of *T2* transformer: C8.2.1 – *T2* transformer with short-circuited turns for secondary winding; C8.2.2 – Unloaded capacitors *C1*; C8.2.3 – No-load for UPS; C8.2.4 – Increased voltage at inverter terminals.
D8.3 – Too low load current: C8.3.1 – Increased voltage at inverter terminals; C8.3.2 – No-load for UPS.

S9 – At rated load the efficiency and power factor are lower than rated values

D9.1 – Low efficiency at rated load: C9.1.1 – Inductance *L1* with short-circuited turns; C9.1.2 – Inductance *L1* with increased or decreased air-gap; C9.1.3 – Short-circuited magnetic core for inductance *L1*; C9.1.4 – Unloaded capacitor *C1*; C9.1.5 – Faulty inverter *Inv*; C9.1.6 – Inductance *L1* with short-circuited turns; C9.1.7 – Inductance *L1* with increased or decreased air-gap; C9.1.8 – Short-circuited magnetic core for inductance *L1*; C9.1.9 – *T2* transformer with short-circuited turns; C9.1.10 – Transformer *T2* with increased or decreased air-gap; C9.1.11 – Short-circuited magnetic core for transformer *T2*; C9.1.12 – Inductance *L2* with short-circuited turns; C9.1.13 – Inductance *L2* with increased or decreased air-gap; C9.1.14 – Short-circuited magnetic core for inductance *L2*; C9.1.15 – Unloaded capacitor *C1*; C9.1.16 – Broken static contactor *CS2*.
D9.2 – Low power factor at rated load: C9.2.1 – Non-linear load mainly inductive or capacitive.

S10 – Overheating of static, electric, magnetic and other components

D10.1 – Most elements are overheated: C10.1.1 – Inverter overload; C10.1.2 – Electronic components out of tolerance limits.
D10.2 – Overheated connecting terminals: C10.2.1 – Faulty contacts.
D10.3 – Overheated inverter *Inv*: C10.3.1 – Insufficient ventilation; C10.3.2 – Aged IGBT modules; C10.3.3 – Increased primary current of *T2* transformer.
D10.4 – Overheated *T2* transformer: C10.4.1 – Short-circuited turns; C10.4.2 – Cross tie rod loosen insulation or short-circuited core;
D10.5 – Overheated inductances *L1* and/or *L2*: C10.5.1, C10.5.2 – similarly defined as causes for the fault D10.4.

S11 – Noises and vibrations during inverter's operation

D11.1 – Faulty fan: C11.1.1 – Eccentric fan.
D11.2 – Inverter *Inv* has voltage oscillation: C11.2.1 – DC voltage with high AC components; C11.2.2 – Faulty microprocessor (DSP) regulation and control

blocks; C11.2.3 – Reference voltage with oscillatory frequency; C11.2.4 – Different IGBT modules.

D11.3 – Faulty inductances *L1* and *L2* within the filters *F1* and *F2*: C11.3.1 – Breakdown insulation; C11.3.2 – Loosen tightening pieces.

D11.4 – Faulty transformer *T2* and/or bypass transformer *T1*: C11.4.1, C11.4.2 – similarly defined as causes for the fault D.11.3.

D11.5 – Loosen connections: C11.5.1 – High-resistance connections; C11.5.2 – Loosen connections.

S12 – The switch between the two input sources (*Source 1* and *2*) does not occur

D12.1 – Desynchronized inverter: C12.1.1 – The two sources frequencies are not equal; C12.1.2 – Locked static contactors *CS*1 or *CS2*; C12.1.3 – Broken static contactors *CS*1 or *CS2*; C12.1.4 – Broken voltage transducers; C12.1.5 – One of sources is faulty; C12.1.6 – Faulty regulation and control block; C12.1.7 – Loosen connections and/or high resistance connections; C12.1.8 – No input/output voltage at *Source 1* terminals; C12.1.9 – *Source 1* or *Source 2* is disconnected.

S13 – Inverter's possible diagnosed symptoms

D13.1 – Overload: C13.1.1 – Load current higher than rated value.
D13.2 – Short-circuit: C13.2.1 – High load current more than 1.5 rated current.
D13.3 – Faulty IGBT: C13.3.1 – IGBT bridge with no-load or short-circuited.
D13.4 – Saturation: C13.2.1 – IGBT protection tripped by the driver.
D13.5 – No feedback: C13.5.1 – Inverter without feedback.

The presented faults and causes, for each of the 14 symptoms, enable user to conclude that between the items there are direct or indirect links. These links can be better highlighted using graph-charts. All the 14 graph-charts along with the connections between them represent the starting point for designing an expert system for the analyzed inverter. As an example, there are depicted only 2 out of 14 graph-charts. In Fig. 3 is shown the graph-chart for symptom S0, while in Fig. 4 it is depicted the graph-chart for the symptom S1. The graph-charts are of great importance for the implementation of the monitoring system. The direct links between faults and causes marked with continuous lines must be completed with the indirect links. Such links can be represented only on a global unitary graph-chart that contains all the 14 graph-charts.

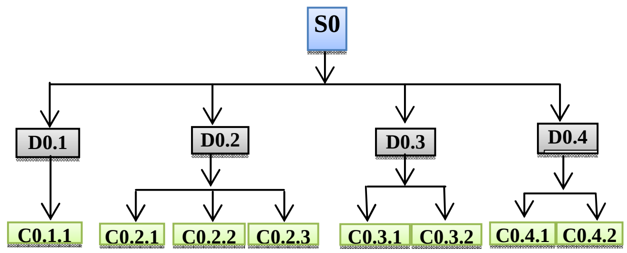

Fig. 3. The graph-chart of the links between the faults and causes of symptom S0

For example, the faults D1.19 and D2.9 have the same significance and they can occur due to symptoms, S1 or S2. The links between these faults are of indirect type.

An expert system that diagnoses and monitors the entire operation of an inverter features a classification of the abnormal behaviours and a classification of the faults that contribute to the abnormal situations. Some types of faults are more severe than others. For this reason, a complete fault leads to a total loss of the desired functionality while a partial fault is the result of one or more deviations from normal characteristics. In other words, a total or complete fault will stop the operation of the module where the faulty component resides, while a partial fault triggers an abnormal operation, that is, the involved modules operate at different parameters that they were designed and with time that partial fault will lead to a total fault of one or more modules. The term “faulty”, used for a given component has various meanings due to the different effect over the system (i.e. over other components within the system). Thus, a total fault of a component within the inverter could be the cause for a partial fault of a subassembly also within the inverter. Sometimes, partial faults are more dangerous because they are subtle and not severe at the beginning. For this reason the expert system must be designed in such a way that it can differentiate between a total fault and a partial one. This means that after the designing stage of the expert system, the second stage is to categorize the total and the partial faults such that the user is informed and he/she can assess the effect of each fault over the entire system. As for example, the analyzed inverter allows for a variation of the intermediate DC circuit link voltage in the range 198 VDC … 275 VDC. If the voltage is different from the rated value of 220 VDC but it fits within the given range then it may be considered that the faults D1.4 and D1.5 are partial type. If the voltage is outside the given range then the same faults are complete or total faults.

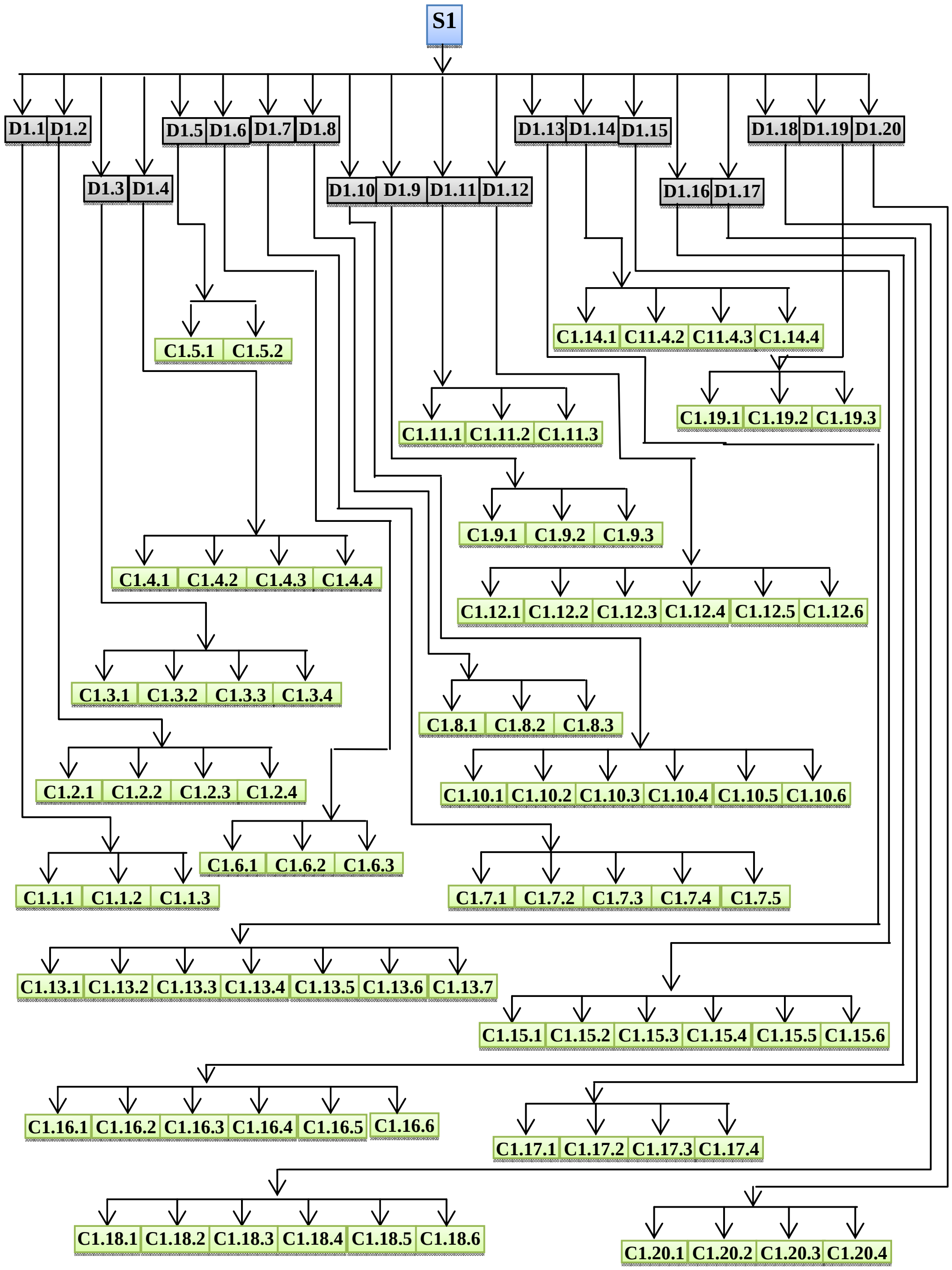

Fig. 4. The graph-chart of the links between the faults and causes of symptom S1

5. Conclusions

An expert system does not replace an expert person but it can help and support the person during the equipment operation. For complex systems that have many modules (components) tracking the cause of the fault it is a time-demanding task even for experienced technicians. In such situations, an expert system is of great help, because it offers appropriate information that an expert person could not provide because the system integrates the knowledge of more expert persons. In this vein, an expert system is capable to solve difficult troubles faster than a human. Because one of the system feature is memory, the current capabilities can be easily transferred and upgraded. Therefore, for upgrading an equipment, few or no adjustments are necessary.

In this paper, the specific faults' symptoms of an UPS embedded inverter along with the faults and their possible causes have been analyzed. Based on the introduced notations a direct link between the fault and causes can be drawn. The UPS has been manufactured by Electrotehnica Echipamente Electrice SRL company from Bucureşti.

The information provided in this paper represents the starting point for designing an expert system that it is specific to single-phase inverters found in high power uninterruptible power supplies.

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