

Reliability block diagrams

## EESTI STANDARDI EESSÕNA

## NATIONAL FOREWORD

See Eesti standard EVS-EN 61078:2016 sisaldab Euroopa standardi EN 61078:2016 ingliskeelset teksti.	This Estonian standard EVS-EN 61078:2016 consists of the English text of the European standard EN 61078:2016.
Standard on jõustunud sellekohase teate avaldamisega EVS Teatajas	This standard has been endorsed with a notification published in the official bulletin of the Estonian Centre for Standardisation.
Euroopa standardimisorganisatsioonid on teinud Euroopa standardi rahvuslikele liikmetele kättesaadavaks 25.11.2016.	Date of Availability of the European standard is 25.11.2016.
Standard on kättesaadav Eesti Standardikeskusest.	The standard is available from the Estonian Centre for Standardisation.

Tagasisidet standardi sisu kohta on võimalik edastada, kasutades EVS-i veebilehel asuvat tagasiside vormi või saates e-kirja meiliaadressile [standardiosakond@evs.ee](mailto:standardiosakond@evs.ee).

ICS 03.120.01, 03.120.99

Standardite reprodutseerimise ja levitamise õigus kuulub Eesti Standardikeskusele

Andmete paljundamine, taastekitamine, kopeerimine, salvestamine elektroonsesse süsteemi või edastamine ükskõik millises vormis või millisel teel ilma Eesti Standardikeskuse kirjaliku loata on keelatud.

Kui Teil on küsimusi standardite autorikaitse kohta, võtke palun ühendust Eesti Standardikeskusega:

Koduleht [www.evs.ee](http://www.evs.ee); telefon 605 5050; e-post [info@evs.ee](mailto:info@evs.ee)

The right to reproduce and distribute standards belongs to the Estonian Centre for Standardisation

No part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, without a written permission from the Estonian Centre for Standardisation.

If you have any questions about copyright, please contact Estonian Centre for Standardisation:

Homepage [www.evs.ee](http://www.evs.ee); phone +372 605 5050; e-mail [info@evs.ee](mailto:info@evs.ee)

English Version

**Reliability block diagrams  
(IEC 61078:2016)**

Diagrammes de fiabilité  
(IEC 61078:2016)

Zuverlässigkeitsblockdiagramme  
(IEC 61078:2016)

This European Standard was approved by CENELEC on 2016-09-16. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.



European Committee for Electrotechnical Standardization  
Comité Européen de Normalisation Electrotechnique  
Europäisches Komitee für Elektrotechnische Normung

**CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels**

## European foreword

The text of document 56/1685/FDIS, future edition 3 of IEC 61078, prepared by IEC/TC 56 "Dependability" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61078:2016.

The following dates are fixed:

- latest date by which the document has to be (dop) 2017-06-16  
implemented at national level by  
publication of an identical national  
standard or by endorsement
- latest date by which the national (dow) 2019-09-16  
standards conflicting with the  
document have to be withdrawn

This document supersedes EN 61078:2006.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

## Endorsement notice

The text of the International Standard IEC 61078:2016 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 61025	NOTE	Harmonized as EN 61025.
IEC 61165	NOTE	Harmonized as EN 61165.
IEC 62551	NOTE	Harmonized as EN 62551.
IEC 60812	NOTE	Harmonized as EN 60812.
IEC 61508:2010 Series	NOTE	Harmonized as EN 61508:2010 Series.
IEC 61511:2016 Series	NOTE	Harmonized as EN 61511:2016 Series.
ISO/TR 12489	NOTE	Harmonized as CEN ISO/TR 12489.

## Annex ZA (normative)

### Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: [www.cenelec.eu](http://www.cenelec.eu)

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60050-192	-	International Electrotechnical Vocabulary - - Part 192: Dependability		-
IEC 61703	-	Mathematical expressions for reliability, availability, maintainability and maintenance support terms	EN 61703	-

## CONTENTS

FOREWORD.....	8
INTRODUCTION.....	10
1 Scope.....	11
2 Normative references.....	11
3 Terms and definitions .....	11
4 Symbols and abbreviated terms .....	18
5 Preliminary considerations, main assumptions, and limitations.....	22
5.1 General considerations.....	22
5.2 Pre-requisite/main assumptions.....	23
5.3 Limitations .....	23
6 Establishment of system success/failed states .....	24
6.1 General considerations.....	24
6.2 Detailed considerations .....	24
6.2.1 System operation.....	24
6.2.2 Environmental conditions .....	25
6.2.3 Duty cycles .....	25
7 Elementary models .....	25
7.1 Developing the model.....	25
7.2 Series structures.....	25
7.3 Parallel structures .....	26
7.4 Mix of series and parallel structures.....	26
7.5 Other structures .....	27
7.5.1 $m$ out of $n$ structures.....	27
7.5.2 Structures with common blocks .....	28
7.5.3 Composite blocks.....	29
7.6 Large RBDs and use of transfer gates .....	29
8 Qualitative analysis: minimal tie sets and minimal cut sets.....	30
8.1 Electrical analogy.....	30
8.2 Series-parallel representation with minimal success path and cut sets.....	32
8.3 Qualitative analysis from minimal cut sets.....	33
9 Quantitative analysis: blocks with constant probability of failure/success .....	33
9.1 Series structures.....	33
9.2 Parallel structures .....	34
9.3 Mix of series and parallel structures.....	34
9.4 $m/n$ architectures (identical items).....	35
10 Quantitative analysis: blocks with time dependent probabilities of failure/success .....	35
10.1 General.....	35
10.2 Non-repaired blocks .....	36
10.2.1 General .....	36
10.2.2 Simple non-repaired block.....	36
10.2.3 Non-repaired composite blocks.....	36
10.2.4 RBDs with non-repaired blocks.....	37
10.3 Repaired blocks .....	37
10.3.1 Availability calculations .....	37
10.3.2 Average availability calculations .....	40

10.3.3	Reliability calculations.....	42
10.3.4	Frequency calculations.....	43
11	Boolean techniques for quantitative analysis of large models.....	43
11.1	General.....	43
11.2	Method of RBD reduction .....	44
11.3	Use of total probability theorem .....	45
11.4	Use of Boolean truth tables .....	46
11.5	Use of Karnaugh maps .....	47
11.6	Use of the Shannon decomposition and binary decision diagrams .....	49
11.7	Use of Sylvester-Poincaré formula.....	50
11.8	Examples of RBD application.....	51
11.8.1	Models with repeated blocks .....	51
11.8.2	$m$ out of $n$ models (non-identical items).....	54
12	Extension of reliability block diagram techniques .....	54
12.1	Non-coherent reliability block diagrams.....	54
12.2	Dynamic reliability block diagrams .....	57
12.2.1	General .....	57
12.2.2	Local interactions.....	58
12.2.3	Systemic dynamic interactions.....	59
12.2.4	Graphical representations of dynamic interactions .....	59
12.2.5	Probabilistic calculations .....	62
Annex A (informative)	Summary of formulae.....	63
Annex B (informative)	Boolean algebra methods.....	67
B.1	Introductory remarks .....	67
B.2	Notation.....	67
B.3	Tie sets (success paths) and cut sets (failure paths) analysis.....	68
B.3.1	Notion of cut and tie sets.....	68
B.3.2	Series-parallel representation using minimal tie and cut sets.....	69
B.3.3	Identification of minimal cuts and tie sets.....	70
B.4	Principles of calculations .....	71
B.4.1	Series structures .....	71
B.4.2	Parallel structures .....	71
B.4.3	Mix of series and parallel structures .....	73
B.4.4	$m$ out of $n$ architectures (identical items).....	73
B.5	Use of Sylvester Poincaré formula for large RBDs and repeated blocks.....	74
B.5.1	General .....	74
B.5.2	Sylvester Poincaré formula with tie sets.....	74
B.5.3	Sylvester Poincaré formula with cut sets.....	76
B.6	Method for disjointing Boolean expressions .....	77
B.6.1	General and background .....	77
B.6.2	Disjointing principle.....	78
B.6.3	Disjointing procedure .....	79
B.6.4	Example of application of disjointing procedure.....	79
B.6.5	Comments .....	81
B.7	Binary decision diagrams .....	82
B.7.1	Establishing a BDD .....	82
B.7.2	Minimal success paths and cut sets with BDDs.....	84
B.7.3	Probabilistic calculations with BDDs .....	86

B.7.4	Key remarks about the use of BDDs .....	87
Annex C (informative)	Time dependent probabilities and RBD driven Markov processes .....	88
C.1	General.....	88
C.2	Principle for calculation of time dependent availabilities .....	88
C.3	Non-repaired blocks .....	89
C.3.1	General .....	89
C.3.2	Simple non-repaired blocks .....	89
C.3.3	Composite block: example on a non-repaired standby system .....	89
C.4	RBD driven Markov processes.....	91
C.5	Average and asymptotic (steady state) availability calculations .....	92
C.6	Frequency calculations.....	93
C.7	Reliability calculations.....	94
Annex D (informative)	Importance factors .....	96
D.1	General.....	96
D.2	Vesely-Fussell importance factor .....	96
D.3	Birnbaum importance factor or marginal importance factor .....	96
D.4	Lambert importance factor or critical importance factor .....	97
D.5	Diagnostic importance factor .....	97
D.6	Risk achievement worth .....	98
D.7	Risk reduction worth.....	98
D.8	Differential importance measure .....	98
D.9	Remarks about importance factors.....	99
Annex E (informative)	RBD driven Petri nets .....	100
E.1	General.....	100
E.2	Example of sub-PN to be used within RBD driven PN models .....	100
E.3	Evaluation of the DRBD state .....	102
E.4	Availability, reliability, frequency and MTTF calculations .....	104
Annex F (informative)	Numerical examples and curves .....	105
F.1	General.....	105
F.2	Typical series RBD structure .....	105
F.2.1	Non-repaired blocks .....	105
F.2.2	Repaired blocks .....	106
F.3	Typical parallel RBD structure .....	107
F.3.1	Non-repaired blocks .....	107
F.3.2	Repaired blocks .....	108
F.4	Complex RBD structures .....	109
F.4.1	Non series-parallel RBD structure.....	109
F.4.2	Convergence to asymptotic values versus MTTR .....	110
F.4.3	System with periodically tested components .....	111
F.5	Dynamic RBD example.....	113
F.5.1	Comparison between analytical and Monte Carlo simulation results .....	113
F.5.2	Dynamic RBD example.....	113
Bibliography	.....	116
Figure 1	– Shannon decomposition of a simple Boolean expression and resulting BDD .....	18
Figure 2	– Series reliability block diagram .....	25
Figure 3	– Parallel reliability block diagram .....	26



Figure 4 – Parallel structure made of duplicated series sub-RBD .....	26
Figure 5 – Series structure made of parallel reliability block diagram.....	27
Figure 6 – General series-parallel reliability block diagram .....	27
Figure 7 – Another type of general series-parallel reliability block diagram .....	27
Figure 8 – 2 out of 3 redundancy.....	28
Figure 9 – 3 out of 4 redundancy.....	28
Figure 10 – Diagram not easily represented by series/parallel arrangement of blocks .....	28
Figure 11 – Example of RBD implementing dependent blocks .....	29
Figure 12 – Example of a composite block.....	29
Figure 13 – Use of transfer gates and sub-RBDs .....	30
Figure 14 – Analogy between a block and an electrical switch.....	30
Figure 15 – Analogy with an electrical circuit .....	31
Figure 16 – Example of minimal success path (tie set).....	31
Figure 17 – Example of minimal failure path (cut set).....	31
Figure 18 – Equivalent RBDs with minimal success paths .....	32
Figure 19 – Equivalent RBDs with minimal cut sets.....	33
Figure 20 – Link between a basic series structure and probability calculations .....	33
Figure 21 – Link between a parallel structure and probability calculations .....	34
Figure 22 – "Availability" Markov graph for a simple repaired block .....	38
Figure 23 – Standby redundancy.....	38
Figure 24 – Typical availability of a periodically tested block.....	39
Figure 25 – Example of RBD reaching a steady state.....	41
Figure 26 – Example of RBD with recurring phases .....	41
Figure 27 – RBD and equivalent Markov graph for reliability calculations .....	42
Figure 28 – Illustrating grouping of blocks before reduction.....	44
Figure 29 – Reduced reliability block diagrams .....	44
Figure 30 – Representation of Figure 10 when item A has failed .....	45
Figure 31 – Representation of Figure 10 when item A is working.....	45
Figure 32 – RBD representing three redundant items.....	46
Figure 33 – Shannon decomposition equivalent to Table 5.....	49
Figure 34 – Binary decision diagram equivalent to Table 5.....	49
Figure 35 – RBD using an arrow to help define system success .....	51
Figure 36 – Alternative representation of Figure 35 using repeated blocks and success paths.....	51
Figure 37 – Other alternative representation of Figure 35 using repeated blocks and minimal cut sets.....	52
Figure 38 – Shannon decomposition related to Figure 35.....	53
Figure 39 – 2-out-of-5 non-identical items .....	54
Figure 40 – Direct and inverted block .....	55
Figure 41 – Example of electrical circuit with a commutator A .....	55
Figure 42 – Electrical circuit: failure paths .....	55
Figure 43 – Example RBD with blocks with inverted states.....	56
Figure 44 – BDD equivalent to Figure 43 .....	57
Figure 45 – Symbol for external elements.....	58

Figure 46 – Dynamic interaction between a CCF and RBDs' blocks.....	60
Figure 47 – Various ways to indicate dynamic interaction between blocks .....	60
Figure 48 – Dynamic interaction between a single repair team and RBDs' blocks .....	60
Figure 49 – Implementation of a PAND gate .....	61
Figure 50 – Equivalent finite-state automaton and example of chronogram for a PAND gate .....	61
Figure 51 – Implementation of a SEQ gate .....	61
Figure 52 – Equivalent finite-state automaton and example of chronogram for a SEQ gate .....	62
Figure B.1 – Examples of minimal tie sets (success paths) .....	68
Figure B.2 – Examples of non-minimal tie sets (non minimal success paths) .....	68
Figure B.3 – Examples of minimal cut sets .....	69
Figure B.4 – Examples of non-minimal cut sets.....	69
Figure B.5 – Example of RBD with tie and cut sets of various order .....	70
Figure B.6 – Reminder of the RBD in Figure 35 .....	82
Figure B.7 – Shannon decomposition of the Boolean function represented by Figure B.6.....	82
Figure B.8 – Identification of the parts which do not matter .....	83
Figure B.9 – Simplification of the Shannon decomposition .....	83
Figure B.10 – Binary decision diagram related to the RBD in Figure B.6.....	84
Figure B.11 – Obtaining success paths (tie sets) from an RBD.....	84
Figure B.12 – Obtaining failure paths (cut sets) from an RBD.....	85
Figure B.13 – Finding cut and tie sets from BDDs .....	85
Figure B.14 – Probabilistic calculations from a BDD.....	86
Figure B.15 – Calculation of conditional probabilities using BDDs .....	87
Figure C.1 – Principle of time dependent availability calculations .....	88
Figure C.2 – Principle of RBD driven Markov processes .....	91
Figure C.3 – Typical availability of RBD with quickly repaired failures .....	91
Figure C.4 – Example of simple multi-phase Markov process.....	92
Figure C.5 – Typical availability of RBD with periodically tested failures.....	92
Figure E.1 – Example of a sub-PN modelling a DRBD block.....	100
Figure E.2 – Example of a sub-PN modelling a common cause failure.....	101
Figure E.3 – Example of DRBD based on RBD driven PN .....	101
Figure E.4 – Logical calculation of classical RBD structures.....	102
Figure E.5 – Example of logical calculation for an $n/m$ gate .....	102
Figure E.6 – Example of sub-PN modelling a PAND gate with 2 inputs .....	103
Figure E.7 – Example of the inhibition of the failure of a block .....	104
Figure E.8 – Sub-PN for availability, reliability and frequency calculations.....	104
Figure F.1 – Availability/reliability of a typical non-repaired series structure .....	105
Figure F.2 – Failure rate and failure frequency related to Figure F.1 .....	106
Figure F.3 – Equivalence of a non-repaired series structure to a single block.....	106
Figure F.4 – Availability/reliability of a typical repaired series structure .....	106
Figure F.5 – Failure rate and failure frequency related to Figure F.4 .....	107
Figure F.6 – Availability/reliability of a typical non-repaired parallel structure .....	107
Figure F.7 – Failure rate and failure frequency related to Figure F.6 .....	108
Figure F.8 – Availability/reliability of a typical repaired parallel structure .....	108

Figure F.9 – Vesely failure rate and failure frequency related to Figure F.8 .....	109
Figure F.10 – Example 1 from 7.5.2 .....	109
Figure F.11 – Failure rate and failure frequency related to Figure F.10.....	110
Figure F.12 – Impact of the MTTR on the convergence quickness.....	111
Figure F.13 – System with periodically tested blocks .....	112
Figure F.14 – Failure rate and failure frequency related to Figure F.13.....	112
Figure F.15 – Analytical versus Monte Carlo simulation results .....	113
Figure F.16 – Impact of CCF and limited number of repair teams .....	114
Figure F.17 – Markov graphs modelling the impact of the number of repair teams .....	115
Figure F.18 – Approximation for two redundant blocks.....	115
Table 1 – Acronyms used in IEC 61078 .....	18
Table 2 – Symbols used in IEC 61078.....	19
Table 3 – Graphical representation of RBDs: Boolean structures .....	21
Table 4 – Graphical representation of RBDs: non-Boolean structures/DRBD .....	22
Table 5 – Application of truth table to the example of Figure 32 .....	46
Table 6 – Karnaugh map related to Figure 10 when A is in up state .....	48
Table 7 – Karnaugh map related to Figure 10 when A is in down state .....	48
Table 8 – Karnaugh map related to Figure 35.....	53
Table A.1 – Example of equations for calculating the probability of success of basic configurations.....	63
Table F.1 – Impact of functional dependencies .....	114

## INTRODUCTION

A reliability block diagram (RBD) is a pictorial representation of a system's successful functioning. It shows the logical connection of (functioning) components (represented by blocks) needed for successful operation of the system (hereafter referred to as "system success"). Therefore an RBD is equivalent to a logical equation of Boolean variables and the probabilistic calculations are primarily related to constant values of the block success/failure probabilities.

Many different analytical methods of dependability analysis are available, of which the RBD is one. Therefore, the purpose of each method and their individual or combined applicability in evaluating the availability, reliability, failure frequency and other dependability measures as may be applicable to a given system or component should be examined by the analyst prior to deciding to use the RBD. Consideration should also be given to the results obtainable from each method, data required to perform the analysis, complexity of analysis and other factors identified in this standard.

Provided that the blocks in the RBD behave independently from each other and that the order in which failures occur does not matter then the probabilistic calculations can be extended to time dependent probabilistic calculations involving non-repaired as well as repaired blocks (e.g. blocks representing non-repaired or repaired components). In this case three dependability measures related to the system successful functioning have to be considered: the reliability itself,  $R_S(t)$ , but also the availability,  $A_S(t)$  and the failure frequency,  $w_S(t)$ . While, for systems involving repaired components, the calculations of  $A_S(t)$  or  $w_S(t)$  can be done quite straightforwardly, the calculation of  $R_S(t)$  implies systemic dependencies (see definition 3.34) which cannot be taken into account within the mathematical framework of RBDs. Nevertheless, in particular cases, approximations of  $R_S(t)$  are available.

The RBD technique is linked to fault tree analysis [1]<sup>1</sup> and to Markov techniques [2]:

- The underlying mathematics is the same for RBDs and fault tree analysis (FTA): when an RBD is focused on system success, the FT is focused on system failure. It is always possible to transform an RBD into an FT and vice versa. From a mathematical point of view, RBD and FT models share dual logical expressions. Therefore, the mathematical developments and the limitations are similar in both cases.
- When the availability  $A_i(t)$  of one block can be calculated by using an individual Markov process [2] independent of the other blocks, this availability,  $A_i(t)$ , can be used as input for the calculations related to an RBD including this block. This approach where an RBD provides the logic structure and Markov processes numerical values of the availabilities of the blocks is called "RBD driven Markov processes".

For systems where the order of failures is to be taken into account, or where the repaired blocks do not behave independently from each other or where the system reliability,  $R_S(t)$ , cannot be calculated by analytical methods, Monte Carlo simulation or other modelling techniques, such as dynamic RBDs, Markov [2] or Petri net techniques [3], may be more suitable.

---

<sup>1</sup> Numbers in square brackets refer to the Bibliography.