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| **General** | | **MPP Tracking**  **(DC-) Mains-Integration of PV systems** | | | | | | | | note  **1** |
| **Abstract** | | | | | | | | | | |
| This note describes the basic principles of the PV power conversion using a maximum power point (MPP) tracker. It provides the information why such a system has to be installed and the basic functionality. PV characteristic and the change of input impedance will be discussed. Also the comparison between an MPP Tracker in DC and AC grids is conducted. Furthermore there will be a short overview about what MPP-tracker systems are already available. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **R** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 12 teacher / 75 student |
| Intermediate | x |  |  | x |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  |  |  |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Basic knowledge about DC/DC and DC/AC converters  - Basic knowledge on electronics (Impedance, diodes, etc...) | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - Basic knowledge about MPP tracking | | | | | | | | | | - MPP Tracking.Hardware  - MPP Tracking.Software  - MPP Tracking.Showcase |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Patrick Deck | TH Köln |  |  |
| Christian Dick | TH Köln |  |  |
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| **Review** |  |  |  |  |
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| **Contact person** |  |  |  |  |

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| **When will the NOTE be available?** | | | | | | | | | | | | | | | | | | | | | | | |
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| **References** |
| * Dissertations * Bachelor- and Master Theses * Lecture notes * Conference papers * Detailed references in final paper |

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| **Table of content** |
| 1. Basic electric principals of the PV generator    * Diode characteristic    * MPP (Cell voltage, current)    * Input impedance    * Temperature    * etc… 2. Mains electrical specifications    * EMI    * AC standards    * DC standards (if available) 3. Converter: MPP Tracker in the system (impedance converter)    * Impedance conversion for MPP (link: strategies see MPP.Software)    * PV system concepts    * Buck or Boost depending on voltage level    * Difficulties using boost converters    * Floating PV potential – Problem and solutions 4. Latest Developments (Converter examples) 5. Special Implications for DC-Mains |

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| **General** | | **MPP Tracking**  **hardware** | | | | | | | | note  **2** |
| **Abstract** | | | | | | | | | | |
| This note describes the basic strategies on building an MPP tracker using a standard 2 quadrant chopper topology. Basic strategies to calculate the inductance and capacitors and for choosing the switches depending on voltage and power level of the PV-system and the grid are presented. The reader can adept basic principles if he wants to build up a converter himself. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **R** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 8 teacher / 50 student |
| Intermediate |  | x |  | x |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  |  |  |
| K = knowledge note   A = application note  I = implementation note   T = tutorial   P = power point   V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Basic knowledge about DC/DC and DC/AC converters  - Basic knowledge on electronics (Impedance, diodes, etc...)  - Basic knowledge about MPP tracking | | | | | | | | | | - MPP  Tracking.Overview |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - Calculation and design strategies to build up an MPP tracker hardware yourself | | | | | | | | | | - MPP  Tracking.Software  - MPP  Tracking.Showcase |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Patrick Deck | TH Köln |  |  |
| Christian Dick | TH Köln |  |  |
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| **When will the NOTE be available?** | | | | | | | | | | | | | | | | | | | | | | | |
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| **References** |
| * Bachelor- and Master Theses * Reports * Conference papers * Detailed references in final document |

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| **Table of content** |
| 1. MPP Tracker as voltage converter (MATLAB Tool) 2. Basic principles of the 2 quadrant chopper  * Maximum voltage ripple * Maximum current ripple * Controlling the power flow / MPP * etc…  1. Calculation of elements  * Inductive elements * Capacitive elements * Switching elements  1. Additional elements  * Controller * Sensors * etc…  1. Short example calculation |

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| **General** | | **MPP Tracking**  **Software** | | | | | | | | note  **3** |
| **Abstract** | | | | | | | | | | |
| This note describes the basic strategies to build up a software for MPP tracking. The basic algorithms are presented and discussed and there will be a manual how to implement the algorithms using standard controllers and programming languages. Furthermore the needs for measurement are presented. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **R** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 8 teacher / 50 student |
| Intermediate |  | x |  | x |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  |  |  |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Basic knowledge about DC/DC and DC/AC converters  - Basic knowledge on programming (C, C++, Java, VHDL, etc...)  - Basic knowledge about MPP tracking | | | | | | | | | | - MPP Tracking.Overview |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - Strategies to design an MPP tracking software on your own | | | | | | | | | | - MPP Tracking.Hardware  - MPP Tracking.Showcase |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Patrick Deck | TH Köln |  |  |
| Christian Dick | TH Köln |  |  |
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| **Review** |  |  |  |  |
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| **Contact person** |  |  |  |  |

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| **When will the NOTE be available?** | | | | | | | | | | | | | | | | | | | | | | | |
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| **References** |
| * Bachelor- and Master Theses * Reports * Conference papers * Detailed references in final document |

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| **Table of content** |
| 1. How to control the MPP tracker using software  * Control circuit * Software/hardware interface * Interrupt routine  1. Classic control strategies  * “Perturb and observe (P&0)” * “Incremental conductance” * etc…  1. Measurements  * Possible sensors in concern of control strategy  1. Software examples  * Buck * Etc.…. * Resonant converters: Pmax for explicit f |

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| **General** | | **MPP Tracking**  **Showcase** | | | | | | | | note  **4** |
| **Abstract** | | | | | | | | | | |
| This note provides all design files, software code and parts-list for building up an MPP tracker showcase including a PV panel lighted by a switchable 3x5 halogen lamp matrix. The tracker is build using an FPGA board. The PCB converts the energy from the PV panel and powers a small lamp, which indicates how much power is transferred (if the MPP is found or not). The students can do the MPP tracking on their own by clicking + and – buttons or switch to automatic mode and see the result of the programmed controller. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 8 teacher / 50 student |
| Intermediate |  |  | x | x |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  |  |  |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Basic knowledge about DC/DC and DC/AC converters  - Basic knowledge on programming (C, C++, Java, VHDL, etc...)  - Basic knowledge about MPP tracking | | | | | | | | | | - MPP Tracking.Overview  - MPP Tracking.Hardware  - MPP Tracking.Software |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - A showcase for MPP tracking  - Students can see MPP tracking in a real application | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Patrick Deck | TH Köln |  | 20190206 |
| Christian Dick | TH Köln |  |  |
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| **Review** |  |  |  |  |
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| **References** |
| * Bachelor- and Master Theses * Reports * Conference papers * Detailed references in final document |

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| **Table of content** |
| 1. Overview and Description:  * Topology * Hardware * Software  1. Operation:  * Button functions * Program flow  1. Appendix:  * Software code * CAD files * Manuals * Parts list * Etc… |

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| **Nanogrid** | | **Off-grid Solar Home Systems** | | | | | | | | | note  **5** |
| **Abstract** | | | | | | | | | | | |
| This note describes the basic steps behind the mathematical modeling of Solar Home Systems (off-grid PV systems). The note will cover the basics of locational issues, PV module temperature estimation, DC yield calculation while also explaining the basic method followed to dimension an off-grid system. | | | | | | | | | | | |
| **NOTE** | **K** | | **A** | **I** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  | |  |  |  |  |  | Certificate |  |  | (10) |
| Intermediate |  | | x |  | x |  |  | Bachelor | x |  | **status** |
| Advanced |  | |  |  |  |  |  | Master | x | (energy) | Development |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | | **previous notes to study** |
| - Basic knowledge of a PV solar cell  - Basic knowledge of loss mechanisms in a solar cell  -  - | | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | | **further notes to study** |
| - Mathematical modelling of PV module  - Model for estimating PV module temperature  - Model for estimating DC yield of a PV module  - Method to dimension an off-grid system | | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Nishant Narayan | Delft University of Technology |  |  |
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| **Review** |  |  |  |  |
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| **Contact person** | Laura Ramirez | Delft University of Technology |  |  |

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| **References** |
| ( witch references will/did you use to write this note? ) |

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| **PV Trailer** | | **How to build a PV trailer as PV and DC demonstrator** | | | | | | | | note  **6** |
| **Abstract** | | | | | | | | | | |
| This note describes how a PV trailer can be built. The aim of the PV trailer is to show the use and possibilities of PV systems, DC and AC nanogrids. The note briefly describes all the components of the electrical design. Basic design choices are discussed and explained. Mechanical drawings, component lists and electrical wiring diagram are provided within the scope of this note. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  | x | x |  |  | Certificate |  |  | 5 |
| Intermediate |  |  |  |  |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  |  |  |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Basic knowledge of PV systems  -  -  - | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - Which are the components of a mobile PV trailer and how do they interact  - What are the specs, possibilities and limitations of the PV trailer system  - Which design choices have been made while building the trailer  - | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Jan Elsen | UCLL | *Sustainable resources* | 20190205 |
| Thomas Vanhove | UCLL | *Sustainable resources* |  |
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| **References** |
| Datasheets   * <https://www.victronenergy.com/support-and-downloads/datasheets>   Manuals   * <https://www.victronenergy.com/support-and-downloads/manuals> * <https://www.victronenergy.com/live/ccgx:start>   VRM app   * <https://www.victronenergy.com/support-and-downloads/software> * [vrm.victronenergy.com](http://vrm.victronenergy.com/)   Open source Venus OS   * <https://github.com/victronenergy/venus/wiki> * <https://github.com/victronenergy/venus/wiki/raspberrypi-install-venus-image> |

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| **Table of content** |
| [1 Introduction 3](#_Toc295969)  [2 Measurement system overview 4](#_Toc295970)  [3 Setup and communication 5](#_Toc295971)  [3.1 Color Control GX communication 5](#_Toc295972)  [3.2 CCGX Communication protocols 6](#_Toc295973)  [3.2.1 VE.Can 6](#_Toc295974)  [3.2.2 VE.Direct 6](#_Toc295975)  [3.2.3 VE.Bus 6](#_Toc295976)  [3.2.4 Modbus TCP/IP 7](#_Toc295977)  [3.3 USB GPS module 7](#_Toc295978)  [4 Real time measurements 8](#_Toc295979)  [5 Data logging 9](#_Toc295980)  [5.1 VRM portal 9](#_Toc295981)  [5.2 Measurement data 9](#_Toc295982)  [5.2.1 Dashboard view 10](#_Toc295983)  [5.2.2 Device list view 11](#_Toc295984)  [5.2.3 Advanced view 12](#_Toc295985)  [5.2.4 Download log files 16](#_Toc295986) |

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| **PV Trailer** | | **PV trailer electrical components** | | | | | | | | note  **7** |
| **Abstract** | | | | | | | | | | |
| This note describes the choice and dimensioning of all the electrical components of a PV trailer. This includes PV panel characteristics, MPPT trackers, Battery protection, Batteries, cabling, DC-DC converters, AC inverter, protection and safety components. The note includes a short lab tutorial on how to use component-specific software to dimension an off-grid PV system and e-learning modules. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
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| Advanced |  |  |  |  |  |  | Master |  |  |  |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Basic knowledge of PV systems  - Basic knowledge of AC and DC systems  -  - | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - How to dimension an off-grid PV system  - How do the components of a PV system work together  - How can we optimize the use of DC in PV systems  - How are electrical safety and protection realised in a mobile PV application | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Jan Elsen | UCLL | *Sustainable resources* |  |
| Thomas Vanhove | UCLL | *Sustainable resources* |  |
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| **When will the NOTE be available?** | | | | | | | | | | | | | | | | | | | | | | | |
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| **References** |
| ( witch references will/did you use to write this note? )   * Component datasheets and design software provided by component manufacturer |

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| **PV Trailer** | | **How to obtain measurement data from the PV trailer** | | | | | | | | note  **8** |
| **Abstract** | | | | | | | | | | |
| Most of the components on the PV trailer have communication possibilities to retain measurement data. This note describes how to setup and configure communication between these components and how to capture measurements both local and in a cloud-based environment. The different communication bus systems onboard are described. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  | x |  | x |  |  | Certificate |  |  | 4 |
| Intermediate |  |  |  |  |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  |  |  |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Which are the components of the PV trailer?  -  - | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - You will have an overview of the communication possibilities of the PV trailer components  - You will be able to collect the measurement data of the various trailer components | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Jan Elsen | UCLL | *Sustainable resources* | 20190206 |
| Thomas Vanhove | UCLL | *Sustainable resources* |  |
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| **Review** |  |  |  |  |
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| **References** |
| Datasheets   * <https://www.victronenergy.com/support-and-downloads/datasheets>   Manuals   * <https://www.victronenergy.com/support-and-downloads/manuals> * <https://www.victronenergy.com/live/ccgx:start>   VRM app   * <https://www.victronenergy.com/support-and-downloads/software> * [vrm.victronenergy.com](http://vrm.victronenergy.com/)   Open source Venus OS   * <https://github.com/victronenergy/venus/wiki> * <https://github.com/victronenergy/venus/wiki/raspberrypi-install-venus-image> |

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| **Table of content** |
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| **PV Trailer** | | **PV trailer measurements** | | | | | | | | note  **9** |
| **Abstract** | | | | | | | | | | |
| This Lab tutorial contains several lab experiments to obtain and analyze measurements from the PV trailer.   * PV panel characteristics and MPP tracking * Batteries and principles of battery management * The use of DC-DC converters and AC inverters * How to share and compare measurements on PV (trailer) systems based at the DCT-REES partner campuses | | | | | | | | | | |
| **NOTE** | **K** | **A** | **L** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 8 |
| Intermediate |  |  | x | x |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  |  |  |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Which are the components of the PV trailer?  -  - | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - You will have an overview of the communication possibilities of the PV trailer components  - You will be able to collect the measurement data of the various trailer components | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Jan Elsen | UCLL | *Sustainable resources* |  |
| Thomas Vanhove | UCLL | *Sustainable resources* |  |
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| **Review** |  |  |  |  |
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| **Contact person** |  |  |  |  |

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| **References** |
| ( witch references will/did you use to write this note? )   * Component datasheets and design software provided by component manufacturer |

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| **Nanogrid** | | **Reconverting existing domestic appliances to work on 350 Volt DC** | | | | | | | | note  **10** |
| **Abstract** | | | | | | | | | | |
| To make the transition from an AC grid to a DC grid successfully it is important that there are domestic appliances whom can work on DC. In the transition time the most appliances will work on AC so they have to be converted to DC.  In this note we will explain how to do that.  Most of the appliances are internally already working on DC. It is here to find out how the transformation from the AC input to the DC output is done. We will do that on the hand of different examples of well-known domestic appliances as: Television, personal computer, charging blocks, vacuum cleaner, induction cooking plate, etcetera. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **L** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 90 |
| Intermediate |  | x | x | x |  |  | Bachelor | x | Power electronics | **status** |
| Advanced |  |  |  |  |  |  | Master | x | Power electronics | In development |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - electrical engineering  - power engineering  - filters  - power electronics: AC/DC converters and DC/DC converters  - | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - reverse engineering  - understand electronic schemes  - reconverting existing domestic appliances to work on 350 volt DC  - | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Johan Woudstra | THUAS | *Energy in transition* |  |
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| **References** | | | | | | | | | | | | | | | | | | | | | | | | | |
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| **General** | | **Lab setup for power electronics** | | | | | | | | note  **11** |
| **Abstract** | | | | | | | | | | |
| In this note a power electronics converter is described that is developed for educational purposes, considering topologies and power transfer for general applications. The considered topology is first evaluated by students via simulation. Secondly, using an experimental setup and regulation via a low cost embedded digital control, the students can experiment with various applications such as solar, battery charging, DCDC conversion and PWM motor control.  Index Terms: Education, laboratory setup, power electronics, converters, learning by doing | | | | | | | | | | |
| **NOTE** | **K** | **A** | **L** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 30 |
| Intermediate |  |  | x | x |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master | x | (energy) |  |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - basic knowledge of electrical engineering  - basic knowledge of electronic circuits  - basic knowledge of power electronics  - basic knowledge of embedded digital control  Basic knowledge of simulation models and programs | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| The aim of the topology is to give students a basic understanding of the conversion process in power electronics. They will learn that there are basic concepts when it comes to the operation of switched mode power supplies [SMPS] and that these concepts can directly be used in single phase or multiphase motor drives, as well as in battery chargers and Maximum Power Point [MPP] trackers in solar applications. First the students have to understand the basic concept and operation of the topology using a circuit simulation. They can study the influence of parameters and the control methods. Second, the students can experiment with a laboratory set up which they can connect freely to appliances like batteries, solar panels or DC loads. Not only teaching power electronics engineers at BSc and MSc level, but also training for the practising engineer on solar and battery applications and implementation in small scale DC grids is feasible with the laboratory set up. Finally the proposed topology is directly applicable for implementation of small scale DC grids in rural areas based on Photo Voltaic technology and battery storage. | | | | | | | | | |  |

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| **References** |
| ( witch references will/did you use to write this note? )  [1] De gepubliceerde paper is hier te downloaden: <https://www.sefi.be/wp-content/uploads/2018/10/SEFI-Proceedings-2-October-2018.pdf> pagina 1429 t/m 1436 |

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| **Nanogrid** | | **BMS for batteries.** | | | | | | | | **note**  **12** |
| **Abstract** | | | | | | | | | | |
| The cost of Lithion-ion batteries is decreasing and becomes a valuable alternative for providing backup and improved reliability for smart **nanogrids**. (Building or home with DC-grid). But these technologies need some precautions when they are used and implemented in homes for unskilled people.  The KN will discuss the most important battery parameters like SOC, SOH, DOD, C-rate and Cycle life without diving into the battery technologies. Insight in these parameters will be the base for the discussion of the Battery-Monitoring-System (BMS).  The main functions of the BMS will be discussed and the importance of the functions will be explained for the integration of the battery within a small Nano-grid. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 6 |
| Intermediate |  |  | x | x |  |  | Bachelor | x |  | **Draft** |
| Advanced |  |  |  |  |  |  | Master | x | (energy) |  |
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| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Basic-knowledge of power-electronics.  - Basic knowledge of DC-DC convertors.  -  - | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Geert Vandensande | KU-Leuven | ESAT-Electa |  |
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| **References** |
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| **General** | | **Labo: Full-bridge DC-DC convertor** | | | | | | | | note  **13** |
| **Abstract** | | | | | | | | | | |
| The H-bridge is often used to drive some small DC-loads like DC-motors. The inductance of the motor is big enough to convert the PWM-signal to a constant current. The target of this labo is to use the same H-bridge as basis for a DC-DC convertor. This labo will discuss the different steps to convert the H-bridge to an efficient DC-DC convertor  Part one: the H-bridge is used to study the different PWM-techniques: unipolar PWM, bipolar PWM and others. The student calculates the expected results and measures the voltage and currents at the output. Based on these calculations he get insight in the different PWM-techniques that can be implemented.  Part two: an extra HF-transformer is added to the H-bridge to realize a galvanic isolated output-signal. An extra rectifier and capacitor are added to realize the DC-voltage at the secondary side of the transfo.  Part three: Extra current and voltage regulation loop are added to realize a regulated output voltage.  Part four: the efficiency can be improved by implementing ZVS or ZCS or both. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **L** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 9 |
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| Advanced |  |  |  |  |  |  | Master | x | (energy) |  |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Basic-knowledge of power-electronics.  - Basic knowledge of DC-DC convertors.  -  - | | | | | | | | | |  |
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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Geert Vandensande | KU-Leuven | ESAT-Electa |  |
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| **References** | | | | | | | | | | | | | | | | | | | | | | | | | |
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| **Microgrid** | | **Microgrid Course edX TUDelft** | | | | | | | | note  **NN** |
| **Abstract** | | | | | | | | | | |
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| **NOTE** | **K** | **A** | **I** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
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| Intermediate |  |  |  |  |  |  | Bachelor |  |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  |  |  |
| K = knowledge note A = application note I = implementation note L = tutorial P = power point V = video | | | | | | | | | | |
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| **MVDC** | | **Transmission means for MVDC compared to MVAC** | | | | | | | | note  **14** |
| **Abstract** | | | | | | | | | | |
| In current transport, the AC voltage ranges have been in demand so far. With growing development in electrical engineering, the transmission paths with the DC range are becoming more interesting. The fundamentals of medium voltage transmission are explained as well as the possible transmission paths. These include the types of lines and their necessary specifications.  The differences between AC- and DC-transmission are explained, considering the following aspects:   * voltage losses * ? | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **R** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 8 |
| Intermediate | x |  |  | x |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  | (energy) | draft |
| K = knowledge note A = application note I = implementation note L = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| -Fundamentals of electrical engeeniering ( e. g. Ohm´s law, definition of powervoltage, current)  -Fundamentals of electric fields (theoretical electrical engineering)  -Fundamentals of electical resistance in solid material | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| -differences between AC and DC transmission  -commonly used voltagelevels for the transmission lines  - transportation losses | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Fabian Peysang | FH Aachen |  | 20190201 |
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| **MVDC** | | **Components used for MVDC** | | | | | | | | note  **15** |
| **Abstract** | | | | | | | | | | |
| Power electronics is a key for the application of medium voltage DC transmission. For example, protective devices are required to disconnect the mains in the event of a fault. Converters and rectifiers are required to integrate MVDC into existing AC networks. The article describes the power semiconductors are used in this article in accordance with their current state of development.  Semiconductors: Converters are explained in more detail:   * IGBT - Boost converter * GTO -Buck converter * Mosfet -recifier   -inverter | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **R** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 12 |
| Intermediate | x |  |  | x |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  | (energy) | draft |
| K = knowledge note A = application note I = implementation note L = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| -Fundamentals of power electroncis  -Fundamentals of Semiconductor devices | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| -Requirements for MVDC power electronics  -semiconductors for MVDC power electronics  -Converter topologies and their basic functions | | | | | | | | | |  |

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| **Author(s)** | Fabian Peysang | FH Aachen |  | 20190201 |
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| **MVDC** | | **Areas of Application for MVDC** | | | | | | | | note  **16** |
| **Abstract** | | | | | | | | | | |
| Different areas of application for MVDC are presented in this paper. It explains how they are used and when it makes sense to choose one of these DC solutions. Furthermore, the function of a Microgrid network is explained, its advantages and disadvantages are listed and compared, and an example is given of how to use a Microgrid. Limitations and different voltage levels are addressed and explained, how they are possible in a Microgrid in the medium voltage direct current range. The difference between a Microgrid and a Macrogrid is also explained. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **R** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 6 |
| Intermediate | x |  |  | x |  |  | Bachelor | x |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  | (energy) | draft |
| K = knowledge note A = application note I = implementation note L = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| -Fundamentals of electrical engeeniering ( e. g. Ohm´s law, definition of powervoltage, current)  -Fundamentals of power conversion  -Fundamentals of power transmission | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| -different application areas for MVDC  -What are Microgrids  -Where the use of Microgrids makes sense. | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Fabian Peysang | FH Aachen |  | 20190201 |
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| MVDC | | **Power electronics for regenerative systems** | | | | | | | | note  **17** |
| **Abstract** | | | | | | | | | | |
| This paper (power point class)provides technical knowledge on selected current topics in power electronics and power engineering.  The technical challenges and opportunities closely related to the energy system transformation are explained. You get an understanding of the technology factors and cost parameters that are crucial for development. In this course the general boundary conditions are explained. Building on this, the possibilities of power electronics (components, topologies, ) are presented. The basics for photovoltaic systems and wind power are described. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
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| Intermediate |  | x |  |  | x |  | Bachelor | x |  | **status** |
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| K = knowledge note A = application note I = implementation note L = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| -Fundamentals of power electroncis  -Fundamentals of Semiconductor devices | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| * Basic understanding of the energy system transformation * Getting to know all components related to regenerative energy | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Oliver Schmitz | FH Aachen |  |  |
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| **MVDC** | | **High-Power DC-DC Converters** | | | | | | | | note  **18** |
| **Abstract** | | | | | | | | | | |
| High-power dc-dc converters are key enabling components in MVDC grids as dc transformers, where galvanic isolation is usually required due to the high voltage-ratio and fault isolation requirement. Depending on different applications, unidirectional topologies e.g. series resonant converter (SRC) or bidirectional topologies e.g. dual-active bridge (DAB) converter are the most promising candidates among others, mainly attributed to the soft-switching operation. This note aims to give an introduction of selected dc-dc topologies, the operation principle, and the corresponding control. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **R** | **P** | **V** | **Education Level** | | | **study load (hours)** |
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| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Fundamental of power electronics (mandatory)  -  -  - | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - Lab note for high-power dc-dc converters  -  -  - | | | | | | | | | | Lab note for high-power dc-dc converters |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Jingxin Hu | RWTH Aachen | MVDC |  |
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| **Contact person** | Jingxin Hu | RWTH Aachen | MVDC |  |

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| **References** |
| [1] Lecture Notes: Power Electronics – Fundamentals, Topologies, Analysis, RWTH Aachen University, 2018  [2] Lecture Notes: Power Electronics – Control, Synthesis, Application, RWTH Aachen University, 2018  [3] R. W. A. A. De Doncker, D. M. Divan and M. H. Kheraluwala, "A three-phase soft-switched high-power-density DC/DC converter for high-power applications," in IEEE Transactions on Industry Applications, vol. 27, no. 1, pp. 63-73, Jan.-Feb. 1991.  [4] Robert Lenke, “A Contribution to the Design of Isolated DC-DC Converters for Utility Applications”, Ph.D. Dissertation, RWTH Aachen University, 2012.  [5] Nils Soltau, “High-power medium-voltage DC-DC converters : design, control and demonstration”, Ph.D. Dissertation, RWTH Aachen University, 2017. |

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| **Table of content** |
| Following chapters are planned in this note.   1. Introduction of high-power dc-dc converters 2. Series-resonant converter 3. Dual-active bridge converter 4. Application examples of high-power dc-dc converters |

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| **MVDC** | | **Lab Note for High-Power DC-DC Converters** | | | | | | | | note  **19** |
| **Abstract** | | | | | | | | | | |
| This note aims to give a lab practice course of dc-dc topologies for MVDC applications. Single active bridge (SAB) and series resonant converter (SRC) with down-scaled power and voltage ratings are designed and compared in this lab tutorial. Printed circuit boards (PCBs) and components are prepared for students. The series capacitor of the SRC converter can be bypassed to be configured as an SAB converter. The switching frequency can be tuned by a potential meter for different operation conditions. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **L** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
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| Intermediate |  | X |  | X |  |  | Bachelor |  |  | **status** |
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| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Fundamental of power electronics  - High-power dc-dc converters  -  - | | | | | | | | | | 43 (How do dc-dc converters work?)  71 (High-power dc-dc converters) |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
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| **Author(s)** | Jingxin Hu | RWTH Aachen | MVDC | 20190205 |
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| **References** | | | | | | | | | | | | | | | | | | | | | | | | | |
| [1] Lecture Notes: Power Electronics – Fundamentals, Topologies, Analysis, RWTH Aachen University, 2018  [2] Lecture Notes: Power Electronics – Control, Synthesis, Application, RWTH Aachen University, 2018 | | | | | | | | | | | | | | | | | | | | | | | | | |

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| **Table of content** |
| Following tasks are planned in this note.   1. Review of operation principle of SAB and SRC 2. Design and commission a high-frequency transformer 3. Assemble an SRC converter 4. Measure waveforms of the SRC converter in different conditions 5. Configure an SAB converter 6. Measure waveforms of the SAB converter in different conditions 7. Compare the characteristics of the SAB and SRC |

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| **MVDC** | | **High Power Multilevel Converters** | | | | | | | | note  **20** |
| **Abstract** | | | | | | | | | | |
| Using power electronics conversion units for applications with power levels in the order of several MW up to GW places certain demand on the converter technology. Special measures have to be taken to cope with voltages in the kV range and currents of several kA. Therefore, this note is dedicated to converter topologies and their corresponding modulation strategies for medium-voltage applications. As power electronics converters with very high voltage and power ratings are increasingly used for transmission and distribution of electrical energy, high-voltage direct current (HVDC) transmission systems are covered as well. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **R** | **P** | **V** | **Education Level** | | | **study load (hours)** |
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| Intermediate | X |  |  | X |  |  | Bachelor | X |  | **status** |
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| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Fundamental of power electronics (mandatory)  -  -  - | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
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| **Author(s)** | Jingxin Hu | RWTH Aachen | MVDC | 20190205 |
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| **References** |
| [1] Lecture Notes: Power Electronics – Control, Synthesis, Application, RWTH Aachen University, 2018 |

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| **Table of content** |
| Following chapters are planned in this note.   1. Multi-level voltage source converter topologies 2. Multi-level modulation strategies 3. High-voltage direct current transmission 4. Reactive power compensation systems 5. Static transfer switch 6. On-load tap changers |

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| **MVDC** | | **DC Circuit Breakers** | | | | | | | | note  **21** |
| **Abstract** | | | | | | | | | | |
| Protection of dc grids is more challenging than ac grids, since dc fault currents do not have natural zero crossing and they are developed much faster. To interrupt dc fault currents, dc circuit breakers with fast fault clearing capability are required. Solid-state circuit breakers exhibit the highest fault current clearing speed, but they are costly and present high conduction losses in the normal operation. Hybrid circuit breakers compromise between the low conduction loss of mechanical switches and the high switching speed of semiconductor devices. This note aims to give an overview of different dc circuit breaker technologies especially for medium-voltage (MV) applications. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **R** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | 6 |
| Intermediate | X |  |  | X |  |  | Bachelor |  |  | **status** |
| Advanced |  |  |  |  |  |  | Master | X | (energy) | Draft version |
| K = knowledge note A = application note I = implementation note T = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| - Semiconductor device (optional)  -  -  - | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| - Protection strategy of dc grids  -  -  - | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Jingxin Hu | RWTH Aachen | MVDC |  |
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| **When will the NOTE be available?** | | | | | | | | | | | | | | | | | | | | | | | |
| 2018 | | | | | | 2019 | | | | | | | | | | | | 2020 | | | | | |
| J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J |
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| **References** |
| [1] ABB circuit-breaker for direct current applications, technical application papers.  [2] X. Pei, O. Cwikowski, D. S. Vilchis-Rodriguez, M. Barnes, A. C. Smith and R. Shuttleworth, "A review of technologies for MVDC circuit breakers," IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society, Florence, 2016, pp. 3799-3805.  [3] G. Li, J. Liang, S. Balasubramaniam, T. Joseph, C. E. Ugalde-Loo and K. F. Jose, "Frontiers of DC circuit breakers in HVDC and MVDC systems," 2017 IEEE Conference on Energy Internet and Energy System Integration (EI2), Beijing, 2017, pp. 1-6.  [4] M. Heidemann, G. Nikolic, A. Schnettler, A. Qawasmi, N. Soltau and R. W. De Donker, "Circuit-breakers for medium-voltage DC grids," 2016 IEEE PES Transmission & Distribution Conference and Exposition-Latin America (PES T&D-LA), Morelia, 2016, pp. 1-6.  [5] A. Qawasmi, N. Soltau, R. W. De Doncker, M. Heidemann, G. Nikolic and A. Schnettler, "A comparison of circuit breaker technologies for medium voltage direct current distribution networks," 2016 IEEE PES Transmission & Distribution Conference and Exposition-Latin America (PES T&D-LA), Morelia, 2016, pp. 1-6.  [6] T. Wang, A. Monti, J. Hu and R. W. De Doncker, "Protection of Dual-Active-Bridge Converters Against Underdamped Surge Current by Current Limiting Reactor," 2018 9th IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Charlotte, NC, 2018, pp. 1-6. |

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| **Table of content** |
| Followings chapters are planned in this note.   1. Characteristic of dc short-circuit fault currents 2. Mechanical circuit breakers 3. Solid-state dc circuit breakers 4. Hybrid dc circuit breakers 5. Application examples |

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| General | | **Cybersecurity for energy automation products** | | | | | | | | note  **22** |
| **Abstract** | | | | | | | | | | |
| Cyber attacks on power networks’ critical components and infra-structure is a reality, and it is quite regularly reported. Two reasons for this are the increased networking of systems and standardization of systems and protocols, which allows hackers the opportunity to exploit loop-holes and vulnerabilities in the systems. Networking simplifies processes and streamlines operations, but this comes at a risk of cyber attacks. Therefore one has to take care of security and develop protocols to ensure safe-guarding of the networks. Note that the proven security controls from the field of Information Technology (IT) do not necessarily fit exactly one by one to the field operational technology, including automation technology, because of the different conditions in the two fields. | | | | | | | | | | |
| **NOTE** | **K** | **A** | **I** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic | x |  |  |  |  |  | Certificate | x |  | (8) |
| Intermediate | x |  |  |  |  |  | Bachelor | x |  | **status** |
| Advanced | x |  |  |  |  |  | Master | x |  |  |
| K = knowledge note A = application note I = implementation note L = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
| * Fundamentals in networking * Networking protocols | | | | | | | | | |  |
| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
| * Cyberspace and the Fundamentals of Cybersecurity * Possible differences between security on Operation Technology (OT) vs Information technology (IT) * Risks and Hazards (Unauthorised access, Administrator rights and abuse of user login credentials, fraudulent firmware and software, internet attacks) * Security on different operating systems * End-to-end cybersecurity for digital substations * International Standards: ISO 27000 series (Information security standards), IEC 62443-2-4 (Integrator processes), IEC 62443-3-3 (Technical functionalities) * Cyber Forensics | | | | | | | | | |  |

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|  | **Name** | **Institute** | **Research Group** | **Date** |
| **Author(s)** | Jaco Jordaan | TUT |  |  |
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| **Review** |  |  |  |  |
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| **Contact person** |  |  |  |  |

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| **References** | | | | | | | | | | | | | | | | | | | | | | | | | |
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| Case | | **Blanco** | | | | | | | | note  **NN** |
| **Abstract** | | | | | | | | | | |
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| **NOTE** | **K** | **A** | **I** | **T** | **P** | **V** | **Education Level** | | | **study load (hours)** |
| Basic |  |  |  |  |  |  | Certificate |  |  | xx |
| Intermediate |  |  |  |  |  |  | Bachelor |  |  | **status** |
| Advanced |  |  |  |  |  |  | Master |  |  |  |
| K = knowledge note A = application note I = implementation note L = tutorial P = power point V = video | | | | | | | | | | |
| **Which knowledge do you need to start this note?** | | | | | | | | | | **previous notes to study** |
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| **What will you have learned after studying this note?** | | | | | | | | | | **further notes to study** |
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| **Contact person** |  |  |  |  |

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| **References** |
| ( which references will/did you use to write this note? )  [1]  [2]  xxx |

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| **Table of content** |
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