D-Suite

Design Specifications of Hardware and Control Algorithms.

Contents

Glossary of Terms

TERM	DEFINITION
AC	Alternating Current.
CAPEX	Capital Expenditure.
CBA	Cost Benefit Analysis.
DC	Direct Current.
DER	Distributed Energy Resource.
DNOs	Distribution Network Operators.
EA	Energy Availability.
ENA	Energy Network Association.
EU	European Union.
FAT	Factory Acceptance Test.
GB	Great Britain.
GHG	Greenhouse gas.
GW	Giga-Watts.
HVDC	High Voltage Direct Current.
HVPD	High Voltage Partial Discharge Ltd.
IGBT	Insulated Gate Bi-Polar Transistor.
kV	Kilo-Volts
LCNI	Low Carbon Network Innovation
LV	Low Voltage
MV	Medium Voltage
MVDC	Medium Voltage DC
MVA	Mega-Volt Amps
MVAr	Reactive Mega-Volt Amps
MW	Mega-Watts
NC	Normally Closed Circuit
NIA	Network Innovation Allowance
NO	Normally Open Circuit
NPV	Net Present Value
OHL	Overhead Line
OPEX	Operational Expenditure
RIIO-ED1	Electricity Distribution 1 Regulatory Period
SAT	Site Acceptance Test
STATCOM	Static Synchronous Compensator
TRL	Technology Readiness Level
UK	United Kingdom
VSC	Voltage Source Convertor
Wh	Watt-hour
WP	Work Package

1. Executive Summary

This report presents a comprehensive analysis of power electronic devices (PEDs) for low-voltage (LV) networks, focusing on the implementation of D-Suite devices to strengthen these networks. The D-Suite is a series of intelligent LV power electronic solutions that provide coordinated functionalities such as voltage, power, and harmonic compensation. By optimising the existing network infrastructure, the proposed D-Suite solution enhances power quality and promotes the adoption of low-carbon technologies in LV distribution networks.

The primary objective of this report is to identify design specifications of suitable PED solutions for various types of D-Suite devices. Potential PED solutions are thoroughly reviewed and compared, leading to the selection of appropriate topologies with their respective functions and advantages.

Key outcomes of this report include:

1. Tailored Hardware Solutions: The development of hardware solutions that are specifically designed to meet the unique characteristics and limitations of LV networks. By selecting suitable PED topologies, the necessary network functions can be achieved effectively.
2. Comprehensive Hardware Design: Detailed operational requirements, protection considerations, and overall network interface requirements are presented. This report provides guidelines and recommendations to ensure that the hardware design adheres to stringent safety standards. This includes the incorporation of fault detection and isolation circuits, implementation of overcurrent and overvoltage protection mechanisms, and compliance with LV safety regulations.
3. Effective Control Methods: Control methods for different types of PEDs are discussed. These control methods enable the regulation of PED operation within the LV network, ensuring voltage support, reactive power compensation, active power flow management, and harmonic elimination.

To advance the Technology Readiness Level (TRL) of D-Suite devices, further development is required. This involves the creation of control units for the PEDs, prototyping and demonstration of different topologies, design and experimental verification of protection mechanisms, as well as a holistic and systematic approach to identifying standard scenarios for future network planning and investment.

By implementing the recommendations outlined in this report, LV networks can benefit from improved power quality and greater integration of low-carbon technologies. The proposed D-Suite solution offers a promising pathway towards resilient power systems and sustainable energy management in LV distribution networks.

2. Project background

As the adoption of electric vehicles, renewable energy sources, and heat pumps reaches record numbers, the next decade becomes critical in repurposing our existing energy infrastructure. Recognising the magnitude of the required transformation and the crucial role played by networks in achieving decarbonization goals is essential.

The Low Voltage (LV) Network, operating at 400 Volts, can be seen as the capillary network of our energy systems. It serves as the direct interface between evolving customer requirements and the grid. Distribution Future Energy Scenarios (DFES) and innovation projects have demonstrated that the LV network will face the most strain as the uptake of Low Carbon Technologies (LCT) increases. To ensure our LV networks are ready for the future, we need enhanced monitoring capabilities and the implementation of new technologies and strategies that optimise available network capacity, enabling an advanced and flexible energy system.

In line with the objective of improving energy system resilience, this project plays a pivotal role in future-proofing LV networks. It brings together SP Energy Networks, UKPN, IPT and Newcastle University, leveraging the latest innovations in power electronics. This includes D-Suite technologies such as the Distributed STATCOM (D-STATCOM), Distributed Soft Open Point (D-SOP), Distributed Smart Transformer (D-ST), and Distributed Harmonic Filter (D-HF).

This project represents a timely, risk-mitigated, and proportionate research investment, featuring a strong team with a proven track record in power electronic technology and distribution networks. The overall innovation of this project includes:

1. Optimised design of several D-Suite power electronic devices suitable for LV deployment.
2. Detailed consideration of operational requirements, protection considerations, and network interface requirements in hardware design.
3. Coordinated control algorithms and supporting infrastructure to maximize the utilization of the existing network.
4. A holistic and systematic approach to identify specific scenarios for future network planning and investment.
5. Introduction of new publicly available tools and intellectual property rights to stimulate competition within the supply chain.

Given the immense challenge and the urgency to repurpose LV networks within the required timescale, this SIF Discovery project establishes a solid foundation for addressing a significant and immediate customer need. In particular, this report is focused on the design specifications of hardware and control algorithms for four D-Suite devices.

3. Design specifications of D-suite devices

3.1 OVERVIEW OF D-SUITE DEVICES

LV networks have been conventionally passive, designed for demand and generation conditions based on historic data. With the increased uptake of low-carbon technologies, such as photovoltaic systems, electric vehicles and electric heat pumps, LV networks will be the most stressed part of the electricity network[1].

To optimise the use of available network infrastructure and facilitate flexible energy control, the D-Suite technologies are developed, which visualise a group of power electronics devices for LV networks. They feature both standalone and coordinated operations, monitored by system-level cloud servers with efficient low-latency communications. The D-Suite devices include but are not limited to LV D-STATCOM, D-SOP, D-ST and D-HF.

Figure 3.1 shows the overall structure of D-Suite devices, which consists of different types of PEDs in series connection (e.g., D-SOP and D-ST) or shunt connection (e.g., D-STATCOM and D-HF) between load busbars of feeders and end-users. Depending on the topology and control of PEDs, D-Suite devices can provide active/reactive power support, compensate harmonics and regulate the voltages of distribution networks. They can be monitored by system-level cloud servers and coordinatively controlled to achieve certain functions. D-Suite devices' data and operation status can be collected and sent to cloud servers so optimised decisions are coordinated in cloud servers for suitable operation scenarios of D-Suite devices.

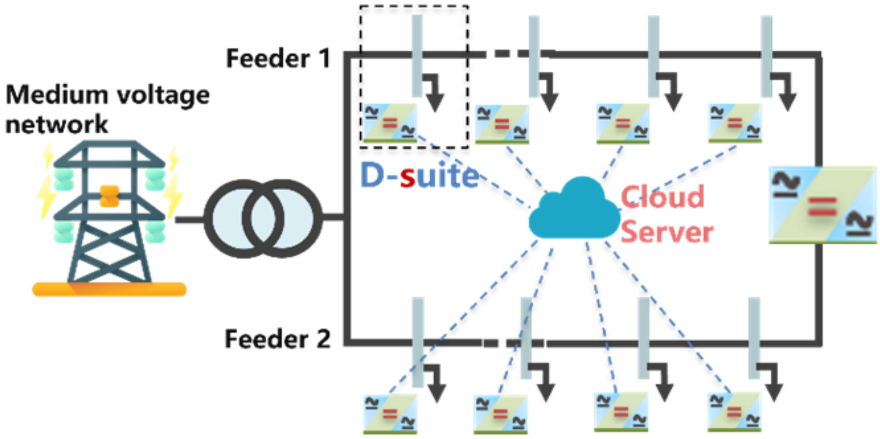


Figure 2.1. The overall structure of D-Suite.

D-Suite devices can jointly contribute to the improvement of power quality and address the impact caused by a large-scale penetration of stochastic distribution renewable power generation. By using the D-Suite technologies, system reliability, cost savings and efficiency can be significantly improved. The rest of this section will be used to introduce the design specifications of four D-Suite devices.

3.2 .DESIGN SPECIFICATIONS OF D-STATCOM

3.2.1 Introduction

D-STATCOMs can adopt either a shunt or series configuration to control the system current or voltage by exchanging real and reactive power with the AC system, thereby maintaining the desired voltage level.

Depending on configurations and topologies, the D-STATCOM can provide the following core functionalities:

1 LVNetworkSolutions (enwl) (https://www.enwl.co.uk/go-net-zero/innovation/smallerprojects/low-carbon-networks-fund/low-voltage-network-solutions/

- Voltage Regulation: The D-STATCOM can regulate voltage levels in power systems.
- Power Factor Correction: D-STATCOMs can provide reactive power support to correct the power factor in an electrical system.
- Reactive Power Compensation: The D-STATCOMs can exchange reactive power with the power grid by absorbing excess reactive power or injecting additional reactive power as required.

3.2.2 Topology selection/design

There are two main types of D-STATCOMs, which are shown in Figure 3.2. Figure 3.2(a) is a series configuration, where the STATCOM is connected in series with the network. This helps regulate the voltage magnitude, compensate for line impedance, and improve system stability by injecting or absorbing reactive power in series. Figure 3.2(b) is a shunt configuration, where the STATCOM is connected in parallel with the power system at a specific location, typically at a bus or substation. This helps control the reactive power flow at the point of connection and is used for reactive power compensation in distribution systems.

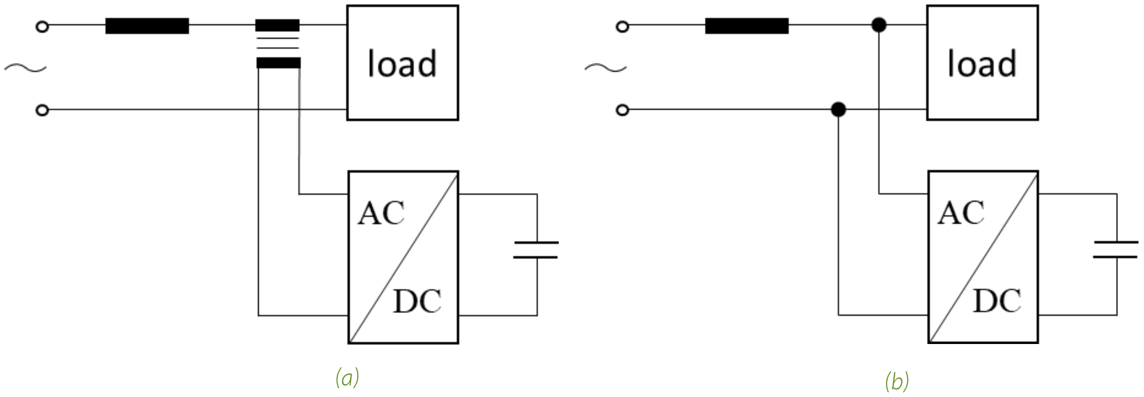
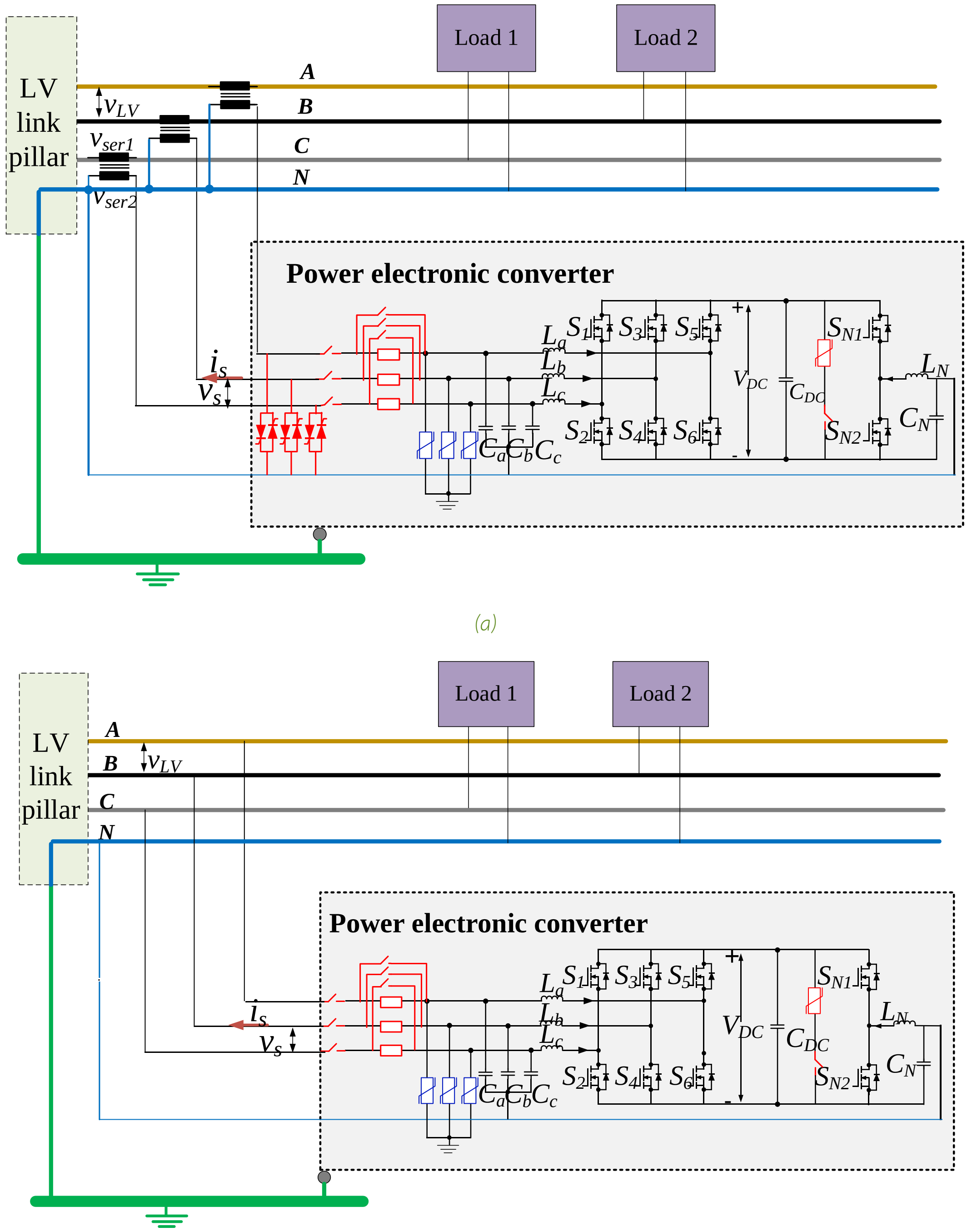


Figure 1.2 Simplified architecture of D-STATCOMs. (a) Series-connected D-STATCOMs. (b) Shunt-connected D-STATCOMs.

In Figure 3.3, the system configurations of a STATCOM are provided, which utilises a three-phase power converter with a neutral wire. Series-connected D-STATCOMs enable voltage balancing/regulating of the load's terminal voltage, while shunt-connected D-STATCOMs facilitate load balancing, resulting in the elimination of current in the neutral wire. A recommended schematic design of the D-STATCOMs, which includes all the designed overcurrent and overvoltage protection circuits, is also presented. The differential mode protection circuits are highlighted in red, whereas the common mode protection circuits are highlighted in blue.



(a)

(b)

Figure 1.3 Design of D-STATCOMs. (a) Series-connected D-STATCOMs, (b) Shunt-connected D-STATCOMs.

3.2.3 Design Specification of PED in D-STATCOMs

It is assumed that the voltage variation in the grid voltage is ΔV_s and the maximum value of ΔV_s is considered as 10% of the nominal grid voltage (V_s) in this report. Thus, for Figure 3.3(a), it's recommended that the series transformer should be able to provide 10% of the rated voltage to counteract the maximum variation of the grid voltage. As for Figure 3.3(b), it is crucial to design the power rating of PED based on the voltage regulation range and short-circuit power S_{SC}. According to the reactive power theory[2], $Q_c = \frac{\Delta V}{V} \times S_{sc}$ is selected. Thus, to compensate for the voltage despite a 10% voltage variation, the capacity of Q_c provided by the STATCOM should be at least $0.1S_{sc}$. The detailed specifications have been given in Tables 3.1 and 3.2.

Table 3.1 Design Specification of PED

	Parameter	Value
Series-connected D-STATCOMs		
Rated AC voltage (L-L)	V_s	400 V
Rated AC current	I_s	35 A
Rated DC voltage	V_{DC}	750 V
Output power range	S	0-24.2 kVA
Shunt-connected D-STATCOMs		
Rated AC voltage (L-L)	V_s	400 V
Rated AC current	I_s	$\frac{0.1S_{sc}}{\sqrt{3}V_s}$A
Rated DC voltage	V_{DC}	750 V
Output power range	S	0-$0.1S_{sc}$ kVA

Table 3.2 Design Specification of Transformers

	Main transformer	
	Parameter	Value
Rated primary voltage	V_{ser1}	40 V
Rated secondary voltage	V_{ser2}	400 V
Rated power	P	24.2 kVA
Frequency	f	50 Hz

3.2.4 Control Schematic

Figure 3.4 shows the D-STATCOM's control schematic. The DC voltage is regulated by the DC voltage controller. The converter can operate in either reactive power control mode or AC voltage control mode. The AC voltage control mode maintains the voltage magnitude at a desired level, thus stabilising the system voltage and compensating for any fluctuations or deviations. On the other hand, the reactive power control mode regulates the flow of reactive power in the system and compensates for any reactive power deficiencies.

2 Naser Mahdavi Tabatabaei, Ali Jafari Aghbolaghi, Nicu Bizon, Frede Blaabjerg, “Reactive Power Control in AC Power Systems”, Springer, 2017.

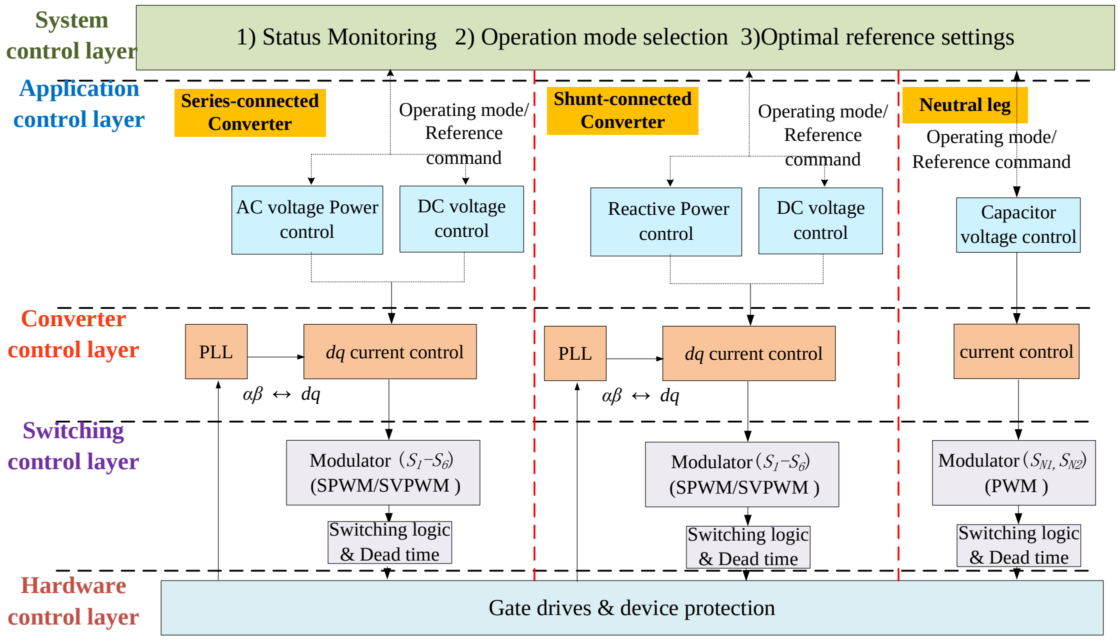


Figure 3.4. The hierarchical control structure of D-STATCOM.

3.3 DESIGN SPECIFICATIONS OF D-SOP

3.3.1 Introduction

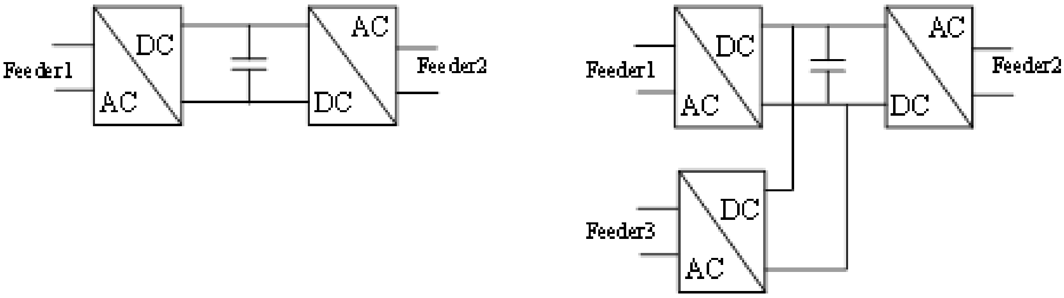
In the context of LV distribution networks, D-SOP is a power electronic interface that has gained significant attention due to its ability to enhance the integration of distributed energy resources (DERs) and improve the overall flexibility and reliability of the grid. D-SOPs are designed to enable active control of power flow and voltage in distribution networks, facilitating the integration of renewable energy sources, energy storage systems, and other DERs.

The D-SOPs can provide the following core functionalities in LV AC networks:

- Feeder Load Balancing: D-SOPs can balance the power flows in different branches.
- Voltage Profile Improvement: D-SOPs can inject/absorb the reactive power output to maintain voltage within acceptable limits, preventing over-voltage or under-voltage conditions.
- Three-Phase Balancing: D-SOPs have the capability to address unbalanced network conditions due to unbalanced three-phase loads.
- Supply Restoration: D-SOPs should enable restoration of the out-of-service power loads from outages through bridging networks.

3.3.2 Topology selection/design

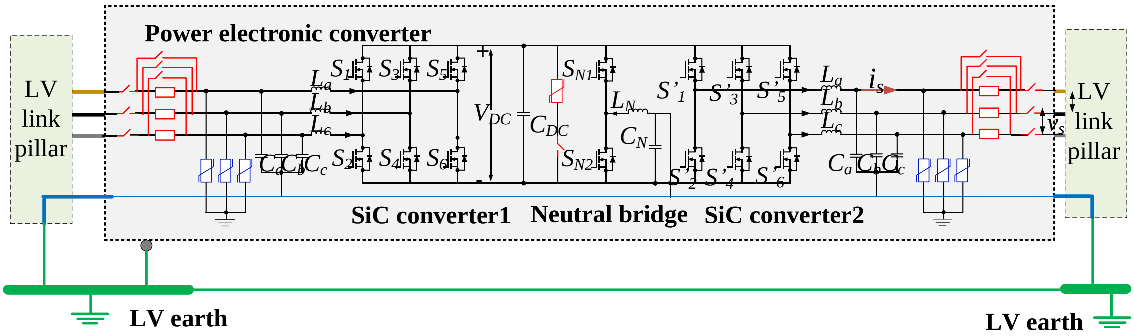
The configuration of the D-SOP is based on a back-to-back AC/DC converter (see Figure 3.5(a)). Each converter can independently control the active and reactive power of neighbouring feeders. However, the total sum of real powers must be zero because there is no energy source inside SOPs. In Figure 3.5(b), the three-terminal configuration is depicted, which extends the D-SOP to connect multiple feeders.



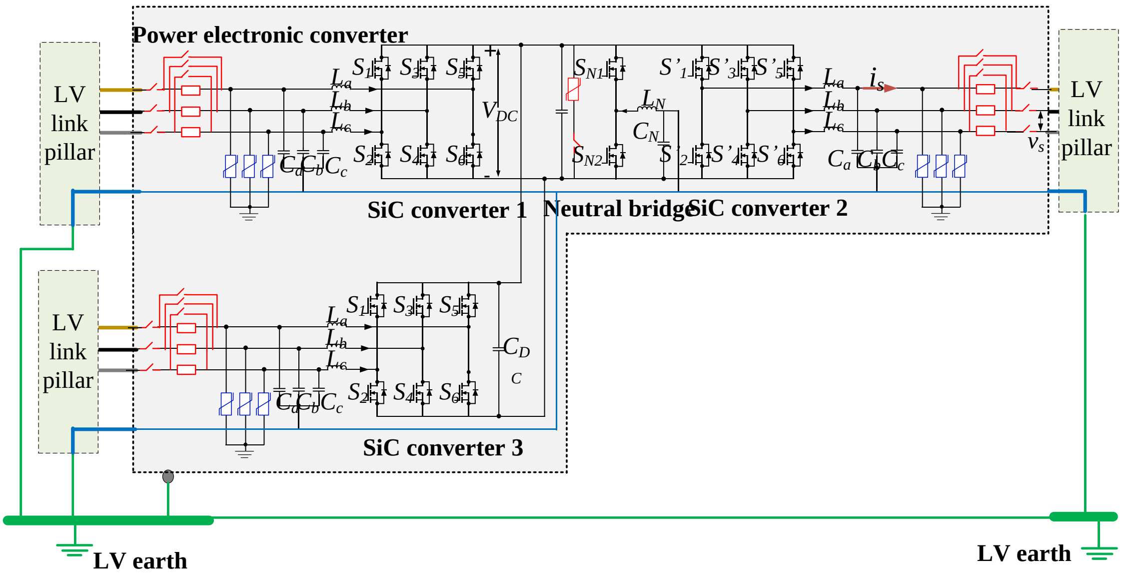
(a) *(b)*

Figure 3.5 Simplified architecture of D-SOPs. (a) Two-terminal configuration, b) Three-terminal configuration.

An example structure of D-SOP is shown in Figure 3.6. The D-SOP is comprised of a back-to-back power electronic converter. The back-to-back converter has full-range voltage and power control of feeders. The three-phase four-wire AC/DC converters are used to supply the unbalanced load. The protection devices such as the pre-charging circuits to mitigate surge current (highlighted in red at the AC side) and discharging circuit to mitigate overvoltage (highlighted in red at the DC side) have been integrated into the D-SOP.



(a)



(b)

Figure 1.6. Design of D-SOP. (a) Two-terminal configuration. (b) Three-terminal configuration.

3.3.3 Design Specifications of PED in D-SOP

The power converter is capable of controlling power across its full range. The maximum power output is set as 242 kVA as an example on how to choose other design specifications. Considering the 400 V line-to-line AC voltage, the DC-bus voltage of the PED is selected as 750V. Therefore, 1200V Si IGBTs or 1200V SiC MOSFETs can be selected as the semiconductors of the PED. Detailed specifications of PED are listed in Table 3.3.

Table 3.3 Design Specification of PED

	Parameter	Value
Rated AC voltage (L-L)	V_s	400 V
Rated AC current	I_s	350 A
Rated DC voltage	V_{DC}	750 V
Output power range	S	0-242 kVA
Power factor	PF	0.0-1.0
Output voltage control range	$\frac{V_S}{V_{LV1}}$	100%

3.3.4 Control Schematic

Figure 3.7 depicts the hierarchical control structure of the PED. The back-to-back converters are operated differently. One side of the converters uses DC voltage control and reactive power/AC voltage control, while the other sides use active power control and reactive power/AC voltage control. To manage three-phase unbalances, a half-bridge converter is utilised to regulate neutral current. A central controller is also in place to dispatch commands and provide appropriate references to the local controllers in the AC/DC converters.

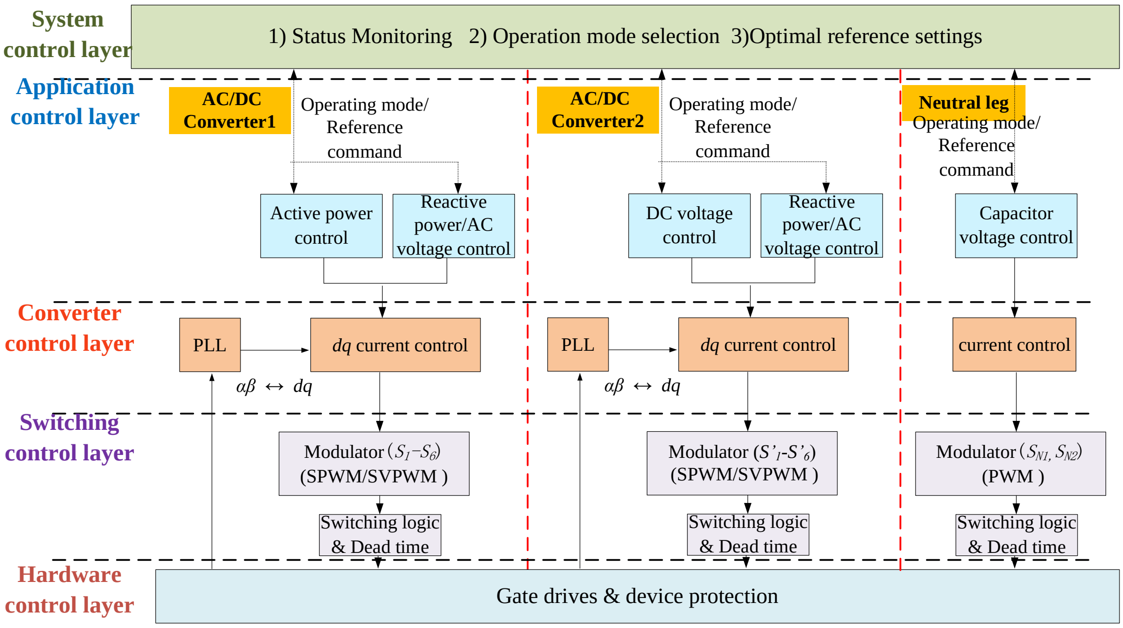


Figure 3.7. The hierarchical control structure of D-SOP.

3.4 DESIGN SPECIFICATIONS OF D-SMART TRANSFORMER

3.4.1 Introduction

The focus of this section is to address the controllability extension through the investigation of the D-Smart Transformer (D-ST). Due to the high cost associated with full solid-state power electronics transformers, only the hybrid D-ST will be discussed in this context. The hybrid D-ST is a combination of a line-frequency transformer (LFT) with PEDs, which was used to enhance the limited functionalities of the LFT. The D-ST allows the integration of a conventional LFT's high efficiency and low cost with the flexibility of PEDs.

The D-ST can provide the following core functionalities in LV AC networks:

- Voltage conversion and galvanic isolation – The D-ST shall provide a voltage conversion function and galvanic isolation;
- LV AC phase voltage regulation – The D-ST shall have the capability to control the voltage at the secondary LV AC terminal for each phase (Phase to Neutral) independently in response to LV voltage set points;
- Power Flow Control – The D-ST shall have the capability to optimally control power flow In the LV AC network. The D-ST also features the control of unbalanced load due to the three-phase four-wire converter topology.

3.4.2 Topology selection/design

Compared to series and shunt configurations, the combined configuration can provide active power flow control. As a result, the combined configuration is selected for this project. There are two types of combined configurations (see Figure 3.8).

Figure 3.8(a) requires PEDs with higher voltage ratings and lower current ratings than those in Figure 3.8(b). Therefore, Si IGBTs or SiC MOSFETs with high voltage ratings are adopted for the PEDs in Figure 3.8(a), while Si MOSFETs or GaN transistors with low voltage ratings are more suitable for Type 2 of D-ST in Figure 3.8(b). Besides, multiple Si MOSFETs need to be connected in parallel to fulfil the large current rating of the PED in Figure 3.8(b), while a single Si IGBT or SiC MOSFET is enough for Topology 1 due to its low current rating. Considering that the number of semiconductors can be reduced due to a low current rating, Type 1 of D-ST is selected for further investigation.

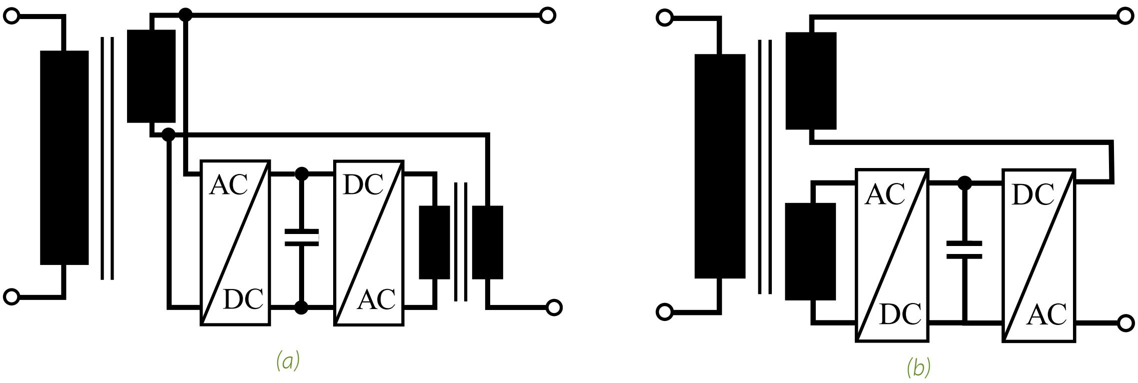


Figure 1.8. Simplified architecture of D-STs. (a) Type 1 of D-ST. (b) Type 2 of D-ST.

Power flow control can be achieved by the D-ST. The shunt converter operates with DC voltage control to stabilise the DC voltage. The series converter is used to control the active and reactive power by injecting a series voltage into the windings of the auxiliary transformer. An additional neutral leg controller is used to provide the neutral current for unbalanced loads (see Figure 3.9). Besides, the schematic of the D-ST including all the designed overcurrent and overvoltage protection circuits is presented. The protection circuits for differential mode are highlighted in red colour, while the protection circuits for common mode protection are highlighted in blue colour.

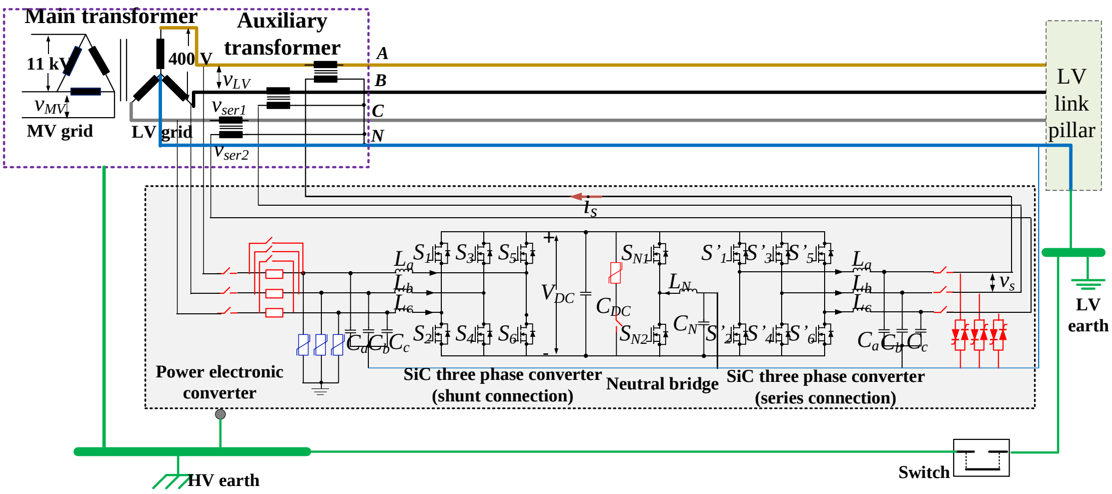


Figure 3.9. Design of D-ST based on Type 1 of D-ST.

3.4.3 Design Specification of PED in D-ST

The LFT (main transformer in Figure 3.9) is a 500 kVA 11kV/400V transformer. The power rating of PED is 5% of the LFT. Thus the injected phase voltage V_{ser1} at the primary windings of the auxiliary transformer is 11.5 V. The turn ratio of the auxiliary transformer is 1:20 so the RMS value of the phase voltage V_{ser2} of the secondary windings is 230 V. The DC-bus voltage of the PED is selected as 750V. Therefore, 1200V Si IGBTs or 1200V SiC MOSFETs can be selected as the semiconductors of the PED. Detailed specifications of transformers and PED are listed in Table 3.4 and Table 3.5.

Table 3.4 Design Specification of PED

	Parameter	Value
Rated AC voltage (L-L)	V_s	400 V
Rated AC current	I_s	72 A
Rated DC voltage	V_{DC}	750 V
Output power range	S	0-25 kVA
Power factor	PF	0.0-1.0
Output voltage control range	$\frac{\sqrt{3}V_{ser1}}{V_{LFT}}$	5%

Table 3.5 Design Specification of Transformers

	Main transformer	
	Parameter	Value
Rated primary voltage (L-L)	V_{MV}	11 kV
Rated secondary voltage (L-L)	V_{LV}	400 V
Rated power	P	500 kVA
Frequency	f	50 Hz
	Auxiliary transformer	

Rated primary voltage (L-L)	$\sqrt{3}V_{ser1}$	20 V
Rated secondary voltage (L-L)	$\sqrt{3}V_{ser2}$	400 V
Rated power	P	25 kVA
Frequency	f	50 Hz

3.4.4 Control Schematic

Figure 3.10 shows the hierarchical control structure of the back-to-back converter system, which comprises two sets of control parts: one for the three-phase AC/DC converter and the other for the neutral-leg half-bridge converter. The only difference between the control of the shunt converter and the series converter is that they have different control modes at the application control level. Specifically, the shunt converter is operated in active and reactive power control modes, while the series converter is operated in DC and AC voltage control modes. The neutral leg is used to provide a flow path for the unbalanced current. By controlling the neutral leg appropriately, second-order ripples caused by the unbalanced load can be decoupled from the DC bus.

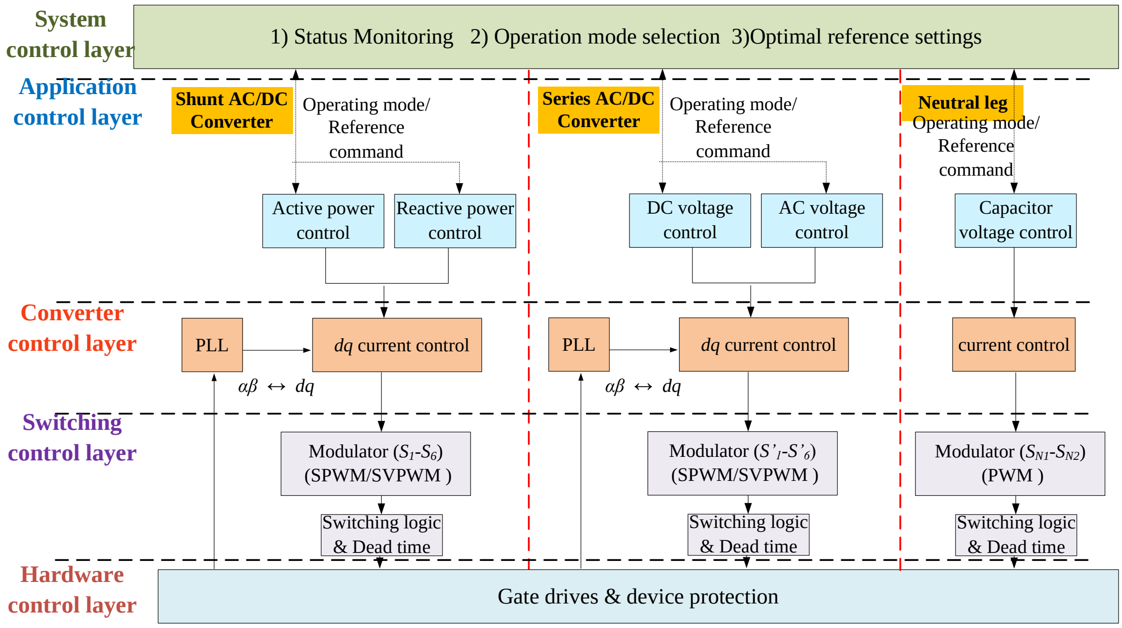


Figure 3.10. Hierarchical control structure of D-ST.

3.5 DESIGN SPECIFICATIONS OF D-HARMONIC FILTER

3.5.1 Introduction

D-harmonic filters (D-HFs) are advanced power-quality devices designed to mitigate the detrimental effects of harmonics in distribution networks. When connected in parallel with feeders, D-HFs can actively detect and counteract harmonic currents generated by non-linear loads, such as electronic equipment and variable speed drives, thereby ensuring a clean and stable power supply to connected loads.

The D-HF can provide the following core functionalities in LV AC networks:

- Harmonic elimination: The D-HF should be able to eliminate harmonics generated by non-linear loads and distorted voltage sources or distorted grids to reduce the total harmonic distortion (THD).

3.5.2 Topology Selection/Design

There are two main types of D-HFs topologies. Figure 3.11(a) involves connecting the D-HFs in parallel with the load, while Figure 3.11(b) involves connecting them in series with the load. In Figure 3.11(a), the D-HFs in parallel connection can absorb the harmonics generated by the non-linear load. This is achieved by creating a much lower equivalent impedance compared with the source impedance at the harmonic frequencies to provide the attenuation required. For the series connection in Figure 3.11(b), a series voltage is injected to counteract the distorted voltage in the power grid although an additional isolation transformer is needed. Considering current harmonics caused by both non-linear load and power supply, the two topologies can be adopted. The detailed design structures including their protections are shown in Figure 3.12.

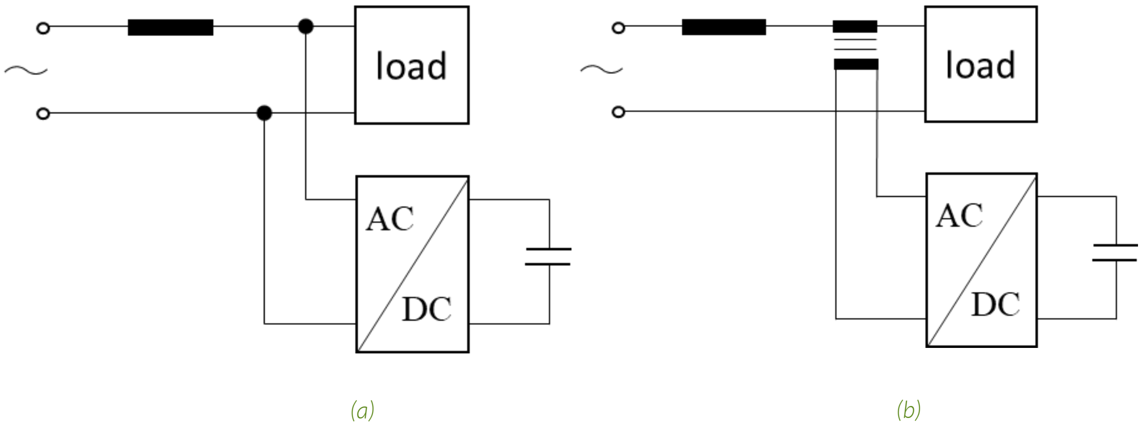
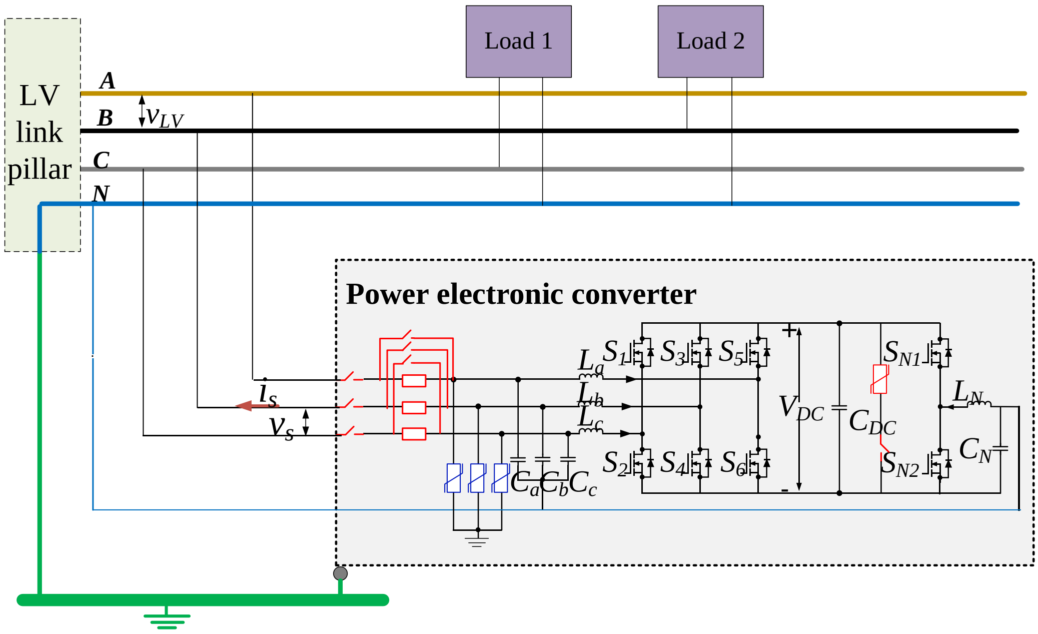
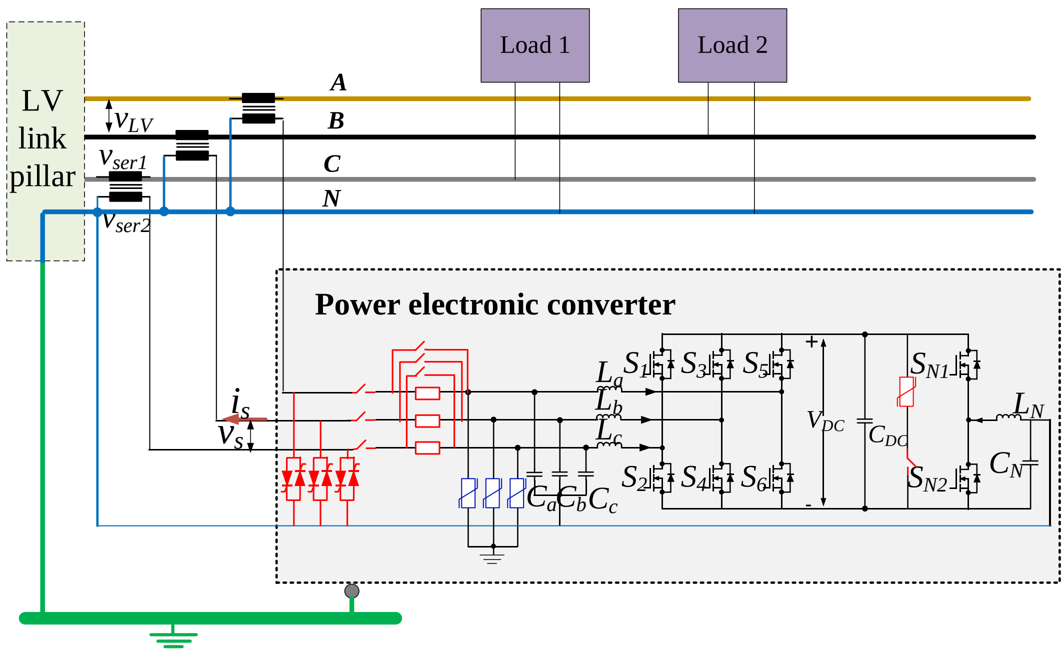


Figure 3.11. Simplified architecture of D-HFs. (a) Shunt-connected D-HF. b) Series-connected D-HF.



(a)



(b)

Figure 3.12. Design of D-HFs. (a) Shunt-connected D-HF. (b) Series-connected D-HF.

3.5.3 Design Specifications of PED in D-HFs

The PED's power rating is 5% of its full capacity so it can only process partial power caused by harmonics[3]. In Figure 3.12(b), the turn ratio of the series transformer is selected as 1:20 so that the phase voltage on the secondary winding is 230V. Therefore, the DC-bus voltage of the PED is selected as 750V. 1200V Si IGBTs or 1200V SiC MOSFETs can be selected as the semiconductors of the PED. According to the IEC standards, total harmonic distortions (THD) should be compliant with the limitations. Detailed specifications of PED and transformers are listed in Tables 3.6 and 3.7.

Table 3.6 Design Specification of PED

Parameter		Value
Rated AC voltage (L-L)	V_s	400 V
Rated AC current	I_s	17.5 A
Rated DC voltage	V_{DC}	750 V
Output power range	S	0-12.1 kVA
Current total harmonic distortions	THD	ER G5/4-1[4]

Table 3.7 Design Specification of Transformers

	Main transformer	
	Parameter	Value
Rated primary voltage	V_{ser1}	20 V
Rated secondary voltage	V_{ser2}	400 V
Rated power	P	12.1 kVA
Frequency	f	50 Hz

3. Hirofumi Akagi; Edson Hirokazu Watanabe; Mauricio Aredes, "Hybrid and Series Active Filters," in Instantaneous Power Theory and Applications to Power Conditioning , IEEE, 2017, pp.237-311, doi: 10.1002/9781119307181.ch5.

3.5.4 Topology Selection/Design

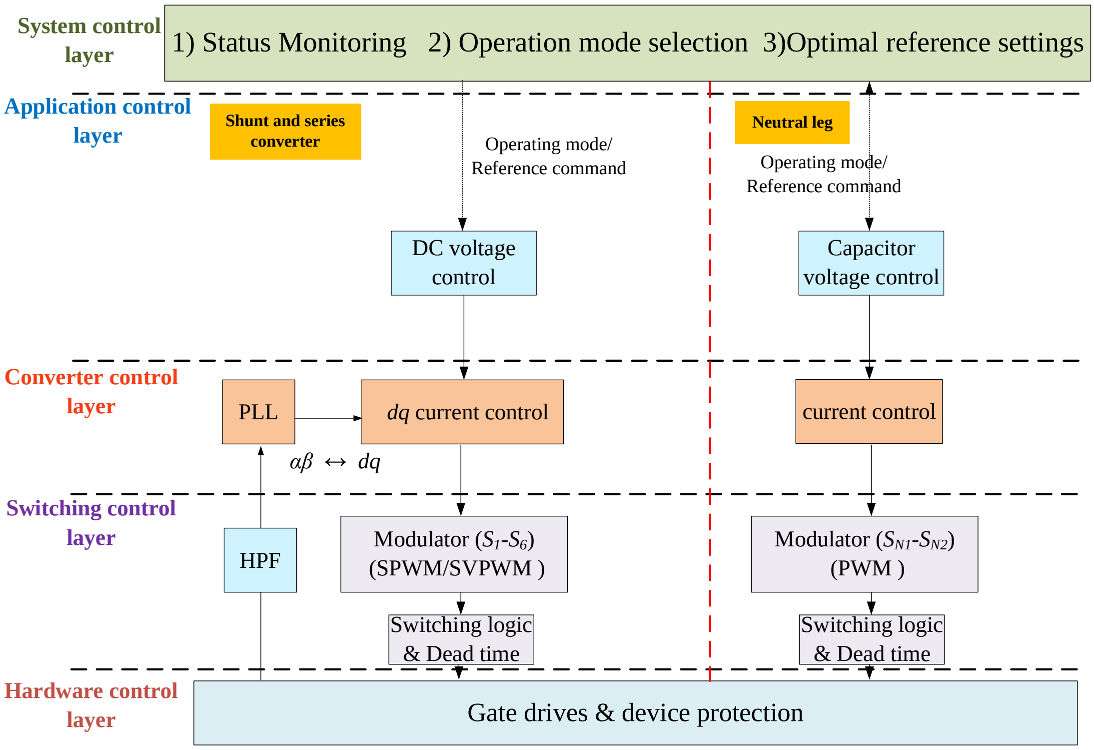


Figure 3.13. Hierarchical control structure of D-HF.

Figure 3.13 shows the control schematic of the D-HF. The DC voltage controller is used to control the DC voltage. The high pass filter (HPF) extracts the harmonic components from the line current. The harmonic current acts as the reference current signal. The current controller accurately tracks the current reference signal to make the PED generate a corresponding harmonic AC current or AC voltage to counteract the harmonic current on the line.

4. ER G5/4-1 (https://www.nienetworks.co.uk/documents/security-planning/ena_er_g5_4-1-(1).aspx)

3.6 MODULAR AND SCALABLE DESIGN OF D-SUITE DEVICES

The PEDs in the D-Suite devices should be designed with modularity for easy 'plug-and-play'. According to the introductions from Section 3.2 to Section 3.5, the basic unit of the PEDs is shown in Figure 3.14, which is a three-phase four-wire converter with the integration of a protection circuit for fault conditions.

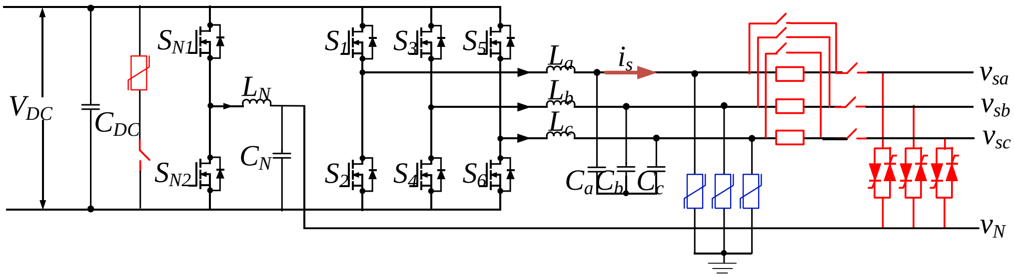


Figure 3.14. The basic unit of PEDs.

To facilitate modular design, multiple basic units can be combined to construct different D-Suite devices (i.e., D-STATCOM, D-ST, D-HF and D-SOP). The D-ST and D-SOP require two basic units while the D-STATCOM and D-HF require only one basic unit. The integrated software configuration of the basic unit allows for the enabling or disabling of functions such as current protection from thyristors.

To comply with LV networks, the power rating of the basic unit is designed with 400 V rated AC voltage and 750 V DC voltage. Thus, the voltage rating of power semiconductors can be chosen as the same parameters (i.e., 1200 V Si IGBT or 1200 V SiC MOSFET). The D-SOP requires fully rated power whereas the D-STATCOM, D-ST and D-HF only withstand 5% to 10% of the rated power. To ensure compatibility with all D-Suite devices and to optimise cost, the basic unit of PEDs can be designed with different power levels across various versions. The specifications of the basic unit of PEDs with maximum power 242 kVA are listed in Table 3.8 as an example.

Table 3.8 Design Specification of Basic Unit

Parameter		Value
Rated AC voltage (L-L)	V_s	400 V
Rated AC current	I_s	350 A
Rated DC voltage	V_{DC}	750 V
Output power range	S	0-242 kVA
Power factor	PF	0.0-1.0
Current total harmonic distortions	THD	ER G5/4-1

4. Justification for Future Innovation Work.

4.1 THE VALUE OF D-SUITE TECHNOLOGIES

The proposed project will deliver significant value by addressing the challenges faced by LV networks in accommodating the increasing uptake of low-carbon technologies (LCT) and transitioning towards a flexible energy system. The project aims to develop and implement power electronics devices (PEDs) integrated into LV networks, specifically focusing on the D-Suite technologies, to enhance network performance and resilience.

The value delivered by this project can be summarised as follows:

1. Improved LV Network Performance: The integration of D-Suite PEDs will optimise the utilisation of existing LV network infrastructure, enabling the accommodation of higher levels of LCT and the efficient management of power flows. This will result in improved power quality, reduced losses, enhanced voltage stability, and increased system reliability, benefiting both utilities and end-users.
2. Facilitation of Energy Transition: By enhancing the capabilities of LV networks, the project will support the widespread adoption of LCT, including electric vehicles, renewable energy sources, and heat pumps. This will accelerate the decarbonisation of the energy system, contribute to carbon reduction targets, and promote sustainable energy usage.
3. Future-Readiness: The project will ensure that LV networks are prepared for future challenges and requirements. By incorporating advanced PEDs and control methods, the project will enable LV networks to adapt to evolving customer demands, technological advancements, and regulatory changes. This future readiness will enhance the long-term viability and flexibility of LV networks.

The Strategic Innovation Fund (SIF) is an appropriate funding source for this project due to the following reasons:

1. Alignment with Strategic Priorities: The project aligns with the strategic priorities and objectives of the SIF, which aims to support innovative projects that address key challenges in the energy sector. The focus on developing and implementing PEDs in LV networks to facilitate the energy transition aligns with the SIF's goals of promoting clean energy, improving network performance, and fostering technological advancements.
2. Collaborative Approach: The proposed project involves collaboration between industry stakeholders, utilities, and academic institutions. This collaborative approach aligns with the SIF's emphasis on partnerships and knowledge sharing to drive innovation and maximize project impact.
3. Technological Innovation: The project involves the development and implementation of cutting-edge power electronics technologies in LV networks. This technological innovation aligns with the SIF's objective of supporting projects that demonstrate novel approaches and have the potential to transform the energy sector.
4. Economic and Environmental Benefits: The project's focus on enhancing LV network performance and enabling the integration of low-carbon technologies will deliver economic and environmental benefits. This aligns with the SIF's aim to support projects that drive economic growth, create jobs, and contribute to a more sustainable energy system.

Overall, the project's value proposition, alignment with strategic priorities, collaborative approach, technological innovation, and economic and environmental benefits make it well-suited to be funded by the Strategic Innovation Fund.

4.2 NETWORK ISSUES THAT CAN BE SOLVED BY D-SUITE TECHNOLOGIES

The problem that this project aims to solve is the increasing strain and limitations faced by low-voltage (LV) networks due to the growing adoption of low-carbon technologies (LCT). LV networks, which serve as the direct interface between customers and the grid, were traditionally designed for conventional demand and generation conditions based on historical data. However, the uptake of LCT, such as electric vehicles, renewable energy sources, and heat pumps, is placing significant stress on LV networks.

The problem can be defined as follows:

1. Inadequate Capacity: LV networks were not originally designed to accommodate the high penetration levels of LCT. As a result, these networks are facing capacity constraints and challenges in delivering reliable and high-quality power supply to meet the increasing demands of LCT.
2. Voltage Instability: The intermittent nature of renewable energy sources and the dynamic power flows associated with LCT can cause voltage fluctuations and instability in LV networks. This can lead to power quality issues, equipment damage, and disruptions to customer services.
3. Limited Flexibility: Conventional LV networks lack the flexibility required to effectively manage and balance the variable power generation and consumption patterns of LCT. This restricts the ability to maximise the utilisation of available network capacity and limits the integration of additional LCT.
4. Safety and Reliability Concerns: The integration of LCT into LV networks introduces new safety and reliability challenges. The increased complexity and variability of power flows require robust protection mechanisms and safety standards to ensure the overall stability and resilience of the LV network.

The problem to be solved, therefore, is to develop and implement innovative solutions leveraging power electronics devices (PEDs) integrated into LV networks. These solutions will address the capacity limitations, voltage instability, lack of flexibility, and safety concerns associated with the increasing uptake of LCT. By doing so, the project aims to enhance the performance, resilience, and adaptability of LV networks, ensuring they can effectively support the transition to a low-carbon energy system.

4.3 HOW D-SUITE SOLVES FUTRE LV NETWORK ISSUES

D-Suite Technologies address the challenges faced by low-voltage (LV) networks through the implementation of power electronics devices (PEDs) integrated into the LV network, specifically focusing on D-Suite technologies. By leveraging these PEDs, we aim to enhance the performance, capacity, flexibility, and safety of LV networks in the context of increasing low-carbon technology (LCT) adoption.

D-Suite technologies address LV Network problems by :

1. Increased Capacity: The integration of PEDs allows for the optimisation of available network capacity by actively managing power flows. Through advanced control algorithms, the PEDs can intelligently balance generation and consumption, effectively utilising the existing network infrastructure and reducing strain on LV networks. This leads to increased capacity to accommodate LCT, addressing the problem of inadequate capacity.
2. Improved Voltage Stability: The PEDs, such as the Distributed STATCOM (D-STATCOM) and Distributed Soft Open Point (D-SOP), provide voltage regulation capabilities. They can actively monitor and control voltage levels in LV networks, mitigating voltage fluctuations caused by intermittent renewable energy sources and dynamic power flows from LCT. This ensures improved voltage stability, addressing the problem of voltage instability.
3. Enhanced Flexibility: The incorporation of PEDs enables greater flexibility in managing power generation and consumption. The distributed smart transformer (D-ST) and Distributed Harmonic Filter (D-HF) facilitate the integration of LCT by regulating power quality, reducing harmonics, and managing reactive power. This improves the network's ability to handle variable and intermittent power generation, addressing the problem of limited flexibility.
4. Safety and Reliability: Our solution emphasises the development and implementation of robust safety protocols and protection mechanisms. The hardware design of the PEDs includes fault detection and isolation circuits, overcurrent and overvoltage protection mechanisms, and compliance with LV safety regulations. These measures ensure the safety and reliability of the LV network, addressing the concerns associated with the integration of LCT.

By integrating PEDs and implementing advanced control algorithms, our D-suite solution optimises LV network operations, increases capacity, stabilizes voltage, enhances flexibility, and ensures safety and reliability. This comprehensive approach effectively addresses the challenges posed by LCT adoption in LV networks, paving the way for a future-ready and resilient LV network capable of supporting the transition to a low-carbon energy system.

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