Heywood BESS

Voltage Control Strategy

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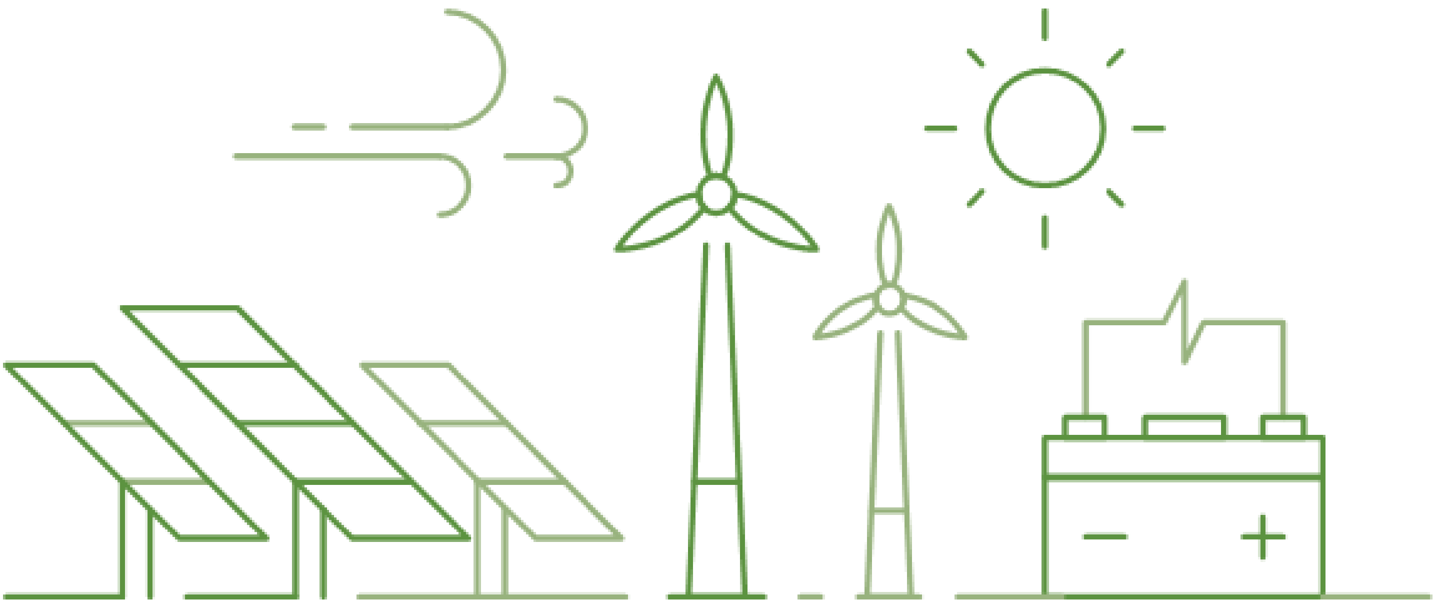

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Contents

Revision History

Table 1: Revision history

Rev.	Date	Prepared By	Reviewed By	Description
1-0-0	25/07/2025	Alvin Bai	Luke Hyett	Preliminary submission to AEMO
1-1-0	30/07/2025	Alvin Bai	Luke Hyett	Addressing Atmos comments

This document uses *Semantic Versioning for Documents* for revision numbering.

Given a version number *MAJOR-MINOR-FIX*, the

- *MAJOR* is incremented when the document has undergone significant changes
- *MINOR* is incremented when new information has been added to the document or information has been removed from the document, and
- *FIX* is incremented when minor changes are made (e.g. fixing typos)

Where appropriate, several revisions may be represented in one table entry with all notable changes described in the *Description* column.

1. Introduction

1.1 Project overview

The Heywood Battery Energy Storage System (Heywood BESS) is a $\pm 285MW/1140MWh$ Battery Energy Storage Project, located 5 km from the town of Heywood and 300 km west of Melbourne in Victoria. As part of this project, the new 275kV underground cable will be constructed between Heywood BESS site and existing 275 kV switchyard.

Heywood BESS will include 92 * SMA Sunny Central 4.6 MVA (SCS 4600 UP-S) inverters which will be connected to two 275/33/33 kV, 160MVA transformers through the 33kV reticulation system. Each inverter will have a dedicated 33/0.69kV, 4.6 MVA step up transformer.

Heywood BESS will operate in voltage droop control mode by default, controlling the 275kV connection point with a 4% droop on a 112.575 MVAr base.

The proposed maximum capacity of Heywood BESS at the connection point is $\pm$ 285 MW at ambient air temperatures up to 50°C.

Table 1.1: Connection Overview

Connection Overview	Description
Project Name	Heywood BESS
Technology	Battery
Geographical location	5 km from the town of Heywood and 300 km west of Melbourne in Victoria
Connection point	HYTS connection to existing 275 kV switchyard
Control point	The connection point as described above
Network Service Provider	AusNet
Maximum capacity at the CP	$\pm$ 285 MW and $\pm$ 112.575 MVAr [$50°$ C]
Units	92 x SMA SCS 4600 UP-S inverters
Rated capacity at the generating unit terminals	423.2 MVA [$35°$C]
Maximum operating temperature	$50°$C
Default Control Mode	Voltage Droop Control
Available Modes	Voltage Droop Control, Remote/local Reactive Power Control and Power Factor Control
Expected Target Reference	1.06 pu (275kV base)
Expected Normal Voltage	291.5 kV
Q Base	112.575 MVAr
Droop %	4.00% on 112.575 MVAr base

Table 1.1: Connection Overview

Connection Overview	Description
System Strength at the POC	3185 MVA (N-1) and 5591 MVA (N)
Owner Contact Details	TBD
24/7 Operator Contact Details	TBD

2. Voltage control strategy

2.1 Plant layout

The PSCAD model is an aggregated representation of the BESS, and is used to demonstrate the proposed structure of the plant for purposes of the Voltage Control Strategy (VCS). Four lumped inverter models, including unit transformers from 0.69/33 kV are connected to the MV sides of two 275/33/33 kV three-winding grid transformers via lumped impedances representing the reticulation network. This model consists of:

- The grid element, which provides facilities to configure the grid SCR and X/R, apply faults and other disturbances.
- The point of connection.
- 1 x 275 kV underground cable between substation and point of connection (POC).
- Two main three-winding 275/33/33 kV transformers with on-load tap changer (OLTC).
- Four aggregated MV reticulation representing the lumped impedance of 33kV feeders (modelled as X,R,B quantities)
- Four aggregated MV reticulation representing the lumped impedance of 33kV transformers to 33kV switch room (modelled as X,R,B quantities)
- Four two-winding MV 33/0.69 kV inverter transformer and current multiplier to represent all ninety-two (92) inverters.
- Four lumped SCS 4600 UP-S inverter models.

The PSCAD single line diagram of the single machine infinite bus model for the BESS is shown in the below Figure 2.1.

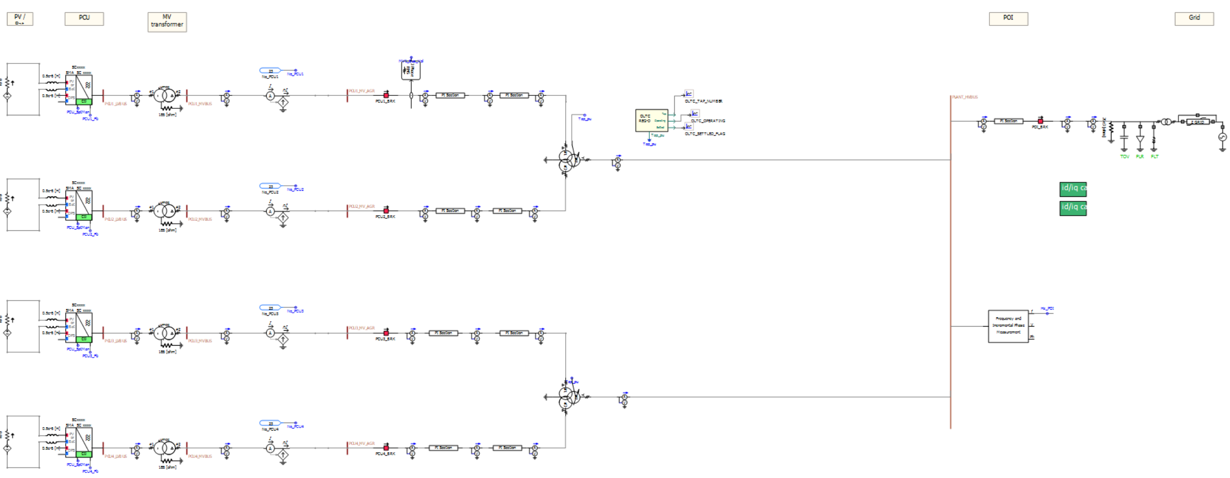

Figure 2.1: PSCAD SMIB model SLD

2.2 Control scheme configuration

2.2.1 Power plant controller

Reactive power control modes

The Power Plant Controller (PPC) acts as an outer loop controller for the plant, sending set-point commands for active and reactive power to converters to control flows at the 275 kV point of connection, regardless of control strategy selected. The Fluence PPC is capable of operating in multiple modes to regulate reactive power flow.

- Power factor control
- Remote reactive power control
- Voltage droop control

Under normal operation, it is expected that the PPC will be set to mode 5 - voltage droop control, to target a voltage setpoint of 1.06 p.u. on a 4% droop, with limits at ±112.575 MVAr. The PPC is capable of controlling the response of the plant under normal operating conditions, but if voltage at the point of connection is outside the 0.85 to 1.15 p.u. range the PPC will freeze the value of the setpoint that it is sending, which is indicated by a PPC freeze flag signal (FRT signal). Under these circumstances, plant converters will control voltage at their own terminals independently via droop control, or will enter FRT mode. These modes of operation are explained in Section 2.2.3.

Voltage droop control

The PPC is set to voltage droop control by default, with a droop of 4% specified for the plant. The PPC targets a setpoint (expected to be 1.06 p.u. in line with the current normal operating voltage at the Heywood 275 kV connection point) to control voltage under a droop characteristic at the generator point of connection. No deadband has been specified for voltage droop control at the point of connection (POC).

The PPC droop characteristic is shown in Figure 2.2.

$$\text{Droop} = \left[\frac{\text{p.u.}}{\text{p.u.}}\right] = \frac{(U - U_{\text{set}})/U_n}{(Q - Q_{\text{set}})/Q_n} = \frac{U - U_{\text{set}}}{Q - Q_{\text{set}}} \cdot \frac{Q_n}{U_n}$$

(with Qn = 112.575 MVAr)

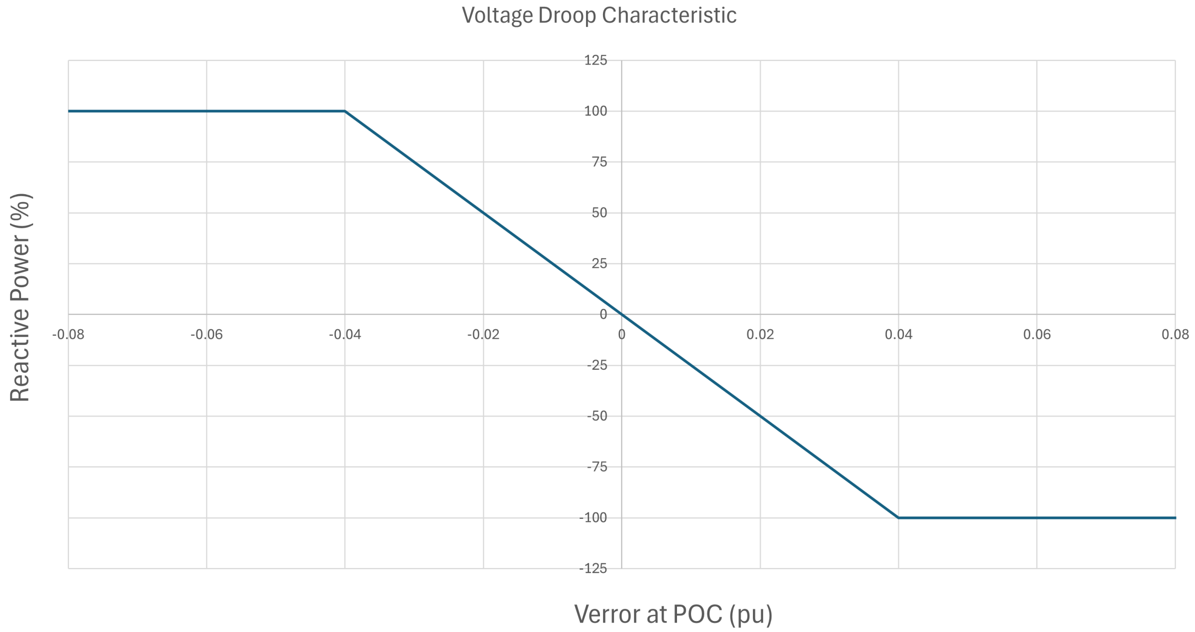

Figure 2.2: Voltage droop characteristic

The values for ± 100% are shown in table below.

Table 2.1: Voltage droop characteristic tabulated

	Normal voltage (pu)	Voltage at POC (pu))	Reactive Power (MVAr)
First Over Voltage	1.06	1.1	-112.575
Second Over Voltage	1.06	1.1	-112.575
Third Over Voltage	1.06	1.1	-112.575
First Under Voltage	1.06	1.02	112.575
Second Under Voltage	1.06	1.02	112.575
Third Under Voltage	1.06	1.02	112.575

The block diagram for the voltage droop control mode is shown in Figure 2.3.

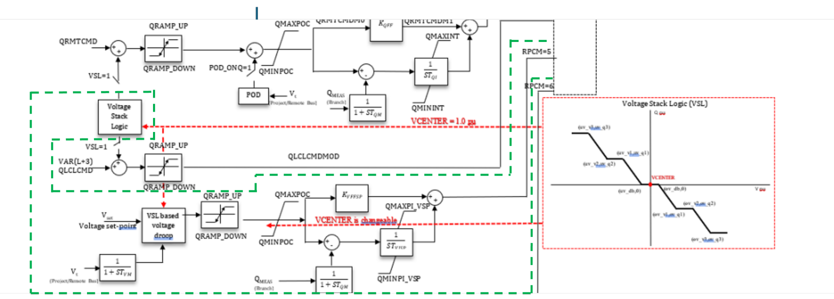

Figure 2.3: Voltage droop control block diagram

Remote reactive power control

Remote reactive power control is available in the PPC. This allows the PPC to target a constant reactive power setpoint at the point of connection, within the limits of the plant rating. The block diagram for the remote reactive power control mode is shown in Figure 2.4.

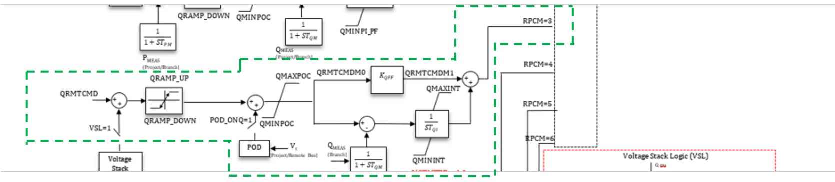

Figure 2.4: Power factor control block diagram

Power factor control

Power factor control is available in the PPC. This allows the PPC to target a constant power factor at the point of connection within the limits of the plant rating. The block diagram for the power factor control mode is shown in Figure 2.5.

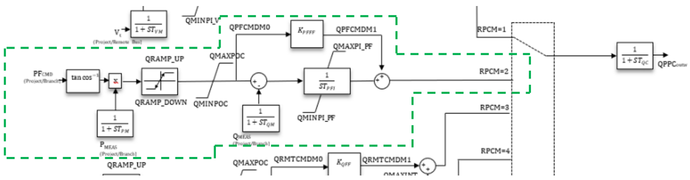

Figure 2.5: Power factor control block diagram

2.2.2 OLTC control

The 275/33/33 kV three-winding transformer is equipped with an on-load tap changer. The OLTC voltage set point is expected to be set to a fixed value of 1.0 pu, independent of the level of generation. The OLTC Automatic Voltage Regulator (AVR) relay utilises a dead band ensuring that the target is achieved to within $\pm$ 0.015 pu. The transformer is set to operate with a time delay of 20 seconds and 7s mechanical operation time. If after a single tap change operation the voltage is still outside the deadband, another tap command will be expected after an additional 20 seconds. This time delay has been selected to ensure no unwanted interference between primary and secondary control loops while ensuring it is fast enough to ensure the generator maintains continuous uninterrupted operation for a variety of network disturbances.

Table 2.2: Grid transformer OLTC Details

Parameter	Value
Tap Changer Type	On-load
OLTC Number of Taps	25
OLTC Nominal Tap	13
OLTC Tap Size	1.25%
OLTC Tapping Range	$\pm$ 15%

Table 2.2: Grid transformer OLTC Details

Parameter	Value
OLTC Voltage Deadband (pu)	0.015
OLTC Voltage Setpoint (pu)	1.0
OLTC Tapped Winding	275kV side
OLTC Total Time Between Taps	20s
OLTC Mechanical Operation Time	7s

OLTC control has been specified for the plant to tap the HV winding of the 3 winding grid transformer, while measuring one of the two medium voltage 33 kV plant buses. This control has been specified to accomplish the following objectives:

- Regulation of voltage to enable plant to meet its continuous uninterrupted operational requirements.
- Regulation of voltage on both plant 33 kV buses without the need for two tap changers per transformer.
- Sufficient delay to avoid interference with faster acting plant control systems, such as the PPC response under voltage droop control.

2.2.3 Inverter level control

SMA inverters are grid-forming and support inverter-level reactive and active power droop control, as well as inertia control. The default operating mode for the inverter is 22321 – P-Inertia and Q-Droop.

Reactive power control

The SMA inverters are grid-forming and capable of operating independently to regulate voltages at their terminals. Under normal operation the grid-forming inverters act as an inner loop control, regulating reactive power output based on a droop setting (of 0.1) independent of the PPC droop during dynamic disturbances. As the outer-loop is regulated by the PPC, the plant will always settle with regards to the PPC droop setting, but performance of the plant during disturbances or reference changes is dependent on this inner loop droop setting.

Fault ride through mode

The fault ride-through (FRT) mode of the grid forming converters is defined by parameter GriForm.Frt.Mod (PSCAD: GriForm_Frt_Mod).The available modes are:

- Disabled (GRIFORM_FRT_MOD_DISABLE)
- Full Virtual Impedance (GRIFORM_FRT_MOD_FULL_VI)
- k-factor Basic (GRIFORM_FRT_MOD_FULL_VI_K_FAC_BASIC)

- k-factor Advanced (GRIFORM_FRT_MOD_FULL_VI_K_FAC_ADVANCED).

The selected operating mode is "k-factor advanced", which uses a virtual impedance to establish a k-factor characteristic to limit the current. This helps shape the inverter's response during a fault by emulating an impedance (resistance + reactance) between the inverter voltage source and the grid.

Unlike grid-following plant, the fault ride through mode of the SMA GFM converters does not have settable entry and exit thresholds. Transition into the "virtual impedance" mode is done based on detection of significant voltage changes at the inverter terminal, which are not configurable by default in the power system model. To prevent windup, the PPC will freeze operation when system voltages are outside of selected thresholds of 0.85 and 1.15 p.u, which means control is done at the inverter level under fault conditions. When in FRT, the active and reactive current contribution of the plant is similar to a strategy set by grid following converters. The configured settings have been set so that:

- The k-factor equivalent gain of the converters during FRT is 6, which implies a 6% contribution per 1% change in voltage measured at the inverter terminals.
- Negative sequence current gain of the converters has also been set to 6.
- Reactive current contribution is limited to a peak of 1.3 p.u. of the continuous current rating of the converters.

During FRT, the converters will not actively control voltages, but will support voltages by provision of reactive current until a fault is cleared by protection. Plant response is not co-ordinated at the point of connection, but is dependant on converter terminal voltage during these events.

3. Reactive capability

The reactive capability curves for Heywood BESS at 35°C, 40°C and 50°C are shown in Figures 3.1, 3.2 and 3.3. The automatic access standard has been shown as a dotted line, and is defined by the upper corner points P_{max}=285 MW, Q_{max}=112.575 MVAr, P_{max}=285 MW, Q_{min}=-112.575 MVAr, and the lower corner points P_{min}=-285 MW, Q_{min}=-112.575 MVAr, P_{min}=-285 MW, Q_{max}=112.575 MVAr.

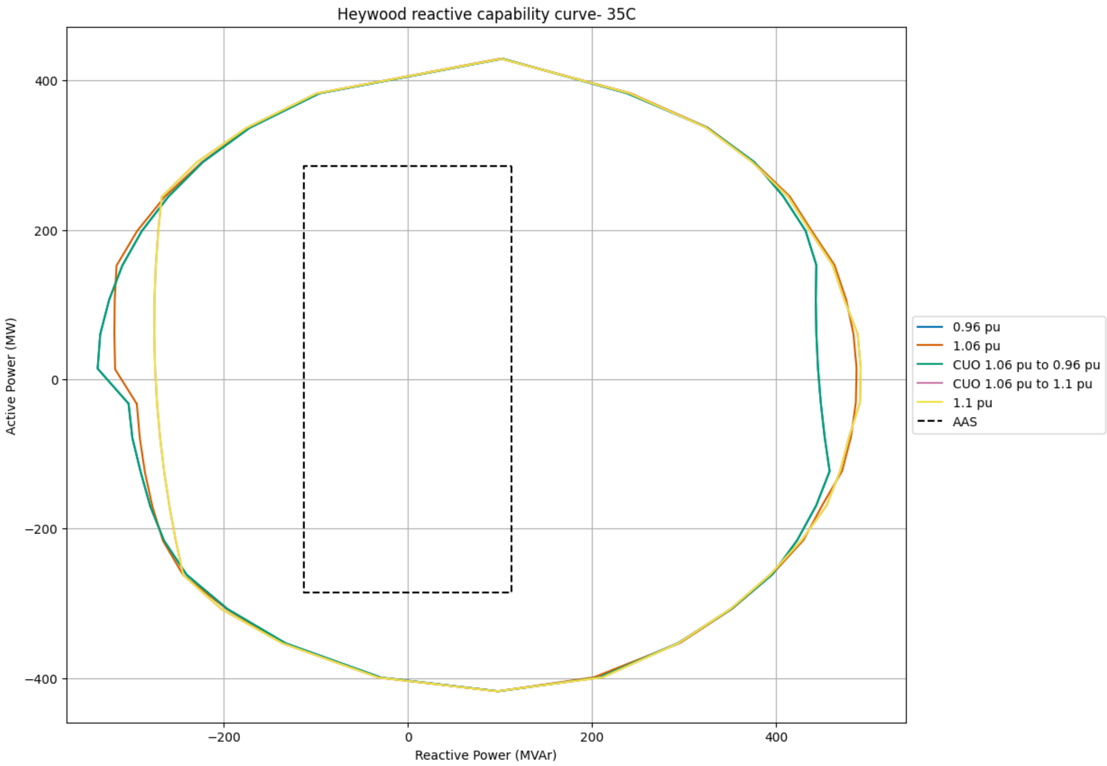

Figure 3.1: 35°C Reactive capability curve for Heywood BESS

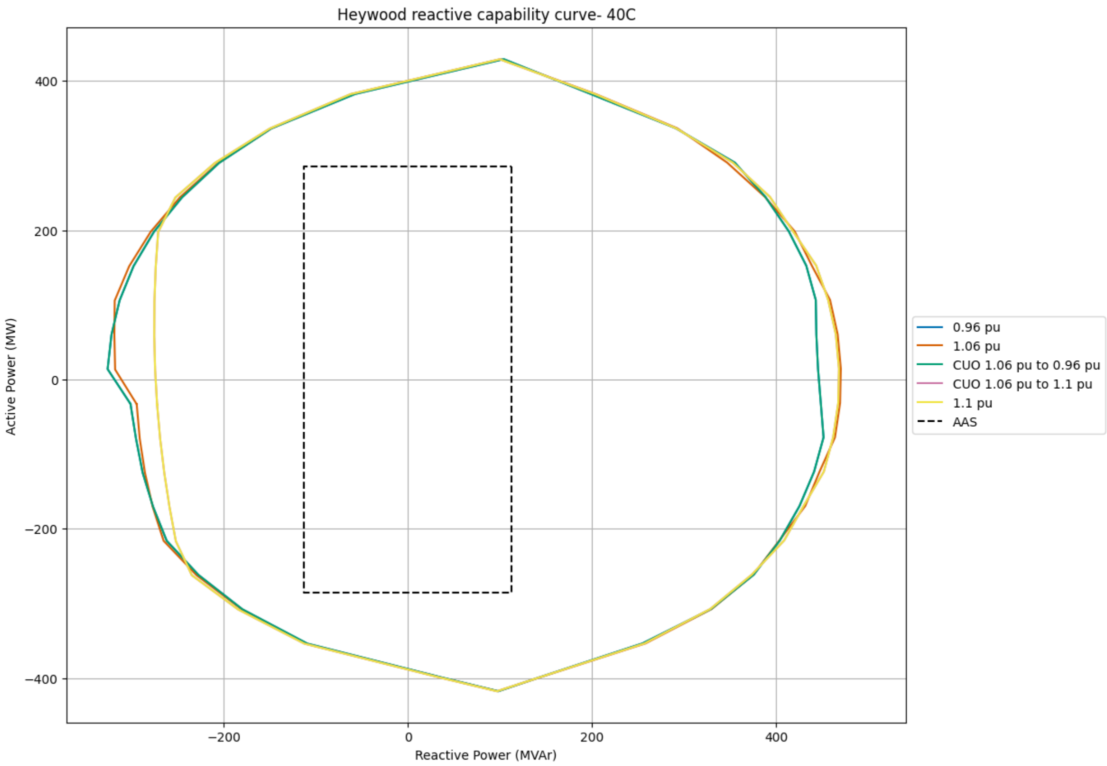

Figure 3.2: 40°C Reactive capability curve for Heywood BESS

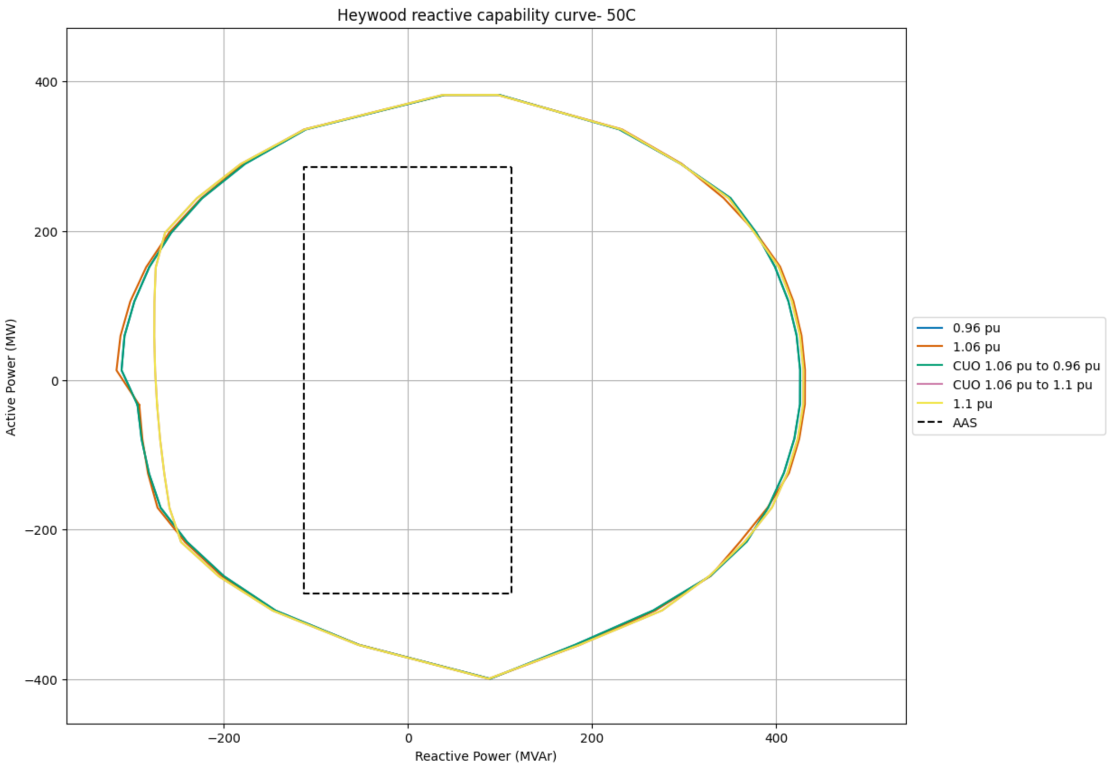

Figure 3.3: 50°C Reactive capability curve for Heywood BESS

4. Voltage protection

The converters are equipped with voltage protection, which have been set as per the maximum capability of the plant converters at their terminals. The voltage protection characteristic is shown in Figure 4.1.

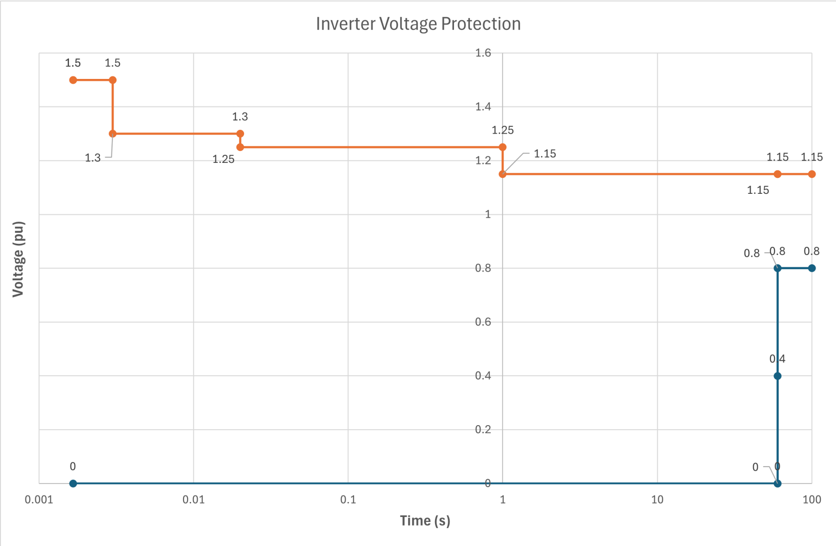

Figure 4.1: Voltage protection characteristics

5. Control mode switching

Heywood BESS is capable of operating in three main reactive power control modes. Transfer between these modes is done by the modification of two parameters in the PPC.

- Reactive power control mode can be selected by changing the RPCM parameter to mode 3.
- Power factor control mode can be selected by changing the RPCM parameter to mode 2.
- Voltage droop mode can be selected by changing the RPCM parameter to mode 5.
- Reactive power and power factor control that Voltage Stackable Logic (VSL) is disabled. This is done by setting the parameter VSL to zero.
- Voltage droop control requires that voltage stack logic is enabled. This is done by setting the parameter VSL to one.

Transfer between voltage control modes can be done with the PPC online. The BESS Energy Management System (EMS) is responsible for ensuring that switching between these modes, whether by a local operator or a remote party is bumpless - which is to say there will not be large changes in reactive power output when transitioning between reactive power modes.

6. Control block diagrams and communications delays

Detailed control block diagrams for plant converters will be provided directly to AEMO by SMA and will not be displayed in this document due to confidentiality.

The block diagram of the PPC reactive power control modes has been extracted from the Fluence PPC manual and is shown in Figure 6.1. Mode(s) 2, 3 and 5 are active for this plant.

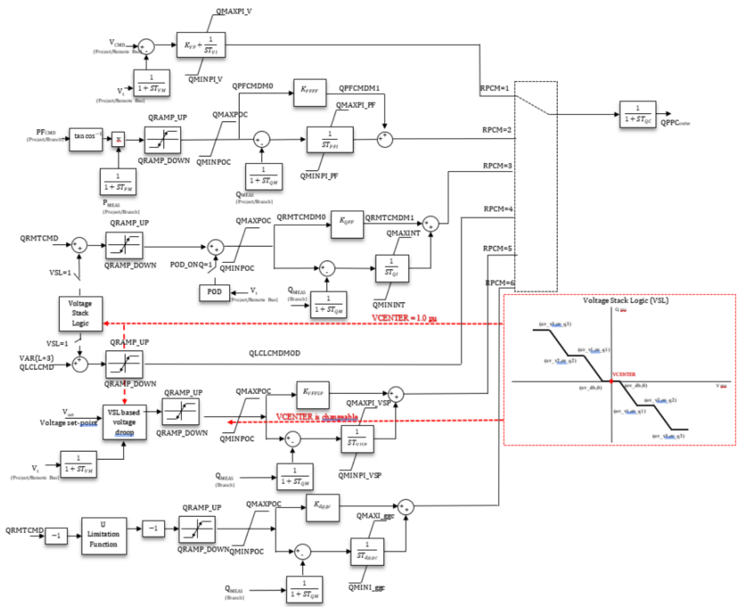

Figure 6.1: PPC reactive power control block diagram

The Fluence PPC has several inbuilt delays which are selected to represent the inherent delays in the measurement of inputs and output of plant setpoints. Key delays within the PPC applicable to the plant control are shown in Table 6.1.

Table 6.1: Measurement and command delay times

Delay Variable	Value (s)
TVM - voltage measurement delay	0.02
TPM - Active power measurement delay	0.02
TQM - Reactive power measurement delay	0.02
TDF - frequency measurement delay	0.02
TPC - Time delay for P inverter command	0.02
TQC - Time delay for Q inverter command	0.1

Table 6.1: Measurement and command delay times

Delay Variable	Value (s)
Tfrzppc - Additional time delay for PPC freeze)	0.4

Measurement and command delay times have not been reduced below the default levels set in Fluence's PPC manual. The PPC freeze command delay has been increased from default level, as this modification was found to significantly improve performance following FRT exit, as this reduced PPC windup occurring while the plant responded to inverter level droop control set-points.

References

[1] SMA SCS R12 Grid Forming Manual_Grid-Link.pdf

[2] Fluence_PPC_PSSE_V1020_Manual_v0.pdf

[3] 250479-ELE-DST-0001_B_275kV Power Transformer Datasheet.pdf

Acronyms

VSL Voltage Stackable Logic . . . 12

AVR Automatic Voltage Regulator . . . 6

Heywood BESS Heywood Battery Energy Storage System . . . 1

EMS Energy Management System . . . 12

FRT fault ride-through . . . 7

OLTC on-load tap changer . . . 3

POC point of connection . . . 3

PPC Power Plant Controller . . . 4

VCS Voltage Control Strategy . . . 3

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