electricity north west

Bringing energy to your door

CLASS Voltage Regulation Scheme

27 February 2014

Functional Specifications and Voltage Regulation Scheme for the Autonomous Substation Controllers (ASCs)

Date: 27 February 2014

Table of Contents

Definitions

Term	Definition
APFR	Automatic Primary Frequency Response
MPFR	Manual Primary Frequency Response
ASFR	Automatic Secondary Frequency Response
DBF	Demand Boost Function
DRF	Demand Reduction Function
ADRF-NRD	Automatic Demand Reduction Function-Network Reinforcement Deferral.
TSF	Tap Stagger Function
ASC	Autonomous Substation Controller
CB	Circuit Breaker
RTU	Remote Terminal Unit
PoF	Power on Fusion
ICCP	Inter-Control Centre Protocol
DSMC	Distribution System Management Centre
SCADA	System Control And Data Acquisition
NMS	Network Management System
AVC	Automatic Voltage Control
DNO	Distribution Network Operator

2. The CLASS project

The Customer Load Active System Services (CLASS) project is funded via Ofgem's Low Carbon Networks (LCN) second tier funding mechanism. Electricity North West received formal notification of selection for funding on 21 December 2012. The project is due for completion by 30 September 2015.

CLASS will demonstrate a low cost, rapidly deployable solution that applies innovative and active voltage management to provide a range of demand response capabilities and network voltage regulation services. By aligning demand to existing network capacity through voltage control, CLASS has the potential to minimise the need for costly asset-based interventions and make a positive contribution to a low carbon future.

3. Autonomous Substation Controllers (ASCs)

CLASS is seeking to demonstrate automatic delivery of the following critical demand response services: Demand Reduction/Boost, Voltage Control, and Demand Reduction at time of system peak.

Key to the CLASS solution is the Autonomous Substation Controller (ASC) developed by Siemens, and which are configured with the necessary logic to control voltage at a Primary Substation.

In the context of CLASS, the ASCs typically interface with the substations' existing Automatic Voltage Control (AVC) schemes. In some instances, replacement AVC schemes have also been installed.

The underlying functionality of the AVC scheme will remain unchanged but will respond to control tap change operation when prompted to do so by the ASC.

Notably, CLASS will be delivered by a combination of local automatic action and central despatch as described below.

3.1 Local Control

The local automatic action will be via the operation of frequency sensitive relays which, subject to the system frequency, will operate appropriate control equipment associated with nominated Primary transformers to deliver both fast primary frequency and secondary frequency response. The frequency sensitive relay interfaces directly with the ASC and will be either a MicroTAPP AVC or ARGUS 8 protection relay depending on the type of installation.

The ASC will in turn initiate one of two automatic actions subject to the magnitude of the frequency variation:

i. Disconnection of one of a pair of Primary substation transformers via use of an interposing relay. There may be cases where the Voltage Controller will not initiate the trip owing to active constraints such as network outages, high loads or tap range limitations; and

ii. Tapping of the transformer tap changers to reduce/increase demand as a means of providing secondary frequency response.

3.2 Network Management System (NMS)

The Power on Fusion (PoF) NMS system will initiate CLASS via Electricity North West's existing SCADA infrastructure. Primary substation remote terminal units (RTUs) have been configured to act as the interface between the NMS and the newly deployed Voltage Controllers. NMS will be used to initiate the following demand response actions:

i. Demand Reduction/Boost for the purpose of generation/demand balancing or wind following;

ii. Tap stagger as a means of providing reactive power absorption to reduce NGT Transmission system voltages; and

iii. Demand reduction at time of system peak at primary substations.

4. Purpose of this document

This document outlines the functionality and the key attributes of the ASC, and outlines how they will regulate and control voltage at a primary substation to deliver the CLASS functionalities.

5. ASC Function Definition

5.1 Functional Overview

Figure 1.0 shows the arrangement of functional blocks within the ASC.

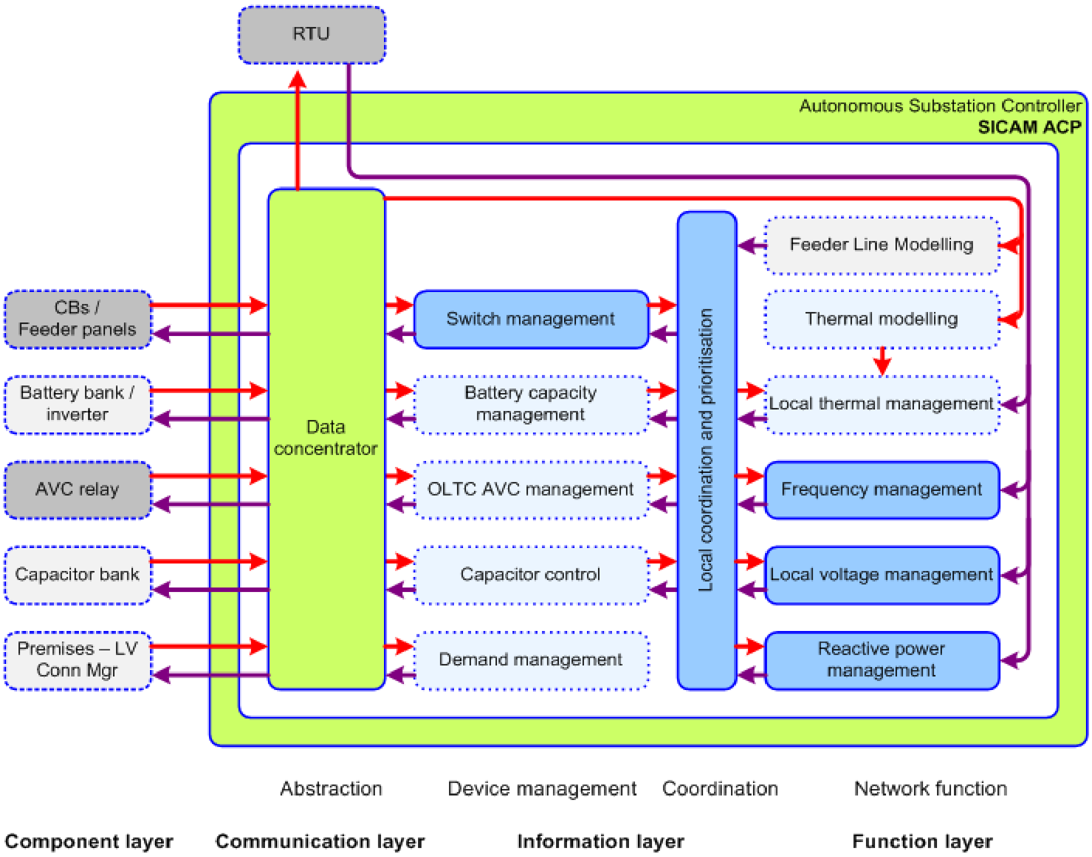


Figure 1.0

The ASC functions included in this project are,

- Local coordination and prioritisation functions,
- Switch Management
- Reactive Power Management
- Local Voltage Management
- Frequency Management

The ASC communicates with the telecontrol RTU (SCADA outstation) in order to perform the above functions via operation of 11/6.6kV Circuit Breakers and on-load Primary Transformer tap position changes to affect voltage changes.

5.2 Communication Routes

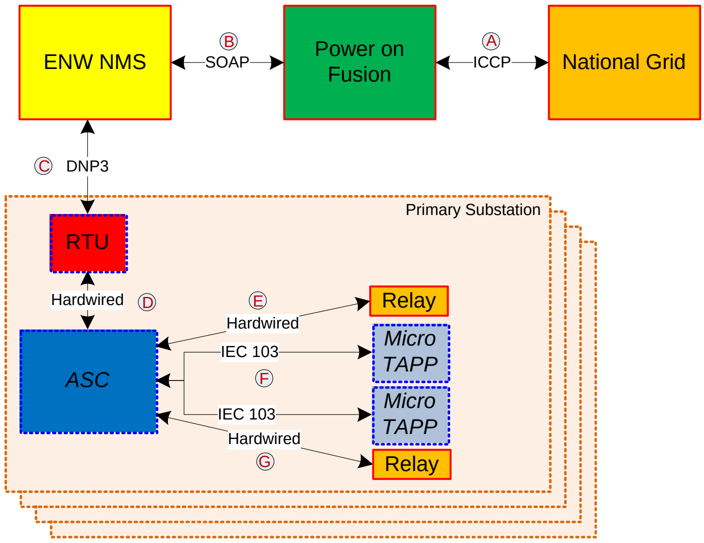


Figure 1.1

Interface	Direction	Information
A ICCP	National Grid to PoF	• APFR – Enable • ASFR – Enable • TSF-ONE – Activate • TSF-TWO – Activate • TSF-THREE – Activate • DBF-HALF – Activate • DBF-FULL – Activate • DRF-NGT – HALF – Activate • DRF-NGT – FULL – Activate
A ICCP	PoF to National Grid	Dashboard Information
B SOAP	PoF to NMS	• APFR – Enable • ASFR – Enable • TSF-ONE – Activate • TSF-TWO – Activate • TSF-THREE – Activate • DBF-HALF – Activate • DBF-FULL – Activate • DRF-NGT – HALF – Activate • DRF-NGT – FULL – Activate • MPFR – Activate • ADRF-NRD –Enable
B SOAP	NMS to PoF	• Inhibit function, Status of T11/T12/Bus-Section CB, Tap Position, Voltage, MW/MVAr and ASC Healthy
C. DNP3	RTU to NMS	• APFR – Enabled

		• APFR –Activated • MPFR –Activated • ASFR – Enabled • ASFR –Activated • DBF-FULL – Activated • DBF-HALF – Activated • DRF-NGT-FULL – Activated • DRF-NGT-HALF – Activated • TSF – Activated • ADRF-NRD Enabled • ADRF-NRD Activated • APFR – RESET (CB can now be closed via NMS) • ASC healthy • Tap position indication • Real Power • Reactive Power • Primary Transformer 11/6.6kV CB status • Primary Bus-Section 11/6.6kV CB status
C. DNP3	NMS to RTU	• APFR – Enable • MPFR –Activate • ASFR – Enabled • DBF-FULL – Activate • DBF-HALF – Activate • DRF-NGT-FULL – Activate • DRF-NGT-HALF – Activate • TSF-ONE – Activate • TSF-TWO – Activate • TSF-THREE – Activate • ADRF-NRD Enable • APFR – RESET (CB can now be closed via NMS) • Primary Transformer 11/6.6kV CB Close Command
D. Hardwire	RTU/CB to ASC	• APFR – Enable • MPFR –Activate • ASFR – Enabled • DBF-FULL – Activate • DBF-HALF – Activate • DRF-NGT-FULL – Activate • DRF-NGT-HALF – Activate • TSF-ONE – Activate • TSF-TWO – Activate • TSF-THREE – Activate

		• ADRF-NRD Enable • APFR – RESET (CB can now be closed via NMS) • Bus Section 11/6.6kV CB CLOSED • T11 11/6.6kV CB CLOSED • T12 11/6.6kV CB CLOSED
D. Hardwire	ASC to RTU/CB	• APFR – Enabled • APFR –Activated • MPFR –Activated • ASFR – Enabled • ASFR –Activated • DBF-FULL – Activated • DBF-HALF – Activated • DRF-NGT-FULL – Activated • DRF-NGT-HALF – Activated • TSF – Activated • ADRF-NRD Enabled • ADRF-NRD Activated • APFR – RESET (CB can now be closed via NMS) • ASC healthy • T11 LV CB Interpose – Open • T12 LV CB Interpose – Open
E. Hardwire	ASC to Relay	• T11 LV CB Interpose – Open • T12 LV CB Interpose – Open
F. Hardwire	CB to ASC	• Bus Section 11/6.6kV CB CLOSED • T11 11/6.6kV CB CLOSED • T12 11/6.6kV CB CLOSED
G. IEC 103	ASC to MicroTAPP	• Voltage Setting Transformer 1 • Voltage Setting Transformer 2
H. IEC 103	MicroTAPP to ASC	Transformer 1: • Voltage • Frequency • Load • Load Angle • Tap Position Transformer 2: • Voltage • Frequency • Load • Load Angle • Tap Position

5.3 Substation Communication Routes

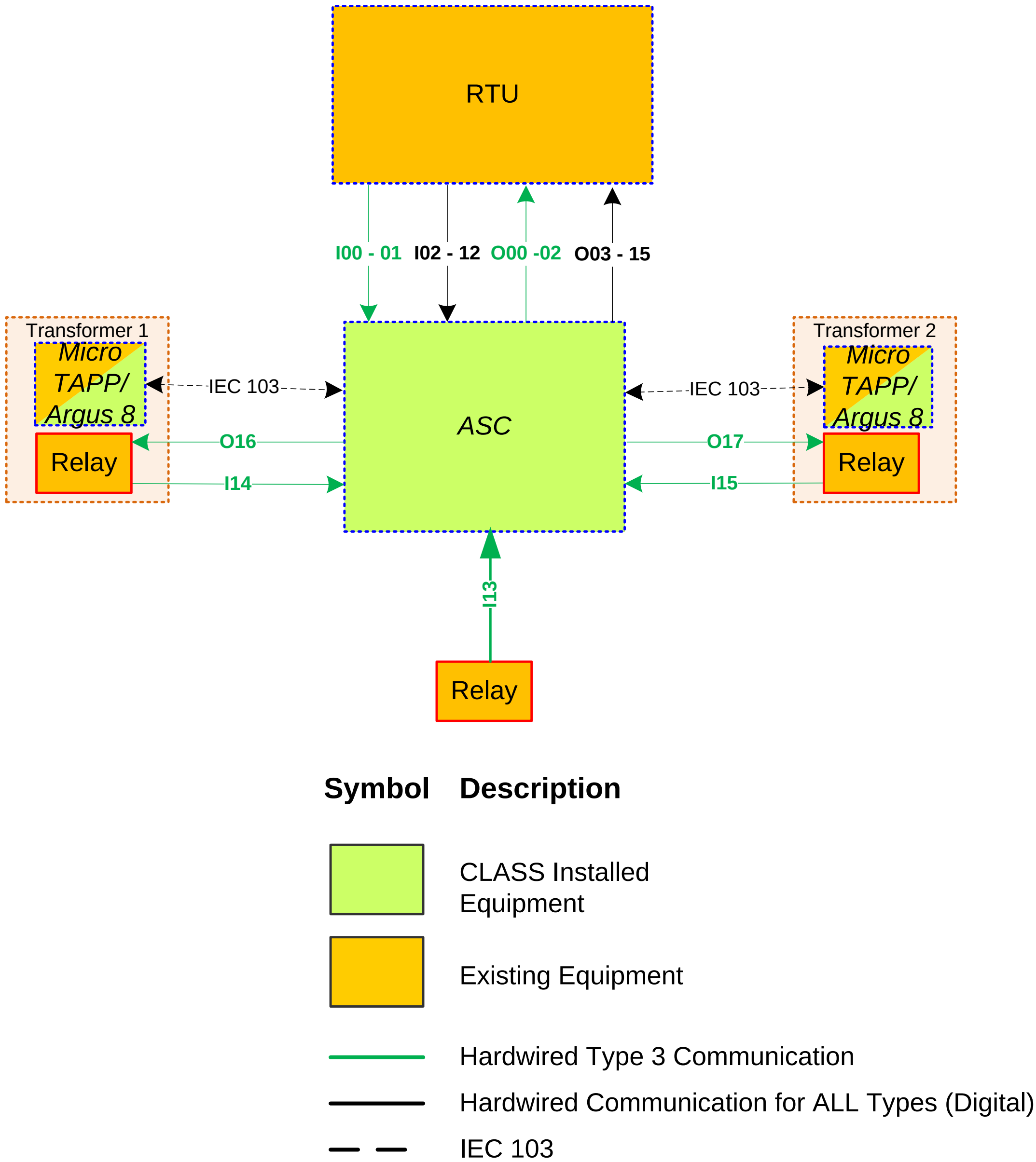


Figure 1.3

Interface	I/0	Information
RTU/CB – ASC	I00	APFR Enable
	I01	MPFR Activate
	I02	ASFR Enable
	I03	DBF-Full – Activate
	I04	DBF-Half – Activate
	I05	DRF-NGT-Full – Activate
	I06	DRF-NGT-Half – Activate
	I07	ADRF-NRD – Enable

	I10	TSF-ONE – Activate
	I11	TSF-TWO – Activate
	I12	TSF-THREE – Activate
	I13	Bus Section – Closed
	I14	TX 11 LV CB – Closed
	I15	TX 12 LV CB – Closed
	I16	Spare
	I17	Spare
ASC-RTU/CB	O00	APFR – Activated
	O01	APFR – Enabled
	O02	MPFR – Activated
	O03	ASFR – Activated
	O04	ASFR – Enabled
	O05	DBF-Full – Activated
	O06	DBF-Half – Activated
	O07	TSF – Activated
	O10	DRF-NGT-Full – Activated
	O11	DRF-NGT-Half – Activated
	O12	ADRF-NRD – Activated
	O13	ADRF-NRD – Enabled
	O14	ASC – Healthy
	O15	APFR-RESET (CB ok to be reclosed by DSMC)- Activated
	O16	T11 LV CB Interpose – Open
	O17	T12 LV CB Interpose – Open
ASC – MicroTAPP	IEC 103 Outputs	• Transformer 1 Circulating Current Target • Voltage Setting Transformer 1 • Transformer 2 Circulating Current Target • Voltage Setting Transformer 2
	IEC 103 Inputs	Transformer 1: • Voltage • Frequency • Load • Tap Position Transformer 2:

		• Voltage • Frequency • Load • Tap Position
ASC – Argus 8	IEC 103 Outputs	• Voltage Setting Transformer 1 • Voltage Setting Transformer 2
	IEC 103 Inputs	Transformer 1: • Voltage • Frequency Transformer 2: • Voltage • Frequency
Transformer Current Transducers - ASC	RS 485	• Transformer 1: • Transformer Current (Load) • Transformer 2: • Transformer Current (Load)

5.4 Frequency Management

5.4.1 Primary/Fast Frequency response (APFR)

This function upon detecting a frequency drop below the defined (adjustable) threshold (49.7Hz in CLASS) will automatically trip one of a pair of primary substation transformers via operation of an appropriately set frequency sensitive relay. For prompt delivery, the frequency relay was set to operate within the required time (maximum of 2 seconds). This results in an immediate reduction in the voltage at the primary.

In response to the frequency reduction, the instantaneous trip will occur in all the substations connected with this function enabled, as long as each substation is within its firm capacity (i.e. the other active Transformer must still have sufficient capacity to supply the site demand) and the voltage remains within the acceptable bandwidth. If the voltage limit in a particular substation will be violated (e.g. due to its loading condition) or the voltage will drop below 12%, the transformer(s) in such substation will automatically ignore the tripping instruction. If any voltage or loading violations occur during the operation of this function, the ASC will also automatically suspend the service.

The APFR will be independent of (and will always override) any active or inactive secondary/slower response (ASFR). However it is worth noting that following the transformer CB trip the remaining transformer will have its voltage target reduced to 95% in line with the response given by ASFR.

This function will remain active only for a specified period (e.g. 30 minutes) regardless of whether the frequency rises back within its operational limits or the voltage has settled at its new lower band. Beyond this specified period, the frequency relay sends a flag signal to alert the NMS of its readiness to close the circuit breakers to ensure security of supply (APFR-RESET). Upon manual re-closure of breakers by the control engineer, the voltage set-point rises back to nominal and APFR is deactivated.

The ASC is capable of automatically reclosing the circuit breaker. It could do this by waiting for a defined (*adjustable*) flag time (see 7 in figure 1.4 below) to allow for a manual re-closure after which if it doesn't get the manual action it automatically closes the circuit breakers and all the tripped transformers come back in service at a delayed sequenced time period. This would serve as a backup service in case a manual re-closure fails within the stipulated time.

This circuit breaker auto re-closure feature is not required for the CLASS project and will hence be de-activated by setting the ASC's flag time to infinity such that it waits forever for a manual re-closure. The random delay timing is to allow the AVC relays to 'naturally' but sequentially bring the voltage back to operational band (by tapping up of the transformers) thereby avoiding any voltage 'hike' on the network due to re-closure of all the transformers. This gradual voltage rise will also be achieved with a manual re-closure since the control engineer will naturally close the circuit breakers in a sequential order.

Upon meeting certain predefined conditions that permit the tripping of a transformer, there is a need to determine which of the parallel transformers in each substation would be more suitable for tripping. Hence, to avoid a constant trip of one of the two substation Transformers, the frequency relay uses a binary sequential decision function to determine which of the two Transformers is next to be tripped.

In substations where master/follower arrangement exists (Type 3B scheme at Romiley), the follower transformer will always be prioritized for tripping in response to APFR function

The frequency will constantly be monitored at intervals. If a frequency excursion is detected during the operation, the function will insure that the excursion is maintained over a number of measurement cycles before triggering a trip. If during operation the transformer carrying all the loads trips, the function will automatically be suspended, an alarm will be issued and the secondary transformer will be brought back in service by the control engineer.

To ensure compliance with regulations, no voltage adjustment will exceed 12%.

5.4.2 Primary/Very Fast Frequency response (MPFR)

This function is identical in action to the APFR function but is manually activated. It's a called service that allows the tripping of one of a pair of Transformers when requested by the control engineer. As detailed in 3.4.1 and 3.4.1.1, but upon a manual activation, the ASC carries out the request by tripping one of the pair of transformer circuit breakers for each primary in that function that are compliant with ASC's condition for decision making, as explained in the APFR function (3.4.1.2)

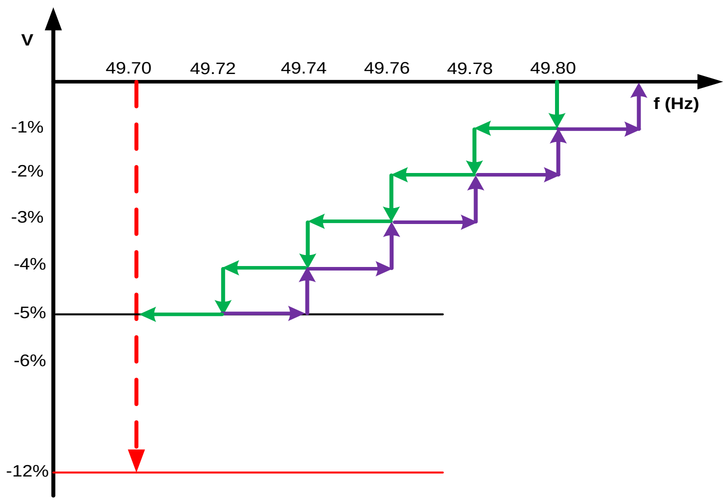
5.4.3 Secondary/Fast Frequency response (ASFR)

This is a conditional function that depends on whether the 'arm/disarm ASFR is Enabled or not, after which the transformer tap changer then initiates or otherwise.

When the frequency drops below the defined ASFR's upper threshold (e.g. 49.8Hz), the frequency reduction, which is detected by an appropriately set frequency sensitive relay, causes an instantaneous reduction in the AVC voltage set point to its lower band (95% of nominal). This causes all the pairs of transformers in all the substations to tap down until they reach their new target voltage of 95% of nominal. In essence, regardless of their loading conditions, all the transformers in all the substations will respond to the voltage set point reduction by tapping down to achieve minimum target voltage, as long as their voltages remain within the acceptable bandwidth. If the voltage limit in a particular substation will be violated (e.g. due to its loading condition), the ASC in such substation will automatically ignore the instruction.

The instantaneous reduction of all the voltage set points is expected to allow the transformers to tap down early enough and give significant effects (MW drop) within the required response times of 10 seconds for initial response and 30 seconds for formal secondary response (which corresponds to a high volts fast tap down and two inter-tap delays). Also, the variance in the transformer loading conditions, hence different tapping times, is expected to allow the voltage reduction to be sustained for the required period (minimum of 30 minutes).

When the frequency returns back to the required level, the voltage set point increases back to nominal. Consequently, each substation transformer taps up sequentially in the increasing order of their loading conditions, then normal operation continues.



5.5 Reactive Power Management (TSF)

This function will attempt to apply the appropriate Tap Stagger position for each transformer. On highly capacitive TSO transmission networks with low loading, voltage control can be challenging due to the inability to regulate capacitive voltage rise. If parallel DNO transformers are staggered (i.e. deliberately operated with differing tap positions), additional VArs are absorbed from the higher voltage network than are consumed by the load. This is caused by a circulating current between the two transformers interacting with each transformers leakage reactance.

In response to a call, transformers are operated with stagger to draw additional VArs to help maintain control of voltages on the higher voltage networks. Depending on their load factors, parallel transformers in different substations will be grouped into 3 classes, each group to be called by GB TSO in their order of relative VAR need.

High Var (TSF – THREE) – Subject to availability, all substations will have their parallel transformers circulating current targets at 10%, thereby giving the maximum VAR absorption upon request. This will be achieved through Microtapps' calculation of MVArs that is approximately equivalent to 3 taps

Mid Var (TSF – TWO) – All substations will have their parallel transformers circulating current targets at 7.5%. This will be achieved through Microtapps' calculation of MVArs that is approximately equivalent to 2 taps

Low Var (TSF – ONE) –All substations will have their parallel transformers circulating current targets at 5%. This will be achieved through Microtapps' calculation of MVArs that is approximately equivalent to 1 taps

If either the loading condition or voltage levels will not satisfy the statutory or defined limits, the ASC the will not permit any Tap staggering instruction. As such, no tap changes occur beyond their tap limits. Also, no further tap staggering will be continued (i.e. action will be suspended) if these limits are violated during performance of this service e.g. due to a trip. The ASC will tap according to demand / voltage levels if required while trying to keep the selected tap stagger in place.

5.6 Voltage Management

This function is classified into manual and automatic service.

5.6.1 Manual Service (DBF/DRF-NGT)

This function works as a called service (rather than automatically detected by the DNO system) for an increase (DBF) or decrease (DRF) in load. The AVC system target voltage will be increased (or decreased) which will impact consumers' voltage delivering load increase or reduction respectively.

Based on the need and subject to the percentage loading available as headroom in each substation, the ASC may maximally (DBF-Full, DRF-NGT-Full) respond to this called service by adjusting the voltage set points to their Upper/Lower safe bands (to enable tapping Up/Down). NGT loading conditions may also require the ASC to respond half way (DBF-Half, DRF-NGT-Half) by adjusting voltage set points half way to the Upper/Lower safe band, thereby causing the MicroTAPP to tap.

5.6.2 Automatic Service (ADRF–NRD)

This function is specifically to defer potential Network reinforcements by ensuring that demand is constantly kept below each primaries capacity.

The ASC constantly monitors the load level (through the MicroTAPP) and attempts to reduce load once it rises above the upper preset (adjustable) threshold (e.g. 98.5% of maximum load). This is achieved by controlling the voltage. When load rises up to this upper demand level (UDL) of 98.5 % site firm capacity, the ASC automatically drops the voltage target to its lower preset (adjustable) threshold of 95% of nominal voltage. .

The function remains active as long as the load stays within this allowed bandwidth (i.e. between 98% and 85% of site firm capacity) until it is remotely switched off by the control engineer. Where the load falls below the lower demand level (LDL) of 85% of the site firm capacity, the ASC waits for a specified (time delay) period of one minute after which the function is deactivated and voltage target goes back to nominal.

The UDL value of 98.5% is set to ensure that if the load rises quickly then the ASC will be in the process of executing a voltage reduction before the load level is above 100% of firm capacity. The maximum time lag between the load reaching the UDL and a full voltage reduction to 95% of nominal, and hence a full demand reduction, will be the sum of the AVC initial time delay plus up to two inter-tap delay times. In modern schemes with fast tap down facilities this will be in the order of 30 seconds to reduce voltage from 99.5% to 95% (3 taps of 1.5%). In older schemes the voltage reduction may take up to around 3 minutes, depending on tap changer design, initial and inter tap delay settings.

The LDL value of 85% of the site firm capacity is set to prevent the function from 'hunting' i.e. turning on and off rapidly. The following is an example of what is likely to occur if there were no LDL or it was set to 98.5% (same as the UDL). Assuming an ohmic load then a reduction in the target voltage from 99.5% to 94% (5.5 percentage points) would result in an 11% reduction in demand. This would mean that if the load did not increase before a tap change occurred then once the voltage had been reduced to 95% the load would now be at 87.5% of firm capacity. The ASC would now see the load level is below it's UDL of 98.5% and would increase the target volts back to 99.5%. Once the tap changes had occurred this would then increase the load level back up towards 98.5% making the ASC reduce the target volts to 95% repeating the same cycle i.e.' hunting'.

As can be seen form the previous example an LDL of 85% (even with a purely ohmic load) would not cause hunting of the tap changers. The function would switch off only after there had been a further natural 2.5% reduction in load below that caused by the voltage reduction.

Hunting would increase primary transformer tap changer operations and cause unnecessary voltage variations.

This function secures the network from getting overloaded and therefore mitigates against the need for possible reinforcements.

It's of note that the ASC performs this function only within the voltage statutory limits.

Since the loading conditions differ per substation and the ASC operation for this function is load driven, each substation's tap operation will occur at different times therefore the staged increase and decrease in voltage (when transformers tap down and up respectively) will ensure smooth control of the load within its limits.

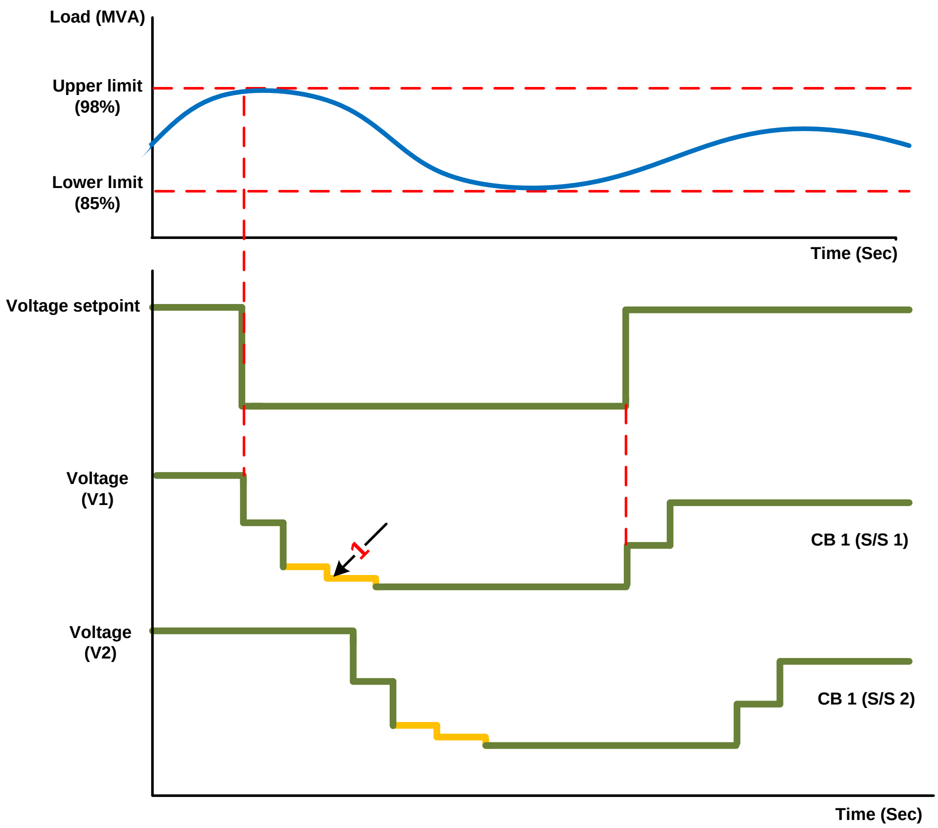
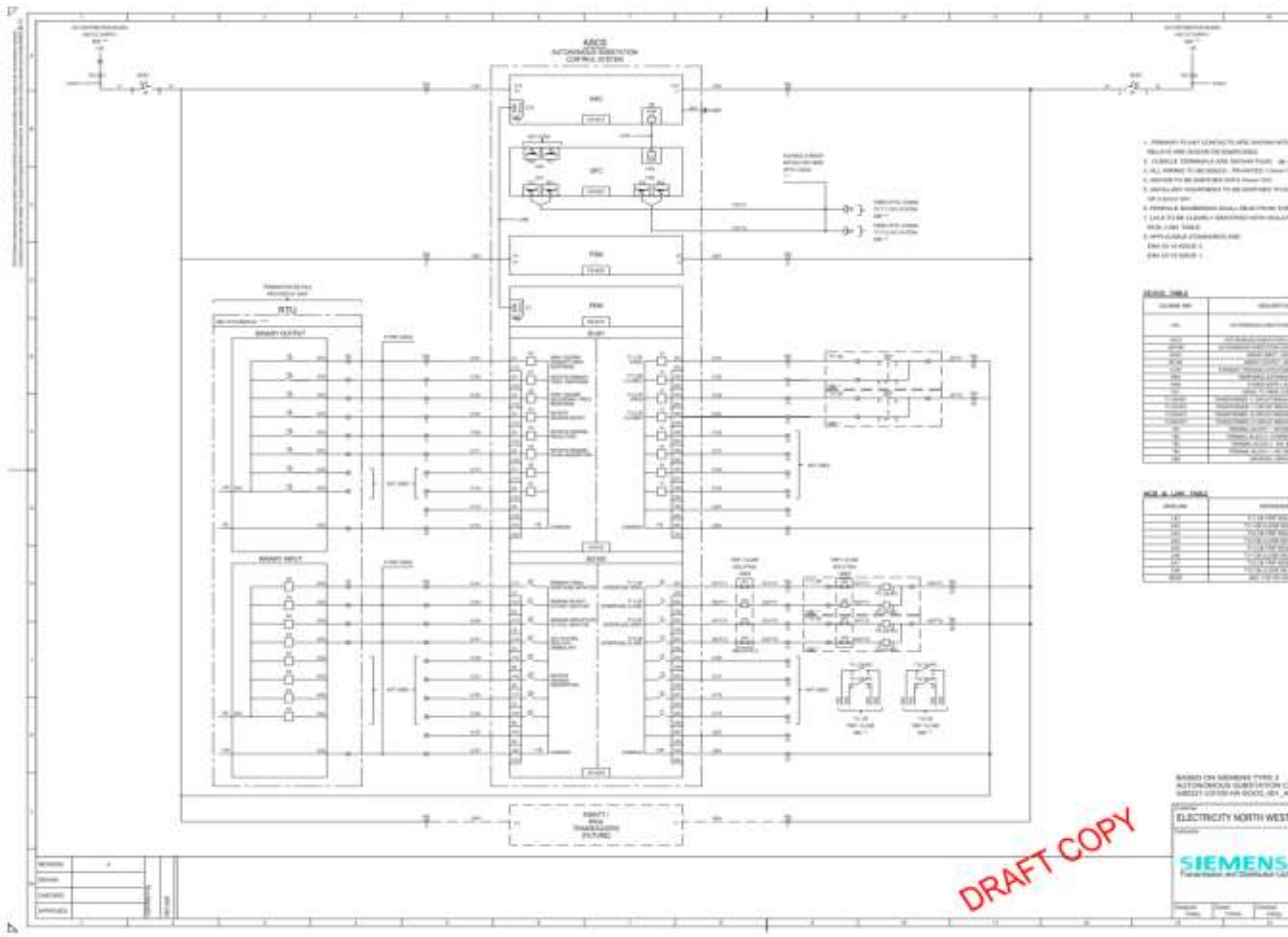


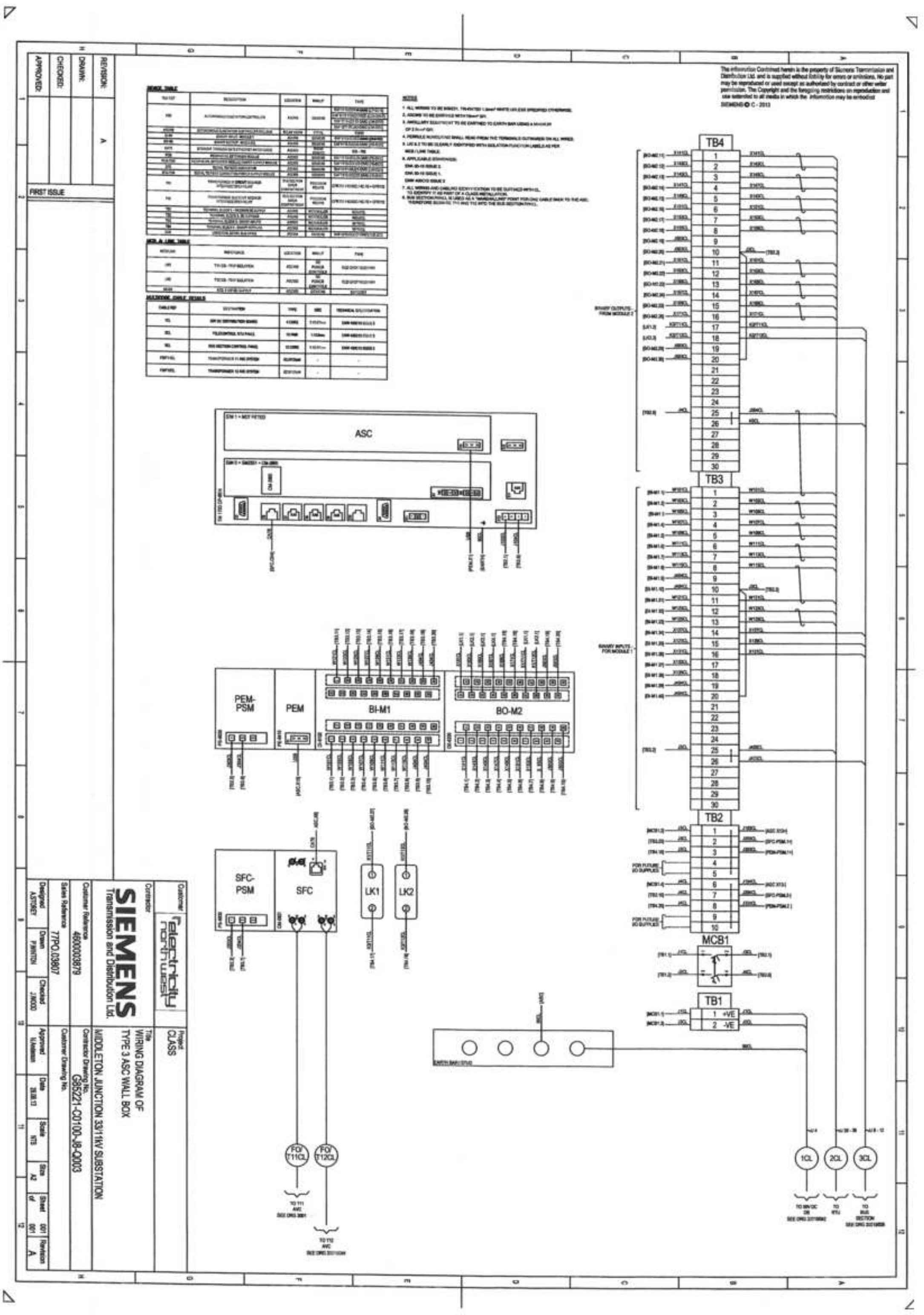
Figure 1.8

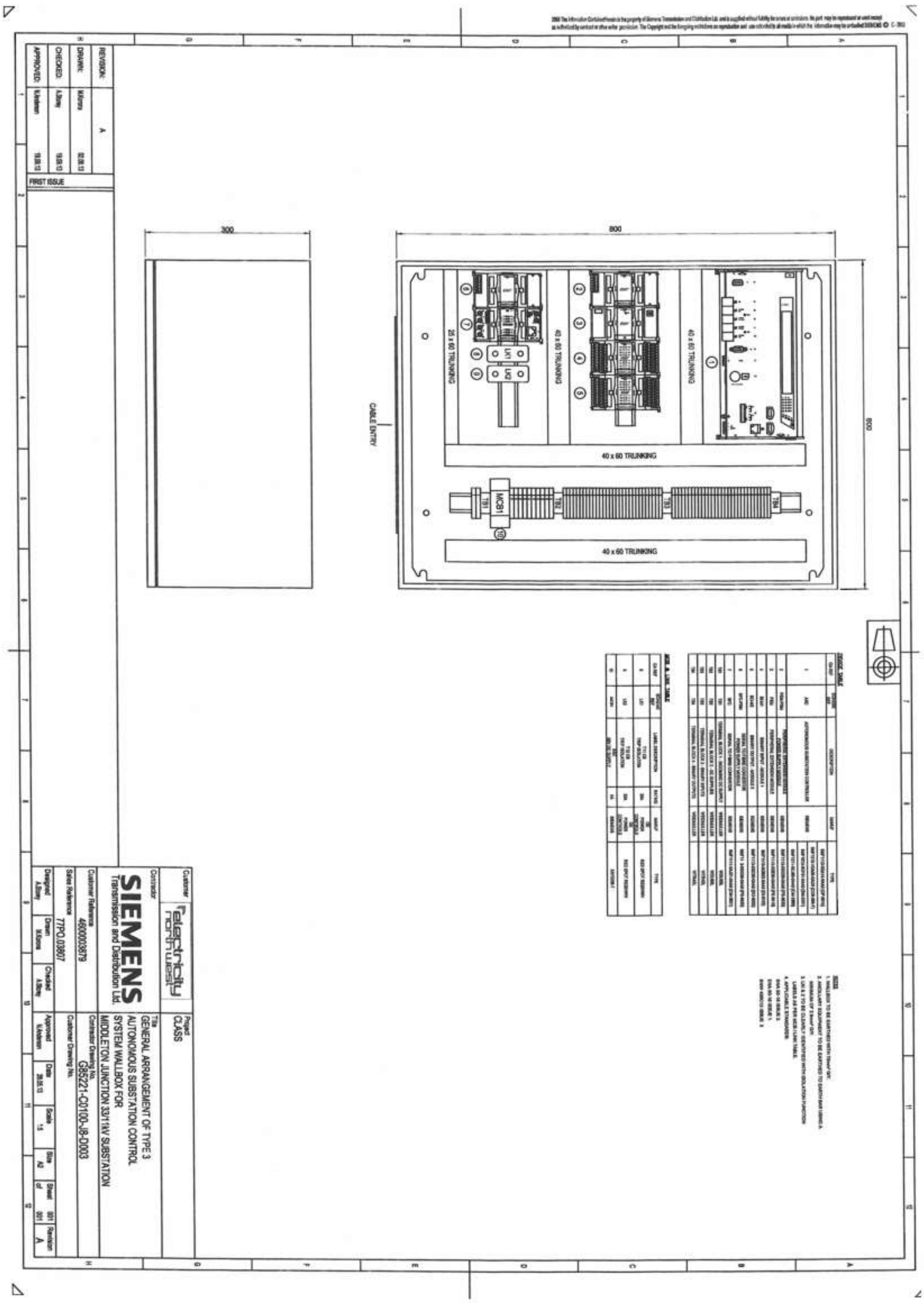
Legend

1 Voltage settlement and time delay period (when load falls below lower limit)

Appendix A – ASC Design Drawings

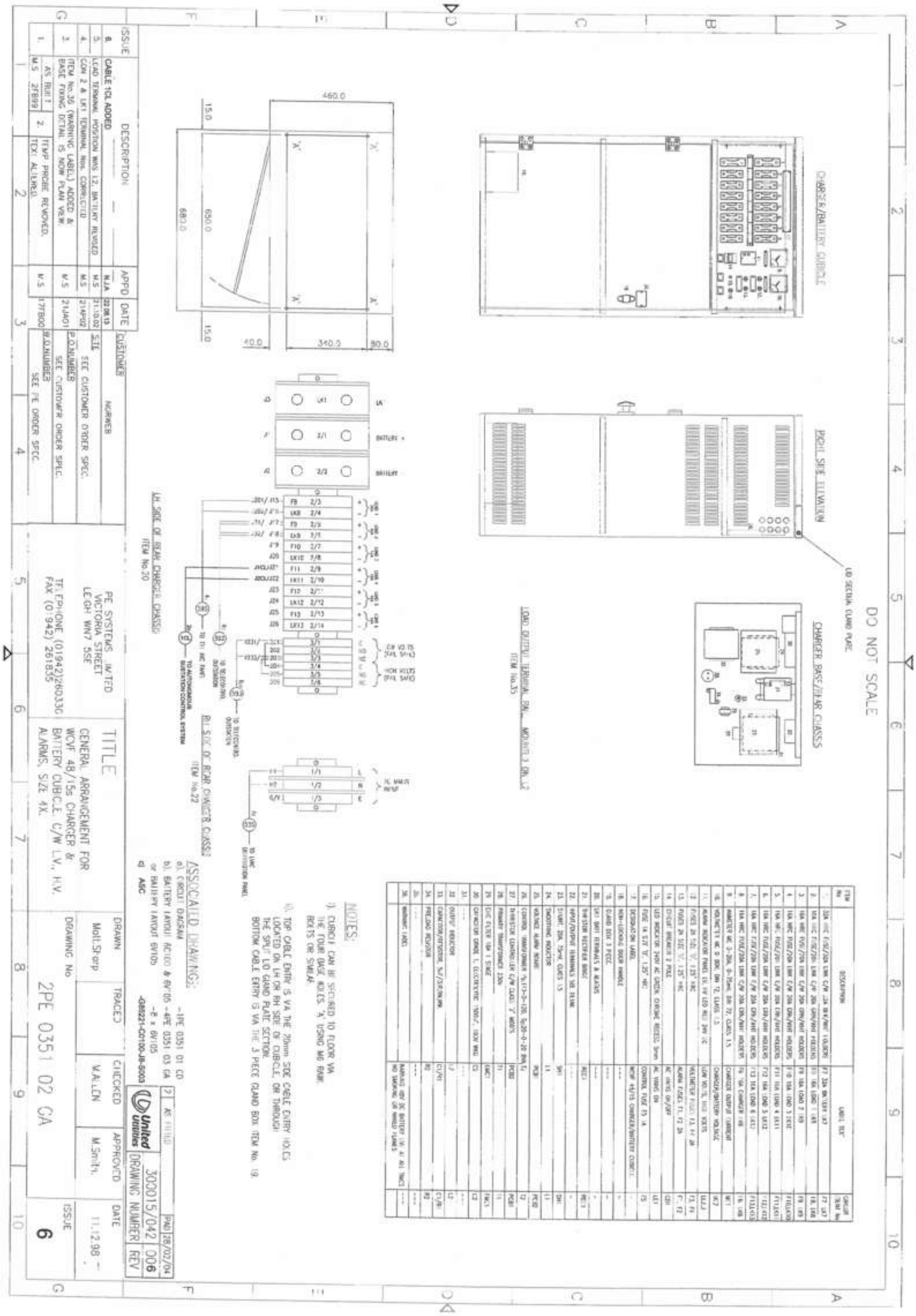




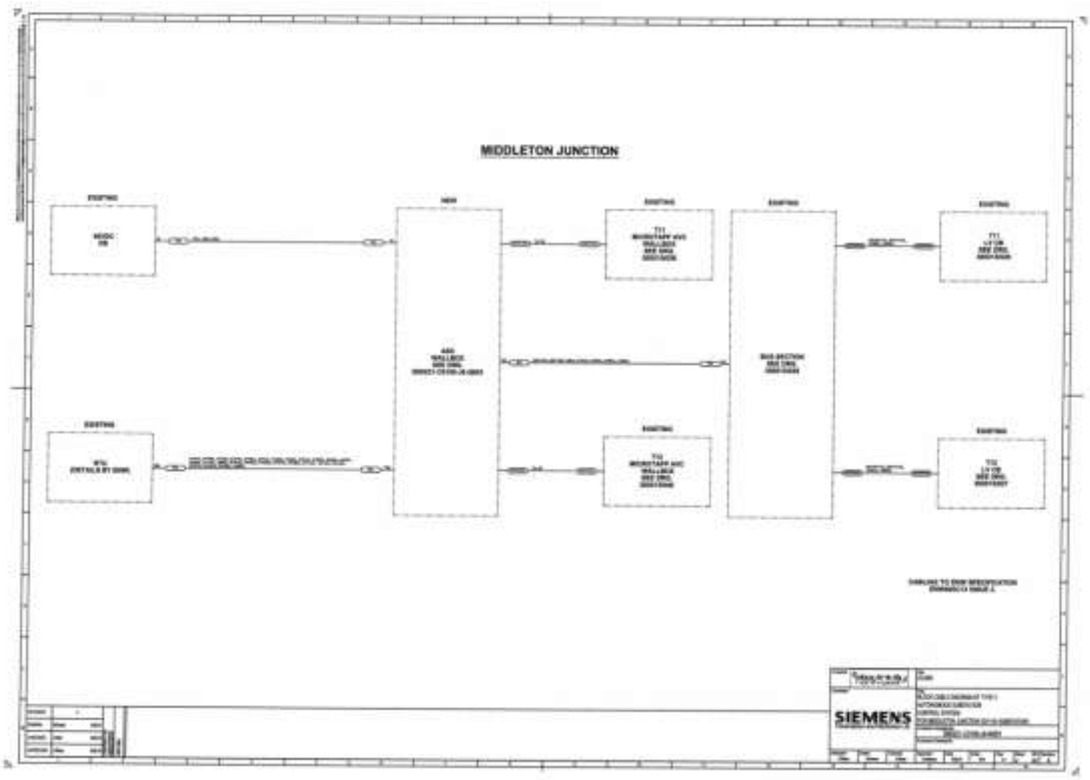

SIEMENS
Transmission and Distribution Ltd
electricity north west
CLASS
GENERAL ARRANGEMENT OF TYPE 3
AUTONOMOUS SUBSTATION CONTROL
SYSTEM WALLBOX FOR
MIDDLETON JUNCTION 33/11kV SUBSTATION
40 x 60 TRUNKING
CABLE ENTRY
MCB1
FIRST ISSUE
300
800

Appendix B – ASC Scheme Drawings

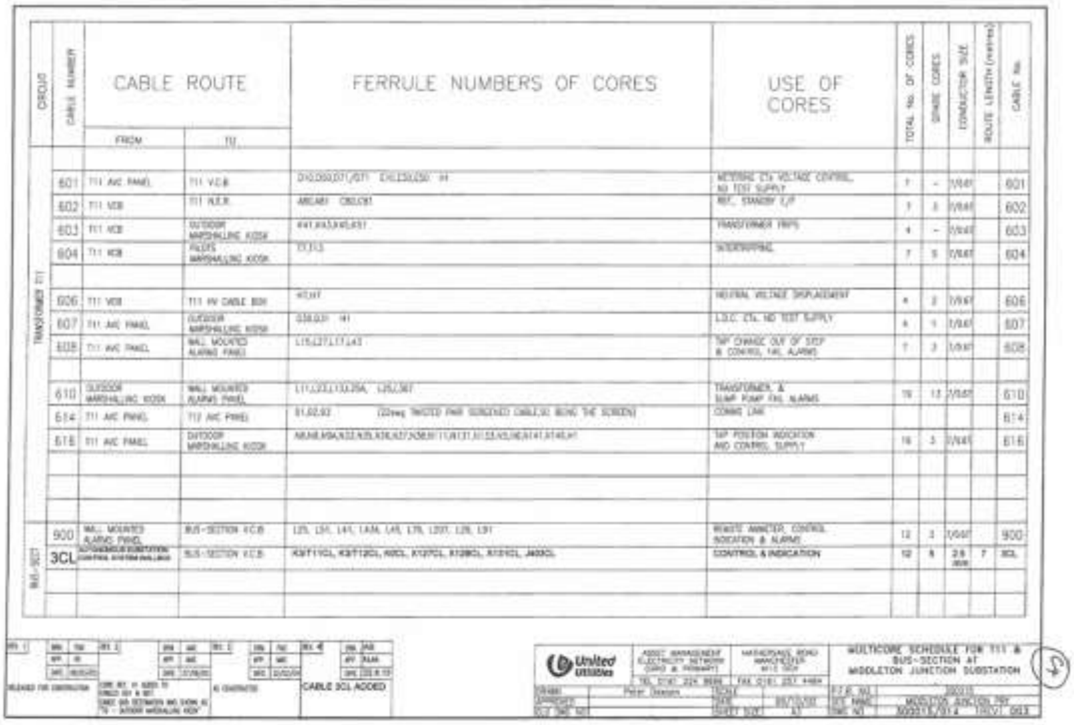
Appendix B I – 48 Battery Charger Drawings



Appendix B II –Block Cable Diagram of Type 3 ASC Scheme



Appendix B III –Multicore Schedule of Type 3 ASC Scheme



GROUP	CABLE NUMBER	CABLE ROUTE FROM	CABLE ROUTE TO	FERRULE NUMBERS OF CORES	USE OF CORES	TOTAL No. OF CORES	SPARE CORES	CONDUCTOR SIZE	ROUTE LENGTH (metres)	CABLE No.
TRANSFORMER T11	601	T11 A/C PANEL	T11 V.C.B	[illegible]	[illegible] CTs VOLTAGE CONTROL, NO TEST SUPPLY	7	-	[illegible]		601
	602	T11 VCB	T11 N.E.R.	[illegible]	REF, STANDBY E/F	7	3	[illegible]		602
	603	T11 VCB	OUTDOOR MARSHALLING KIOSK	[illegible]	TRANSFORMER TRIPS	4	-	[illegible]		603
	604	T11 VCB	[illegible] MARSHALLING KIOSK	[illegible]	[illegible]	7	5	[illegible]		604
	606	T11 VCB	T11 HV CABLE BOX	[illegible]	NEUTRAL VOLTAGE DISPLACEMENT	4	2	[illegible]		606
	607	T11 A/C PANEL	OUTDOOR MARSHALLING KIOSK	[illegible]	L.D.C. CTs, NO TEST SUPPLY	4	1	[illegible]		607
	608	T11 A/C PANEL	WALL MOUNTED ALARMS PANEL	[illegible]	TAP CHANGE OUT OF STEP & CONTROL FAIL ALARMS	7	3	[illegible]		608
	610	OUTDOOR MARSHALLING KIOSK	WALL MOUNTED ALARMS PANEL	[illegible]	TRANSFORMER & SUMP PUMP FAIL ALARMS	[illegible]	13	[illegible]		610
	614	T11 A/C PANEL	T12 A/C PANEL	[illegible] (2 core TWISTED PAIR SCREENED CABLE, [illegible] BEING THE SCREEN)	COMMS LINK					614
	616	T11 A/C PANEL	OUTDOOR MARSHALLING KIOSK	[illegible]	TAP POSITION INDICATION AND CONTROL SUPPLY	[illegible]	3	[illegible]		616
BUS-SECT	900	WALL MOUNTED ALARMS PANEL	BUS-SECTION V.C.B	[illegible]	REMOTE AMMETER, CONTROL INDICATION & ALARMS	12	3	[illegible]		900
	3CL	AUTOMATIC SUBSTATION CONTROL SYSTEM [illegible]	BUS-SECTION V.C.B	[illegible]	CONTROL & INDICATION	12	[illegible]	2.5	7	3CL

RELEASED FOR CONSTRUCTION

AS CONSTRUCTED

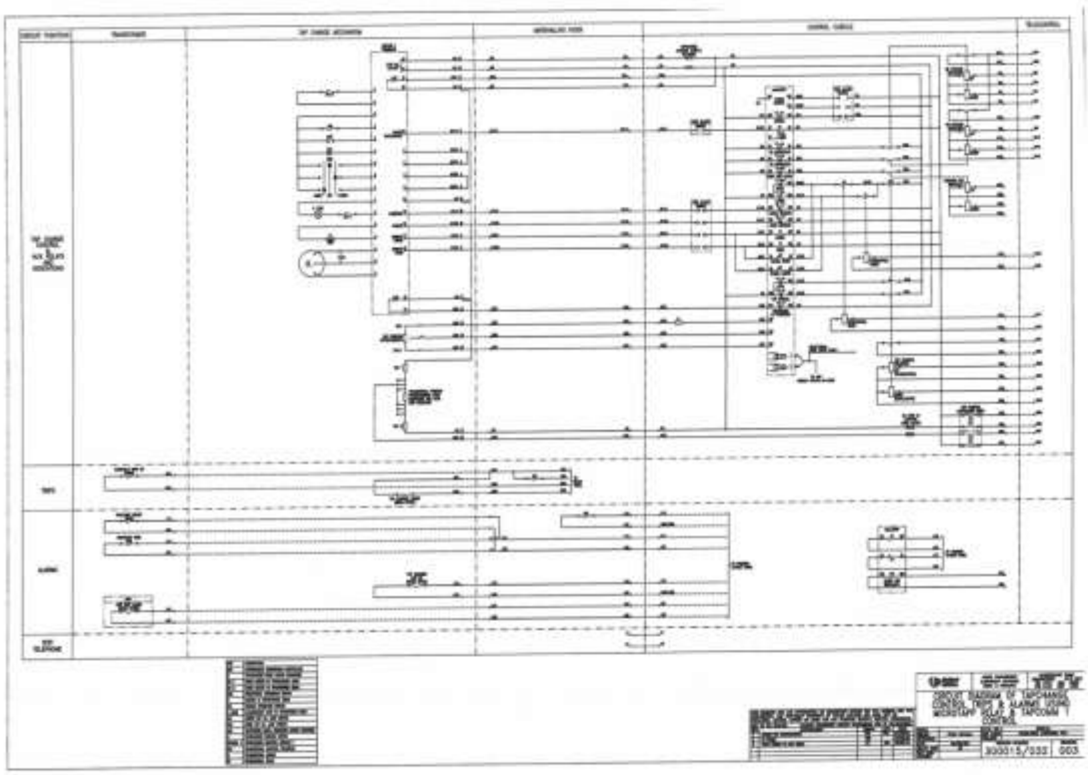
CABLE 3CL ADDED

United Utilities

ASSET MANAGEMENT ELECTRICITY NETWORK

MULTICORE SCHEDULE FOR T11 & BUS-SECTION AT MIDDLETON JUNCTION SUBSTATION

Appendix B IV –Schematic of AVC Scheme (with Fibre Optic connection to ASC shown at lower end of MicroTAPP module)



Appendix C – ASC Technical Manuals

Siemens SICAM 1703 PS-663x
TM 1703ACP PE-641x/TCi06
ACP1703 AX 1703 CM-0821
SICAM TM 1703 I/O modules
Automation Unit TM 1703 ACP
SICAM TM system data sheet