

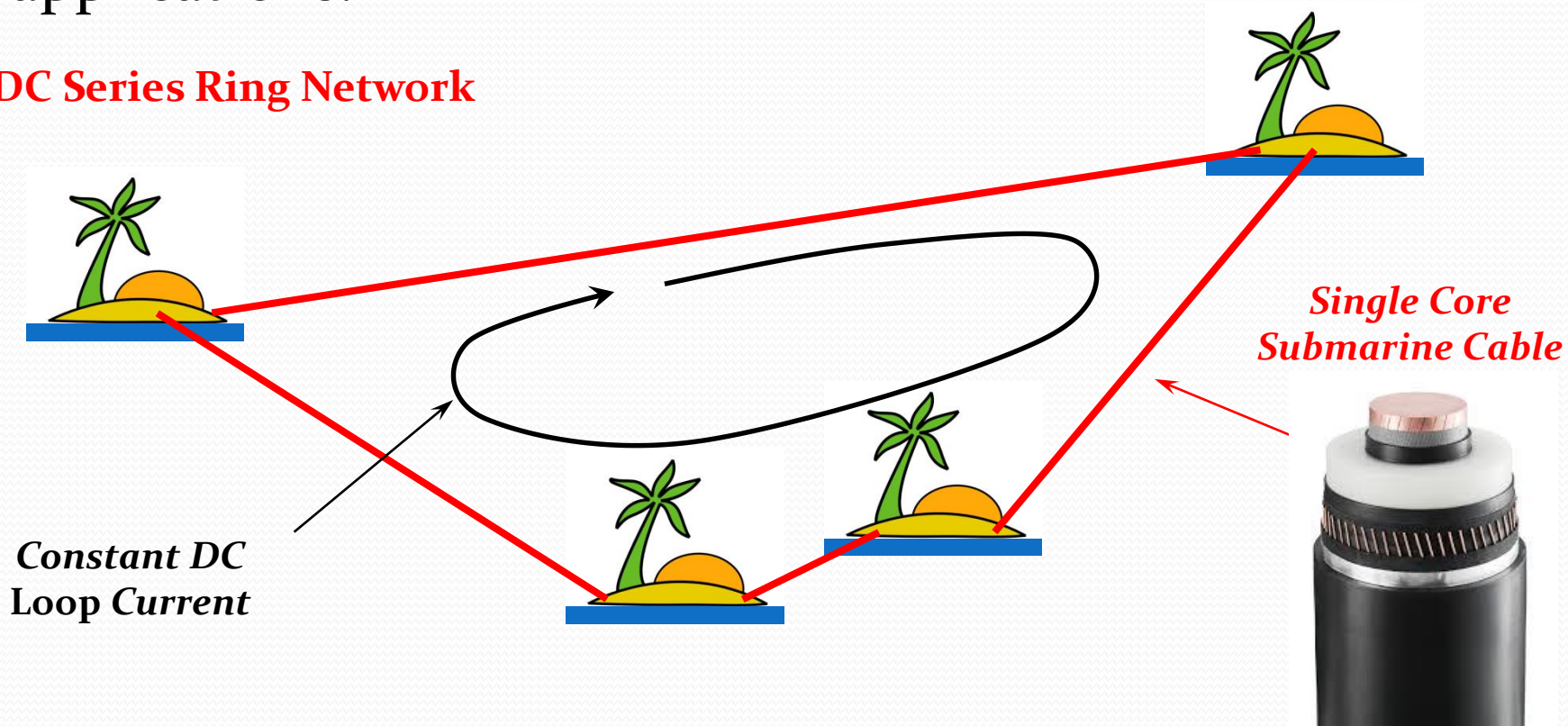
Case Study: Low Cost Inter-Island DC Power Transmission for Chuuk State

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Background

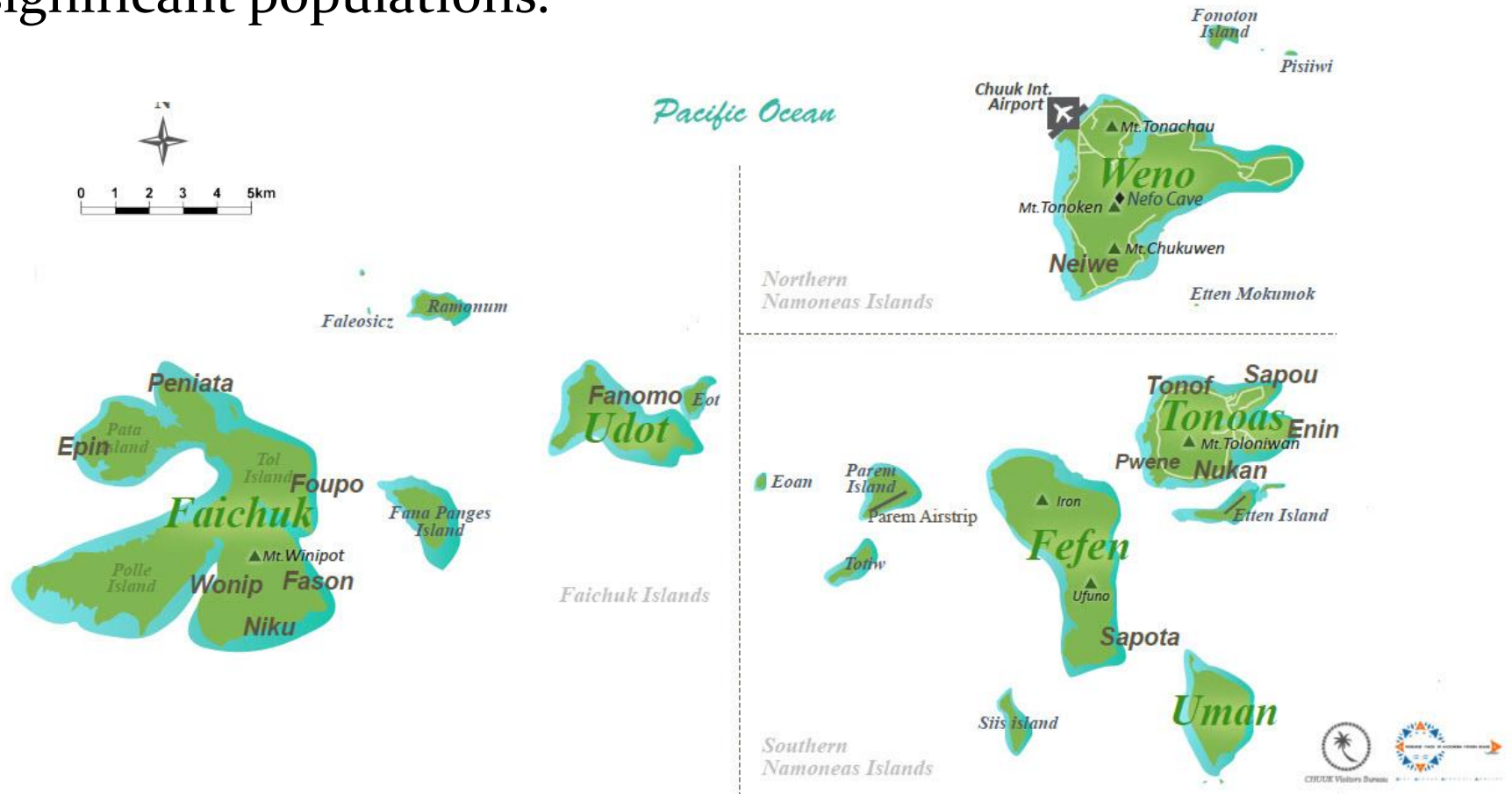
- Self initiated case study to demonstrate the practicality of a DC Series connected, constant current, single core subsea transmission architecture for certain applications.

DC Series Ring Network



Background

Chuuk Lagoon was chosen for the study as only one island is currently electrified and there are several nearby islands with significant populations.



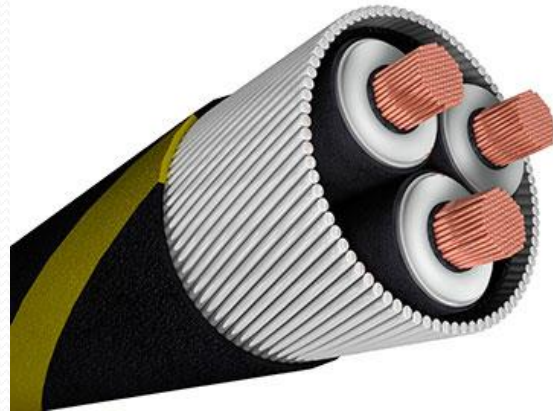
Advantages

- Utilises existing power station capacity and infrastructure on Weno Island. Many benefits:
 - 1) higher power station efficiencies,
 - 2) simplified fuel logistics (delivery & storage).
 - 3) reduced maintenance & skilled personnel requirements.
 - 4) reduced land footprint on outer islands.
- Significantly cheaper option for reaching the other islands in the lagoon.

AC or DC Transmission?

HV AC approach. 3-core HV submarine cable

→ 3-Core. Expensive.

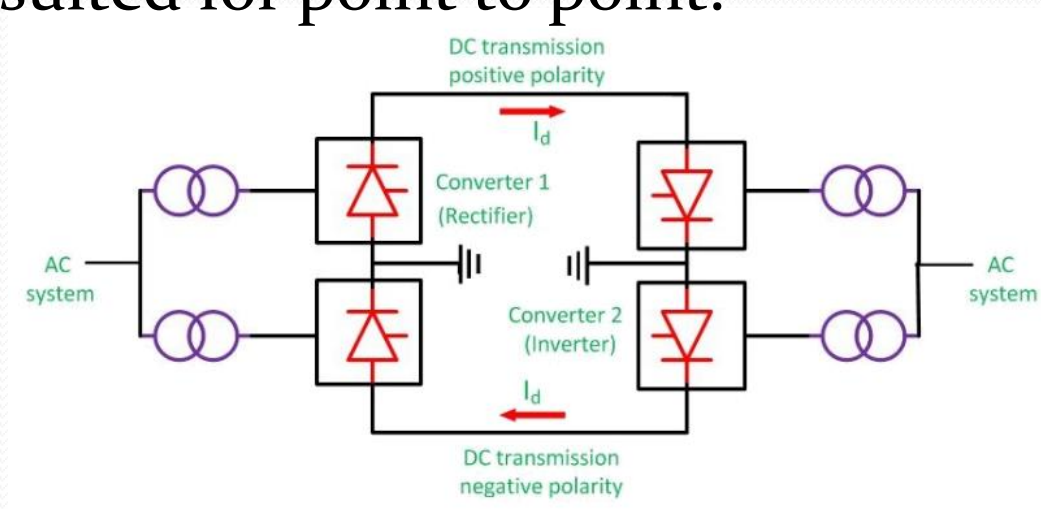


→ Potential reactive power & voltage regulation issues.

Traditional DC

Constant Voltage HV DC:

→ Better suited for point to point.



→ Expensive protection equipment.

→ 2-Core for bipolar.



Single Core DC Series Loop

Economic savings are substantial compared to 2-core or 3-core.

→ Cable price is reduced.

→ Laying costs are reduced:

- Lighter cable.
- Longer lengths per drum = fewer splices.
- Cheaper splices- only 1-core.

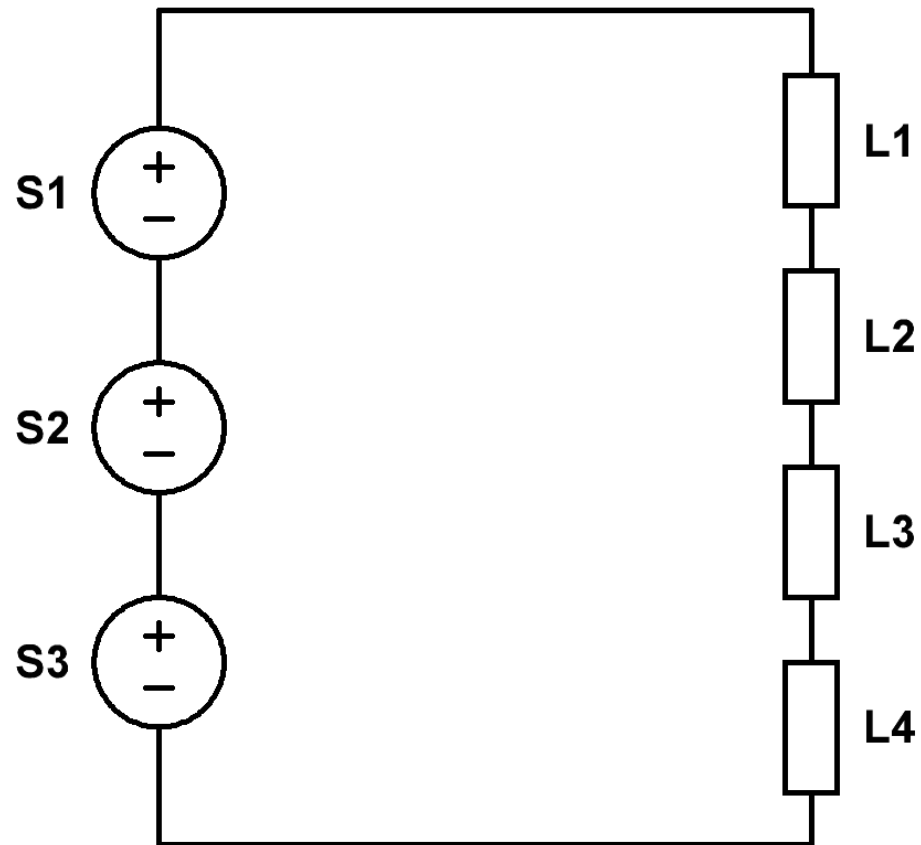


The Basic DC Series Ring

1.

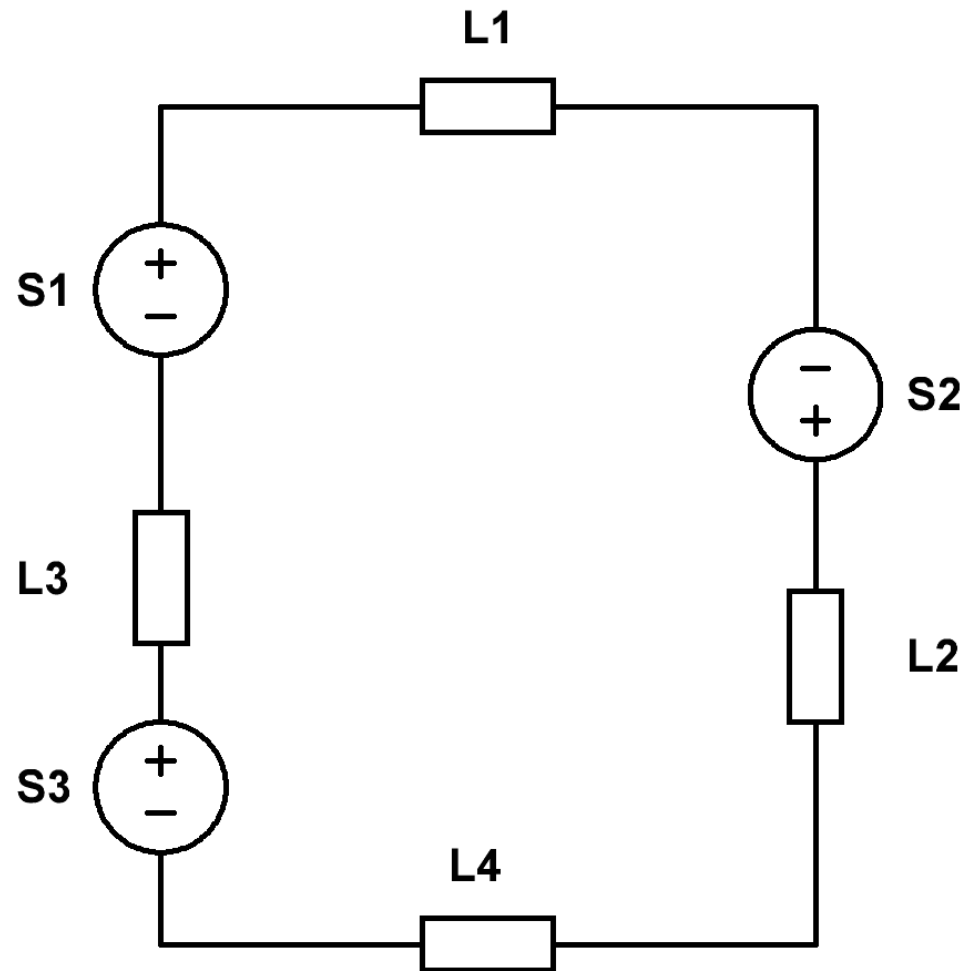
Standard schematic layout.

Clearly 1-core only.



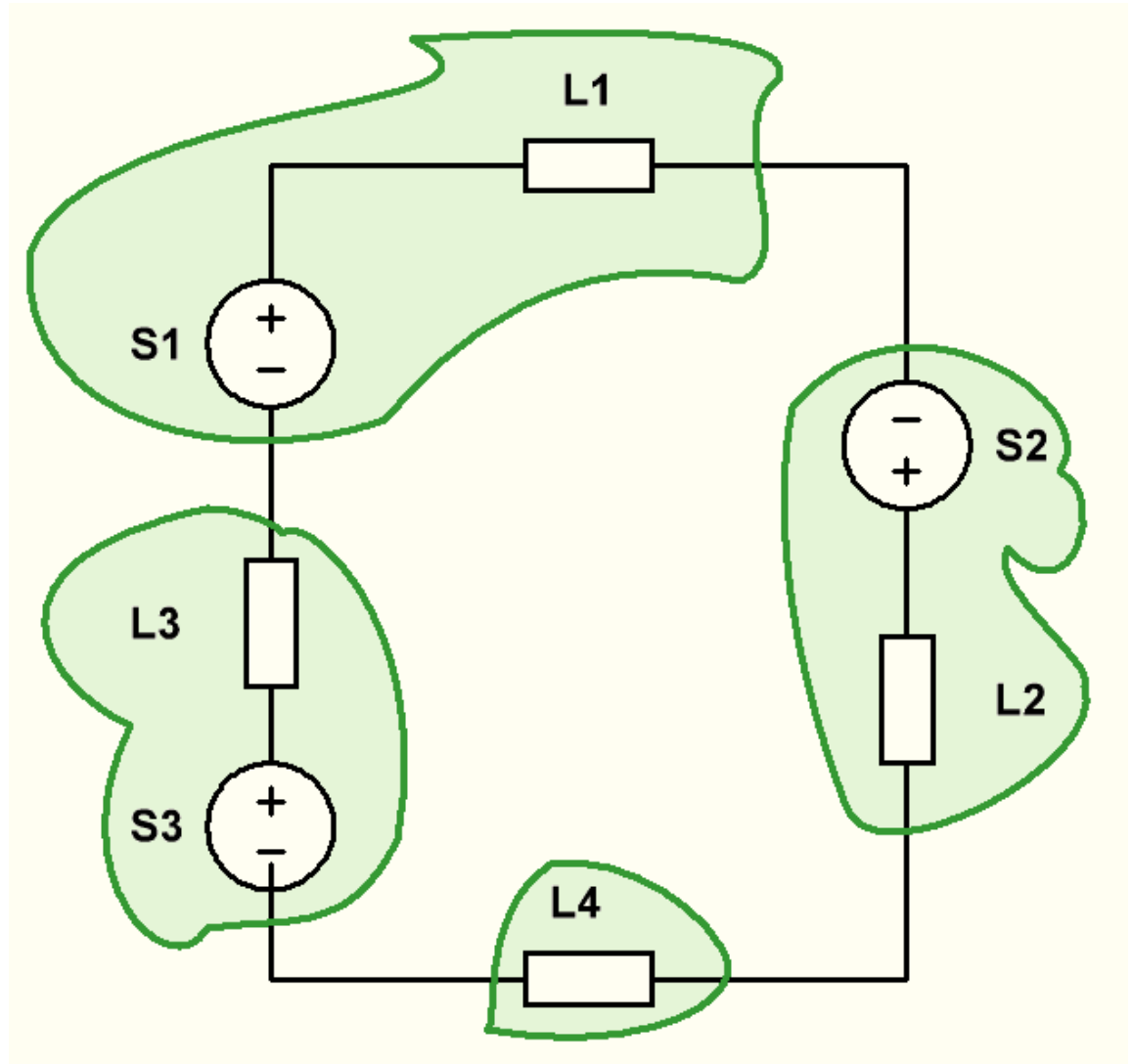
The Basic DC Series Ring

2.
Randomly ordered.



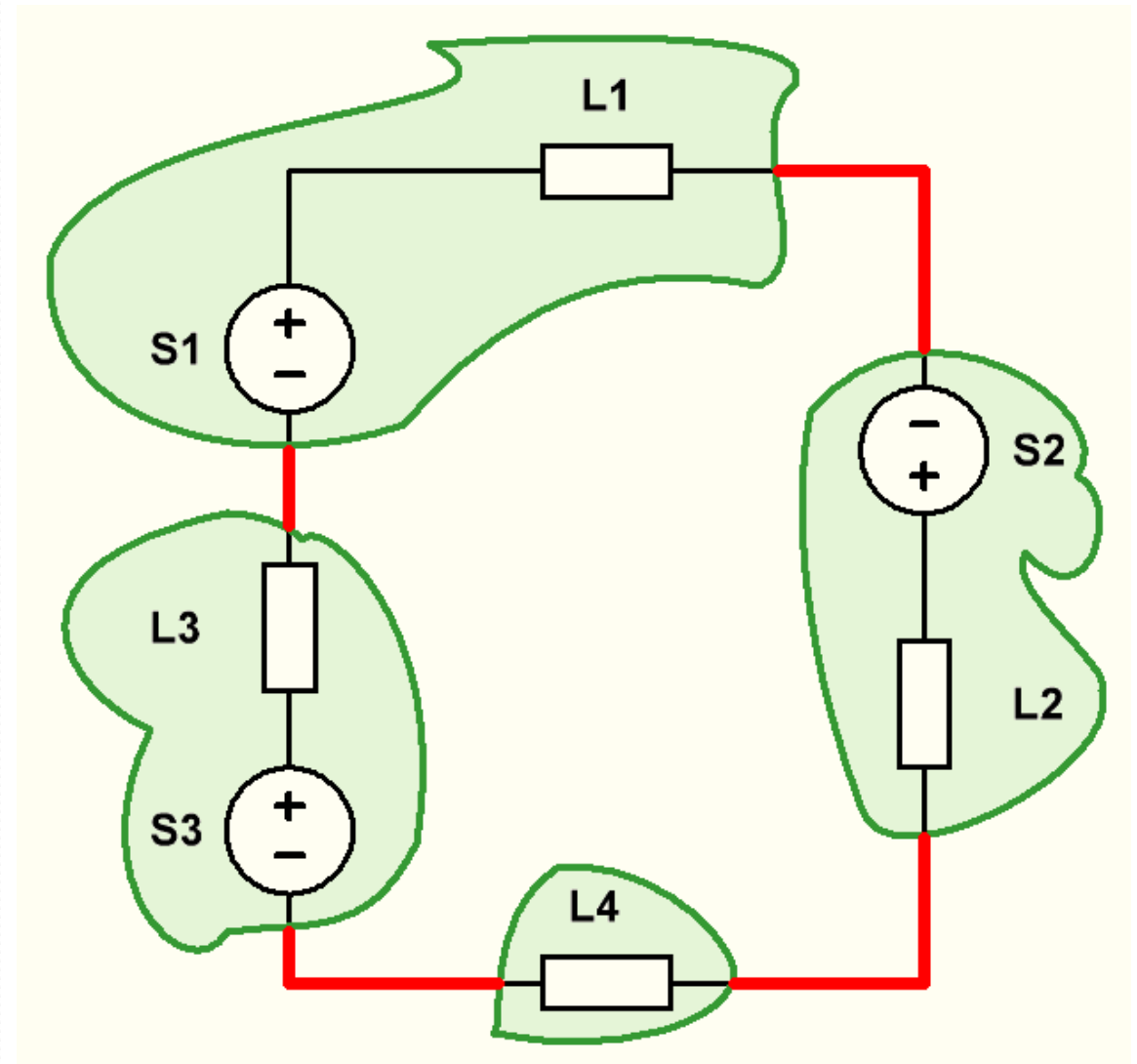
The Basic DC Series Ring

3.
Grouped by island.



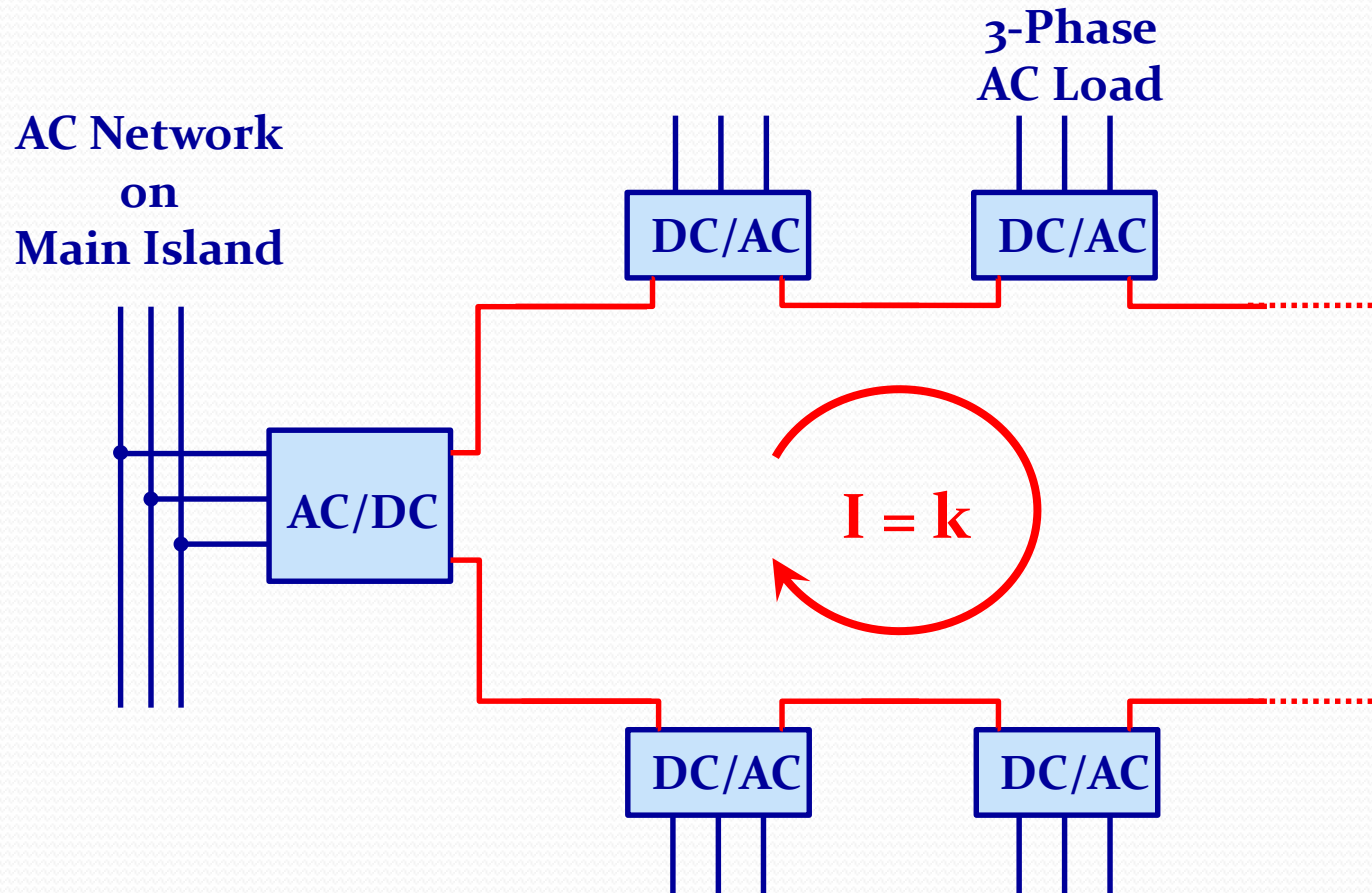
The Basic DC Series Ring

4.
Highlighting the
1-core submarine
cable.

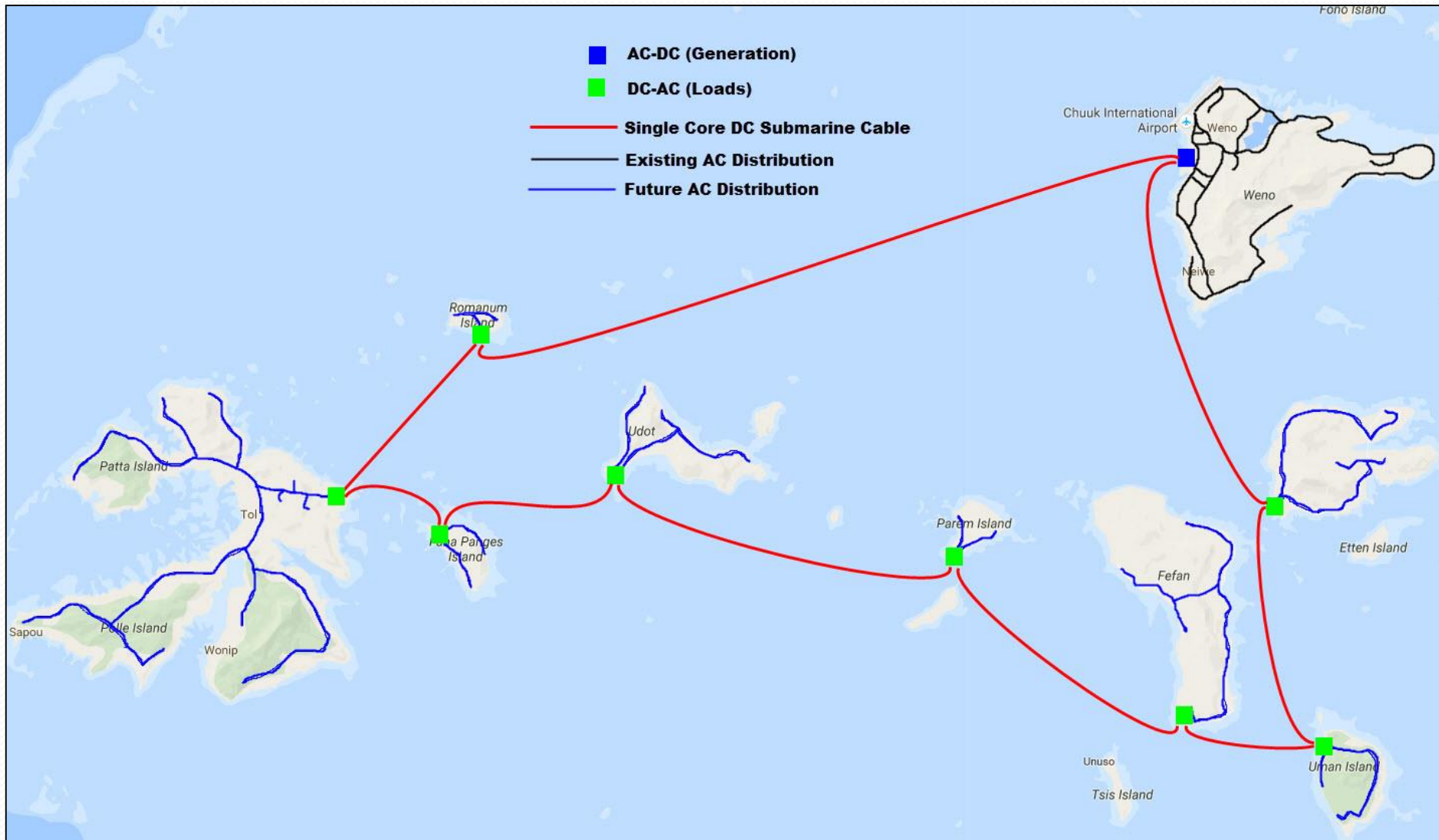


AC-DC Interfaces

All load locations are converted to 3-phase AC.

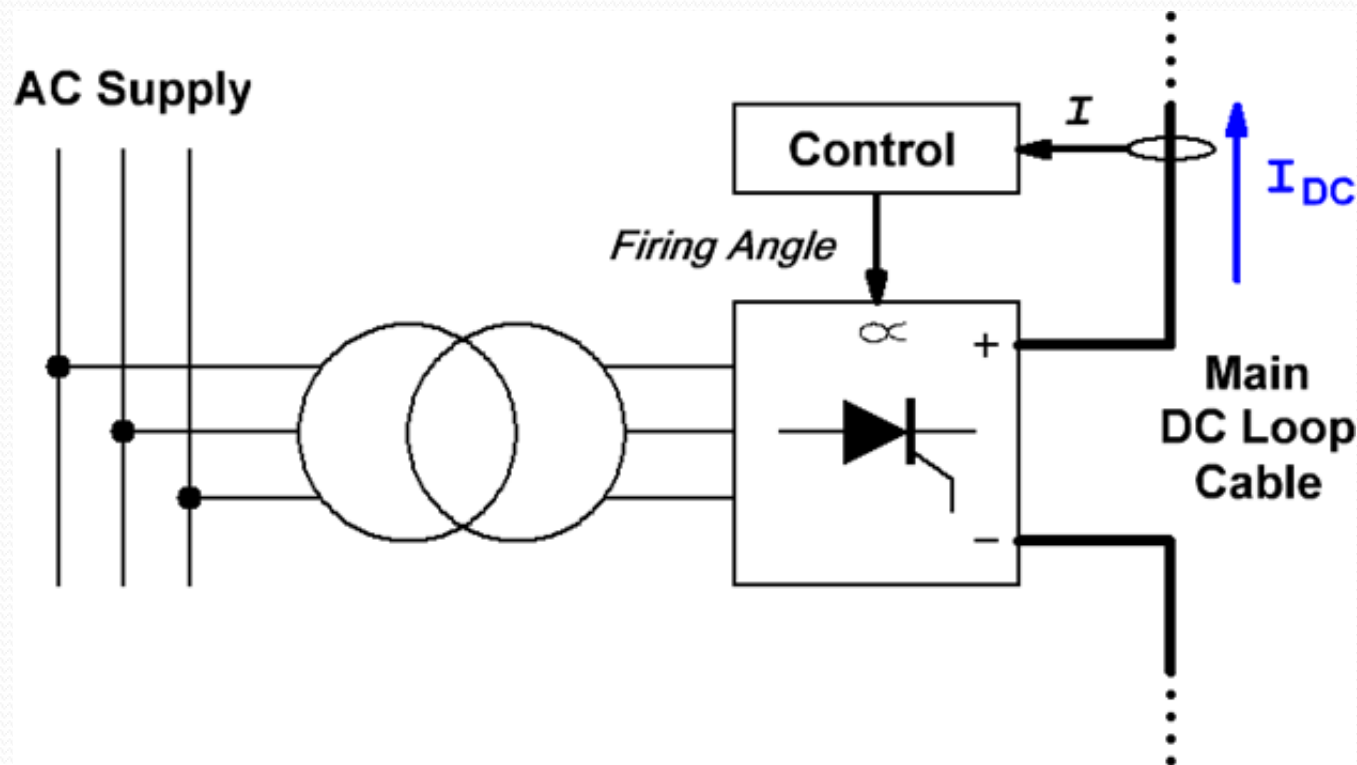


DC Transmission / AC Distribution



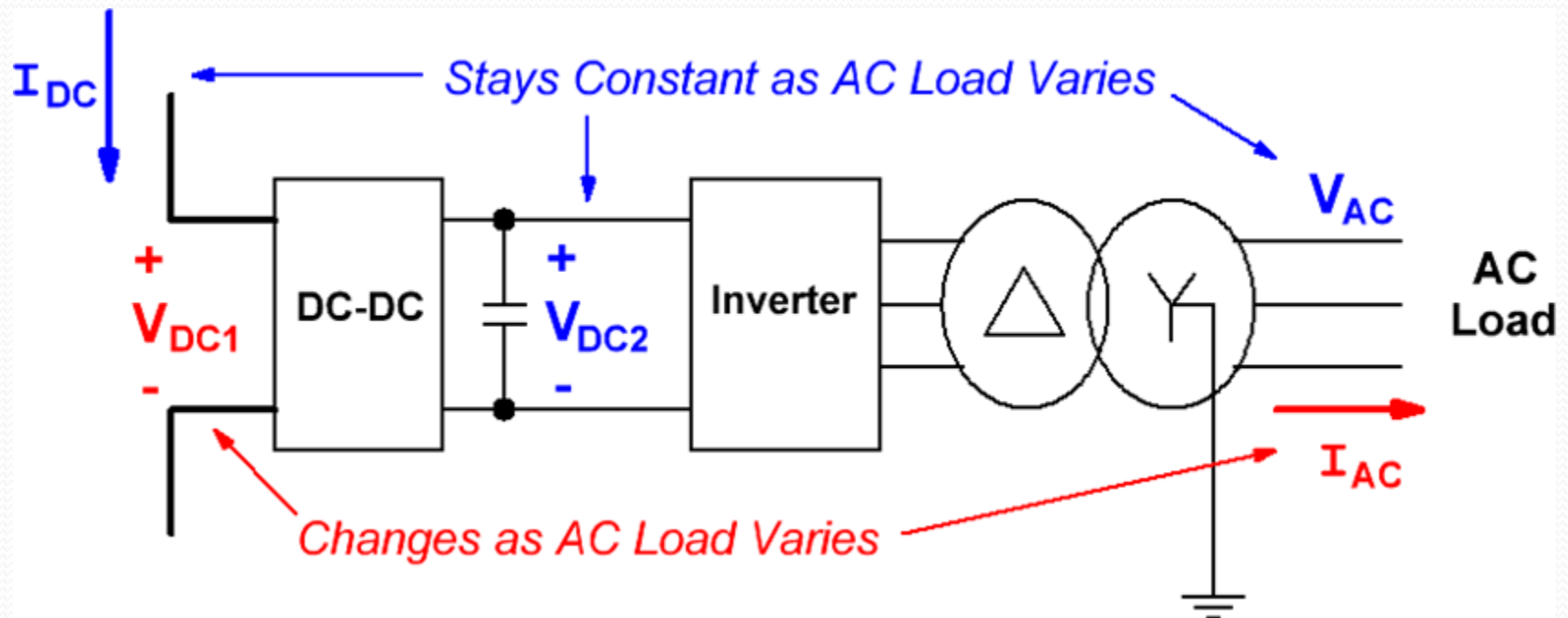
DC Constant Current Source

- Requires a controllable DC voltage source. Easily achieved with a thyristor rectifier.



Power Conversion for Loads

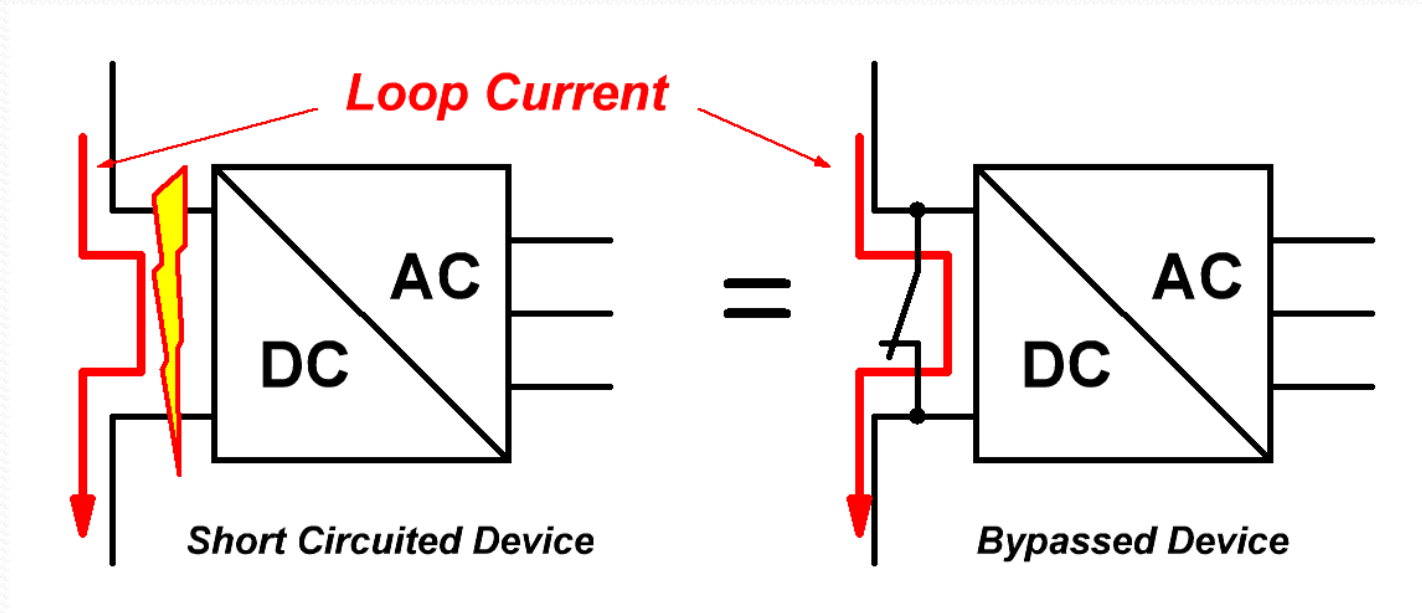
- DC-AC conversion for loads employs widely utilised industrial power conversion modules – DC-DC modules and inverters.



Short Circuit Fault

- Constant current supply means no change in current for a short circuit.

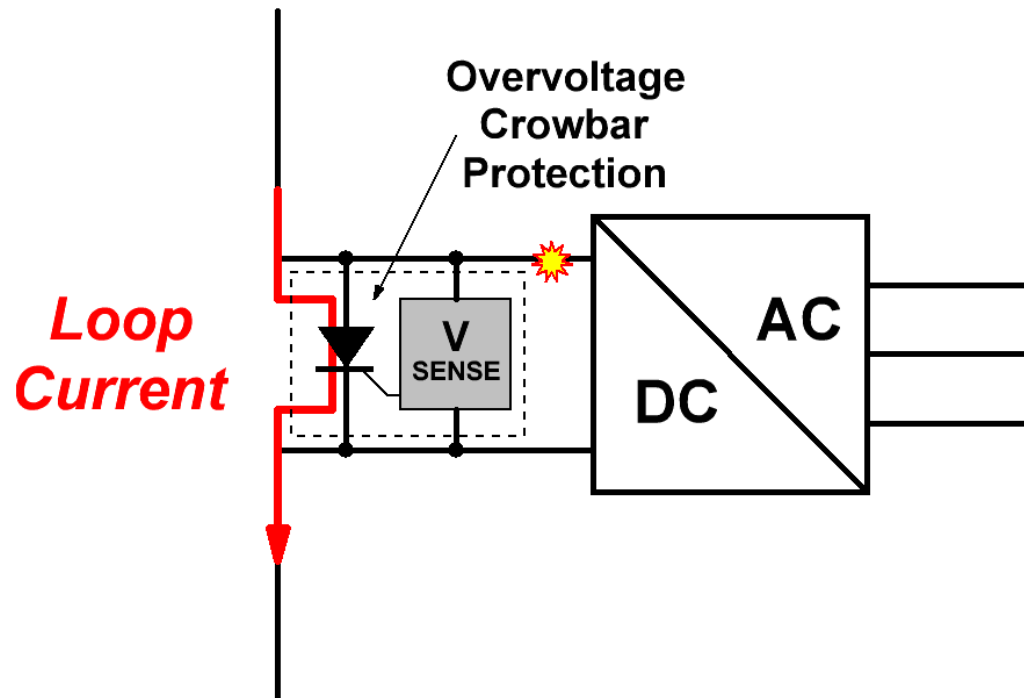
Therefore, no such thing as Fault Current Levels!



Open Circuit Fault

- Current will drop towards zero & voltage will rise.

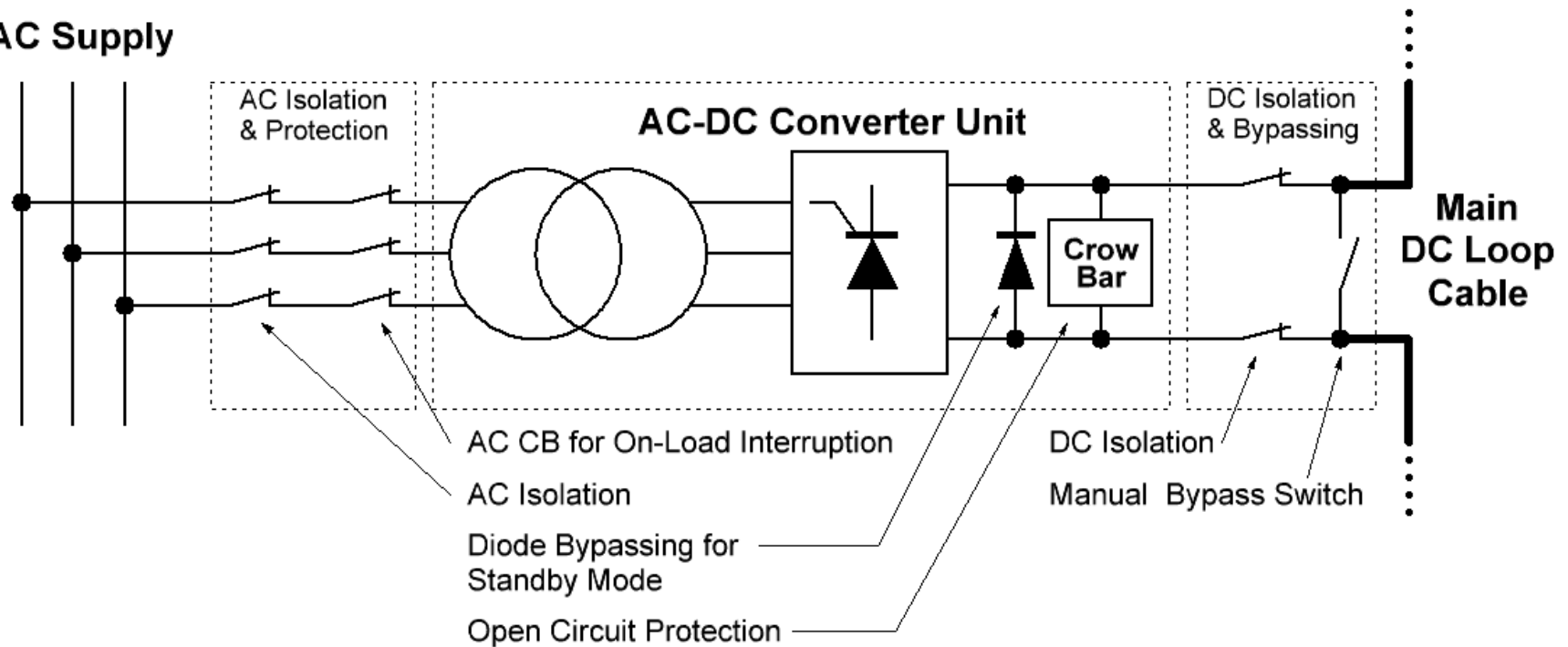
Crowbar protection will trigger and bypass faulty unit.



Protection - Sources

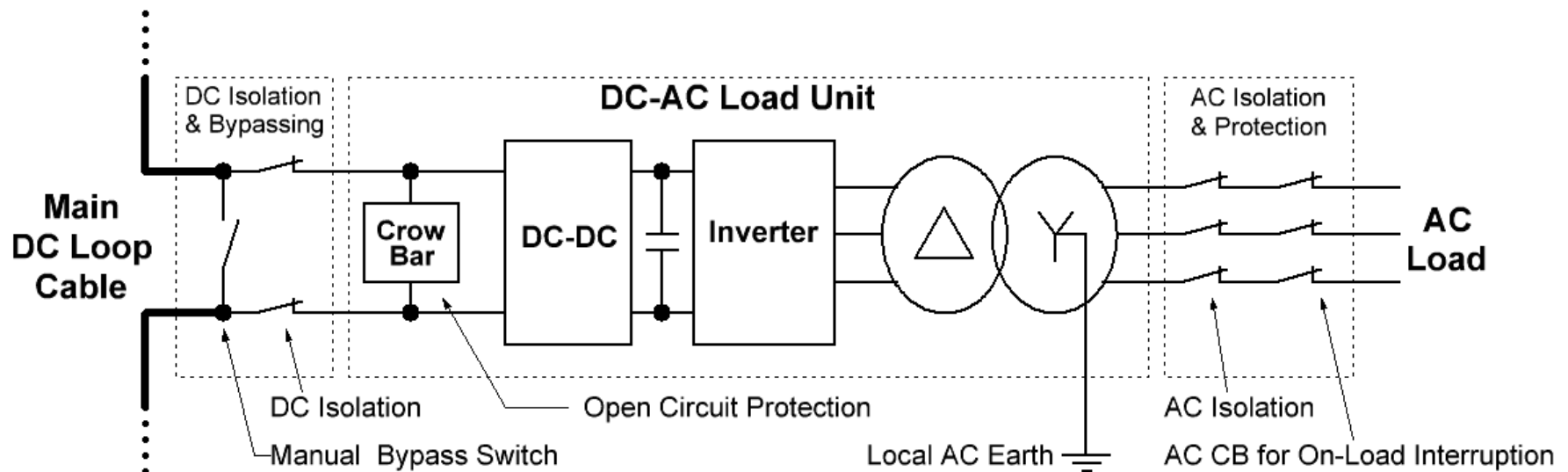
No need for 'on load' DC breaking ability.

AC Supply



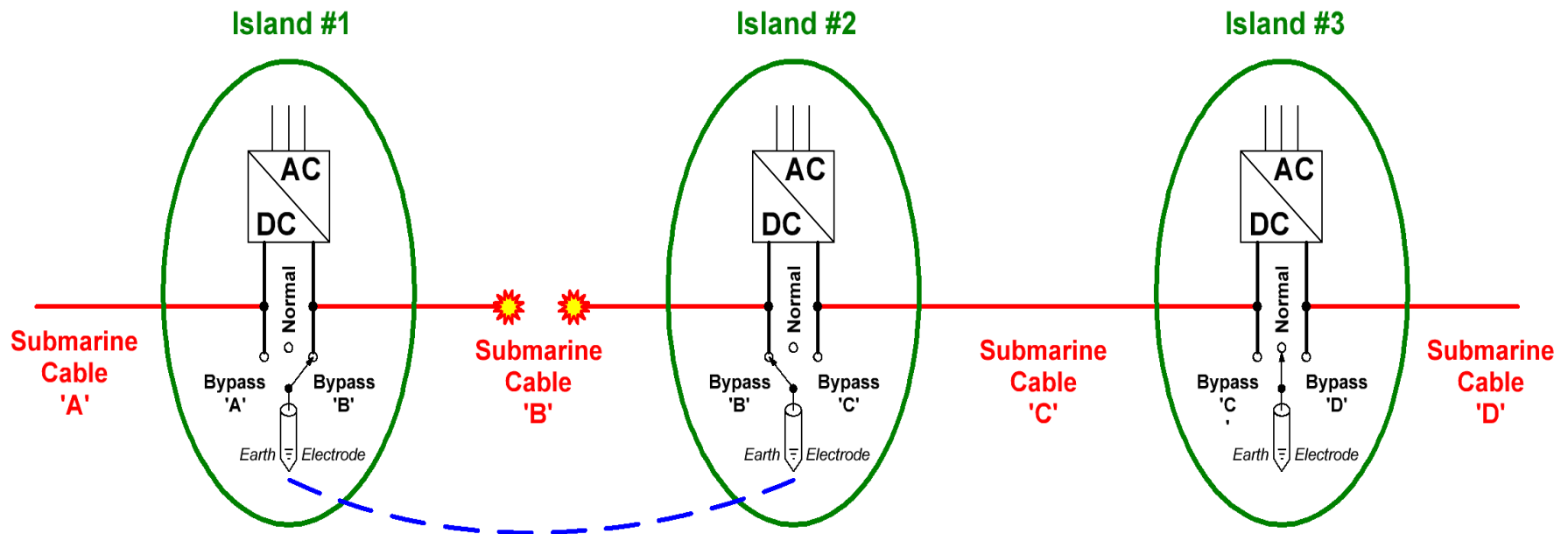
Protection - Loads

Again, DC switchgear 'makes' , but does not 'break'.



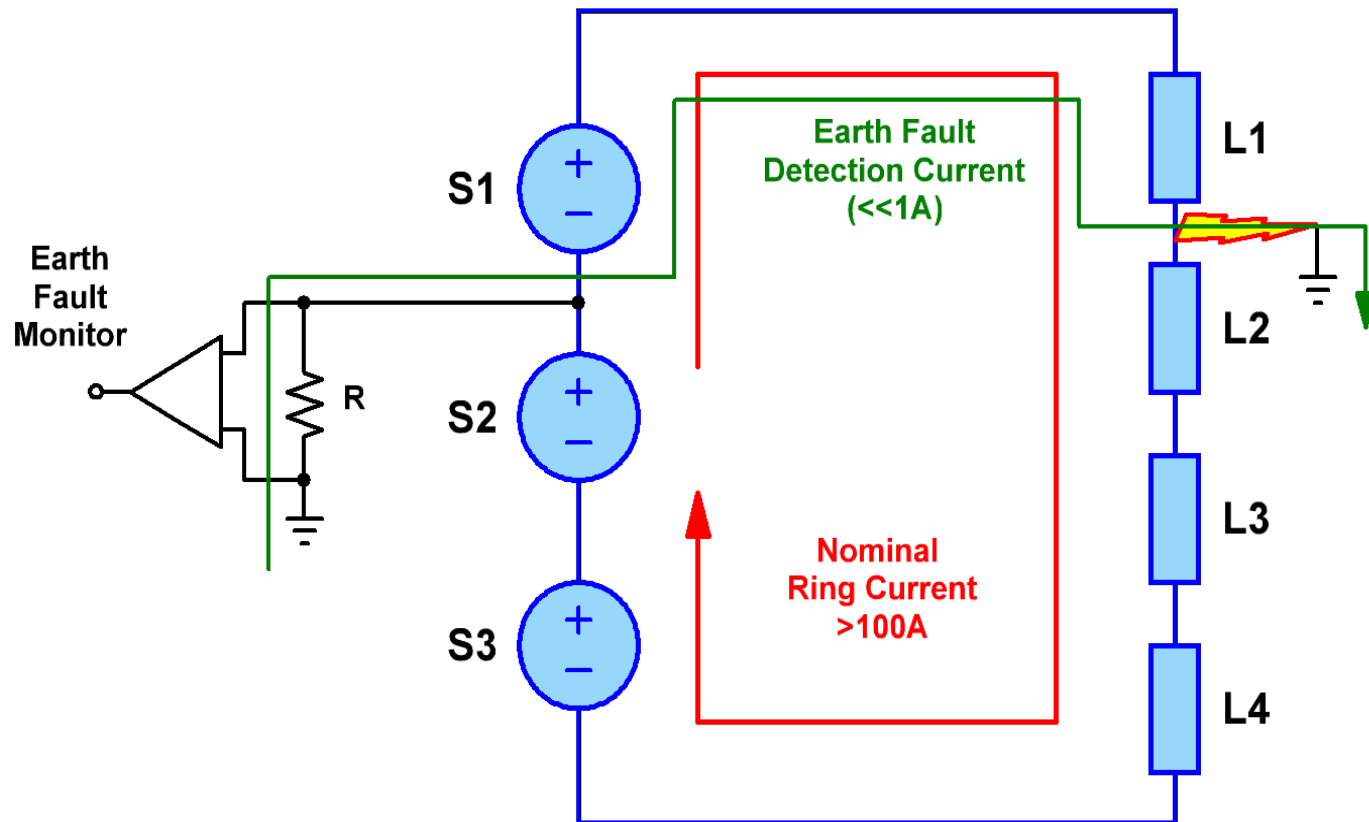
Redundancy

- A submarine cable failure can be bypassed until the cable repair is completed.

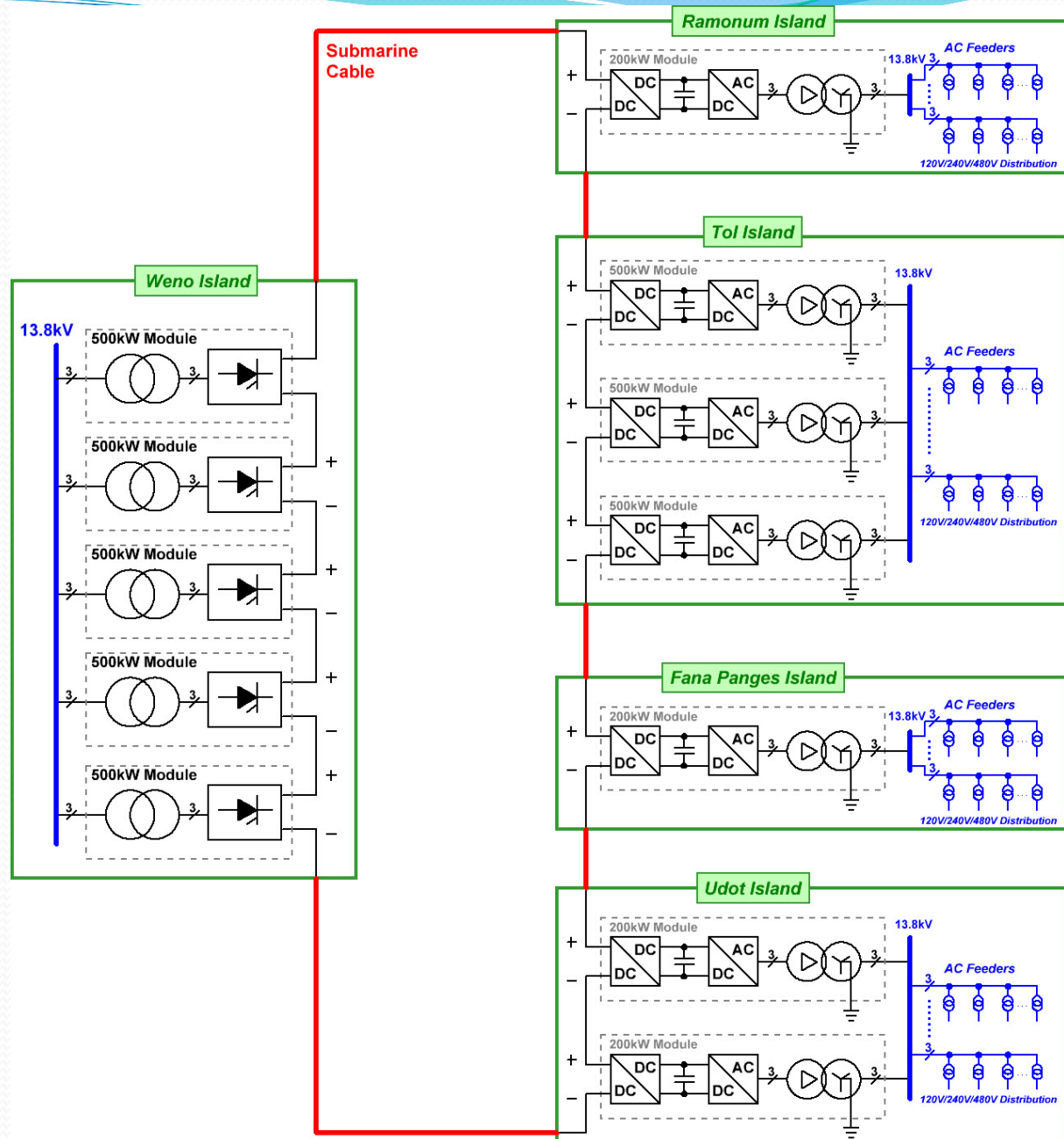


Earth Fault Detection

- Normal operation is maintained for a single earth fault on the DC transmission network.

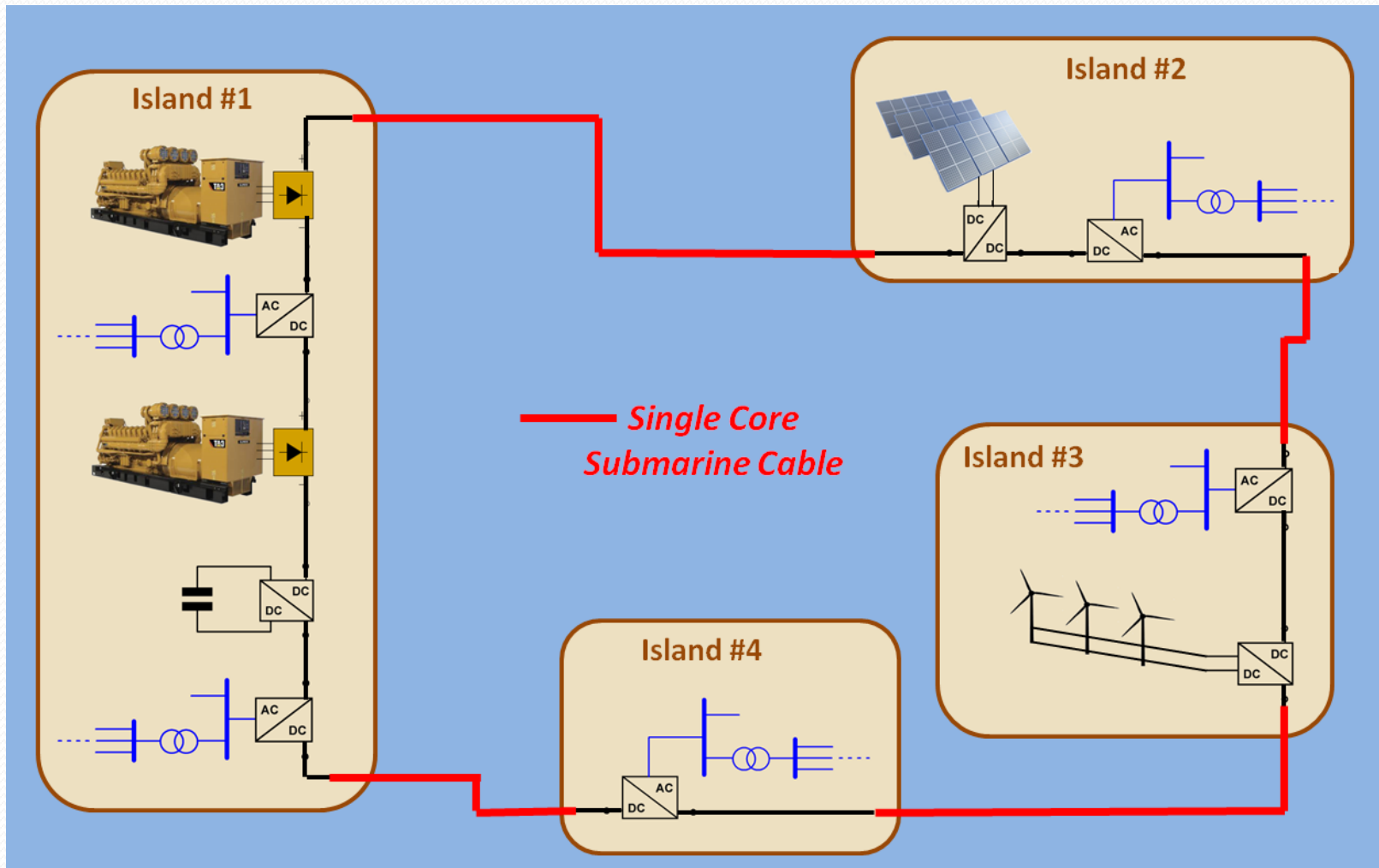


Modular Design



Future Expansion

- Other Diesel/RE generation easily added at any time



Chuuk Lagoon Study

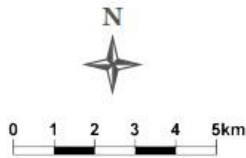
- A detailed design application and modelling of a potential DC Series Transmission network as could be applied to Chuuk Lagoon was performed as an exercise

Peak Load Estimates

- Population data based on 2010 FSM Census.
- Load vs population data based on KEMA/NREL energy snapshots. Averaged across ~10 PPA countries.
- Resulting formula:

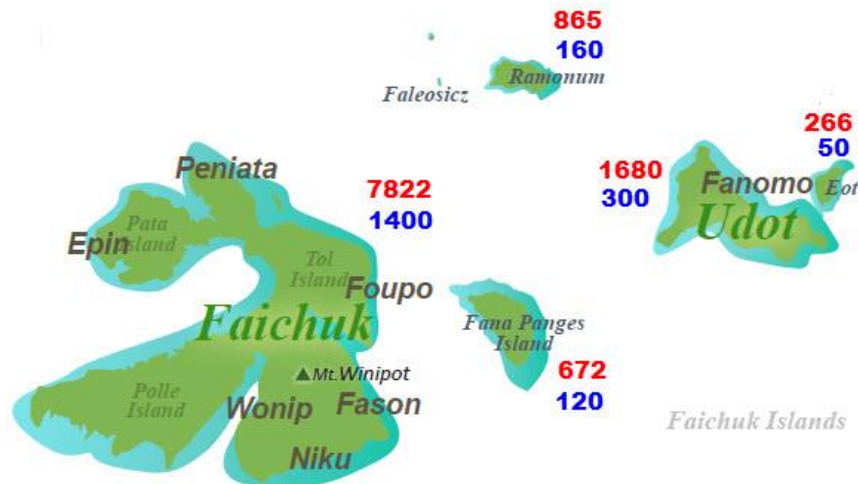
$$\text{Peak Load (kW)} = \frac{\text{Population}}{5.6}$$

Peak Load Estimates

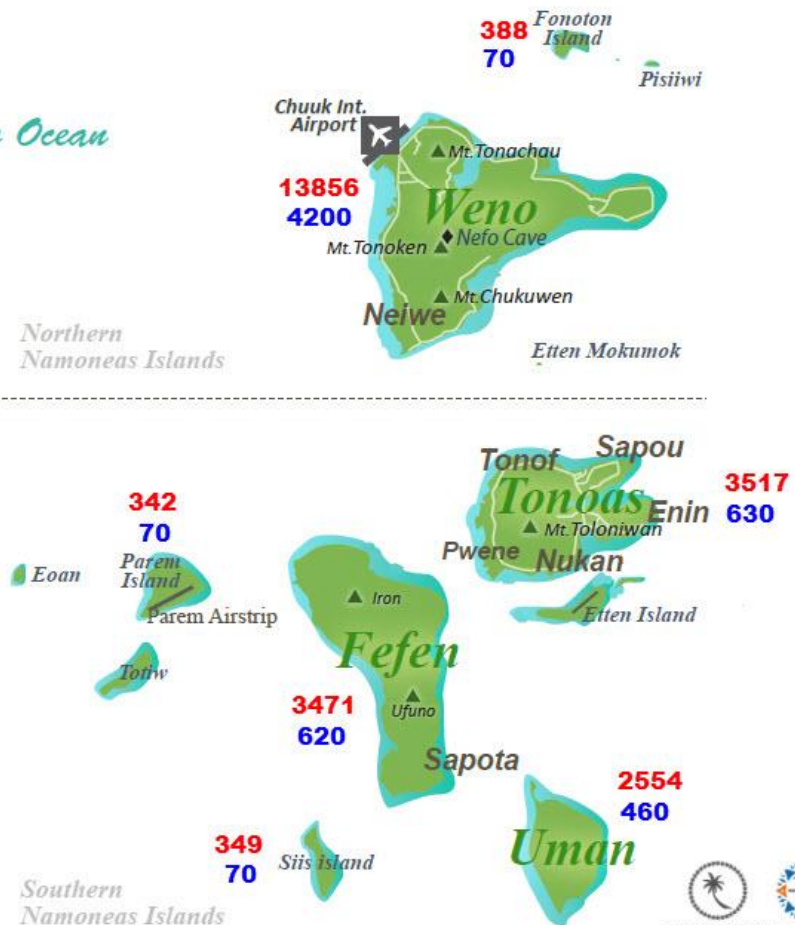


Population (2010 Census)
Est. Peak Demand (kW)

Pacific Ocean



Faichuk Islands

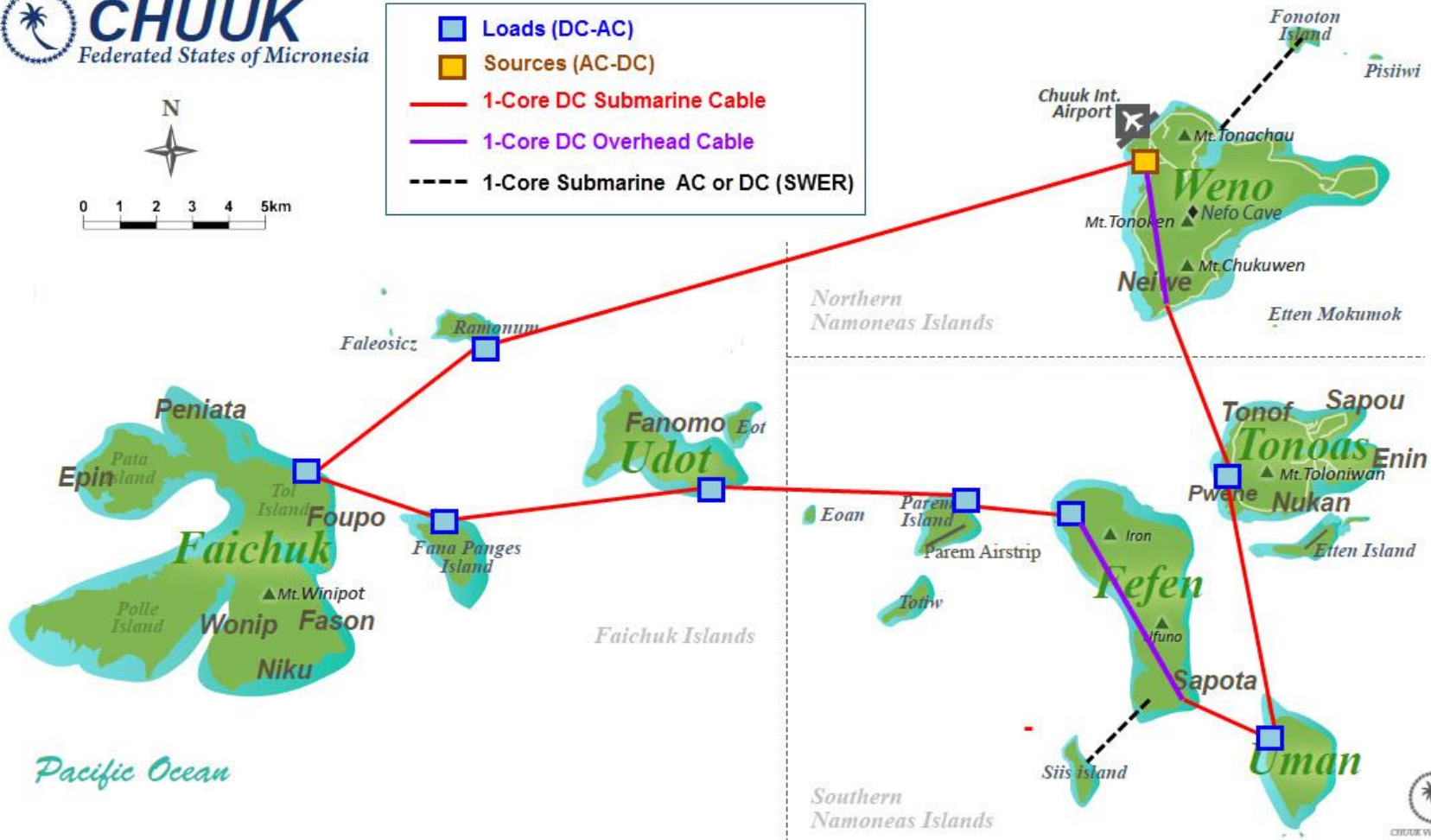
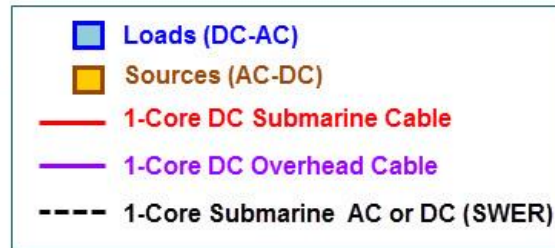
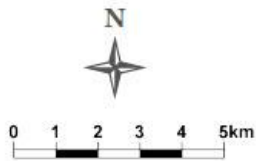


Northern Namoneas Islands

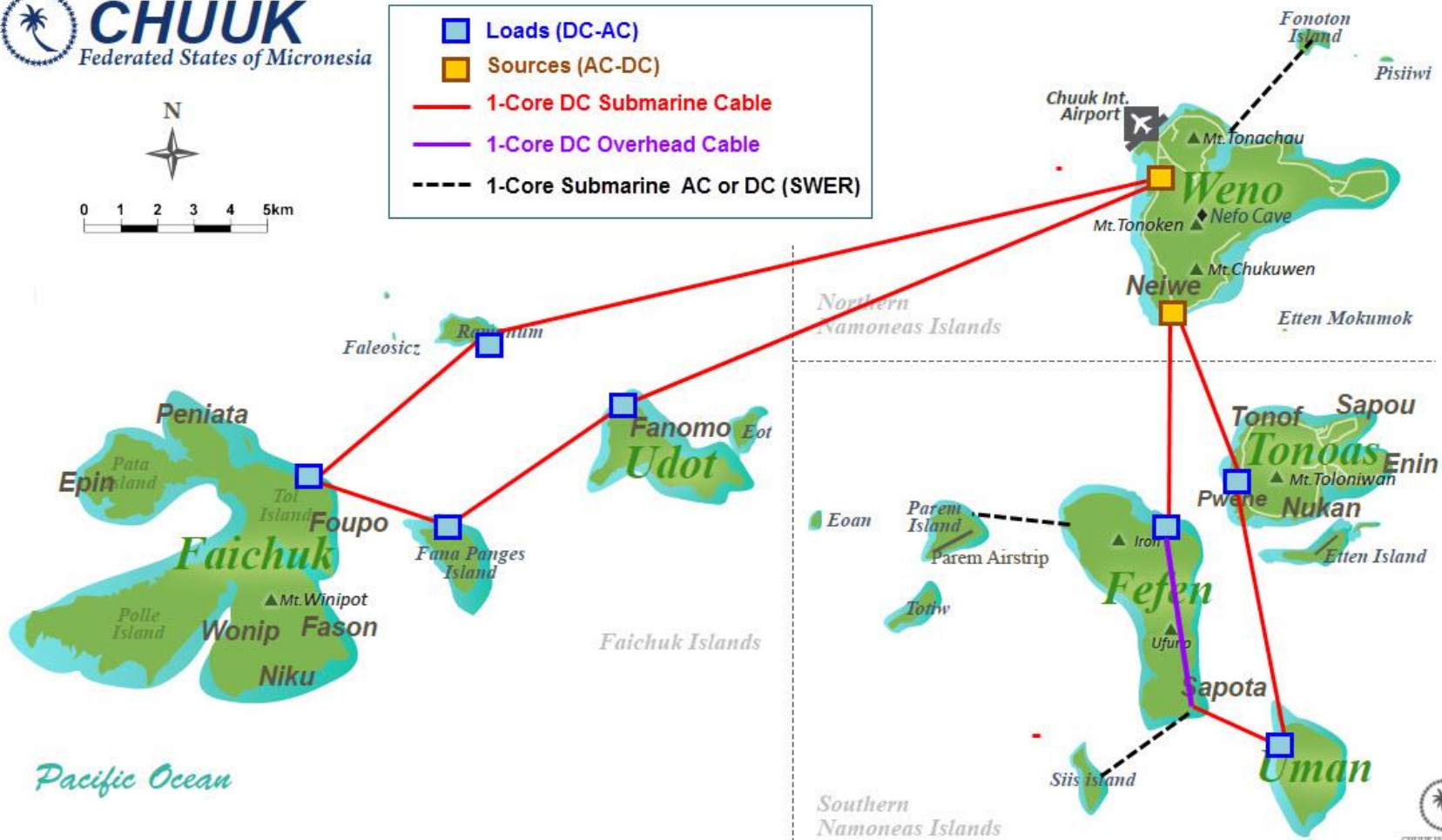
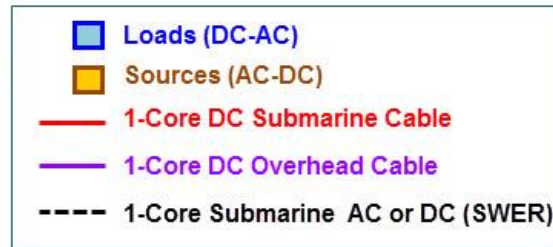
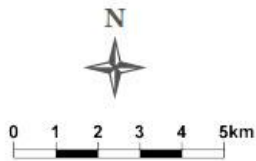
Southern Namoneas Islands



Loop Options - Single



Loop Options – Double



Loop Calculations

- Based on Max DC voltage of 20kV.

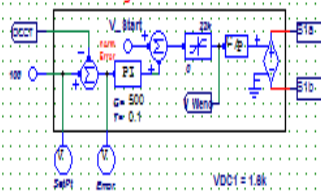
Parameter	One Loop	Two Loops	
		Faichuk Islands	Nomoneas Islands
Length (km)	70	50	25
Peak Demand (MW)	3.9	2.0	1.9
Average Demand (MW)	2.7	1.4	1.3
Cable Size (mm ²)	240	95	50
I_{LOOP} for Peak Demand (A)	200	105	100
I_{LOOP} for Average Demand (A)	150	75	70
Cable Losses @ Peak Demand (%)	5.4	5.3	5.1
Cable Losses @ Average Demand (%)	4.4	3.9	3.6

Modelling - PSIM

Need to watch ripple voltage on V_{Weno} as this will directly impact on the grid supply. (i.e. a rapidly fluctuating voltage for a constant current will reflect back onto the AC side of the supply).

It will boil down to how much inductance is practical to add on in series. The stray loop inductance is most likely insufficient and as a combination of added inductance + PID control the low frequency provides a reasonable response.

Current Regulator on Weno Island



$$V_{D01} = 1.6k$$

$$V_{D03} = 1.4k$$

$$V_{D03} = 1.2k$$

$$V_{D04} = 1.6k$$

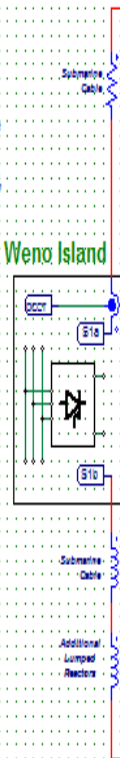
$$f_1 = 2.2k$$

$$f_2 = 1.6k$$

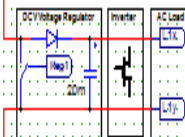
$$f_3 = 2.6k$$

$$f_4 = 1.53k$$

Weno Island

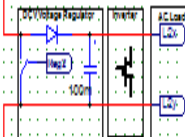


Ramonum Island



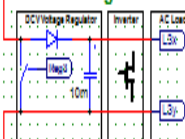
Island Specs:
 $Ave P = 100kW$
 $P_{peak} = 150kW$
 2M Voltage: 180V @ 100A
 $R: 32.2 - 22.3 - 16.8 \text{ ohms}$

Tol Island



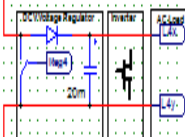
Island Specs:
 $Ave P = 100kW$
 $P_{peak} = 150kW$
 2M Voltage: 180V
 $R: 280 - 195 - 140 \text{ ohms}$

Fana Panges Island



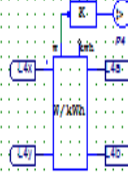
Island Specs:
 $Ave P = 25kW$
 $P_{peak} = 30kW$
 2M Voltage: 120V
 $R: 24.2 - 16.9 - 120 \text{ ohms}$

Udot Island

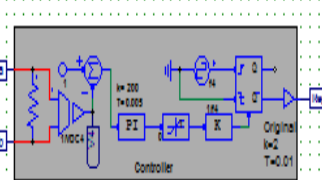
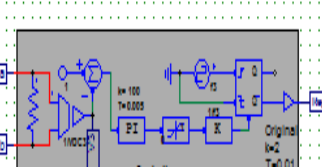
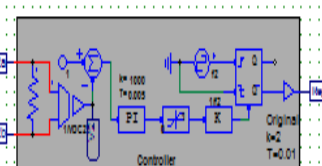
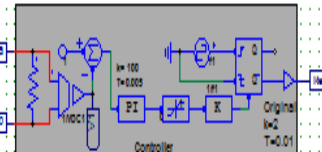


Island Specs:
 $Ave P = 245kW$
 $P_{peak} = 350kW$
 2M Voltage: 350V
 $R: 71.4 - 50 - 35 \text{ ohms}$

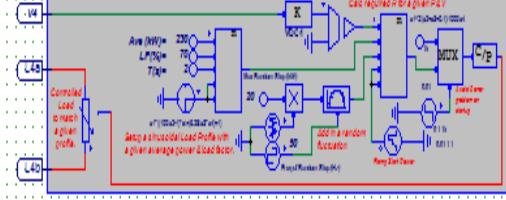
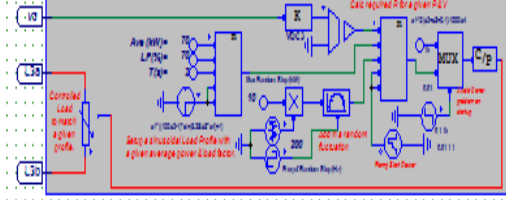
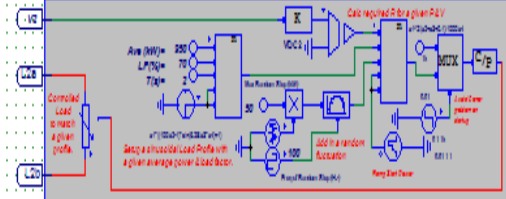
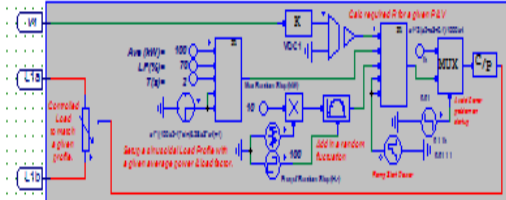
Power (kW) Monitoring



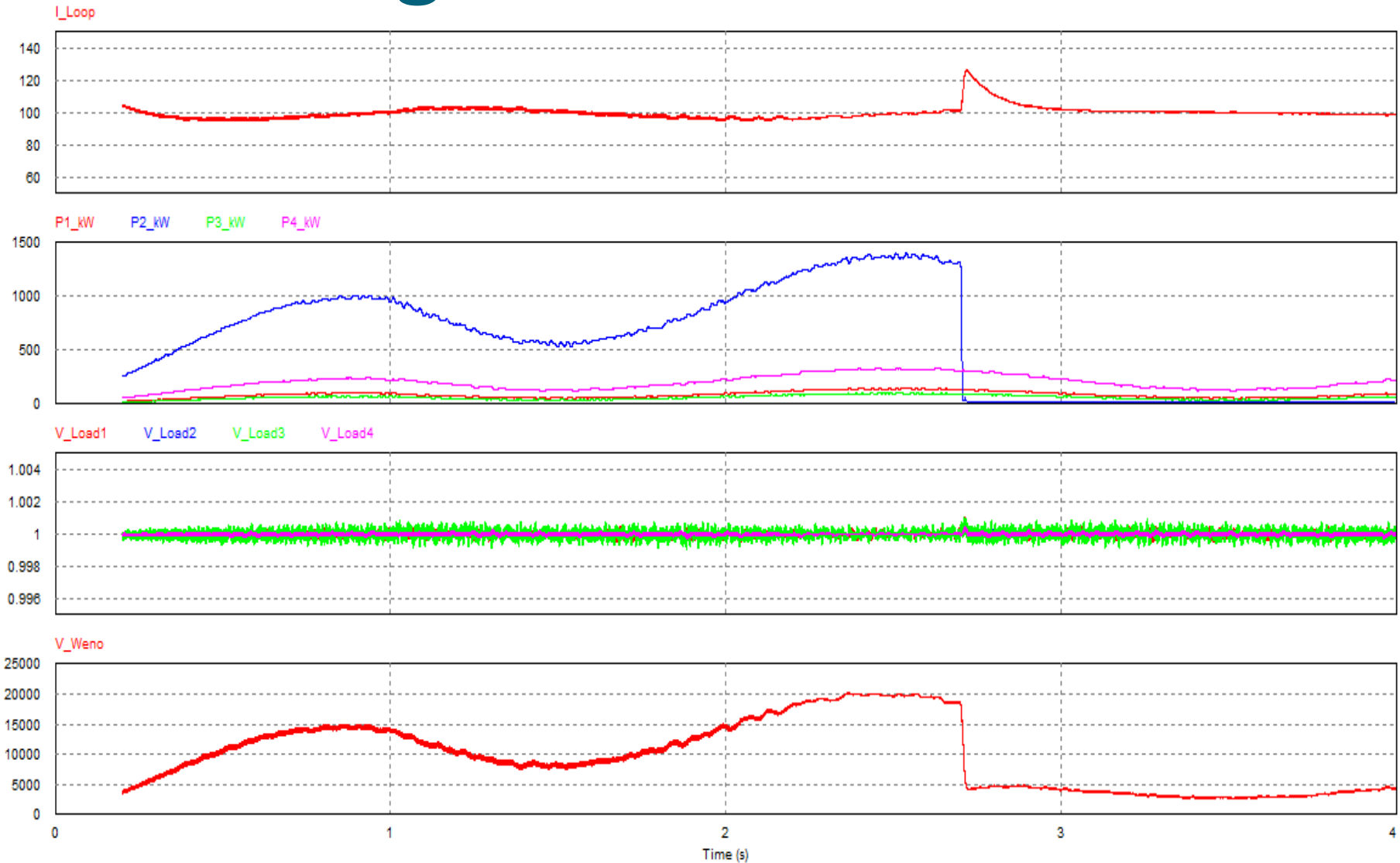
DC Voltage Regulators for Each Island



Variable Loading for Each Island

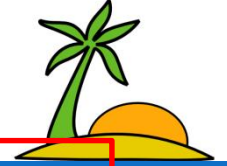
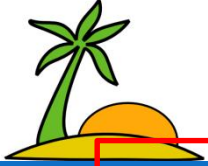


Modelling - PSIM



Costing

Equipment Required	DC Series Loop	13.8kV 3-Phase AC
Substations		
Weno	\$ 950,000	\$ 300,000
Faichuk	\$ 475,000	\$ 150,000
Fefen	\$ 385,000	\$ 150,000
Tonoas	\$ 385,000	\$ 150,000
Uman	\$ 325,000	\$ 125,000
Udot	\$ 325,000	\$ 125,000
Ramonum	\$ 290,000	\$ 100,000
Fana Panges	\$ 290,000	\$ 100,000
Parem	\$ 270,000	\$ 100,000
Siis	\$ 270,000	\$ 100,000
Subtotal	\$ 3,965,000	\$ 1,400,000
Submarine Cable		
75km of Cable	\$ 2,925,000	\$ 9,375,000
Transport	\$ 235,000	\$ 750,000
Installation Cost	\$ 3,085,000	\$ 9,900,000
Subtotal	\$ 6,245,000	\$ 20,025,000
Total	\$ 10,210,000	\$ 21,425,000



Thank you.

Any Questions?

