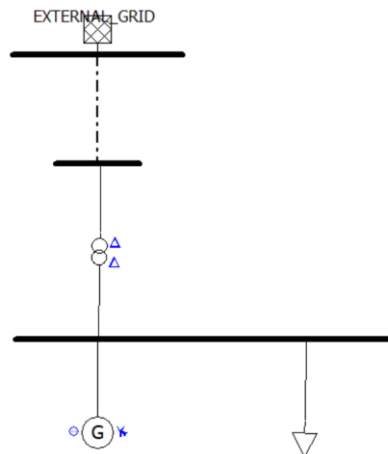


Power System Studies on CYME (Learning Note)

- **CYME One line drawing power system modelling**



- The above one-line drawing power system represents a power generator attached with an external power utility grid and a consumption load. The external grid provides the voltage and frequency references, and the generator operates as a local power source.
- The external grid has 33kV rated voltage with 100MVA rated power
- Cable sizing:
 - ◆ KERITE 35kV MV105 1/0AWG 3C CU is selected as the cable between the grid bus and the HV bus
- Transformer configuration:
 - ◆ Delta-delta type
 - ◆ The transformer ratio is between 33kV HV bus bar and 0.4kV LV generator bus bar
- Generator configuration
 - ◆ Select swing generator type
 - ◆ Configure generator in the library with 1000kVA power rating 85% PF, and 0.4kV rated voltage
- Load configuration
 - ◆ The load is defined with 500kW and 15kVAr power consumption

- **Balanced Load Flow analysis**

- Applying Newton-Raphson Balanced analysis method
- The load flow analysis result is shown below:

	Node Id	Base Voltage (kVLL)	V (kVLL)	V (p.u.)	Angle V (°)	PGen (MW)	QGen (Mvar)	PMotor (MW)	QMotor (Mvar)	PCap (MW)	QCap (Mvar)	PLoad (MW)	QLoad (Mvar)
1	8	33.000	33.0	1.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	12	0.400	0.4	1.000	0.00	0.50	0.02	0.00	0.00	0.00	0.00	-0.26	0.43
3	GRID_HV	33.000	33.0	1.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

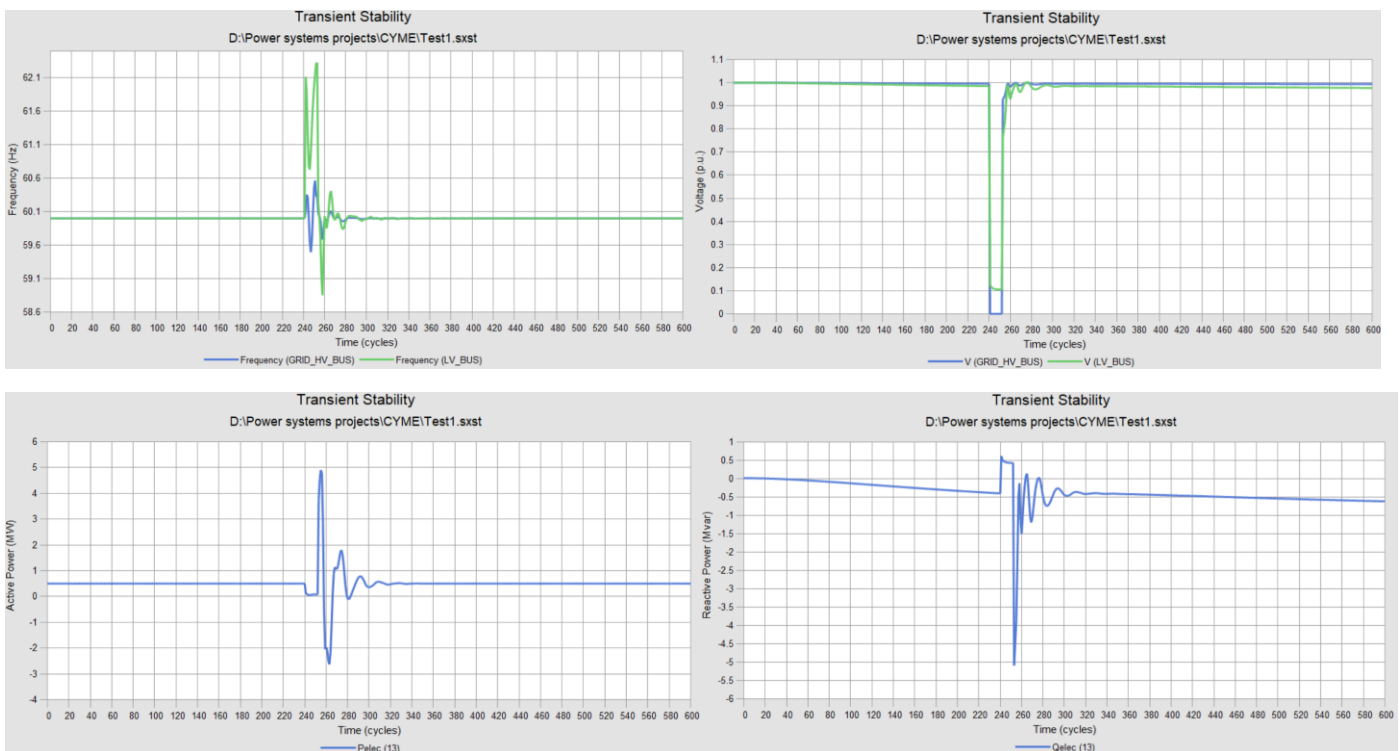
- From the above result
 - ◆ As all the voltages nodes remain 1 pu, the system is well-regulated and there are no voltage-drop issues under this operating condition.
 - ◆ From the LV bus bar, the generator is producing 0.5 MW and 0.02MVAR power while the attached load is consuming 0.26MW and 0.43MVAR power. It means the generator has covered all the real power demand from the load and the extra 0.24MW real power is exported to the grid, and the grid has supplied the extra reactive power the load needed.

● Transient Stability Analysis

- Important note: cycles = seconds * frequency. Ex. 240 cycles = 4secs*60hz
- Based on the above power system, a motor is added as an extra load
 - ◆ The motor with 0.4kV rated voltage 3.7HP (2.76kW), and 79%PF
- A three-phase fault is applied on the external grid bus
 - ◆ The fault starts at 12 seconds
 - ◆ And the fault will be cleared at 12.2 seconds

↑ ↓	<input checked="" type="checkbox"/> Cycles	Event Type	Device Type	Device Number	Properties
	<input checked="" type="checkbox"/> 240	Apply Fault	Bus	GRID_HV_BUS	Fault Type: LLL
+ ×	<input checked="" type="checkbox"/> 252	Clear Fault	Bus	GRID_HV_BUS	

- The transient stability simulation results are shown in below graphs
 - ◆ From top to bottom, the results shows the frequency of the HV grid bus and the LV bus, the voltage of the HV grid bus and the LV bus, the active power of the electrical generator, and the reactive power of the electrical generator.

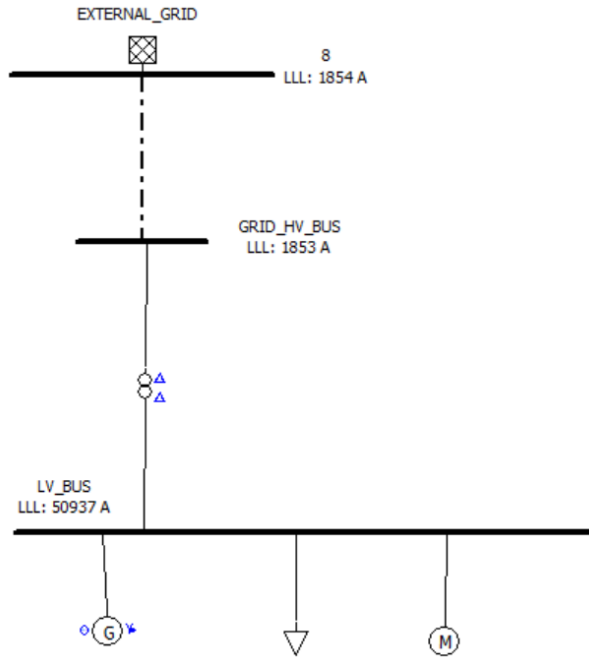


- ◆ 1st: When the fault at the HV bus occurs between 240 (4sec) and 252 (4.2sec) cycles, the LV bus bar has higher frequency spike compared to the HV bus bar, and they both back to normal frequency around 300 cycles. It indicates the generator and the grid lost synchronism during the fault, but they resynchronized after the fault was cleared. And it shows the transient stability of the system.
- ◆ 2nd: For the voltage, the HV bus goes down to zero while the LV bus goes down to around 0.8 pu. And they both back to normal voltage around 300 cycles once the fault is cleared. It indicates the system has quick restoration of the voltage.
- ◆ 3rd: when the fault occurs – grid voltage suddenly drop, the stored energy is distributed.
 - When fault just occurred: $P_{mech} > P_{elec}$, the machine inertia injects energy, which causes a temporary power spike
 - When the fault is cleared: $P_{mech} \ll P_{elec}$.

- ◆ 4th: the reactive power result of the generator indicates the electromagnetic power exchange. The generator tried to preserve synchronization by absorbing reactive power. And the severe spike also indicates the aggressive fault.

● **Short circuit analysis**

- a short circuit analysis at all buses is operated.
- The below one line drawing gives the three phase line-line fault current at each bus bar. It shows lower fault current at HV bus bar and higher fault current at LV bus bar, because the impedance is higher at the HV level.

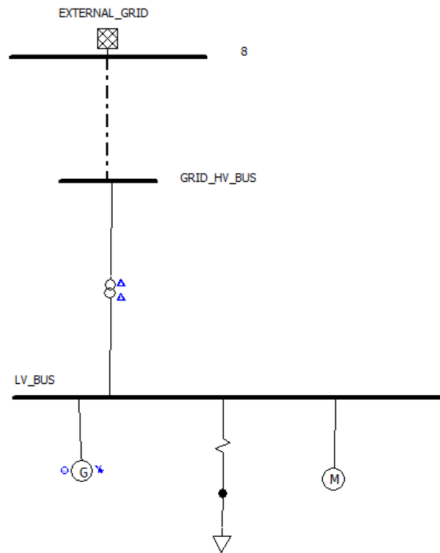


	Feeder Id	Node Id	Phase	kVLN (kVLN)	LLL (A)	LLL Kmax (A)	LLL Kmax Z (A)	LLL Kmin (A)	LLL Kmin Z (A)	LLG (A)	LLG Kmax (A)	LLG Kmin (A)
1	EXTERNAL_GRID	8	ABC	19.1	1854	1854	1854	1854	1854	1829	1829	1829
2	EXTERNAL_GRID	LV_BUS	ABC	0.2	50937	50937	50937	50937	50937	48362	48362	48362
3	EXTERNAL_GRID	GRID_HV_BUS	ABC	19.1	1853	1853	1853	1853	1853	1828	1828	1828

LL (A)	LL Min (A)	LL Kmax (A)	LL Kmax Z (A)	LL Kmin (A)	LL Kmin Z (A)	LG Max (A)	LG Min (A)	LG Kmax (A)	LG Kmax Z (A)	LG Kmin (A)	LG Kmin Z (A)	Total distance (ft)
1606	1606	1606	1606	1606	1606	1799	1799	1799	1799	1799	1799	0.0
44112	44112	44112	44112	44112	44112	41762	41762	41762	41762	41762	41762	96.8
1605	1605	1605	1605	1605	1605	1796	1796	1796	1796	1796	1796	96.8

● **Arc flash study**

- Definition of arc flash: The circuit breaker is not triggered when the fault occurred, which generates a lot of heat on the circuit. The arc flash is caused by the currents that cannot be caught by the circuit breaker.
- The arc flash study provides the safe distance the operator should keep away from the equipment.
- Based on the above one line drawing power system, a fuse is added to perform the arc flash study.



- ◆ Fuse sizing: the LV bus bar is 0.4kV, and the load consumes 500kW power
- ◆ The load current is calculated to help size the fuse (assume 90% load factor)

$$I_{load} = \frac{P}{\sqrt{3} * V * \cos\phi} = \frac{500kW}{\sqrt{3} * 0.4kV * 0.9} = 800A$$

- ◆ Also from the previous short circuit analysis, the fault current at LV bus bar level is 50kA
- ◆ Above, the fuse should have 800A nominal current at 0.4kV rated voltage, and it's with 50kA breaking capacity. The selected fuse is shown below

General		Loading Limits	Reliability	Costs	Symbol
Information					
Manufacturer:	BUSSMAN				
Model:	BUSS NH gTR				
Rating:	800 KVA				
Voltage Rating:	0.4 kV				
Classification:	Low Voltage				
Standard:	IEC				
Class:	None				
Nominal Rating					
Rated Continuous Current:	800.0	A			
Rated Voltage:	0.4	kV			
Interrupting Rating Capability:	120000.0	A			
Test Circuit Power Factor:	20.0	%			
Operation Mode					
<input checked="" type="checkbox"/> Reversible					

- Arc flash study simulation:
 - ◆ In this example, the IEEE-1584-2018 standard is applied, and the arc flash clearing time is set as 100ms.
 - ◆ The result is shown below

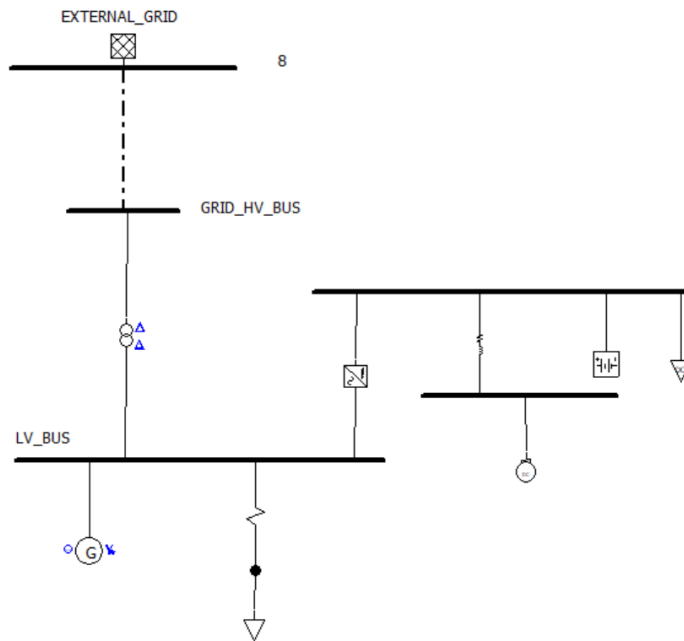
Node ID/Bus ID	Protective Device Type	Base Voltage (kV)	I (arc) seen by device (kA)	Bolted Fault (kA)	Arcing Fault (kA)	Arcing Fault Mult	Clearing Time (ms)	Arc Flash Boundary (ft)	Min Arc Rating (cal/cm ²)	PPE Category	Standard / Method
LOAD	Fuse	0.4	21.584	50.937	21.584	87%	18	11	0.536	n/a	IEEE-1584

- ◆ The 0.536 cal/cm² indicates a extreme low incident energy. Based on the standard, it's safe for bare-hand work as it's below 1.2 cal/cm² threshold.

- **DC system design**

- For DC design, a AC/DC charger, battery, DC motor, and DC load are added. The one line

drawing is shown below:



◆ AC/DC charger sizing

- As there has a battery, DC motor, and a DC load, the DC current for the charger is selected to be 50A, based on 125V DC voltage, and 90% efficiency, the nominal power can be:

$$P_{charger} = (V_{dc} * I_{dc})/\eta = (125 * 50)/0.9 \approx 7kW$$

Nominal Data	
Type:	Battery Charger
Phase Type:	Three-phase
Nominal Rating:	<input checked="" type="radio"/> 7.0 kW <input type="radio"/> 56.0 A
Input AC Voltage:	0.48 kVLL
Output DC Voltage:	125.0 V
Power Factor:	85.0 %
Efficiency:	90.0 %
Maximum Output Current	
<input checked="" type="radio"/> Percentage of Rated Current:	100.0 %
<input type="radio"/> Current:	56.0 A

◆ DC cable sizing:

- A 100A nominal current rating and 400V voltage rating cable is selected

◆ DC motor sizing: the info of the designed DC motor is shown below:

Nominal Data	
Mechanical Power:	<input type="radio"/> 2.68097 HP <input checked="" type="radio"/> 2.0 kW
Rated Power:	2.22 kW
Rated Voltage:	48.0 V
Efficiency:	90.0 %
Speed:	1200.0 RPM

◆ Battery sizing

- From previous setup, the DC bus has 125V rated voltage due to the charger sizing.

- The nominal voltage of the battery is designed as 120V with 60 cells.
- As the DC motor mentioned above consumes 2kW power, the DC load is sized as 4kW.
- The battery is designed to provide 6kW for 1hr backup time:

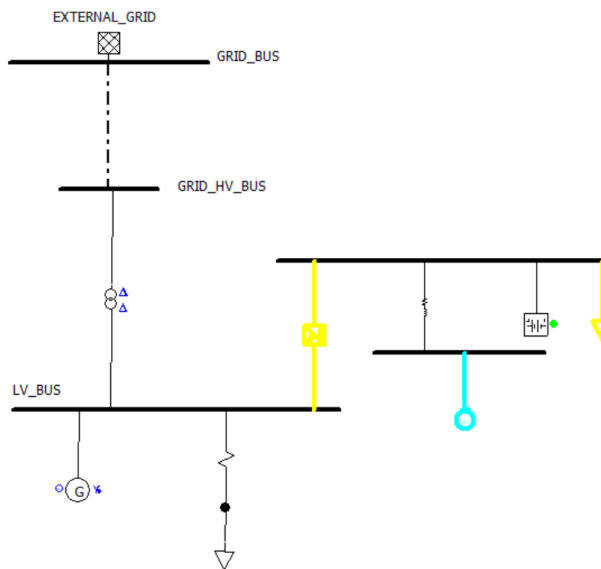
$$Ah = \frac{P_{battery} * t}{V_{battery}} = \frac{6kW * 1}{120V} = 50Ah$$

- From above computation, the battery sizing is summarized below:

General		Costs	Symbol
Battery Type			
Nominal Rating from Battery Datasheet			
Battery			
Nominal Voltage:	120	V	
Number of Cells:	60		
Nominal Capacity:	50	Ah	
Internal Resistance per Cell:	1.0	mΩ	
Maximum Discharge Current:	500	A	
Short-Circuit Current:	2000.0	A	Estimate...
Cell			
Voltage per Cell:	2.0	V	
Capacity:	50.0	Ah	
Number of Plates:	25		
Resistance per Positive Plate:	12.0	mΩ	
Maximum Discharge Current:	500.0	A	
Short-Circuit Current:	2000.0	A	Estimate...

■ DC load flow analysis

- ◆ The DC load flow analysis is performed on DC buses, battery, charger, motor, and DC load. The results are shown below:



Equipment Id	Code	Nominal Voltage (V)	# Cells	Nb per String	Capacity (Ah)	# Parallel Strings	System Voltage (V)	System Capacity (Ah)	Internal Resistance (Ω)	Power (kW)	Current (A)	Loading (%)
BATTERY	Battery	120.0	60	1	50.0	1	120.0	50.0	0.0610	0.0	0.0	0.0

Equipment No	From Node	To Node	Equipment Id	Code	Nominal Power (kW)	Output Voltage (V)	Operating Voltage (V)	Output Power (kW)	Output Current (A)	Loading (%)	Losses (kW)
ACDC_CHARGER	18	LV_BUS	INVERTER_MODEL 1	Charger	7.0	125.0	125.0	36.1	289.2	516.5	4.0

Equipment No	From Node	Equipment Id	Code	Rated Voltage (V)	Voltage (p.u.)	Power (kW)	Current (A)	Loading (%)
DC_MOTOR	20	DC_MOTOR	DC Motor	48.0	0.996	2.2	17.8	100.0

Equipment No	From Node	Code	Type	Rated Voltage (V)	Voltage (p.u.)	Power (kW)	Current (A)	Loading (%)
DC_LOAD	18	DC Load	Heater	48.0	1.000	33.9	271.3	678.1

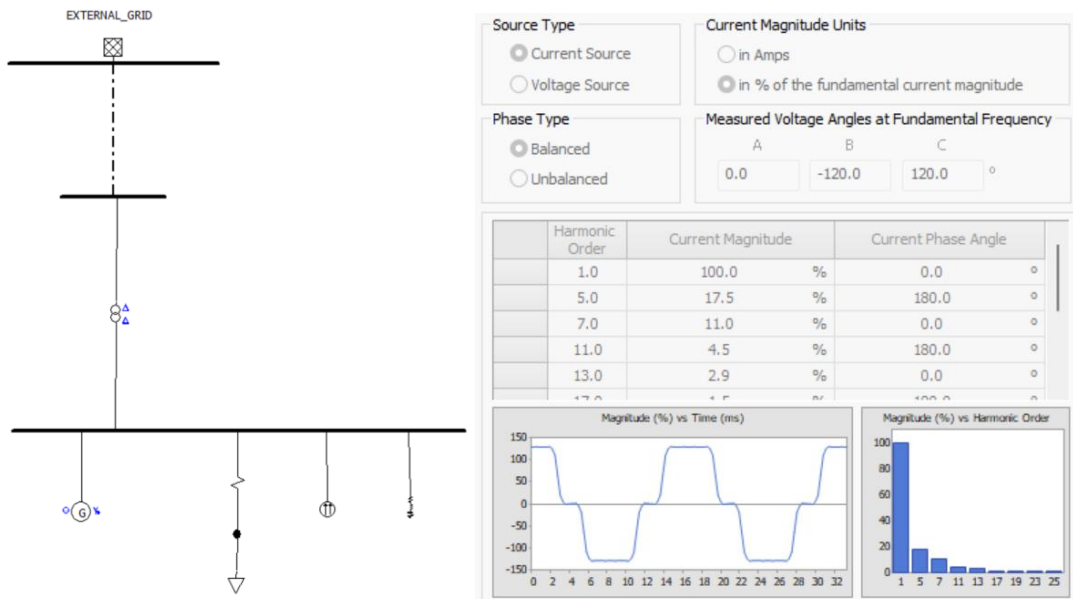
- Battery: the battery is under floating condition, as it's not under either charging or discharging operation.
- Charger: the charger is overloaded as it's supplying 36kW power that is above its nominal 7kW rated power, and it's overloading 5 times higher than its rating/
- DC motor: the motor is operating normally under full load based on the 0.996pu voltage
- DC load: the load is consuming 34 kW power that is far beyond its rated 5kW power.
- ◆ Solution: the rated voltage on DC load is not same as the DC bus bar (adjust from 48V to 125V)
 - Now the new load flow analysis is shown below:

Equipment No	From Node	Code	Type	Rated Voltage (V)	Voltage (p.u.)	Power (kW)	Current (A)	Loading (%)
DC_LOAD	18	DC Load	Heater	125.0	1.000	5.0	40.0	100.0

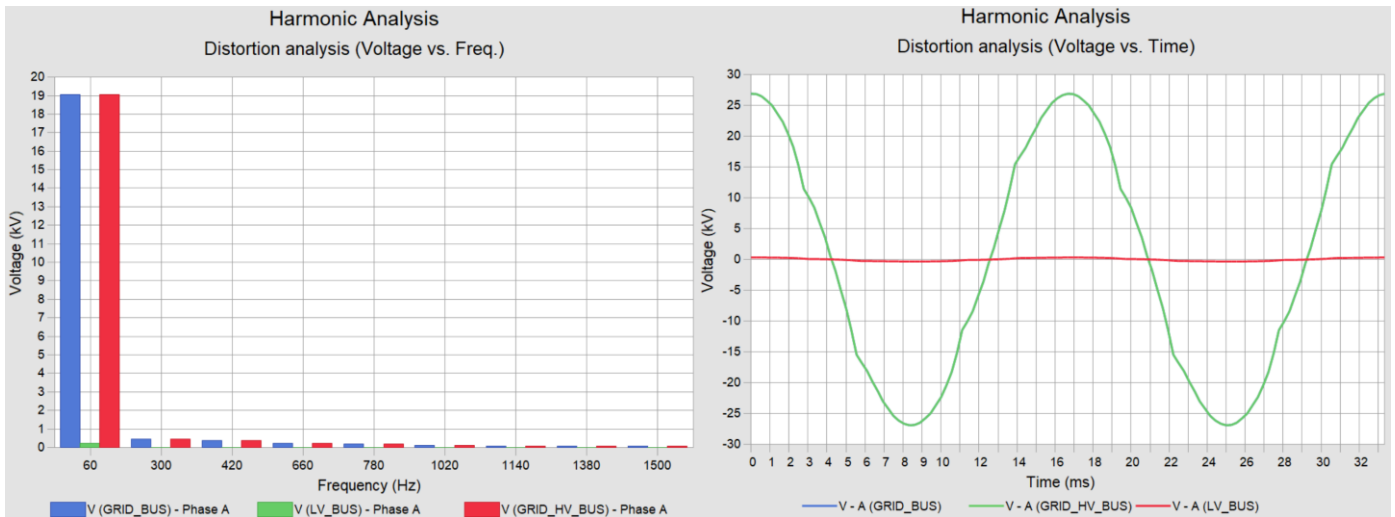
- The DC load is operating normally.

● Harmonics Study

- The harmonics is caused by the devices that are not operating under normal frequency such as 50 and 60 hz.
- Design filters (RLC group) to catch harmful harmonics
- 1st step: add harmonics injection, here the 'shunt frequency source' is applied. And the applied harmonics 6pulse IEEE 519.81 is shown below. The harmonics absorbs 2MW active and 0.25KVAR reactive power as a load.



- 2nd step: operate harmonics analysis
 - ◆ Frequency scan from impedance calculation
 - The fundamental frequency is 50hz, and the biggest order of the harmonics is 25 for the selected harmonics. So the frequency scan is determined from 50hz to 1250hz
 - ◆ The harmonics analysis results are shown below:



Device Number	Device Type	Fund. Current (A)	300.00 Hz IHD (%)	420.00 Hz IHD (%)	660.00 Hz IHD (%)	780.00 Hz IHD (%)	1020.00 Hz IHD (%)	1140.00 Hz IHD (%)	1380.00 Hz IHD (%)	1500.00 Hz IHD (%)	THD (%)	KVT (kV)	ITIF	PCC	Isc/I _L	TDD (%)
1	10-A Cable	20.98	41.033	24.438	9.381	5.844	3.009	1.992	1.799	1.578	49.200	8.87	379.21	GRID_BUS	88.35	46.383
2	10-B Cable	20.98	46.383	28.835	12.883	7.814	3.952	2.452	2.249	1.975	57.404	10.94	452.37	GRID_BUS	88.35	57.404
3	10-C Cable	20.98	40.211	26.137	10.816	6.708	3.669	2.624	2.226	2.081	54.256	10.94	458.37	GRID_BUS	88.35	54.256
4	10-N Cable	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	225.00			
5	TRANSFORMER_G2HV-A Two-Winding Transformer	21.01	46.383	24.398	9.373	5.838	3.005	1.990	1.798	1.578	49.135	8.87	378.81	GRID_HV_BUS	88.19	46.383
6	TRANSFORMER_G2HV-B Two-Winding Transformer	21.01	46.383	26.800	12.887	7.814	3.947	2.449	2.244	1.971	57.328	10.94	451.92	GRID_HV_BUS	88.19	57.328
7	TRANSFORMER_G2HV-C Two-Winding Transformer	21.01	40.877	26.137	10.816	6.708	3.664	2.620	2.223	2.078	54.184	10.94	457.91	GRID_HV_BUS	88.19	54.184
8	TRANSFORMER_G2HV-N Two-Winding Transformer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	225.00			

Node ID	kV L-N	300.00 Hz IHD (%)	420.00 Hz IHD (%)	660.00 Hz IHD (%)	780.00 Hz IHD (%)	1020.00 Hz IHD (%)	1140.00 Hz IHD (%)	1380.00 Hz IHD (%)	1500.00 Hz IHD (%)	THD (%)	KVT (kV)	TIF	
1	GRID_BUS-A	19.05	2.447	2.041	1.232	0.922	0.610	0.452	0.488	0.470	3.682	1413.84	74.16
2	GRID_BUS-B	19.05	2.897	2.225	1.586	1.094	0.801	0.556	0.644	0.589	4.332	1783.95	93.55
3	GRID_BUS-C	19.05	2.550	2.519	1.432	1.198	0.744	0.595	0.608	0.621	4.243	1782.59	93.48
4	GRID_HV_BUS-A	19.05	2.451	2.044	1.233	0.923	0.611	0.452	0.489	0.471	3.688	1416.11	74.28
5	GRID_HV_BUS-B	19.05	2.902	2.229	1.588	1.096	0.803	0.557	0.645	0.589	4.339	1786.88	93.70
6	GRID_HV_BUS-C	19.05	2.555	2.524	1.434	1.200	0.745	0.596	0.609	0.622	4.250	1785.52	93.63
7	LV_BUS-A	0.23	6.980	5.066	2.329	1.540	0.820	0.551	0.501	0.447	9.144	24.66	106.35
8	LV_BUS-B	0.23	9.695	12.549	6.573	6.231	3.613	3.119	3.022	3.261	19.392	108.89	462.90
9	LV_BUS-C	0.23	13.826	9.262	8.184	5.153	4.197	2.725	3.382	2.939	20.386	109.08	462.82

- ◆ The first graph shows the voltage distortion across harmonics orders, the tall bar relates to the fundamental voltage, and the small bars at higher frequencies relates to harmonics voltages. And the magnitude of the harmonics indicates the distortion is quite minimal.
- ◆ In the second graph, the waveform of the grid connected HV bus reflects to the result of the harmonics voltage shown in the first graph, the waveform is fairly sinusoidal with minor distortion. And the LV bus voltage waveform has very small magnitude, which associates with the low fundamental voltage shown in the first graph for LV bus.
- 3rd step: add single tuned filter
 - ◆ The key points to design a single tuned filter:
 - The target harmonic order
 - Select the 5th harmonic order to target
 - The desired fundamental reactive power for L & C calculation
 - Based on the previous load flow analysis of the LV bus bar, the load consumes 0.43MVar reactive power, the generator produces 0.02MVar reactive power, and the harmonics generator consumes 250kVar reactive power. The net reactive power is 0.66MVar, here the example aims the fundamental reactive power as 0.5MVar.
 - Q factor for R resistance calculation
 - Higher Q factor (60-80) provides sharp tuning, strong harmonic absorption.
 - Lower Q factor (20-40) provides more damped response
 - Above, this example picks 60 as the Q factor to calculate the resistance'
 - The rated capacitor relates to the LV bus bar rated voltage 0.4kV

◆ The designed single tuned filter is shown below:

The image shows two software windows. The left window, titled "Single Tuned Filter Parameters", contains the following settings:

- Data Set:**
 - Filter Total Reactive Power: 550 kvar (selected)
 - Capacitor Three-Phase Reactive Power: 100.0 kvar
 - Tuned Frequency: 5.0 harmonic order
 - Quality Factor: 60
 - Configuration: [Y-connection icon]
 - Rated Capacitor Voltage: 0.4 kVLL
- Nominal Values:**
 - Frequency: 60.0 Hz

The right window, titled "Equivalent Impedances", displays the calculated values for a series R-L-C circuit:

- Resistance (R): 0.0002 Ω
- Inductance (L): 0.03215 mH
- Capacitance (C): 8753.5218 μF

A schematic diagram of the R-L-C circuit is shown to the right of these values. Below the impedances, the "Tuned Frequency" is 5.0 harmonic order and the "Configuration" is [Y-connection icon].

■ Harmonics analysis with single tuned filter

	Node ID	kV L-N	300.00 Hz IHD (%)	420.00 Hz IHD (%)	660.00 Hz IHD (%)	780.00 Hz IHD (%)	1020.00 Hz IHD (%)	1140.00 Hz IHD (%)	1380.00 Hz IHD (%)	1500.00 Hz IHD (%)	THD (%)	KVT (kV)	TIF
1	GRID_BUS-A	19.05	0.013	0.954	0.732	0.552	0.353	0.255	0.262	0.246	1.439	794.06	41.67
2	GRID_BUS-B	19.05	0.013	0.913	0.883	0.547	0.481	0.278	0.390	0.294	1.568	975.41	51.19
3	GRID_BUS-C	19.05	0.013	1.037	0.710	0.695	0.372	0.359	0.304	0.376	1.601	975.38	51.19
4	GRID_HV_BUS-A	19.05	0.013	0.956	0.733	0.552	0.354	0.256	0.262	0.247	1.441	795.23	41.73
5	GRID_HV_BUS-B	19.05	0.013	0.914	0.884	0.548	0.482	0.278	0.391	0.295	1.571	976.95	51.27
6	GRID_HV_BUS-C	19.05	0.013	1.039	0.711	0.696	0.373	0.360	0.304	0.376	1.604	977.11	51.28
7	LV_BUS-A	0.23	0.044	3.340	2.487	1.838	1.125	0.792	0.769	0.703	4.868	30.40	131.50
8	LV_BUS-B	0.23	0.045	3.590	2.773	2.553	1.551	1.380	1.316	1.489	5.947	46.79	202.27
9	LV_BUS-C	0.23	0.045	3.387	3.182	2.190	1.824	1.176	1.532	1.286	5.925	46.77	202.18

Comparing the above and previous result, the harmonics voltage distortion is gone.