Ground Fault Protection of Microgrid Interconnection Line Using Distance Relay with Residual Voltage Compensation

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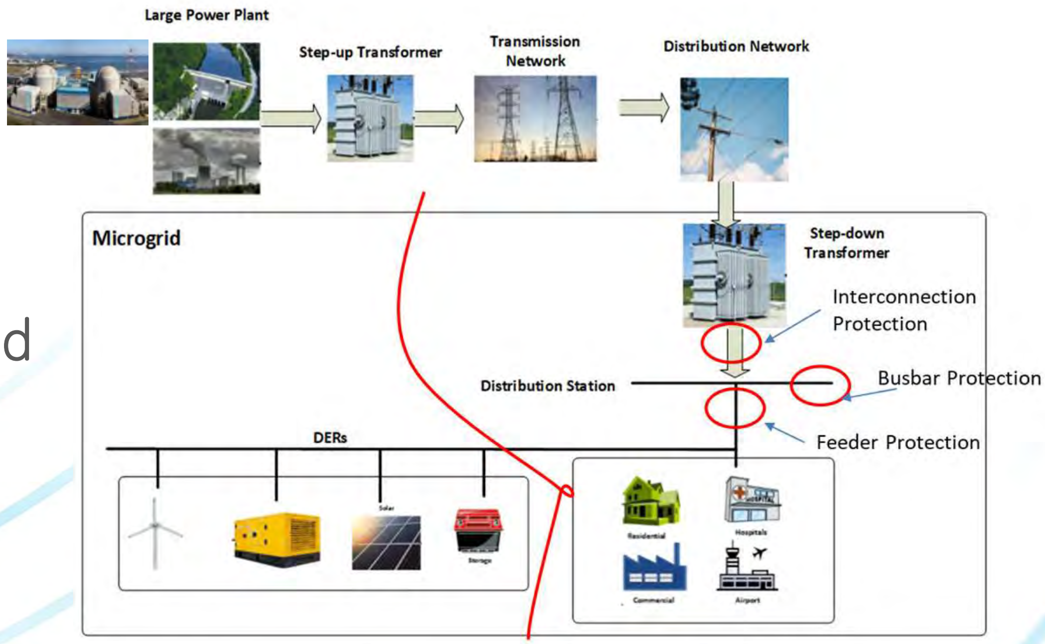
Introduction

1. Challenges of Microgrid Protection
2. Point of Interconnection Protection
3. Proposed Method for Detecting
SLG Fault on Interconnection Line
4. Case Studies and Results
5. Conclusion

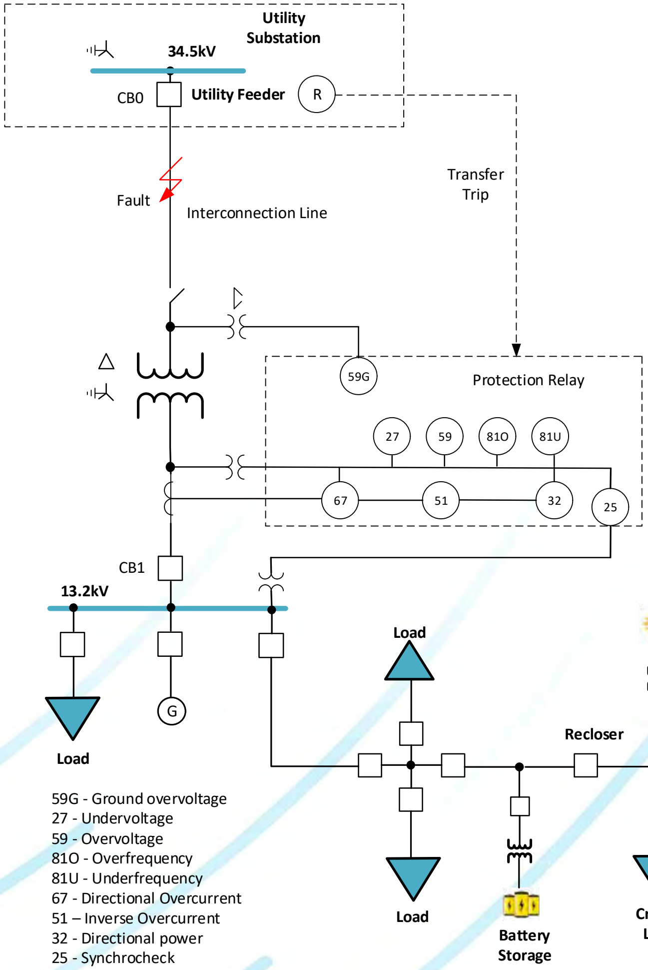
Challenges

1. Fault current may change significantly between grid-connected mode and islanded mode. Low fault current contribution from microgrid for a fault at interconnection line.
2. Bidirectional power flow.
3. Detecting loss of utility.
4. Adaptive protection
5. Seamless change of grid-connected mode to islanded mode or verse versa



Current Methods

1. DTT: The direct transfer trip (DTT) can send trip signal from the utility substation to the microgrid protection relay to solve the above concerns.
2. 59G Relay: The using of 59G to detect the SLG fault at the interconnection line is more challenging than the SLG fault at an ungrounded feeder due to the grounding of the interconnection line at utility side.

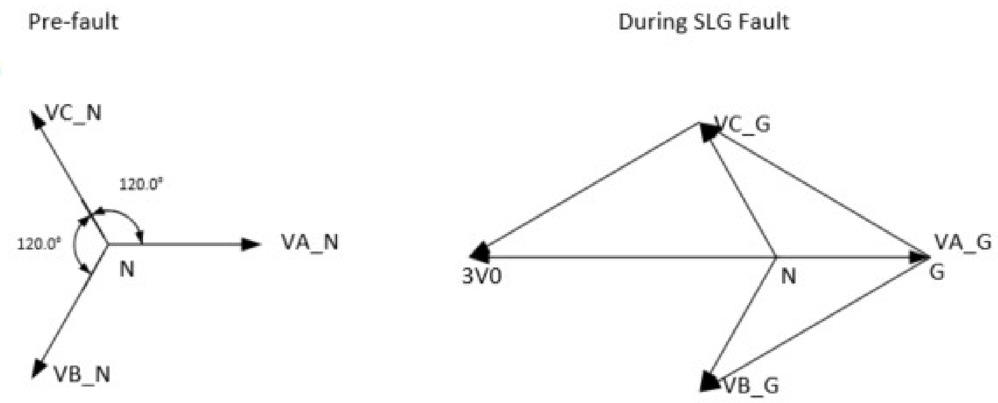


Current Methods

1. 59G Relay:

$$3V_0 = V_a + V_b + V_c$$

$$= 0 + \sqrt{3}|V_a|\angle -150° + \sqrt{3}|V_a|\angle 150° = 3|V_a|\angle 180°$$

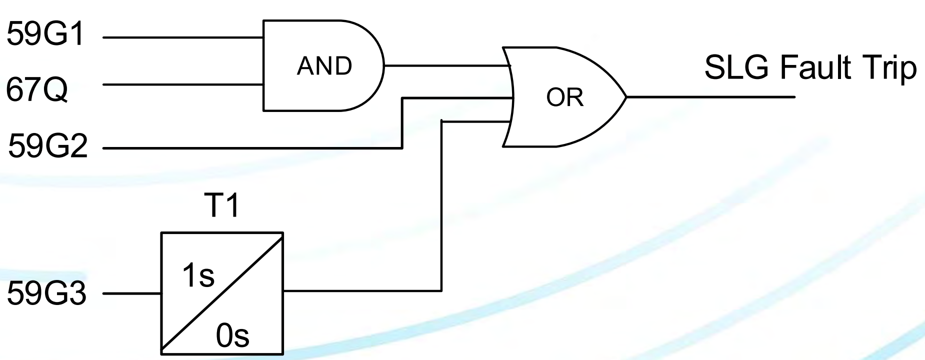


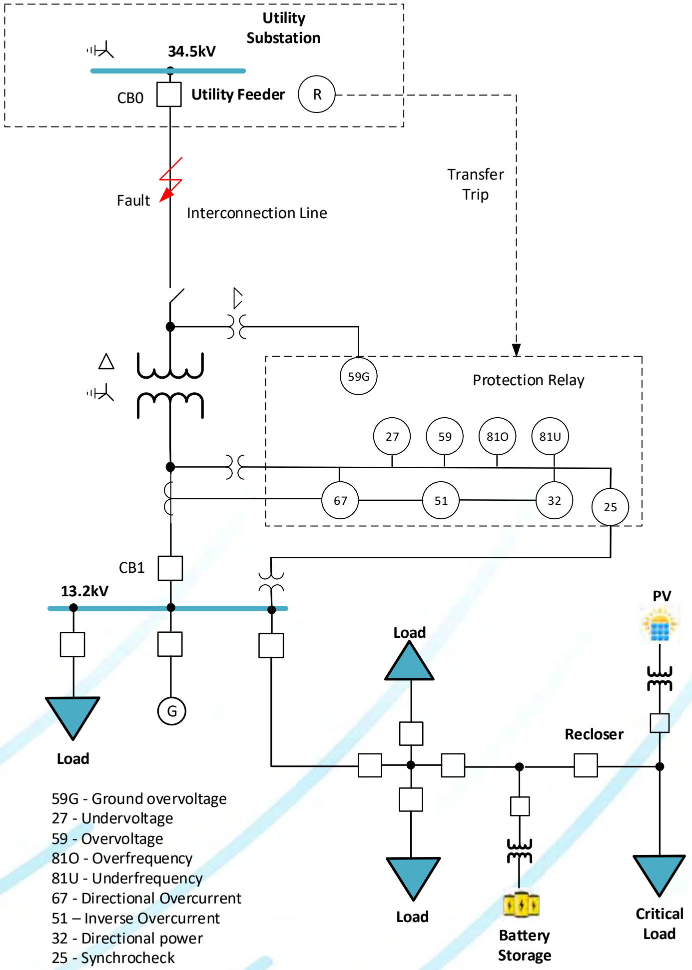
May overtrip if not set properly. So set the timer and wait for the utility breaker to trip first.

Current Methods

3. 59G+67Q

67Q can be used to secure the operation of 59G

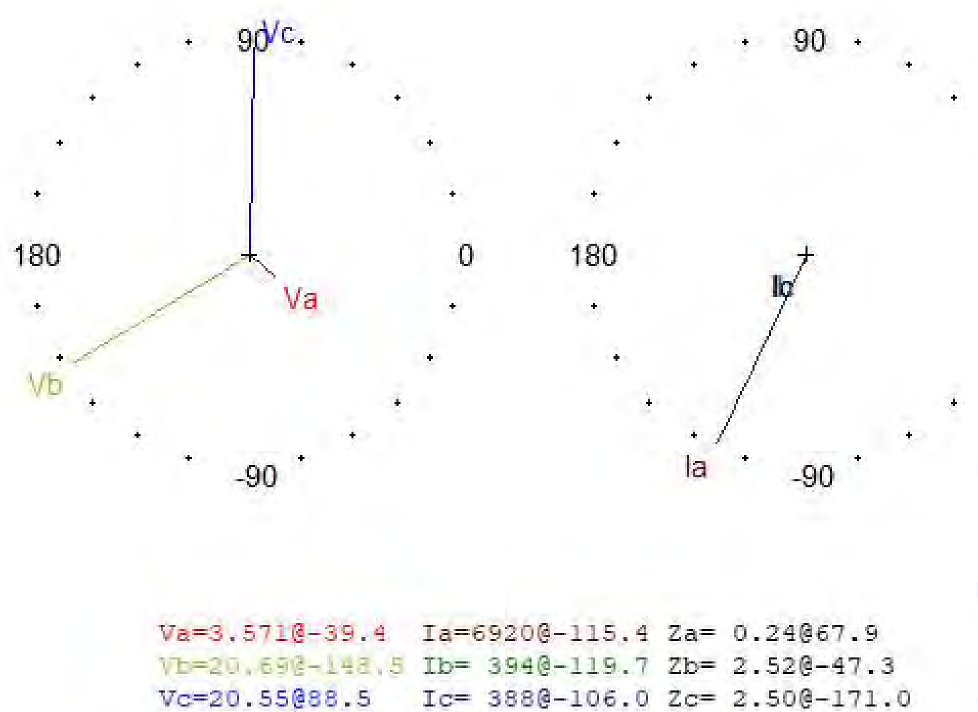




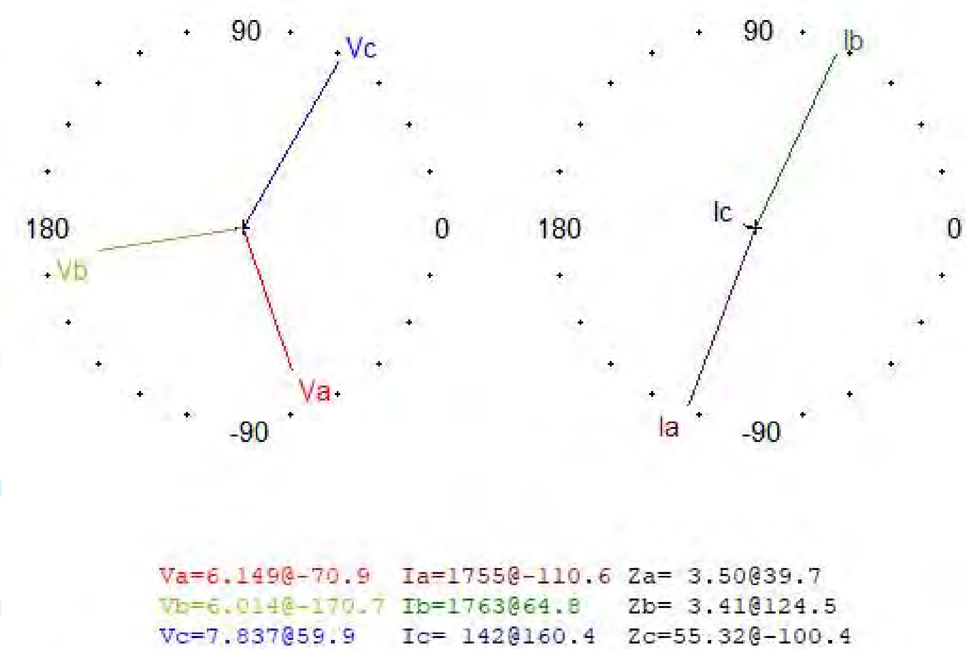
Short Circuit Study

SLG Fault on the interconnection line - before utility circuit breaker open

Utility Feeder Relay



LV side of the Power Transformer Relay



Short Circuit Study

SLG Fault on the interconnection line - after utility circuit breaker open

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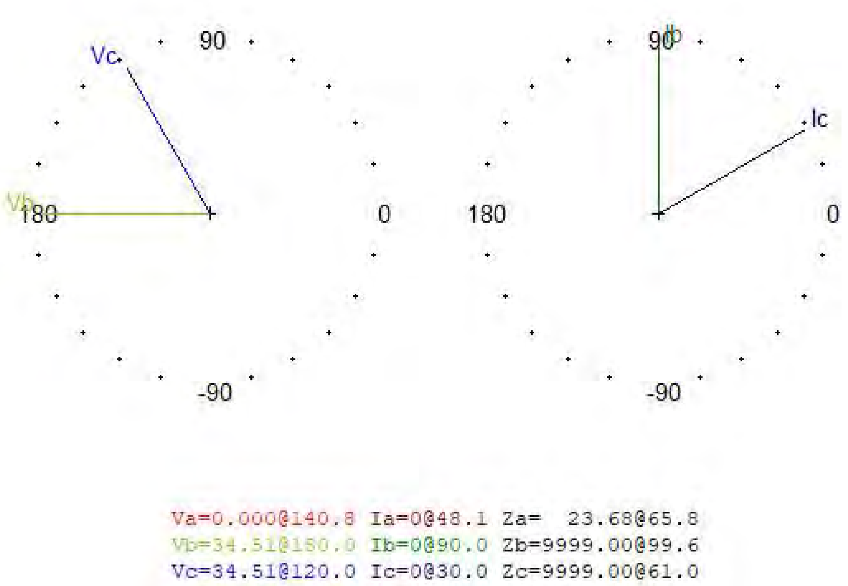
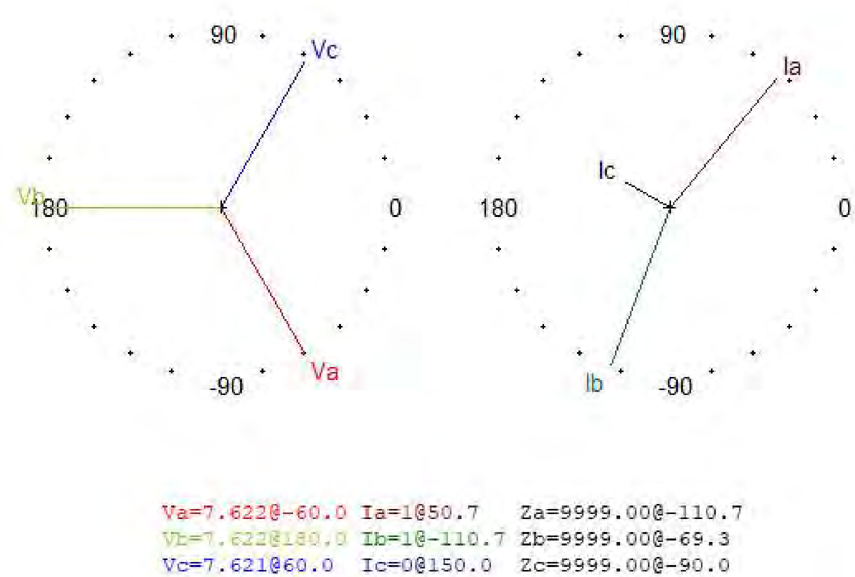
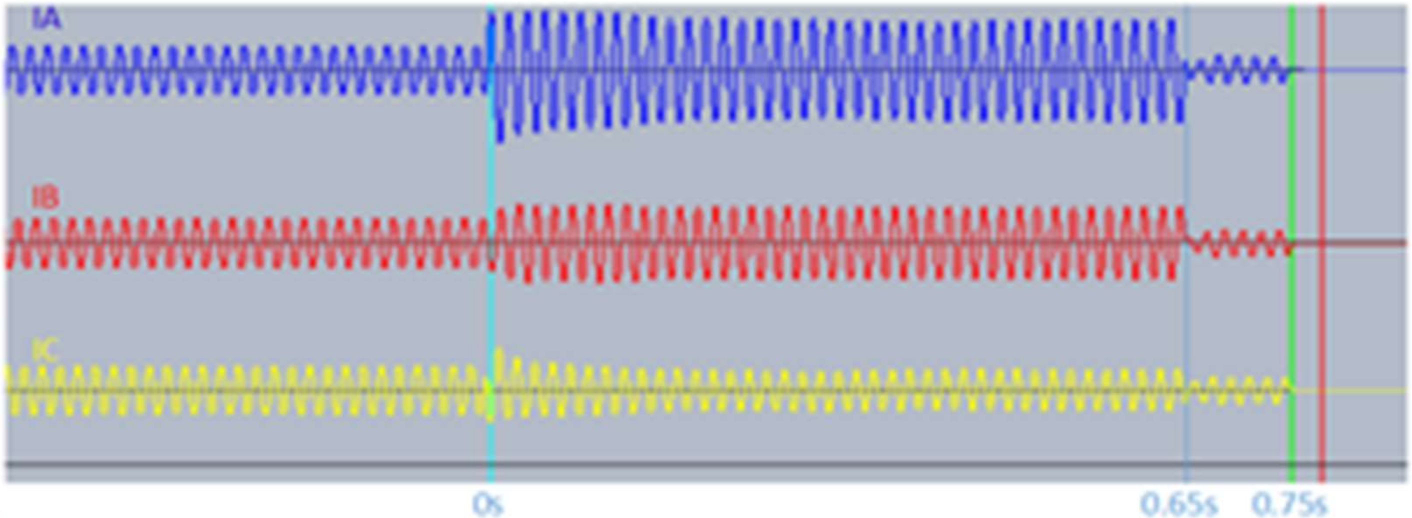


LV side of the Power Transformer Relay



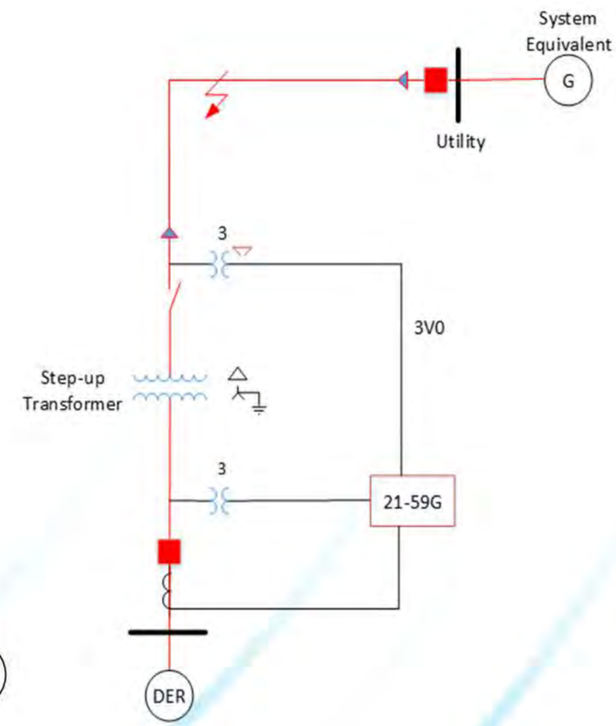
Short Circuit Study

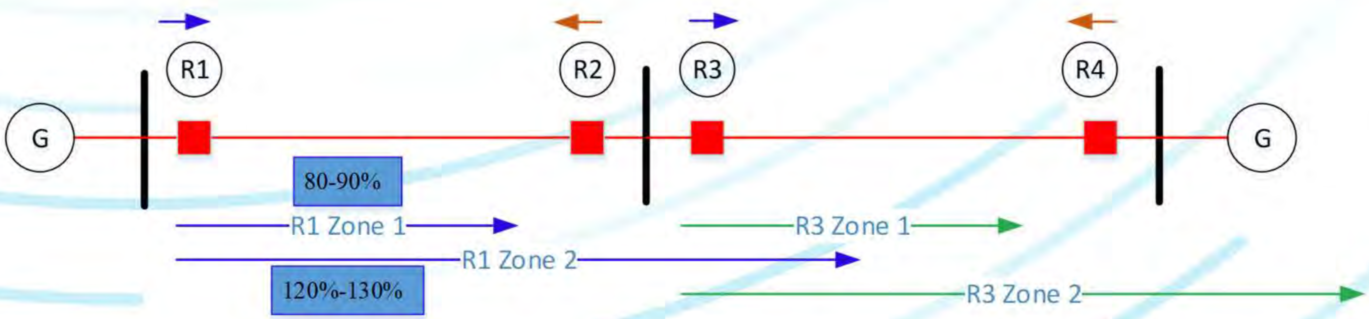
Current Seen from LV side of the interconnection transformer. Utility protection tripped the substation breaker at 0.65s. The breaker at microgrid side is opened at 0.75s.



Potential of Distance Protection

- Limitations of existing method
  I. High cost communication channel
  II. Slow operation and lack of sensitivity
- Distance method
  I. Less affected by small fault current
  II. Inherit directionality
  III. Fixed reach setting
  IV. Independence of changing system conditions
  V. Fault location





Impedance Calculation

- Typical distance relay

$$Z_{ag} = \frac{V_a}{I_a + k_0 I_R} \mid Z_{bg} = \frac{V_b}{I_b + k_0 I_R} \mid Z_{cg} = \frac{V_c}{I_c + k_0 I_R}$$

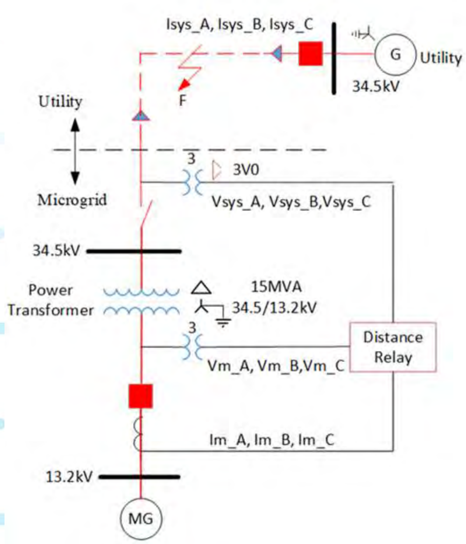
$$Z_{ab} = \frac{V_a - V_b}{I_a - I_b} \mid Z_{bc} = \frac{V_b - V_c}{I_b - I_c} \mid Z_{ca} = \frac{V_c - V_a}{I_c - I_a}$$

- Distance relay with voltage and current transformation looking through a Y/D connection transformer

$$Z_{ab} = \frac{-3V_b}{I_a + I_c - 2I_b} \mid Z_{bc} = \frac{-3V_c}{I_a + I_b - 2I_c} \mid Z_{ca} = \frac{-3V_a}{I_b + I_c - 2I_a}$$

Why Residual Voltage Compensation

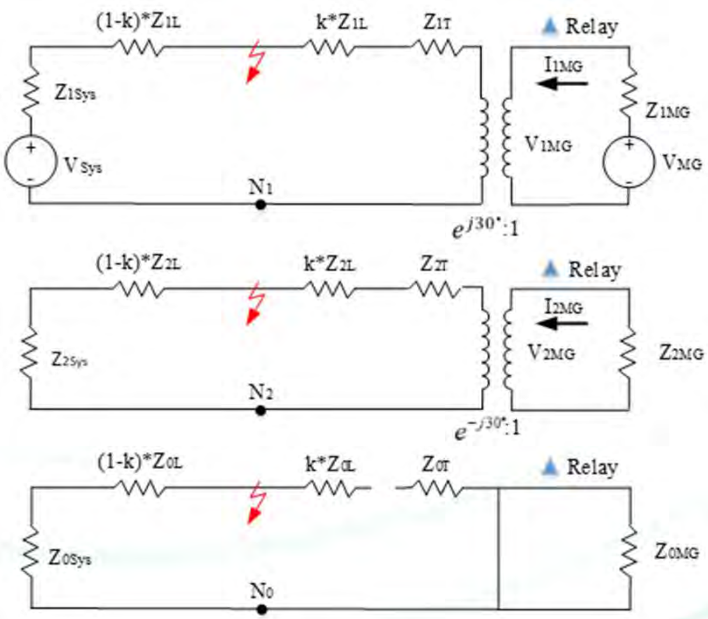
SLG fault on the interconnection line is seen by the distance relay at DER side as phase-phase fault due to the Delta-Y connection of the step-up transformer

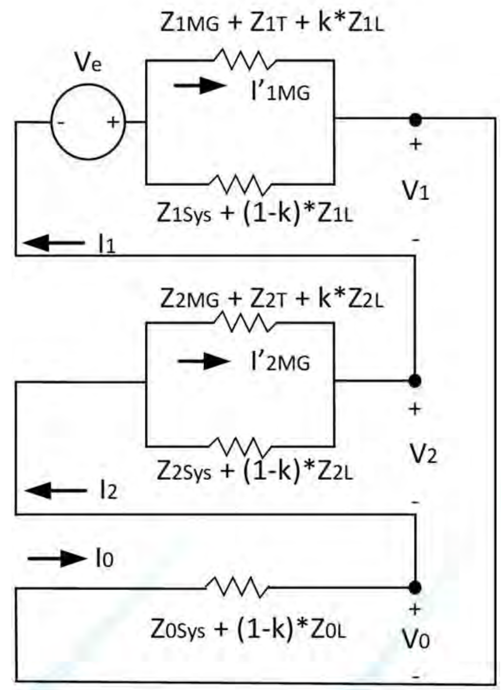


EXAMPLE 34.5KV LINE FAULT SIMULATION RESULTS BASED ON DISTANCE RELAY PROTECTION ONLY

SLG Fault Location	Measurement At Relay Location	Fault Values at DER 13.2kV	Angle (deg)	V0 at DER 34.5kV bus	Angle (deg)
0% of interconnection line (DER 34.5kV bus)	Zab (Ω)	4.550	87.00	13.30	150.30
	Zbc (Ω)	10.660	163.10		
	Zca (Ω)	11.050	10.10		
	Ia (A)	1161.000	-113.10		
	Ib (A)	1176.000	59.60		
	Ic (A)	149.000	159.20		
	Va (kV)	6.578	-66.30		
	Vb (kV)	6.601	-173.50		
	Vc (kV)	7.824	60.00		
50% of interconnection line	Zab (Ω)	4.010	84.50	11.93	150.1
	Zbc (Ω)	9.680	160.60		
	Zca (Ω)	9.960	8.60		
	Ia (A)	1285.000	-111.50		
	Ib (A)	1295.000	61.90		
	Ic (A)	148.000	159.30		
	Va (kV)	6.499	-67.40		
	Vb (kV)	6.465	-173.10		
	Vc (kV)	7.827	60.00		
100% of interconnection line (Utility 34.5kV bus)	Zab (Ω)	2.280	81.70	6.408	150.8
	Zbc (Ω)	6.330	158.30		
	Zca (Ω)	6.530	7.40		
	Ia (A)	1941.000	-111.10		
	Ib (A)	1951.000	-64.80		
	Ic (A)	140.000	160.90		
	Va (kV)	5.995	-72.30		
	Vb (kV)	5.854	-169.40		
	Vc (kV)	7.841	59.90		

Why Residual Voltage Compensation



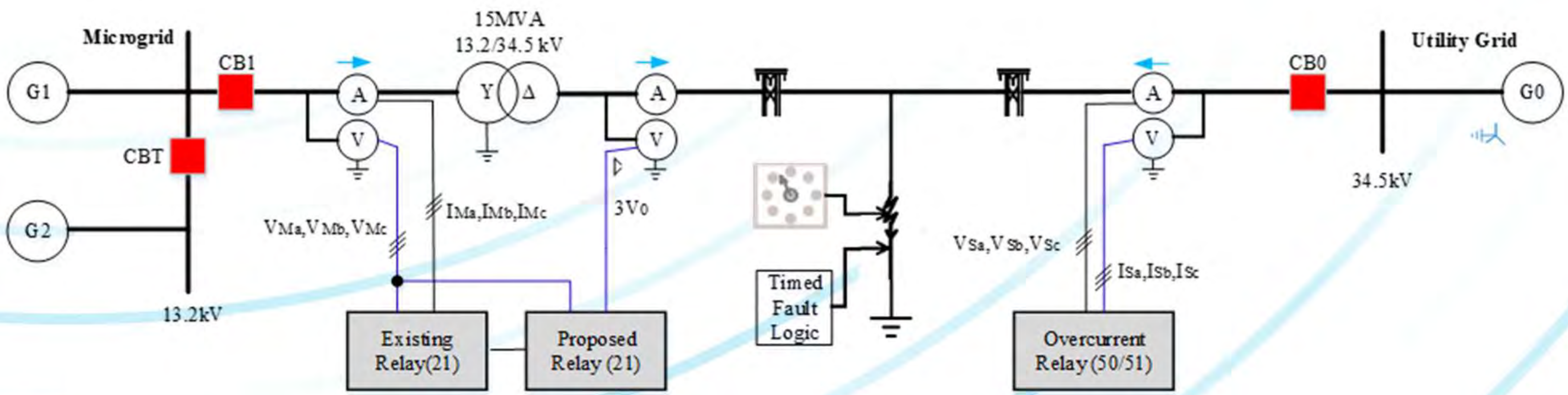


$$Z_{ab}=\frac{V_a-V_b}{I_a-I_b}$$

$$\boxed{Z_{ag}=\frac{V_a-V_b}{I_a-I_b}+\frac{V_0*e^{-j30}}{2I_{1MG}}}$$

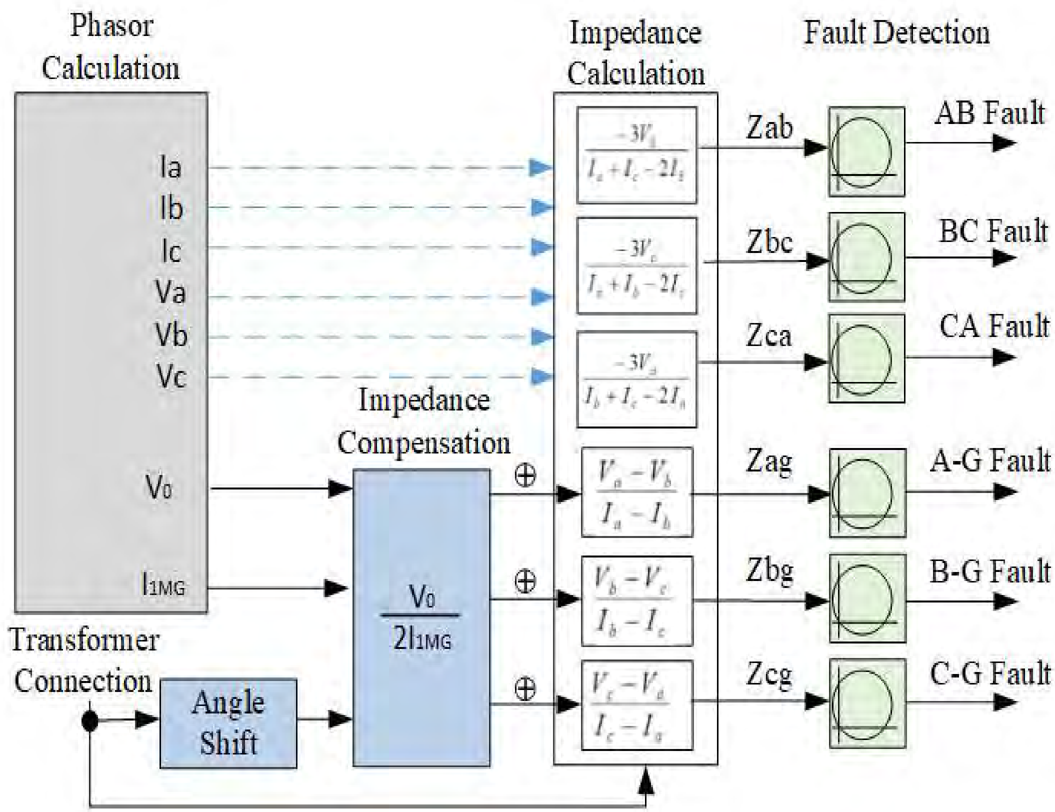
Case Studies

I. Phase A to Ground Fault
II. Transformer Y-D connection
III. Simulated using PSCAD



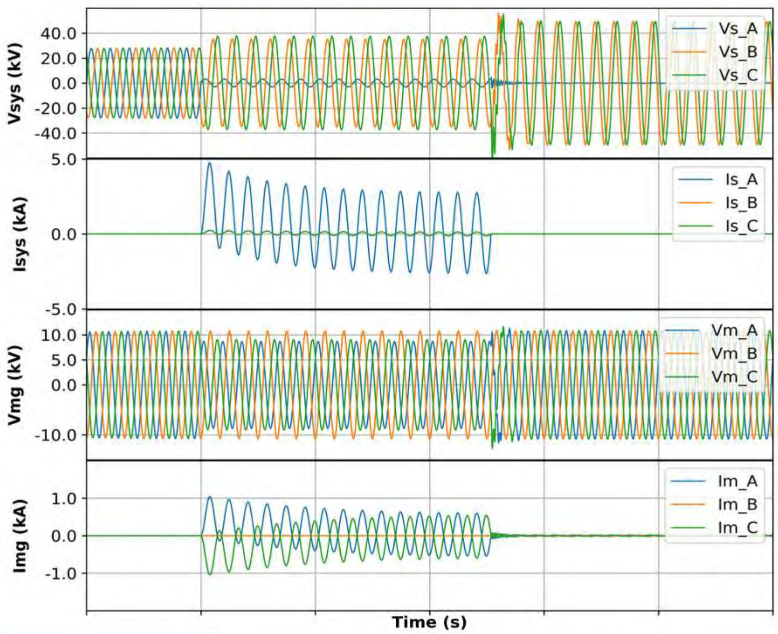
Case Studies

- Block diagram of the distance relay with residual voltage compensation

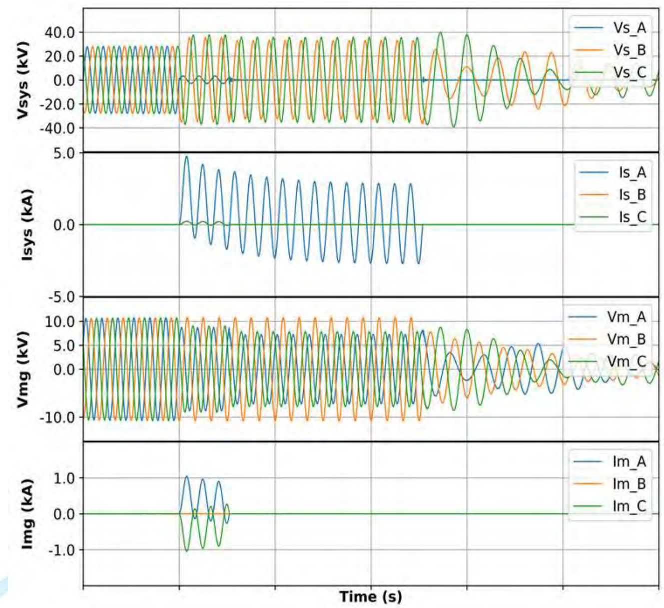


Case Studies -Results

SLG 0% fault (HV bus of the interconnection transformer)



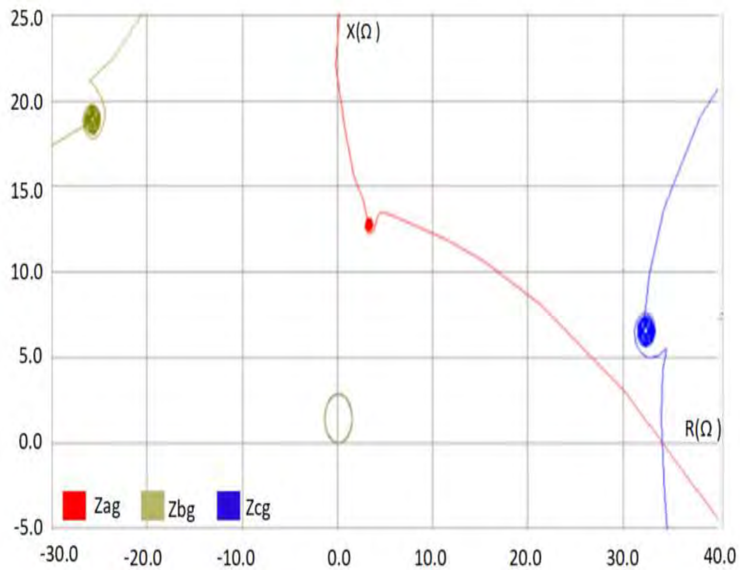
Fault not cleared with existing distance relay



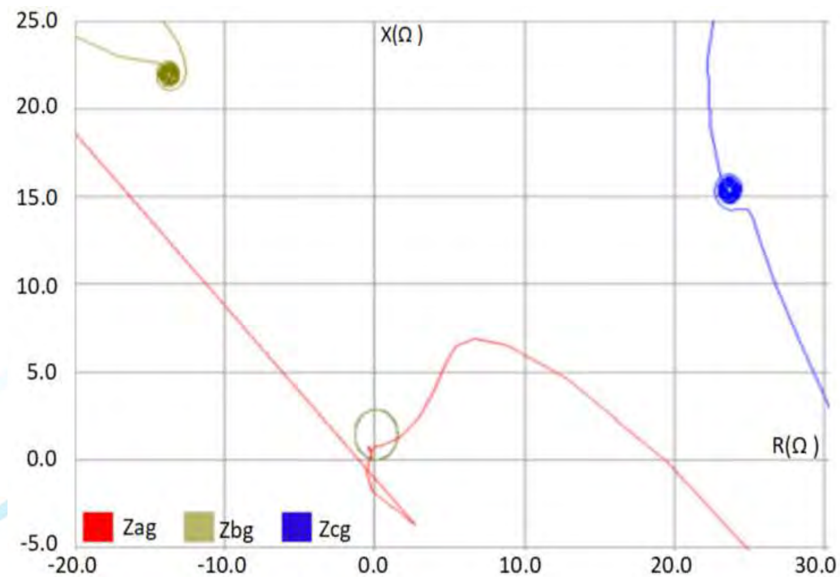
Fault cleared with proposed distance relay

Case Studies -Results

SLG fault at 0% of the interconnection line Z_{Tx} only



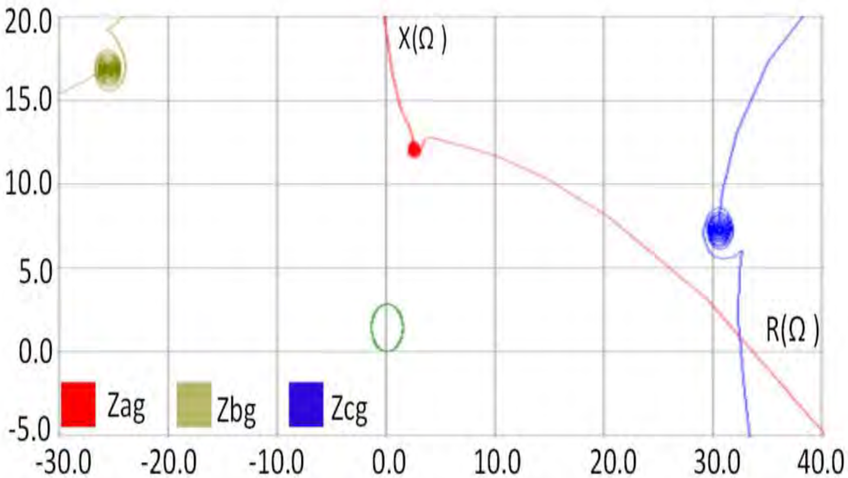
Impedance diagram - existing distance relay



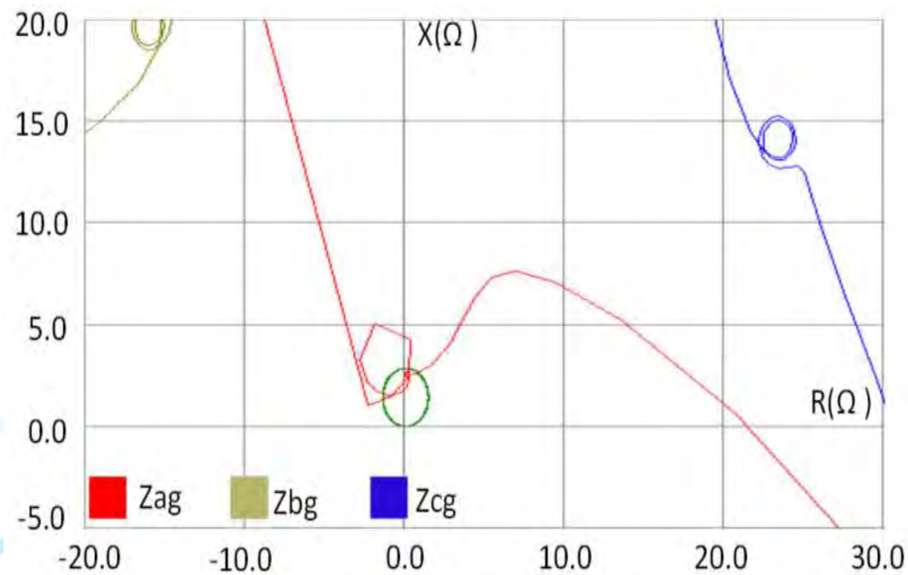
Impedance diagram - proposed distance relay

Case Studies -Results

SLG fault at 75% of the interconnection line (Z_{Tx}+75%*Z_L)



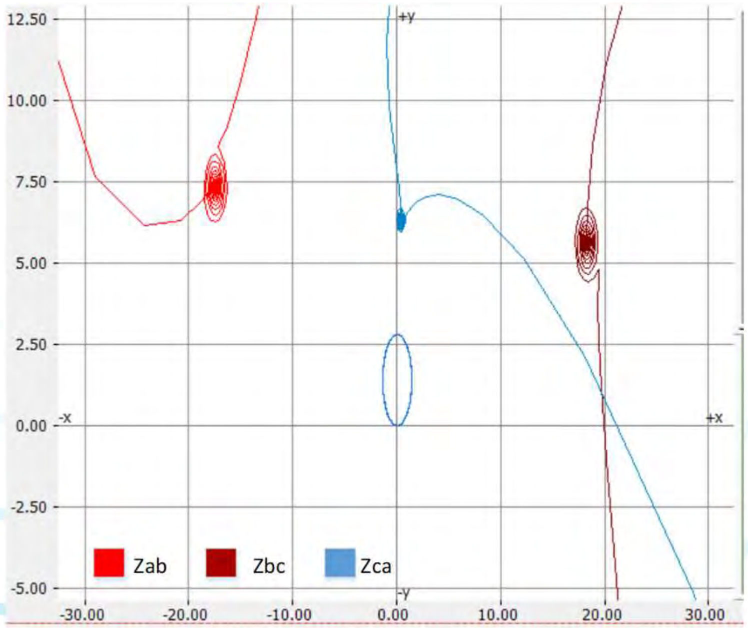
Impedance diagram - existing distance relay



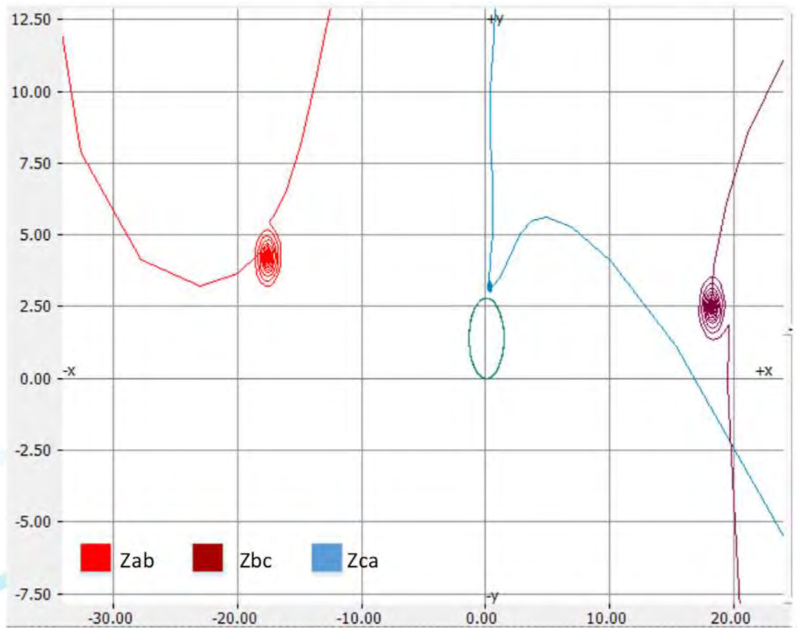
Impedance diagram - proposed distance relay

Case Studies -Results

SLG fault at remote bus –external fault



Impedance diagram - existing distance relay



Impedance diagram - proposed distance relay

Case Studies -Results

FAULT IMPEDANCE CALCULATED THROUGH WYE-DELTA TRANSFORMER

Fault Type (HV bus fault, 50 percent of line)	Phase	Voltage at Relay	Current at Relay	HV side V0	Typical Distance Relay	GE Distance Relay with Compensation	Voltage Compensation
3LG	A	4.210@-62.6	3445@-144.1		1.22@81.5	1.22@81.5	1.22@81.5
	B	4.210@177.4	3445@95.9		1.22@81.5	1.22@81.5	1.22@81.5
	C	4.210@57.4	3445@-24.1		1.22@81.5	1.22@81.5	1.22@81.5
2LG (BC-G)	A	6.778@--48.3	1763@168.9		16.9@85.9	4.3@10.9	17.8@85.8
	B	6.913@167.1	1730@143.3		1.8@40.6	1.22@81.5	2.5@54.8
	C	4.164@57.7	3407@-23.8		1.7@124.4	4.2@155.7	2.5@110.7
2L (B-C)	A	7.154@-47.1	1714@157.2		230.6@109.1	4.3@10.9	230.6@109.1
	B	7.295@166.3	1688.2@155.4		1.9@34.9	1.22@81.5	1.9@34.9
	C	4.158@57.7	3402@-23.7		1.8@130.2	4.2@155.7	1.8@130.2
1LG (A-G)	A	6.969@-65.2	1046@-114.5		5.4@83.7	6.6@118.4	1.26@80.7
	B	6.93@-175.4	1051@66.2		12.5@147.5	644.0@109.7	11.2@166.9
	C	7.949@60.0	12.3@-49.8		12.7@20.5	6.7@49.3	11.5@1.5
	I1		611@-144.4	13.341 @-29.8			

Conclusion

- Methods of protecting the microgrid at POI are discussed.
- A new distance relays algorithm with residual voltage compensated is proposed. It can detect the SLG fault happened at HV side of the step-up transformer and interconnection line when the existing methods are not sensitive or fast enough to detect the fault.
- It can prevent unintentional islanding of microgrid system and protect the system from dangerous overvoltage and reducing the arcing condition at the fault location.

Thank You

Questions?