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New Type of Current Differential Protection for Distribution Networks with High Penetration of DGs

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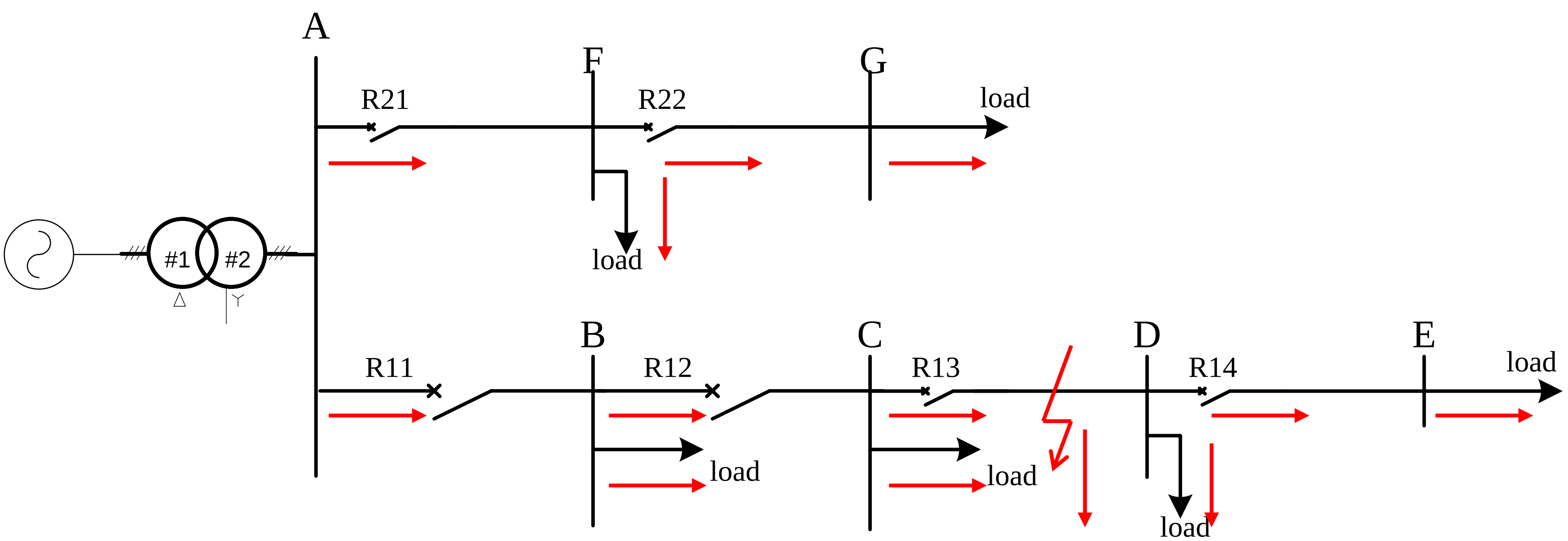
Contents

1. Background

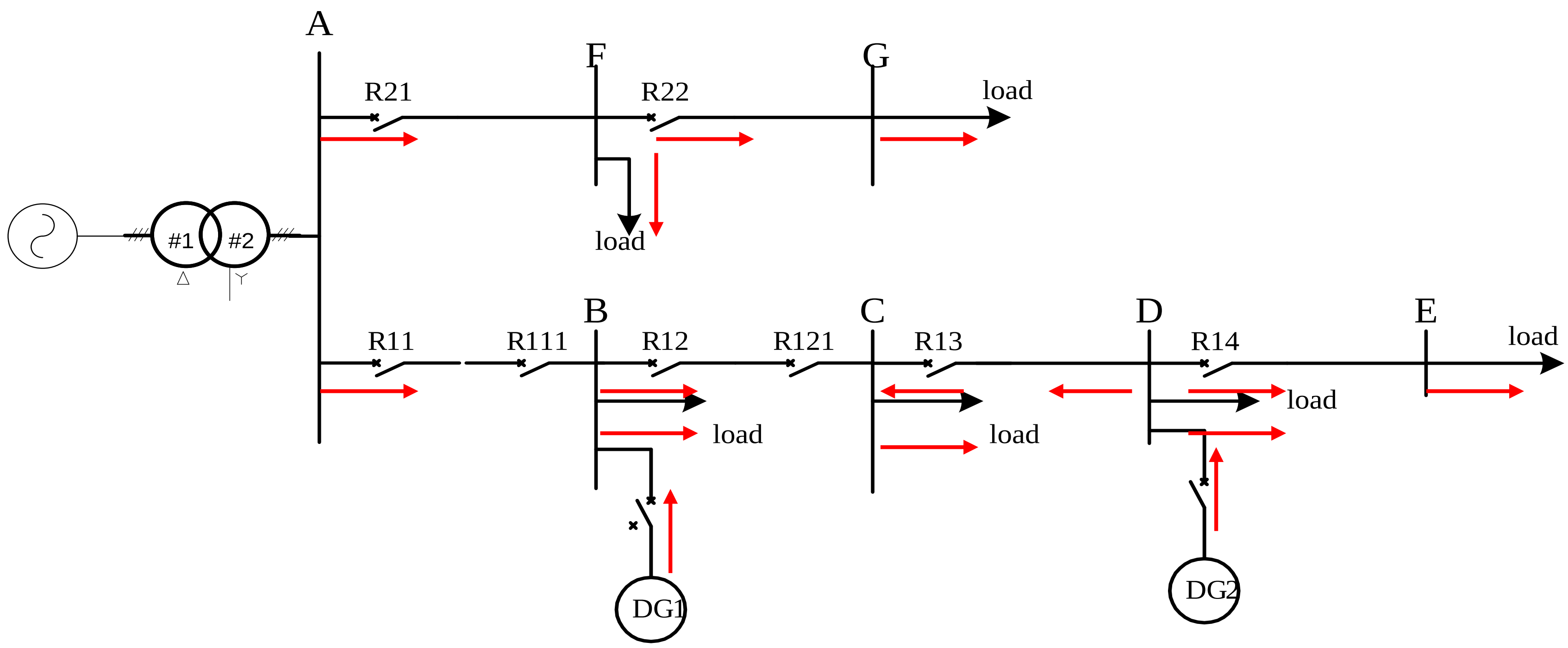
（1） Traditional distribution network



- **Both load and fault currents flow in one direction.**
- **Traditional over-current protection is feasible.**

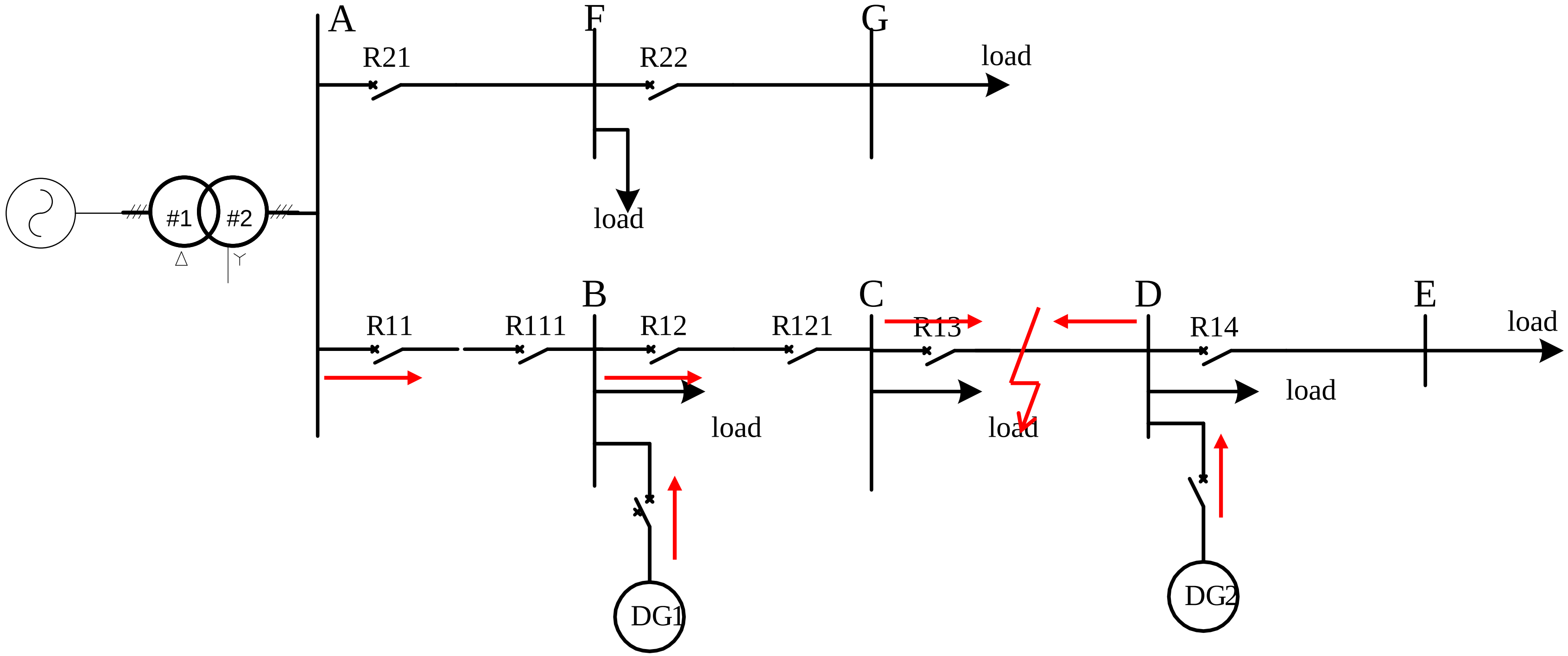
1. Background

（2） Active distribution network (ADN)



1. Background

（2） Active distribution network (ADN)



- Both load and fault currents are bidirectional.
- Traditional over-current protection can not work correctly, even fail.
- Need new type of protection scheme.

1. Background

（3） Problems faced by protecting ADN

- Bidirectional fault current provided by multi-source
- “Weak infeed ” caused by inverter interfaced DGs
- Phase angle difference between fault currents generated by different sources
- “T ” type connection of feeders
- Impact of load
- No sufficient voltage information
- Deal with double phase or three phase faults

1. Background

（4）Selection of protection principle

To cope with above problems, the current differential protection based on positive-sequence fault components(PSFC) is chosen to protect ADN.

Advantages:

- Suitable for two-terminal or T-type feeders
- Suitable for weak-infeed fault condition
- Suitable for phase-to-phase faults or three-phase faults
- No need for voltage information
- Remove impact of load
- Reduce communication load

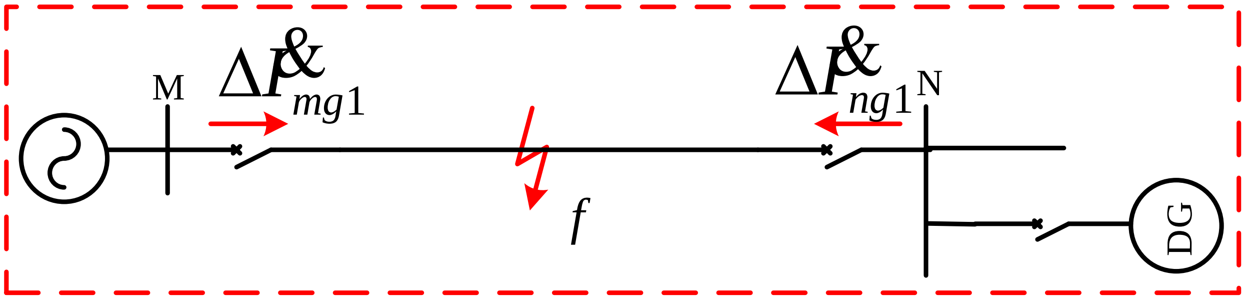
2. Protection Criterion

The establishing of criterion is based on the PSFC equivalent circuits and its analysis by considering different fault conditions and DG types.

When establishing protection criterion, two typical feeder structures are mainly considered .

2. Protection Criterion

（1） Criteria for feeder section without branch

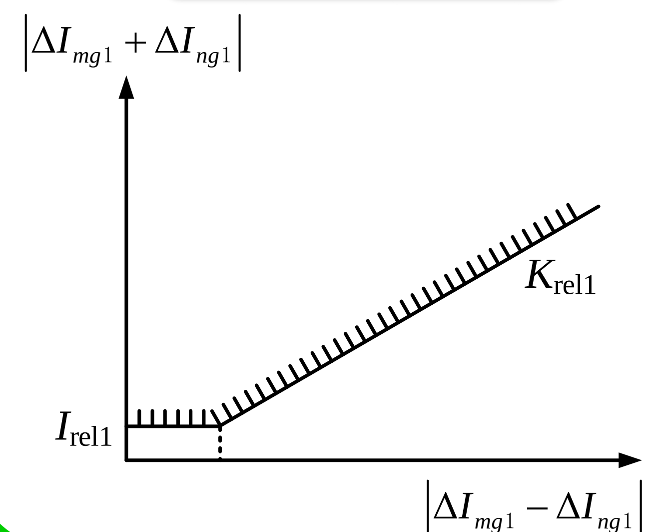


$$\begin{cases} \left|\Delta\dot{I}_{mg1} + \Delta\dot{I}_{ng1}\right| \geq I_{set1} \\ \left|\Delta\dot{I}_{mg1} + \Delta\dot{I}_{ng1}\right| \geq K_{rel1}\left|\Delta\dot{I}_{mg1} - \Delta\dot{I}_{ng1}\right| \end{cases}$$

I_{set1}-threshold (considering maximum unbalanced current)

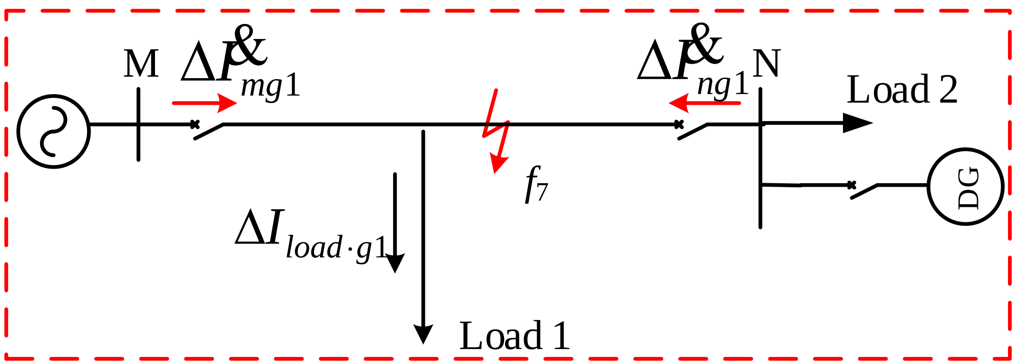
K_{rel1} - restraint coefficient

Operating characteristic



2. Protection Criterion

(2) Criteria for feeder section with non-measured branch

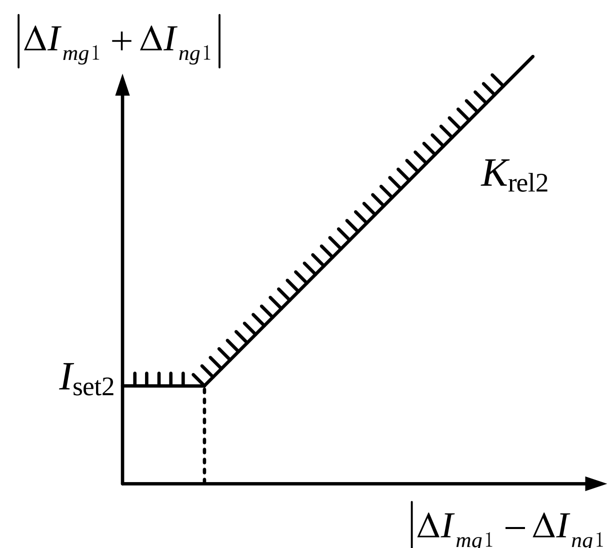


$$\begin{cases} \left|\Delta\dot{I}_{mg1}+\Delta\dot{I}_{ng1}\right| \geq I_{set2} \\ \left|\Delta\dot{I}_{mg1}+\Delta\dot{I}_{ng1}\right| \geq K_{rel2}\left|\Delta\dot{I}_{mg1}-\Delta\dot{I}_{ng1}\right| \end{cases}$$

I_{set2} – threshold (considering maximum branch load)

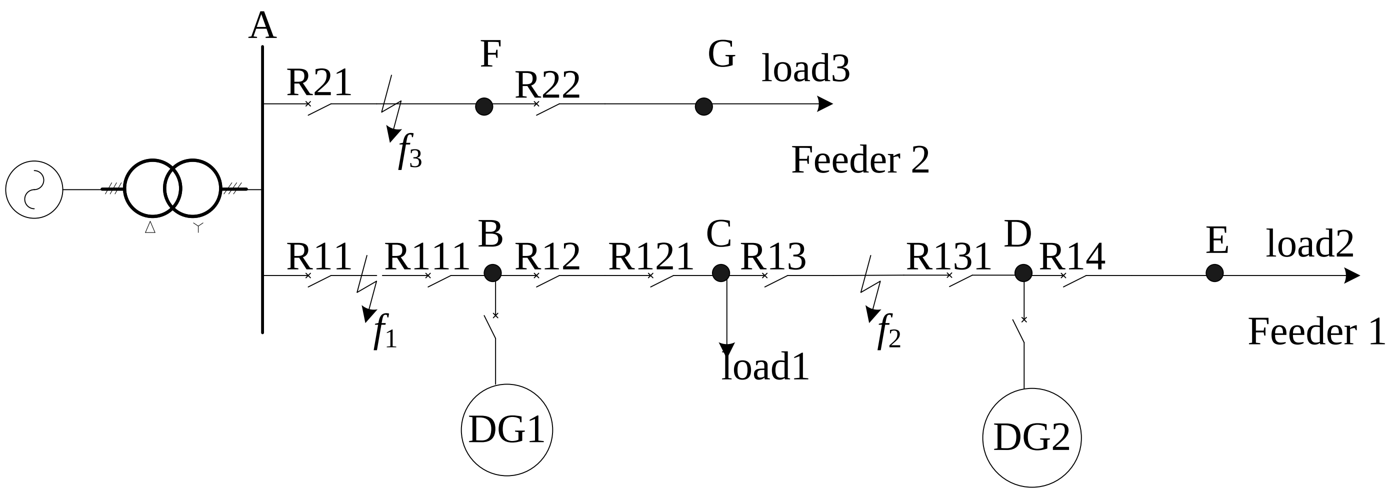
K_{rel2}–restraint coefficient

Operating characteristic



3. Simulation and Results

(1)Simulation model of ADN



System parameters:

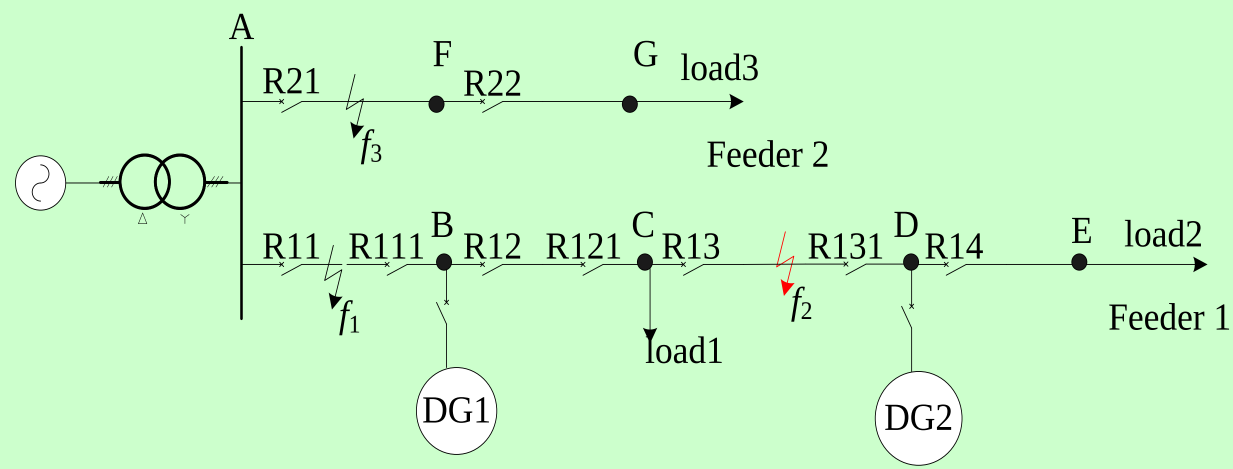
Transformer: 50MVA, 110/10.5kV

Lines: AB 2km ,BC 2km, CD 7km, DF 14km, AF 4km, FG 6km

DG1 /DG2： Inverter interfaced DG , Penetration rate 30%,

short circuit current limited to twice of normal rating

(2)Simulation result for A-B fault at f2



The PSFC values in different line sections

Section		PSFC values（A）	
		Left Terminal	Right Terminal
Feeder 1	AB	861∠136°	861∠-44°
	BC	887∠133°	887∠-47°
	CD	911∠136°	59∠137°
Feeder 2	AF	12∠13°	12∠193°

Fault section identification

Section		Current (A)		Fault Section ?
		Differential Current	Restraint Current	
Feeder 1	AB	0	861	No
	BC	0	887	No
	CD	970	426	Yes
Feeder 2	AF	0	12	No

4. Implementation technique

(1) Two key technologies for realizing line current differential protection

- Data synchronization for currents at all terminals of the protected line

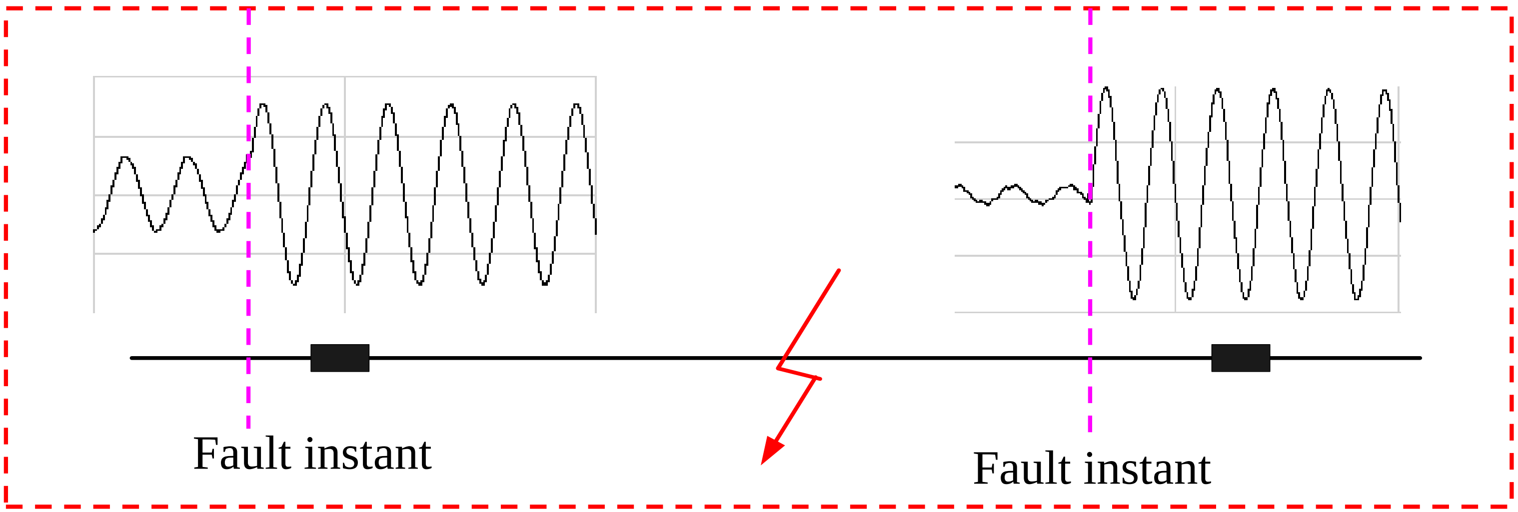
  (Transmission line: Pingpong method ,GPS clock)

- Data exchange for currents at all terminals of the protected line

  (Transmission line: dedicated communication channel)

4. Implementation technique

(2) How to realize data synchronization in ADN?



New idea---fault instant based self-synchronization

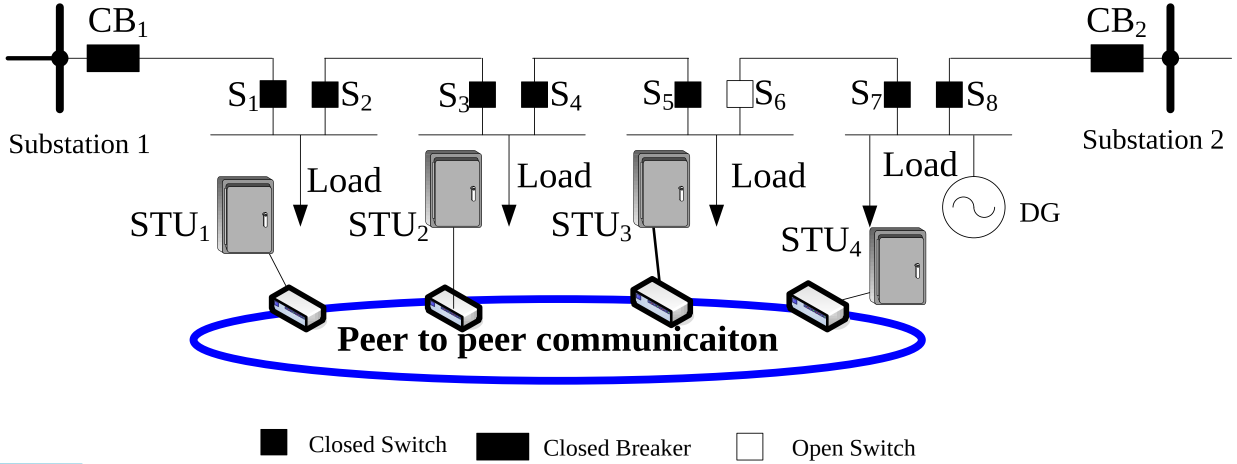
- Detect fault instant at both terminals
- Calculate PSFC by using fault instant as reference

4. Implementation Technique

(3) How to realize data exchange?

Traditional centralized communication mode in DA is not suitable for the data exchange of proposed differential protection.

Peer-to-peer communication mode via fiber-optical Ethernet is utilized to realize the data exchange , in which Goose over UDP transmission method is adopted.



5. Prototype and Test

(1) Development of prototype

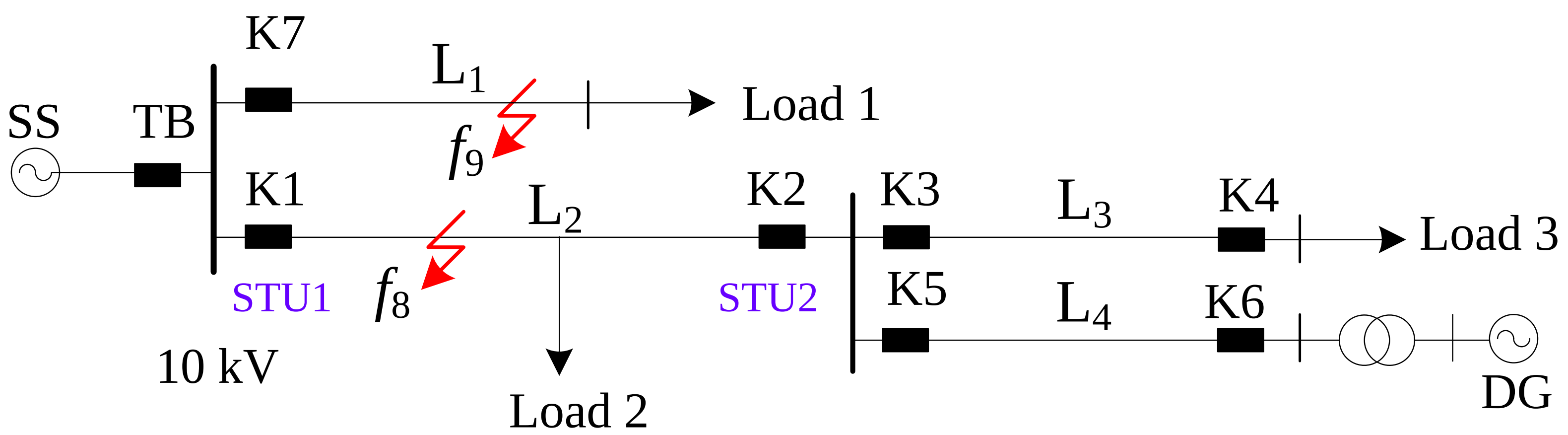
Based on the proposed protection principle and implementation techniques, two relay prototypes have been developed. Here the relay is called STU(Smart Terminal Unit) ,which has the function of both differential protection and FTU.

5. Prototype and Test

(2) Test platform based on RTDS

5. Prototype and Test

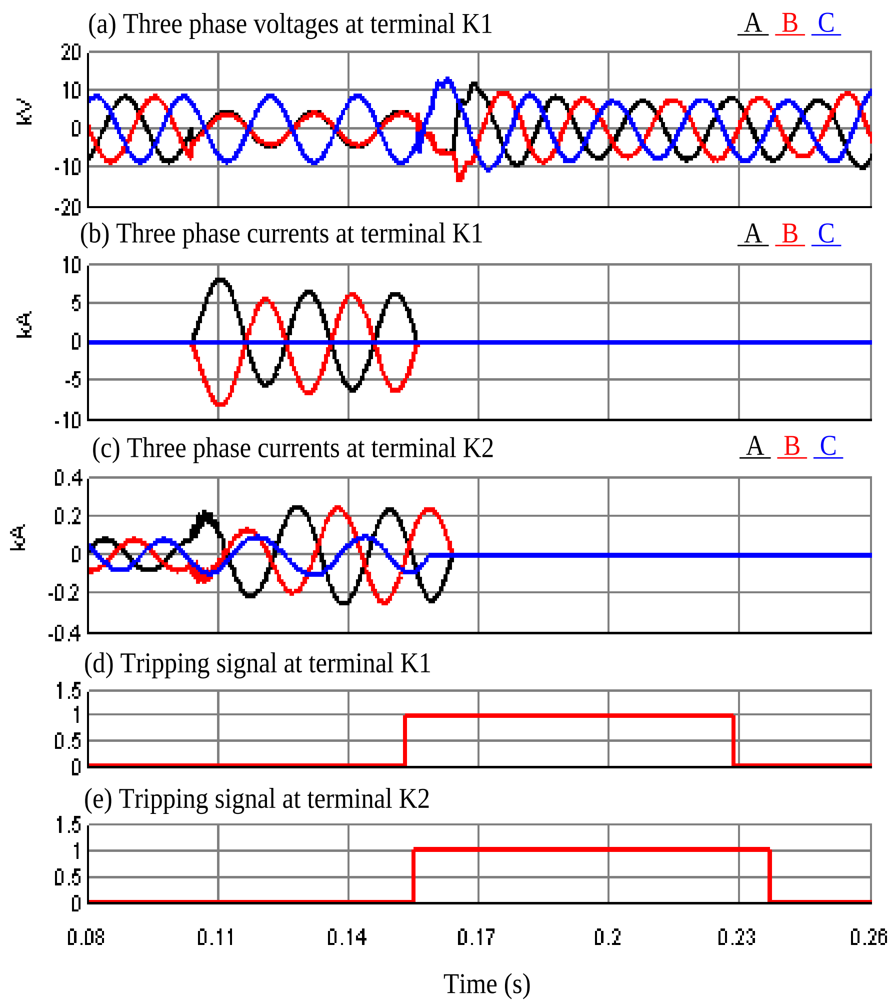
(3) System model used in test



SS	V=10.5kV, $Z_1 = 0.5\angle 80^\circ\ \Omega$
DG	Inverter interfaced PV with current control strategy Capacity：2 MW
Feeder	L1 = 1 km, L2 = 3 km, L3 = 4 km, L4 = 1 km Z1 =（0.17+j0.34）Ω/km, Z0 =（0.42+j1.51）Ω/km Load 2 is 2 km long from K1
load	Cosφ = 0.9, Load 1=2 MW, Load 2=1 MW, load 3=2 MW

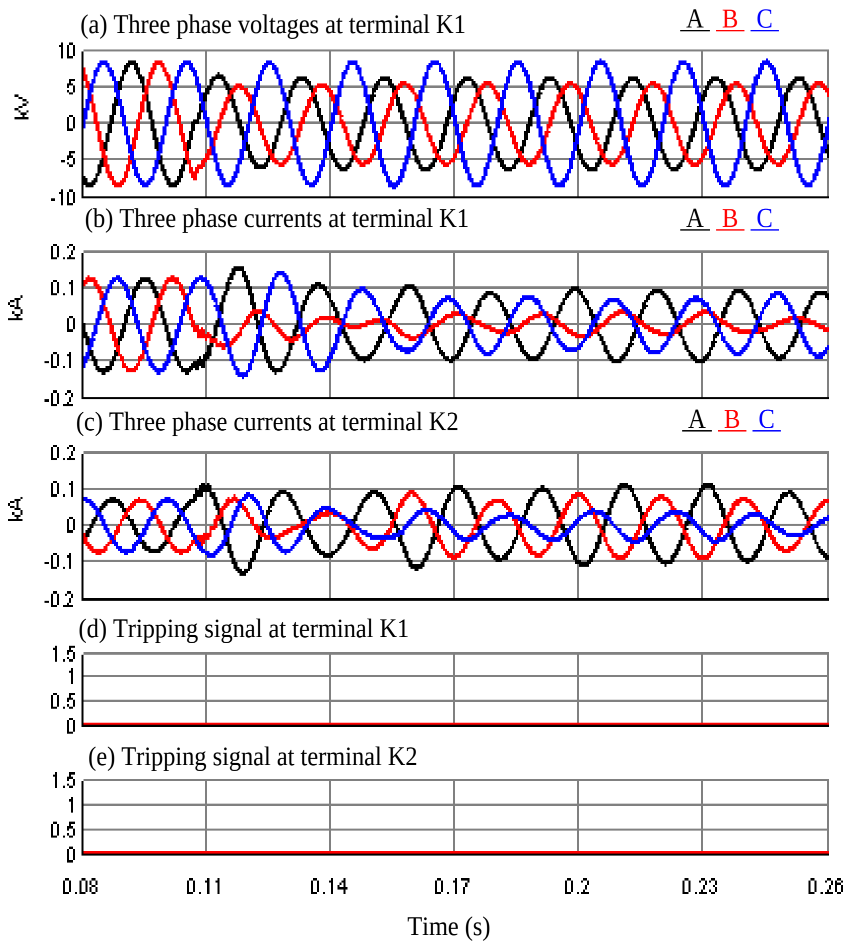
5. Prototype and Test

(4) Fault record for an internal A-B fault at f8



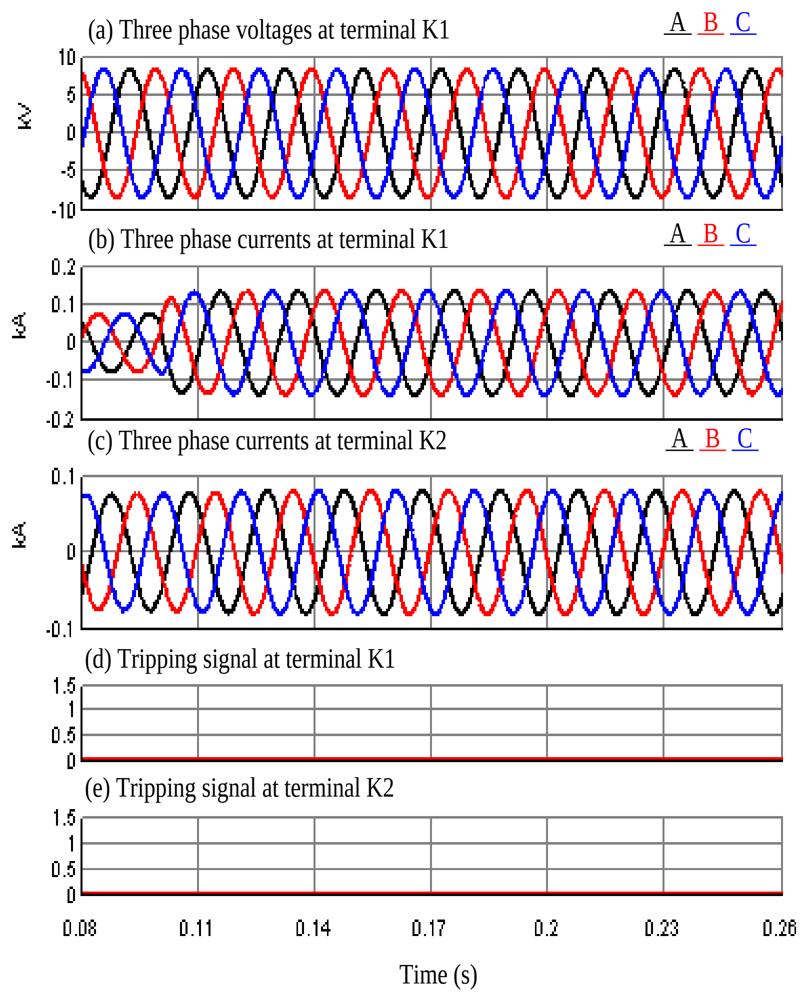
5. Prototype and Test

(5) Fault record for an external A-B fault at f9



5. Prototype and Test

(6) Fault record for the response to switching on load2



5. Prototype and Test

(7) Summary of test results

- The developed prototype operates correctly to all the simulated internal faults, external faults and load switching.
- The average operating time is around 50 ms.
- The peer to peer communication time is ranged from 2 ms to 10 ms.
- The self-synchronization error is less than 8° under the sampling rate of 6400 Hz.

6. Conclusions

- The fault characteristics of active distribution networks are much different from those in traditional distribution networks.
- Pilot current differential protection based on PSFC is a effective way to protect distribution networks with high penetration of DGs.
- The proposed protection scheme can be used to realize fast fault section location and isolation in Feeder Automation (FA).

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- Main references:

[1] Houlei Gao, Juan Li, and Bingyin Xu. "Principle and Implementation of Current Differential Protection in Distribution Networks with High Penetration of DGs. " *IEEE Transactions on Power Delivery , Vol. 32, No. 1, February 2017, PP:565-574*

[2] Lijuan, "Current differential protection principle and implementation technologies for active distribution networks," *Ph.D Dissertation, Shandong University , June 2016*

Thanks for your attention !

Questions?