MICROGRID PROTECTION ISSUES SOLUTION

Outline

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- Microgrid System Components
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- Some Challenges in Microgrid Protection
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Outline

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- ✓ Fault type
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- ➢ Different Methods of Protecting Microgrids
- ✓ Changing protective devices or settings
- ✓ Disconnecting DG unit during faults
- ✓ Creating a balance among different DG technologies
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Outline

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- ➢ Discussion
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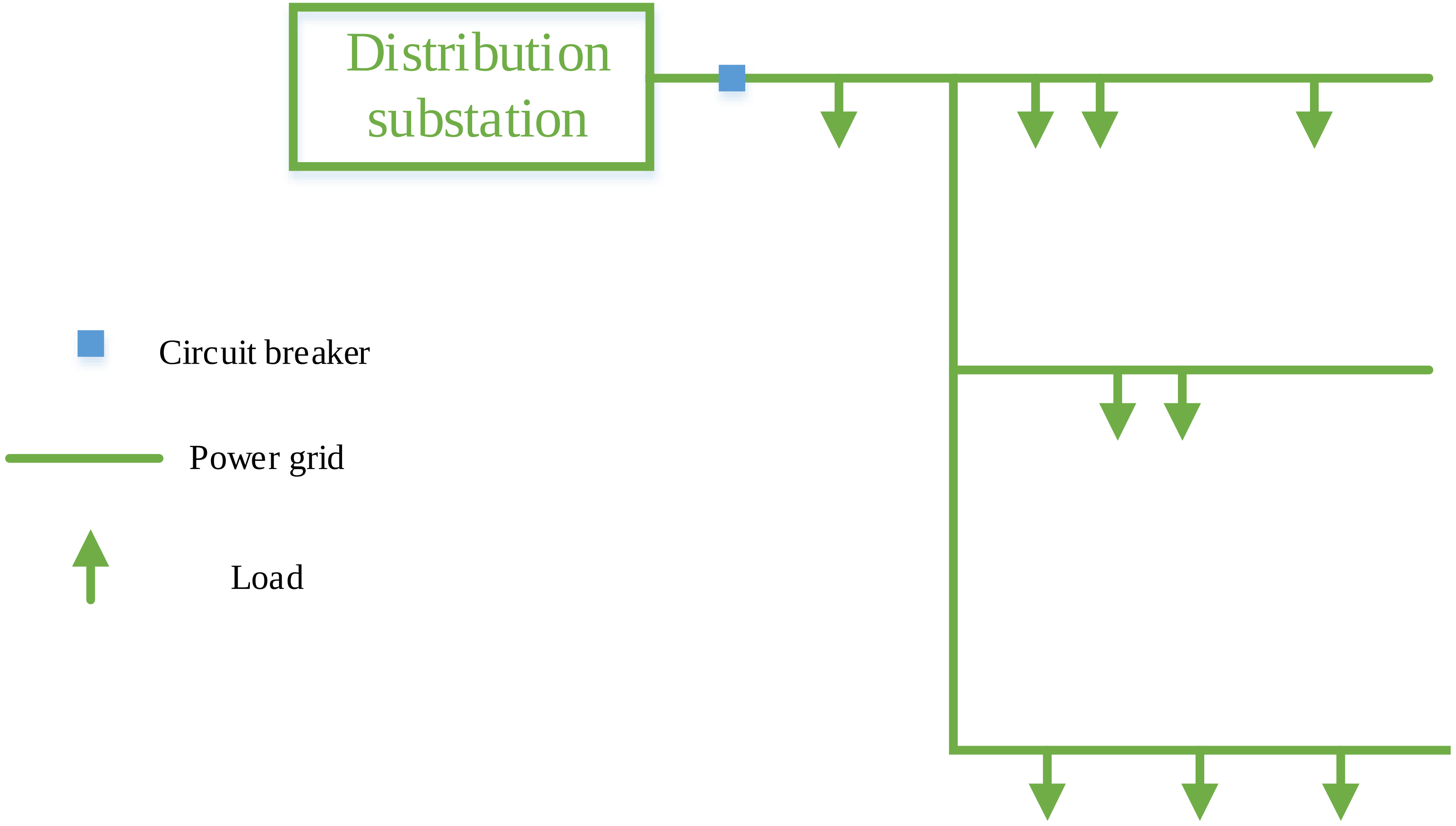
Microgrid Evolution



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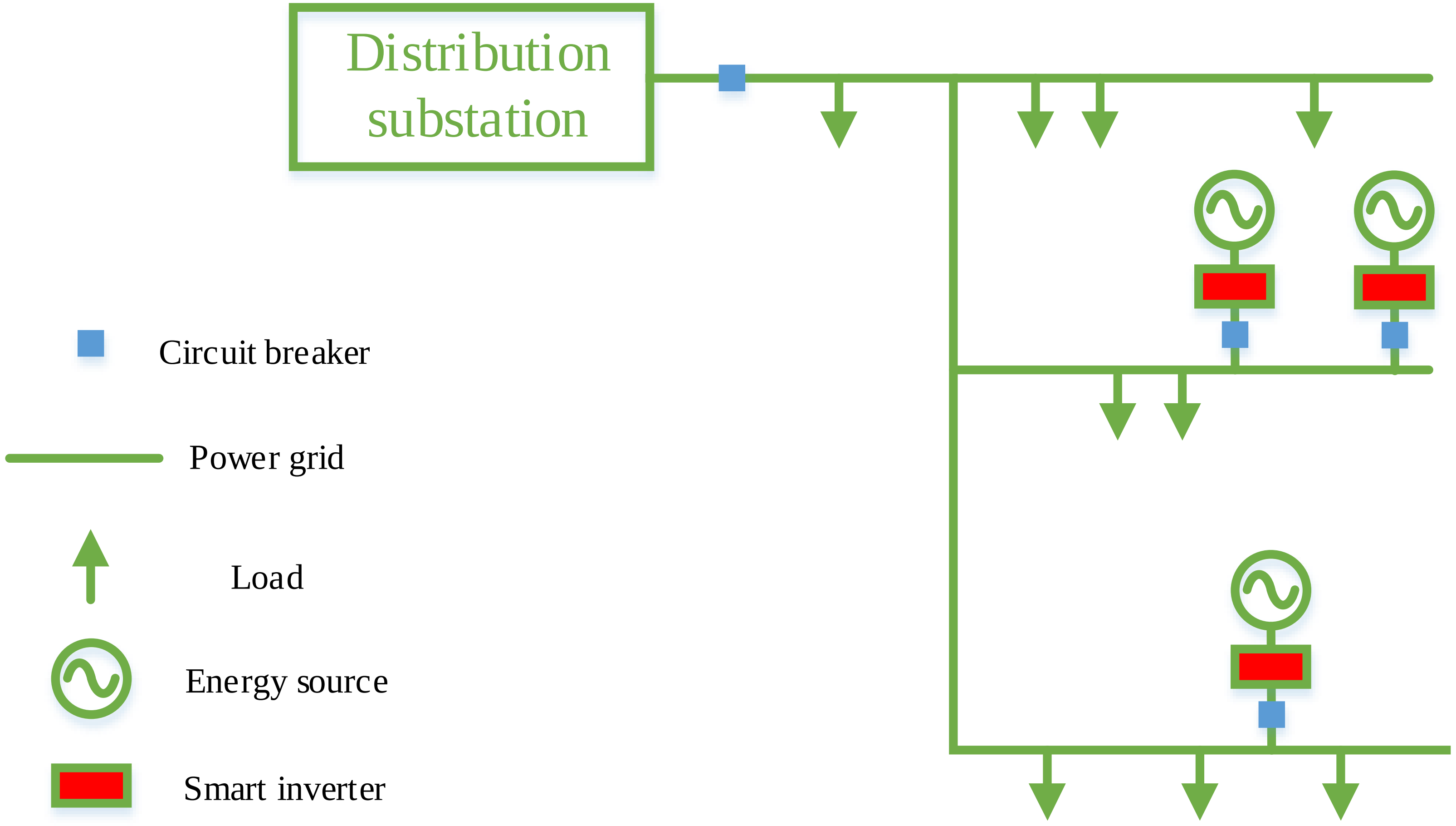
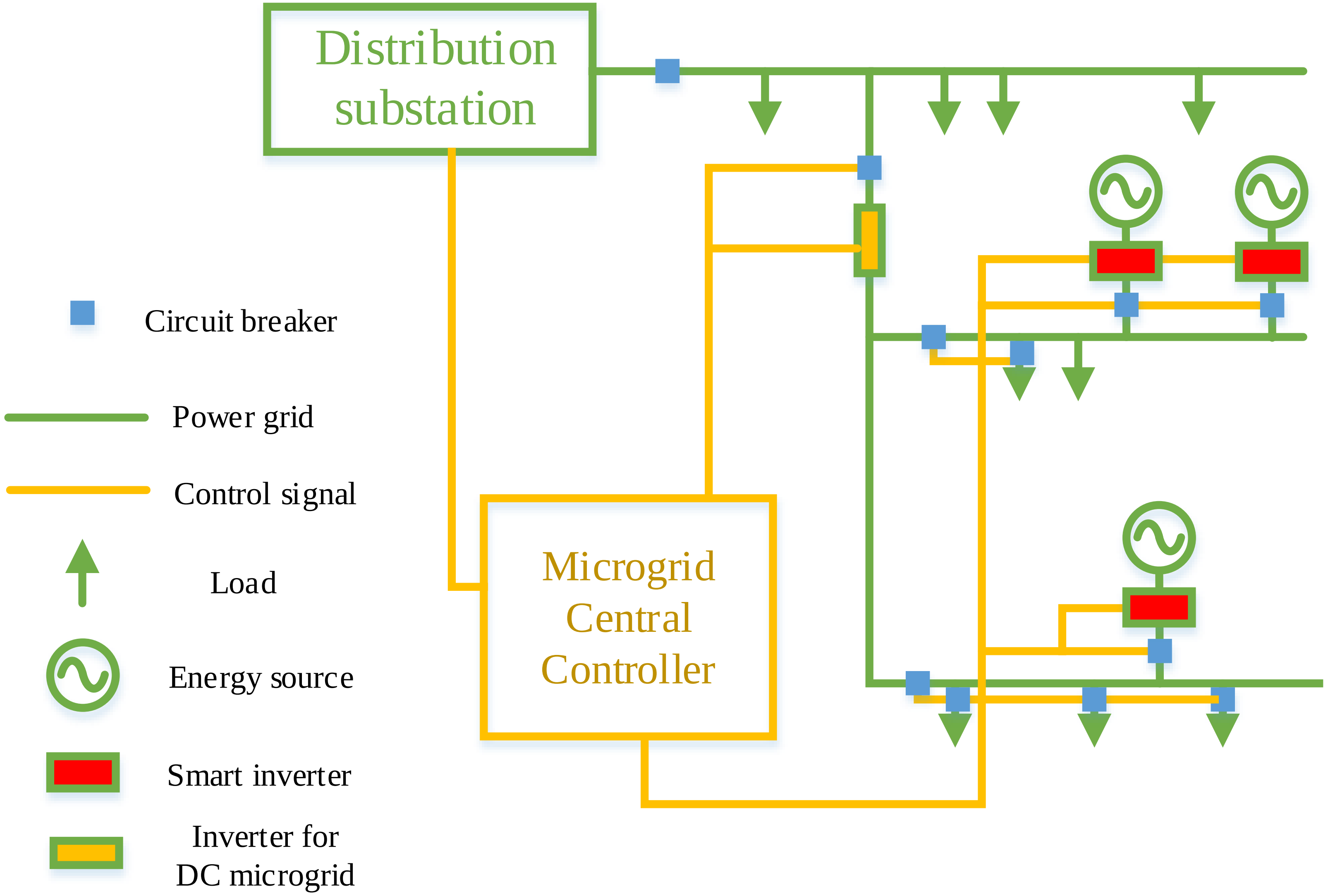
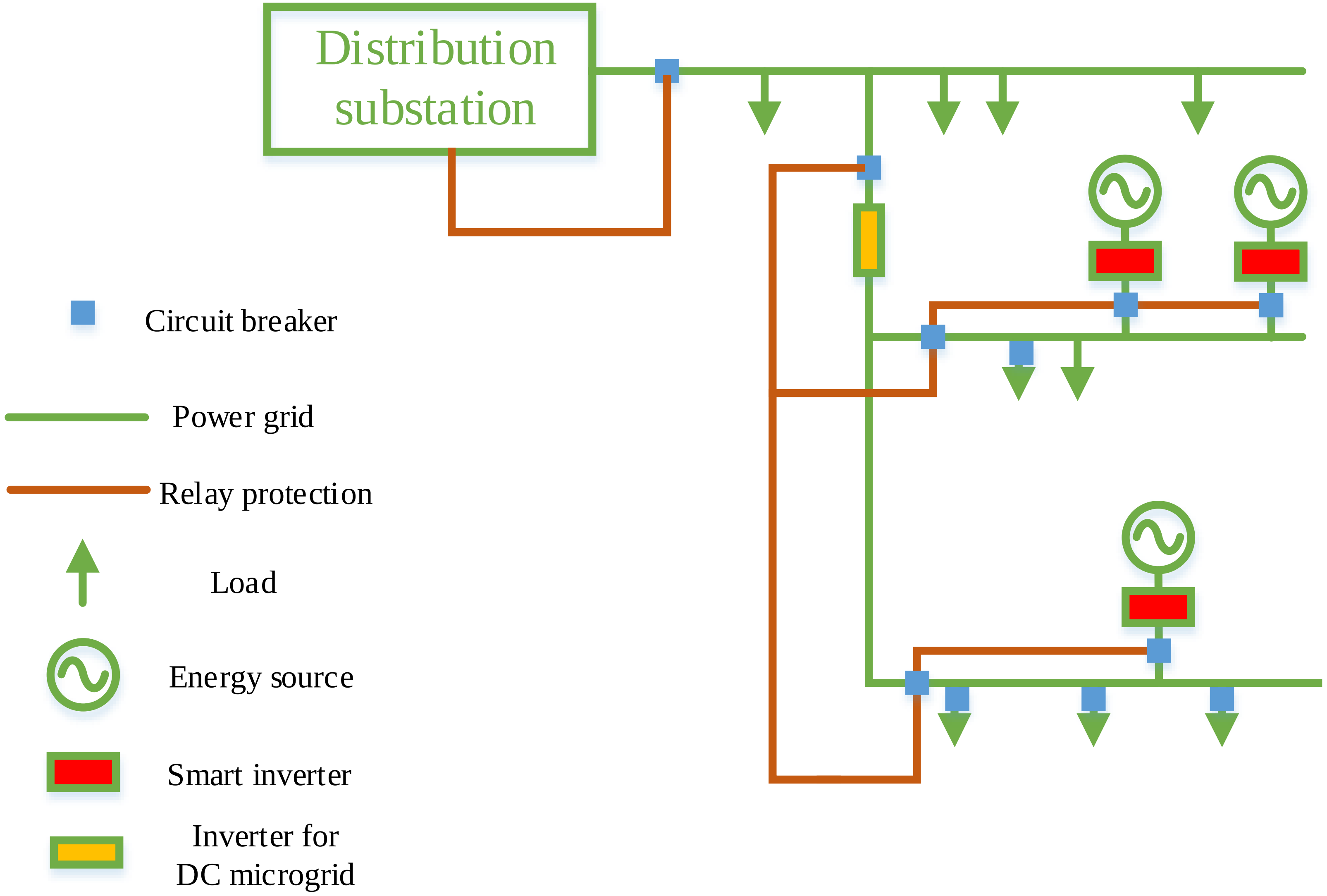
Microgrid Evolution



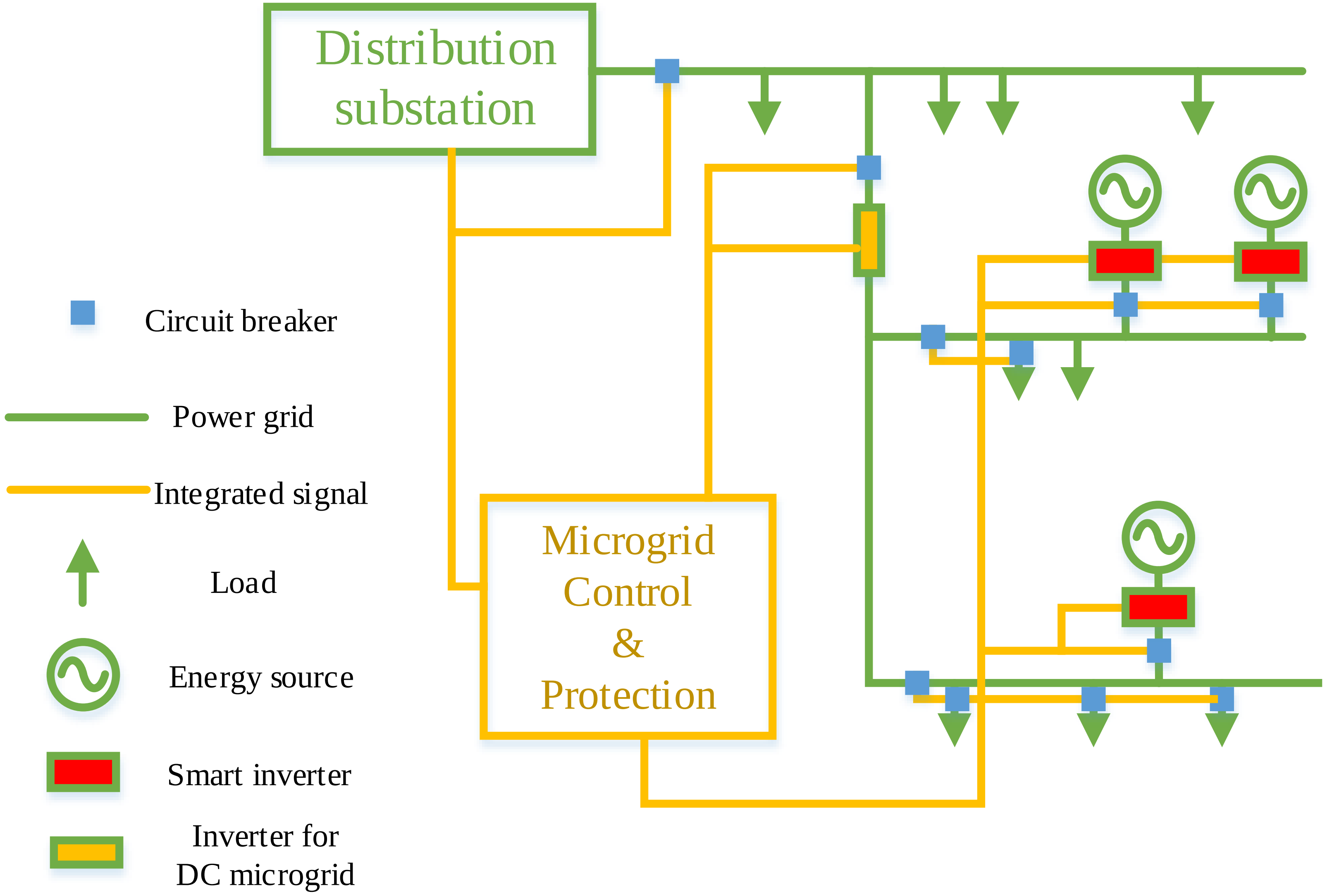
Microgrid Evolution



Microgrid Evolution



Microgrid Evolution



Microgrid System Components

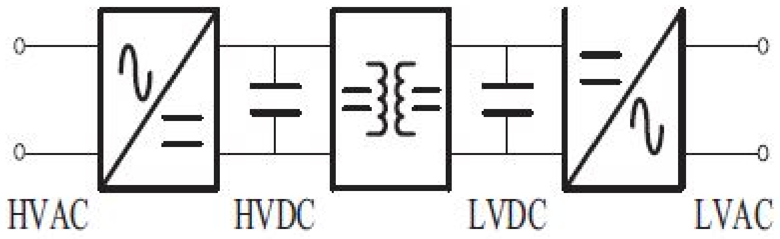
✓ Smart transformers in FREEDM microgrid:

- Future renewable electric energy delivery and management (FREEDM) networks are looped microgrids with renewable DG resources, energy storages, power electronic devices, and residential and industry customers.
- Many issues such as bi-directional power flow due to insert DG in distribution networks, single phase DGs and loads which imbalance distribution networks, and renewable DGs with DC output which require a DC bus or a DC/AC converter, have intensified the necessity of designing new instruments for FREEDM network realization.
- Many reasons have stimulated the researchers to replace traditional transformers with smart or solid state transformers (SST) in FREEDM systems.[16]
- SSTs are transformers based on power electronic devices and are invented in 1970.
- With the improvements semiconductor technologies, higher frequencies (from 50 Hz up to 10 kHz) have been capable to be used. [12]

Microgrid System Components

✓ Smart transformers in FREEDM microgrid:

- SST has a three layer conversion in which high frequency isolation is carried out in DC-DC stage.
- SST is a three-port power exchanger.
- the SST acts as a smart plug-and-play interface for trans- forming and distributing electric energy from different sub- systems, some via the AC port and others via the DC port.
- Insulation created by SST can affect protective plans of microgrid since distortions in each end is not observed in the other end. [3,12-14]

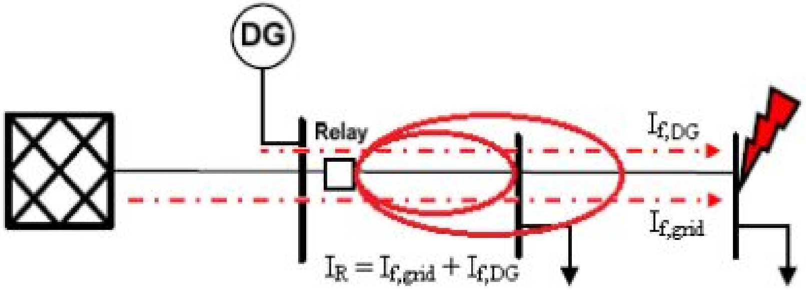


SST configuration

Some Challenges in Microgrid Protection

✓ Changes in the short-circuit level:

- Microgrid can operate in two normal and islanded modes
- This issue is due to the significant difference found in short circuit levels in these modes.
- In the normal operation mode, both the network and DGs contribute to supplying fault currents. Thus The contribution of DGs might increase the network short-circuit level over its rated value.
- in the islanded mode, only the DGs supply fault current during fault events. Therefore, the total level of fault current in the islanded mode is significantly lower than that of the normal mode.
- This issue highlights necessity of a method which is able to protect microgrid in both normal and islanded mode. [3,4,26]



Change in short-circuit current

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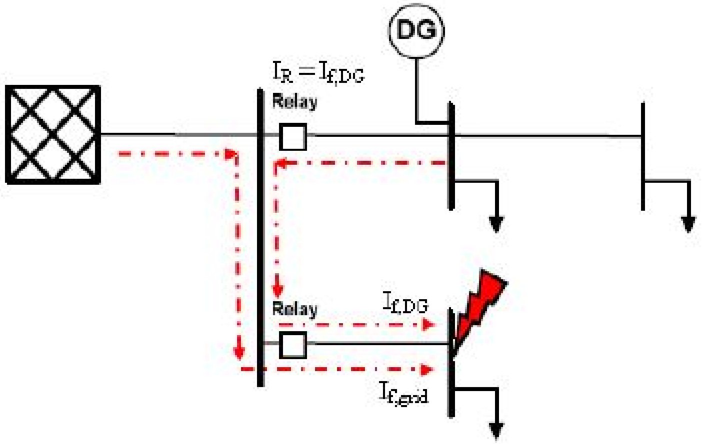
Some Challenges in Microgrid Protection

✓ False tripping:

- False tripping occurs when the fault current occurring in a feeder is supplemented by the fault current generated by a DG in a neighboring feeder attached to the same substation.
- In such circumstances, the protective equipment of the neighboring feeder might disconnect the circuit, causing a problem called “unnecessary outage of feeder” or “false tripping”. [5,26]

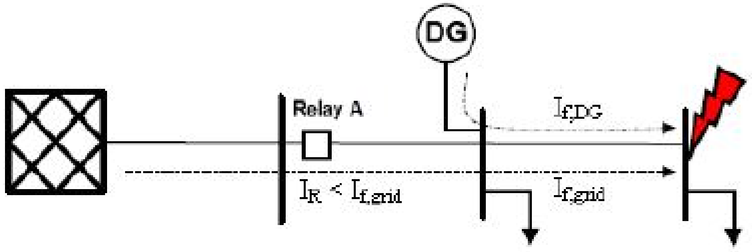


False tripping

Some Challenges in Microgrid Protection

✓ Blindness of protection:

- Operating region of over current relay is identified by pick up current which depends on the feeder impedance.
- Pick up current is configured in a way that it is more than rated current of feeder and less than minimum short circuit current of the protected region.
- When DG is connected to a network, the feeder equivalent impedance is increased and as a result, fault current detected by over current relay is decreased.
- This issue decreases operation zone of relay and relay cannot cover end of its protected line. [3,26]



Blindness of protection

Key Factors in Microgrid Protection

✓ Microgrid type:

- Microgrids are generally a combination of AC and DC systems.
- The main challenge in protection scheme of DC microgrids is shortage in having a practical experience.
- Another problem with protecting DC microgrids is that their time constant is great and the CB operates with delay.
- Protection plans of DC and AC microgrids are similar in terms of line and bus protection but have different settings.
- Adaptive protection is suggested to protect lines in both DC and AC microgrids.
- As for bus protection, differential protection is proposed for both DC and AC microgrids. [3,4,6]

Key Factors in Microgrid Protection

✓ Microgrid topology:

- Microgrid structure may whether be looped, meshed or mixed.
- Topology is one of the factors affecting the direction and magnitude of fault current and protection strategies in microgrid.
- Fault current divides between two parallel paths in a loop structure. Accordingly, protection devices on upstream feeder observe fault current which is twice the fault current of each path within a loop.
- Fault current in meshed topology is equal in upstream and downstream branches. [3,7]

Key Factors in Microgrid Protection

✓ Type of DG resources:

- DG units can be divided up into three categories: synchronous, asynchronous, and inverter-interfaced DG (IIDG).
- The model for synchronous DG units is derived from voltage equations and flux linkage equations, expressed in a rotational reference frame.
- A dynamic model was proposed for asynchronous DG resources because these units are very sensitive to grid disturbances, especially voltage dips.
- The model for the IIDG units is obtained from a nonlinear V–I characteristic with in the 2–60 cycle time range.
- The most important issue in microgrid protection is the amount of fault current generated by these three types of DG resources during a fault. [3,30]

Key Factors in Microgrid Protection

✓ Type of DG resources:

- Synchronous and asynchronous DG resources reduce operation time of over current relays, but the impact of asynchronous DGs outweighs the synchronous DGs. [46]
- The amount of fault current created by a synchronous DG unit will be 1.2 times as much as the fault current generated by an IIDG unit. [47]
- As soon as fault is occurred in one phase, control loop limits current of all phases in d–q method. Thus, IIDG unit operates like a constant current source with a slight
- Amount of current in a way that over current relays would be unable to detect the fault.
- But in abc control method, each phase is controlled separately, thus in faults, the current of other phases will remain constant. [3,31]

Key Factors in Microgrid Protection

✓ Communication type:

- They are divided into the Four groups:

I. Local information-based: A local detection plan depends on local parameters such as voltage and current signals of where a DG unit is located. This plan is so similar to the protection schemes of traditional distribution networks. In this plan, only local data of the DG unit and the relay are gathered.

II. Regional area measurement

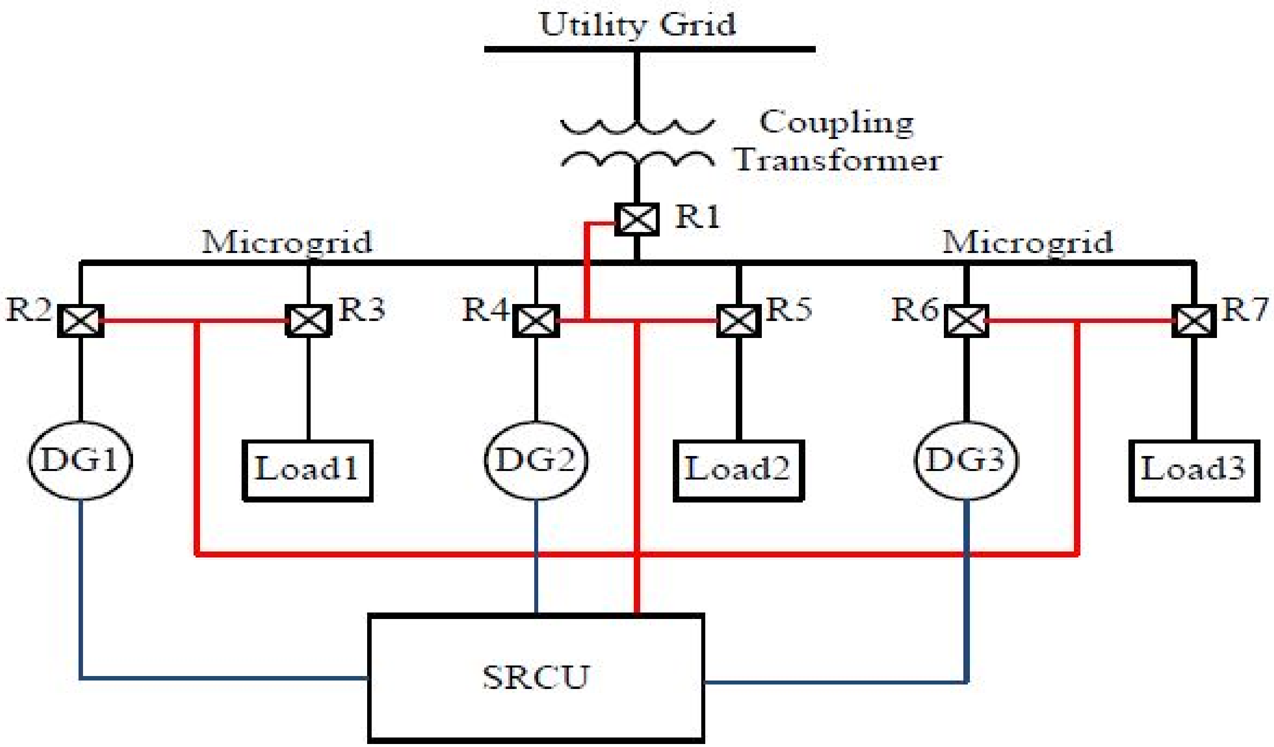
III. Wide area measurement: The more complex decision processes employ communication links for information gathering that allows a time frame only of several seconds for actions.

IV. Hybrid scheme: The protection system in this scheme consists of three SRCU, regional, and local layers, with the SRCU being the highest layer. [3,6]

Key Factors in Microgrid Protection

Key Factors in Microgrid Protection

✓ Communication type:



Protective system with SRCU and communication

Key Factors in Microgrid Protection

✓ Time delay of communication links:

- Communication includes both types of wired systems (telephone lines, fiber optic cables, and power lines) and wireless systems (satellite links).
- Time delay associated with communication links are generally due to delay of voltage and current transducers, window size of discrete Fourier transform (DFT), required time of data processing, data size of the PMUs output, multiplexing and transitions data, and data concentrators.
- Fiber optic cables and digital microwave links have the shortest delay which is 100ms up to 150ms while satellite link has the longest delay time which is 500ms up to 700ms. [3,32]

Key Factors in Microgrid Protection

✓ Method of analyzing data and detecting faults:

- In this section, the most important methods that are commonly used for processing distorted signals and fault detection are reviewed. [3,8,9]

I. Conventional analysis
II. Voltage analysis
III. Wavelet transform
IV. S-transform
V. Harmonic analysis

Key Factors in Microgrid Protection

✓ Fault type:

- Generally, three types of faults are considered in the literature: low-impedance faults (LIF), high-impedance faults (HIF), and faults due to voltage sags.
- Low-impedance faults are common faults which are detected using ordinary methods discussed earlier on.
- High-impedance faults are faults whose fault current is equal to load current. Thus, the current of these kinds of faults and the voltage drop they bring about are not enough to trigger the operation of protective devices.
- Another type of fault which is considered in microgrid protective schemes is the voltage sag. In this situation, large currents can flow through the small line impedance. This will damage semiconductor devices in the inverters and the microgrid components if the sag is not cleared or the circuit breaker does not open. [3,33-37]

Key Factors in Microgrid Protection

✓ Relay type:

- types of relays are used in microgrid protection plans: [3,10,11]

I. Over current relay
II. Distance relay
III. Voltage relay
IV. Differential relay
V. Admittance relay
VI. Innovative relay

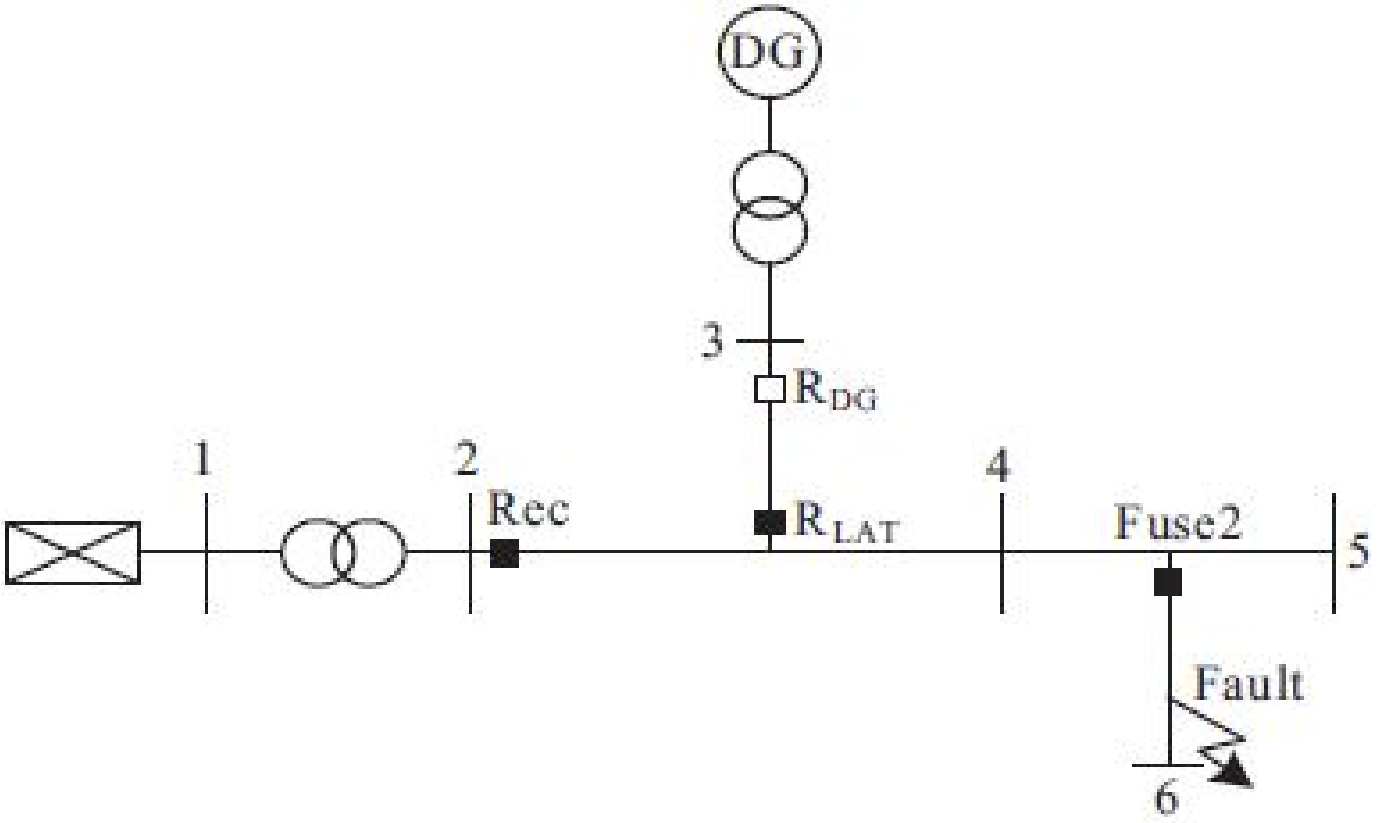
Different Methods of Protecting Microgrids

✓ Changing protective devices or settings:

- In this method, in locations where DG addition has disrupted the traditional protection plan, protective devices or their settings are changed so as to achieve desirable protection.
- In this method, protective settings should be re-calculated after each change in network topology or after installing each DG.
- The major problem with the plans involving changing protective devices and settings is ignorance of the fact that microgrids are dynamic.
- These methods are almost impractical because they do not consider the ever increasing number of DG units and their various types, the uncertainty of the presence of these resources and the loads of the system, and also network reconfiguration. [3,15-17]

Different Methods of Protecting Microgrids

✓ Changing protective devices or settings:



Different Methods of Protecting Microgrids

✓ Disconnecting DG unit during faults:

- In this method, when a fault occurs, the Current Sensing Unit (CSU) preempts protective devices by quickly detecting the fault and disconnecting the DG unit from the network using fast switches.
- Once the DG facility is disconnected, the network will return to its pre-DG state, and all the settings and protective devices designed for the no-DG situation will start to operate normally.
- It is not appropriate to disconnect the DG units from the network for all faults.
- This prevents exploitation of microgrid in islanded mode. Therefore it is in conflict with definition of microgrid which can be used in islanded mode.[3,39]

Different Methods of Protecting Microgrids

✓ Creating a balance among different DG technologies:

- Fault current caused by inverter-interfaced DG is at most twice the rated current.
- A negative issue about this method is that it has not considered dynamic behavior of microgrid since balancing fault current for all possible situations of microgrid is so complicated.
- implementing this method requires high expenses. [3,40,41]

Different Methods of Protecting Microgrids

✓ Microgrid protection using smart transformer:

- Primary voltage of the bus which is connected to SST is always constant, even during load oscillations.
- the maximum voltage drop must not exceed 0.1 pu and primary voltage of SST must not be less than 0.9 pu in normal situation.
- If the SST primary voltage was less than 0.9 pu, it can be comprehended that demand of loads is more than maximum power of SST.
- If primary voltage of SST was less than 0.8 pu, it is clear that a fault is occurred in the network. In this situation, the SST would be separated from the network and loads would be supplied by DGs and energy storages in secondary of the SST.
- The issue which is obvious in this method is neglecting the microgrid dynamic topology. [3,45]

Different Methods of Protecting Microgrids

✓ Microgrid protection using smart transformer:

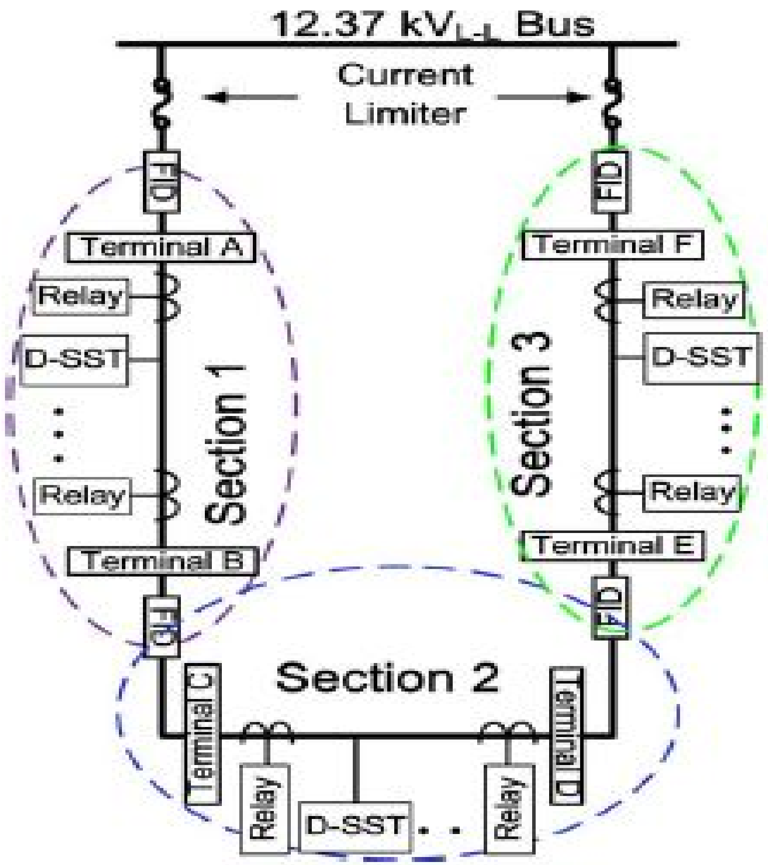


Illustration of system protection with sections

Different Methods of Protecting Microgrids

✓ Adaptive protection:

- According to this plan, protection system continuously monitors the system and applies new protection coordination in case of any changes in topology or operation.
- This procedure calls for the following requirements:

  - Using directional and digital over current relays.
  - Digital over current relays should have group settings. These group settings are changed locally or remotely.
  - Using high speed and secure communicative infrastructure in framework of communicative protocols such as IEC61850.
- Adaptive protection can be implemented generally by two infrastructures of centralized structure and decentralized structure or multi-agents.
- Adaptive protection is an effective method for protecting microgrid in both normal and islanded modes. [3,20]

Different Methods of Protecting Microgrids

✓ Adaptive protection:

I. Centralized adaptive protection

- In this topology a SRCU send required control and protective orders to devices being aware of their situation and overall situation of network.
- In this method, the information of the network, including the number of DG units, the number and name of the buses, the amount of load existing in each bus, and characteristics of the power switches should be given to the SRCU as input data.
- Some studies use offline database for the purpose of microgrid protection coordination with SRCU topology.
- Some studies use online calculations for protection coordination. In these studies, if any DG connects or disconnects to the network, a control signal is sent to SRCU to do new calculation online and set operational current of each relay according to new situation. [3,20,21]

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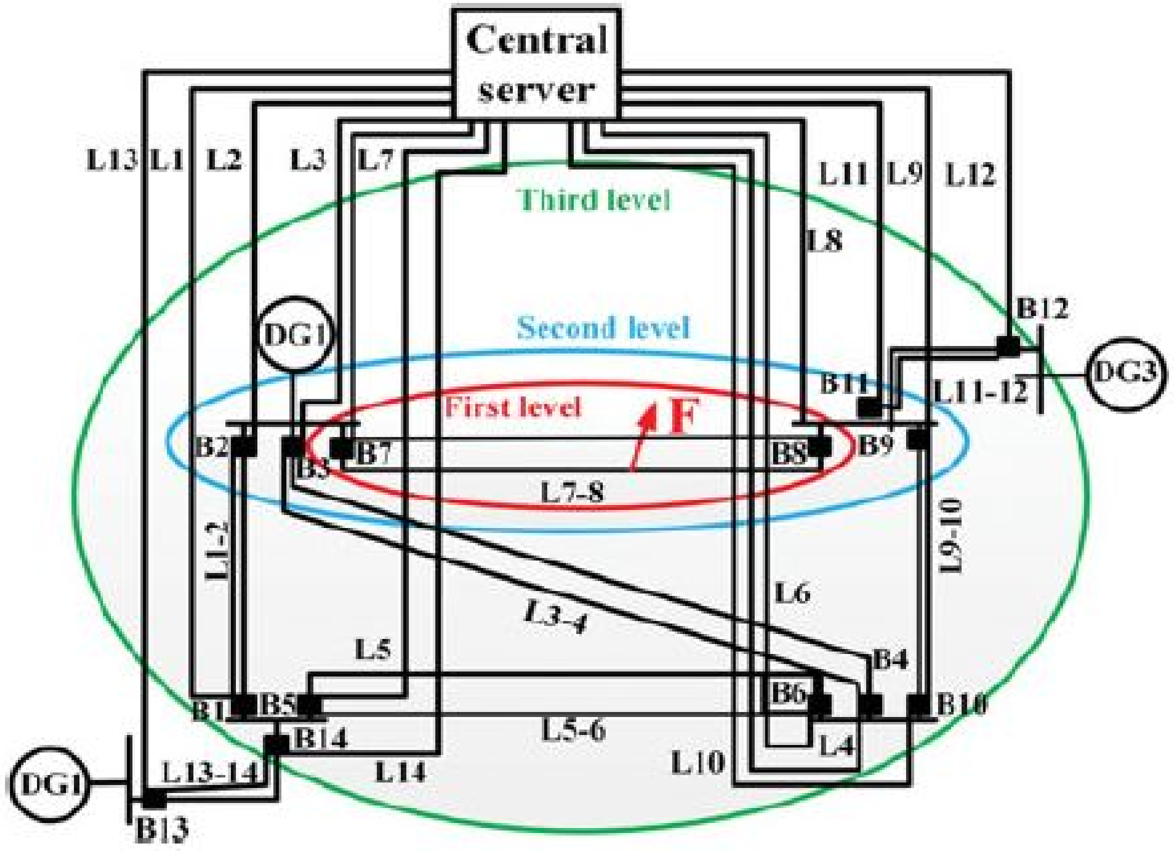
Different Methods of Protecting Microgrids

- ✓ Adaptive protection:



Central adaptive protection system with different protective layer levels.

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Different Methods of Protecting Microgrids

✓ Adaptive protection:

II. Decentralized adaptive protection

- Decentralized adaptive protection is a set of distributed agents in different devices of network (e.g. relays, CBs, and DGs) which are operating in complete coordination and can communicate through communicative infrastructure and are compliant with local and wide area data.
- Feathers of agent system include:

  1) Autonomy 2) Social ability 3) Reactivity 4) Pre-activeness
- Some studies has used offline database to update agents setting.
- Contrary to offline calculation and using offline database, online calculation and decision making exists. [3,20]

Different Methods of Protecting Microgrids

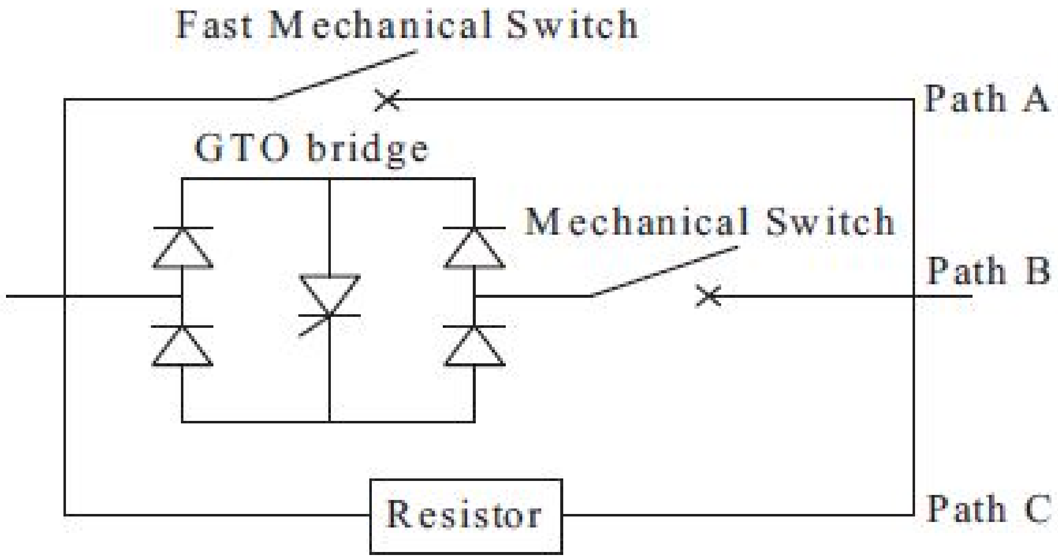
✓ Using fault current limiter:

- One of the most efficient methods of reducing side effects of DGs on the protection of distribution networks is limiting the short-circuit level.
- FCL is indeed an impedance which is placed in series with the DG unit. One major advantages of locating FCL in the same branch as DG is that it removes the necessity of changing CBs in the branch where DGs are installed.
- Each microgrid operational topology requires calculations in order to decide the best locations of installing FCLs, and this is in conflict with dynamic topology of microgrid.
- Since FCL is generally expensive, it is not possible to add FCL in all network busses to use each one in necessary situations.
- This method is only applicable in networks which have a certain topology. [3,6,18,19,42-44]

Different Methods of Protecting Microgrids

✓ Using fault current limiter:

- This FCL consists of three parallel paths.
- Path A has a fast mechanical switch which commutates the current on to path B which has power semiconductor elements. This path forces the current on to the resistor in path C for fault current limitation. [3,6,19,42-44]



Single-phase diagram of hybrid FCL.

Some Example Results of Microgrid Protection (Using FCL)

- ✓ Protection without FCL
- ✓ Protection with FCL

- o different solutions is proposed for reduction of the impact of DG on overcurrent coordination.
- o The aim of this paper is studying of restoration of network protection by installing fault current limiter in series with DG.
- o With using FCL the coordination of relays is restored without need to change the relay settings or DG disconnecting during the fault. [27]

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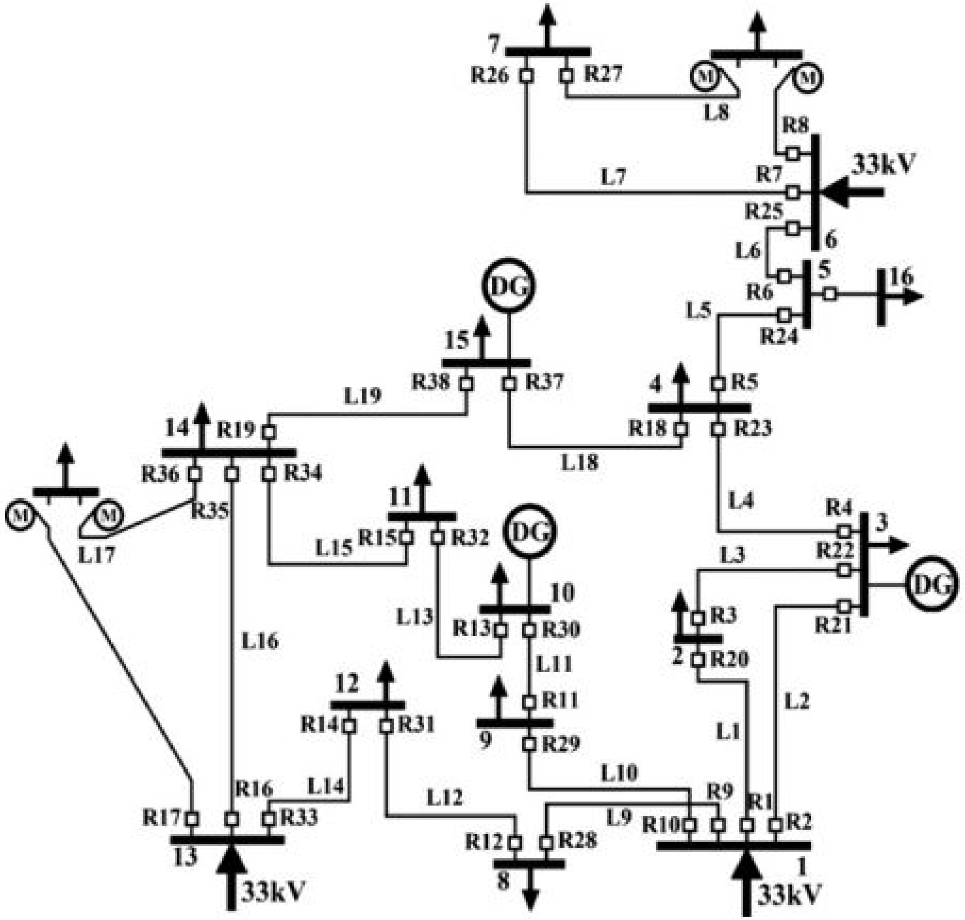
Some Example Results of Microgrid Protection (Using FCL)

✓ Protection with FCL



IEEE 30 Buses Distribution Network

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Some Example Results of Microgrid Protection (Using FCL)

✓ Protection with FCL

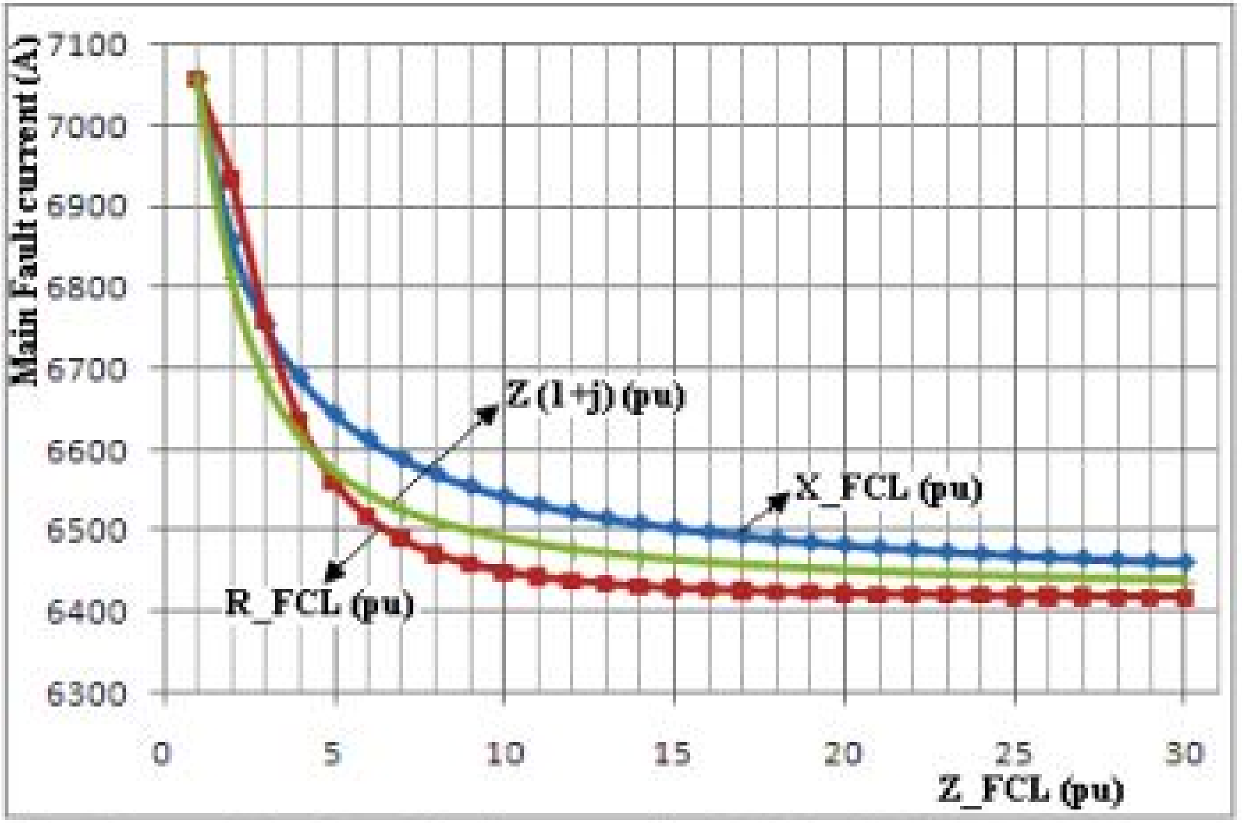

Fig. 4. Restoration of main fault current using R-FCL , X-FCL and Z-FCL

Some Example Results of Microgrid Protection (Using FCL)

✓ Protection with FCL

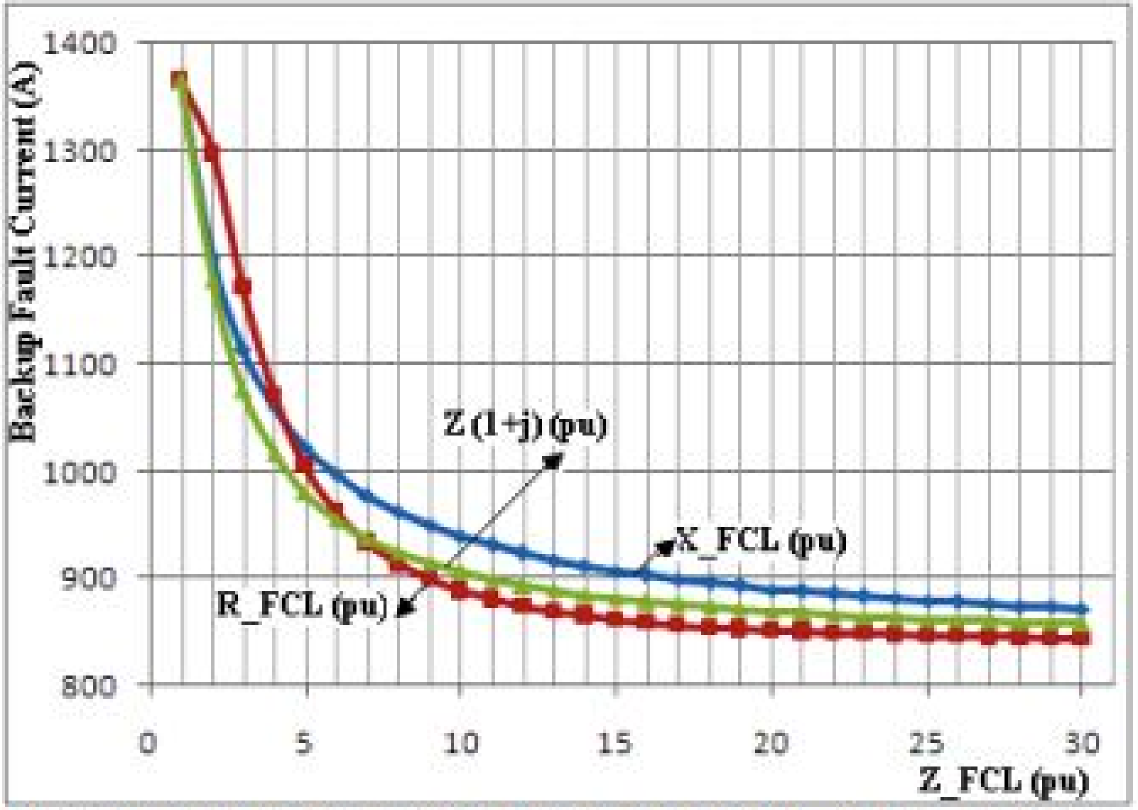

Fig. 5. Restoration of backup fault current using R-FCL , X-FCL and Z-FCL

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Some Example Results of Microgrid Protection (Using FCL)

✓ Protection with FCL

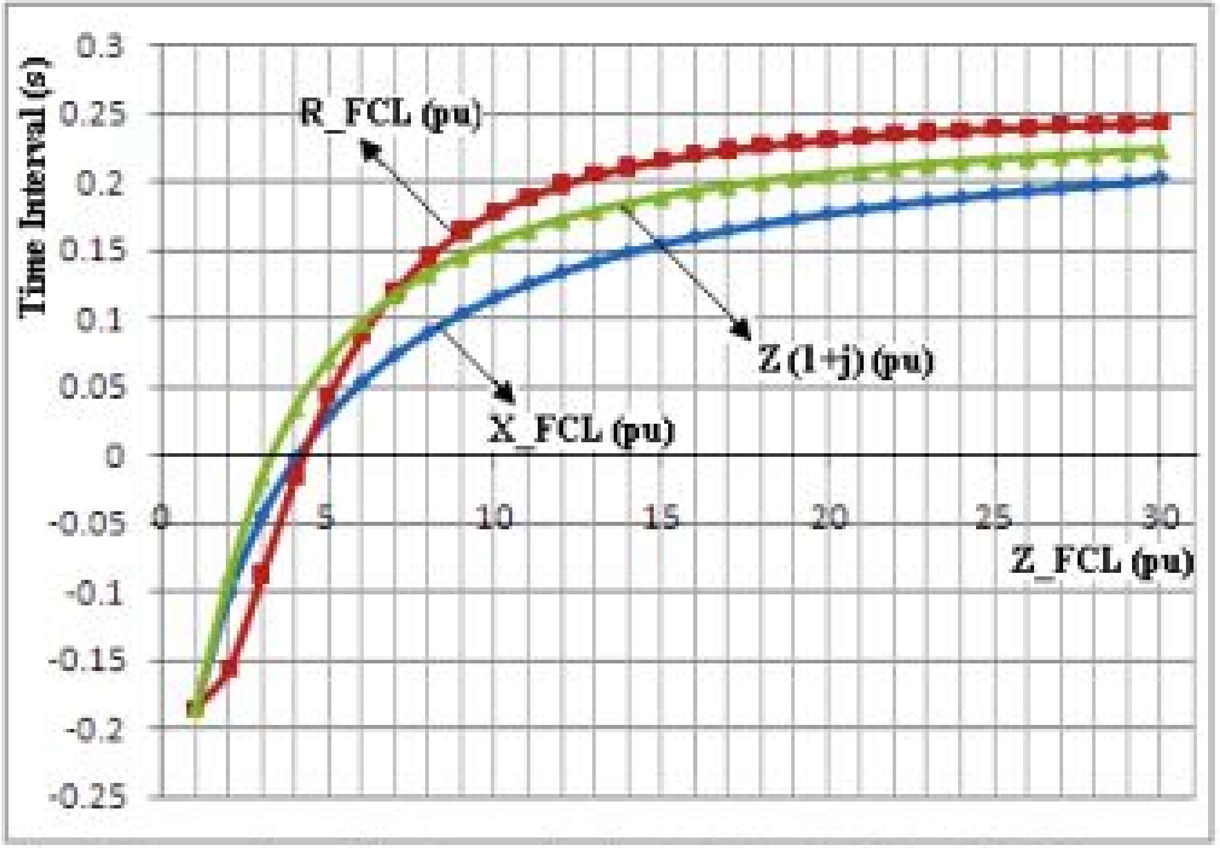


Fig. 6. Restoration of Time interval using R-FCL , X-FCL and Z-FCL

Some Example Results of Microgrid Protection (Using FCL)

✓ Protection with FCL

- compared in 4 cases as below:
  1)Without FCL
  2)Pure inductive FCL (X-FCL)
  3)Combined resistive and inductive FCL (C-FCL)
  4)Pure resistive FCL (R-FCL)
- For comparison the effect of various FCL types the impedance of FCL in all cases is chosen to be 10 pu.
- It can be seen from the figure 7 that the time interval of P/B relays is increased in mentioned cases respectively.
- For 10 pu impedance FCL the case of pure resistive is given best result for all P/B relays i.e. the time interval of all P/B relays reach higher than 0.2 second.

Some Example Results of Microgrid Protection (Using FCL)

✓ Protection with FCL

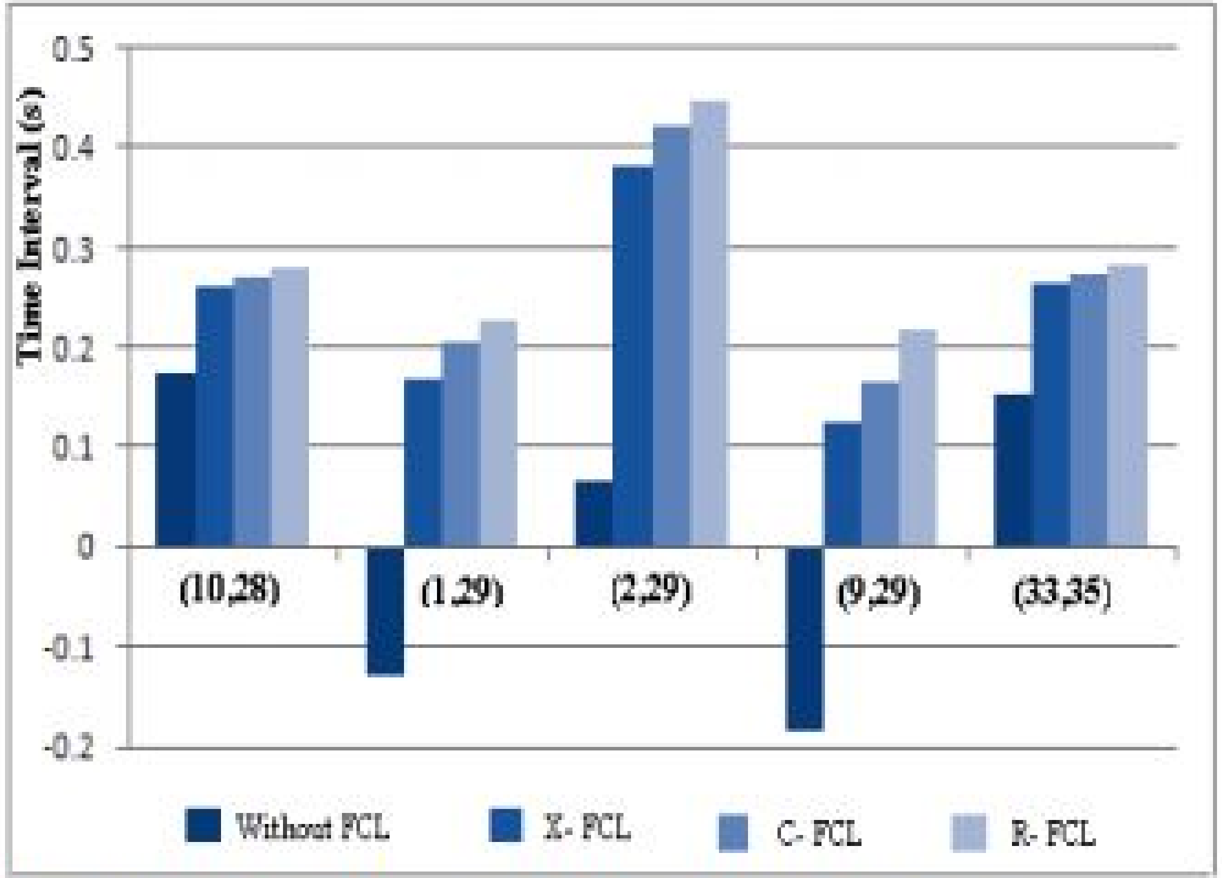


Fig. 7. Time interval of 5 worst pair relays for various FCL type

Some Example Results of Microgrid Protection (Using FCL)

✓ Protection of microgrid considering transient behavior (Relay, DG and FCL)

- The use of DG and FCL in distribution networks causes to some transient currents during fault conditions.
- Steady-state coordination methods do not result in accurate settings in such networks.
- A new method is proposed for coordination of O/C relays by considering the transient behavior of the network
- This method is based on the genetic algorithm and uses the dynamic model of O/C relays instead of the fixed characteristic curves. For this purpose, transient behavior of DG and FCL are simulated and the relay operating status is calculated for all primary and backup relays to achieve the optimal settings of relays in transient condition. [28]

Some Example Results of Microgrid Protection (Using FCL)

✓ Protection of Microgrid Considering Transient Behavior (Relay, DG and FCL)

$$i_{AC}(t) = \sqrt{2}E_g\left[\left(\frac{1}{X''_d} - \frac{1}{X'_d}\right)e^{(-t/T''_d)} + \left(\frac{1}{X'_d} - \frac{1}{X_d}\right)e^{(-t/T'_d)} + \frac{1}{X_d}\right]\sin(\omega t + \alpha)$$

$$i_{DC}(t) = \frac{E_g}{\sqrt{2}}\left[\left(\frac{1}{X''_d} + \frac{1}{X''_q}\right)e^{(-t/T_a)}\right]\cos\alpha$$

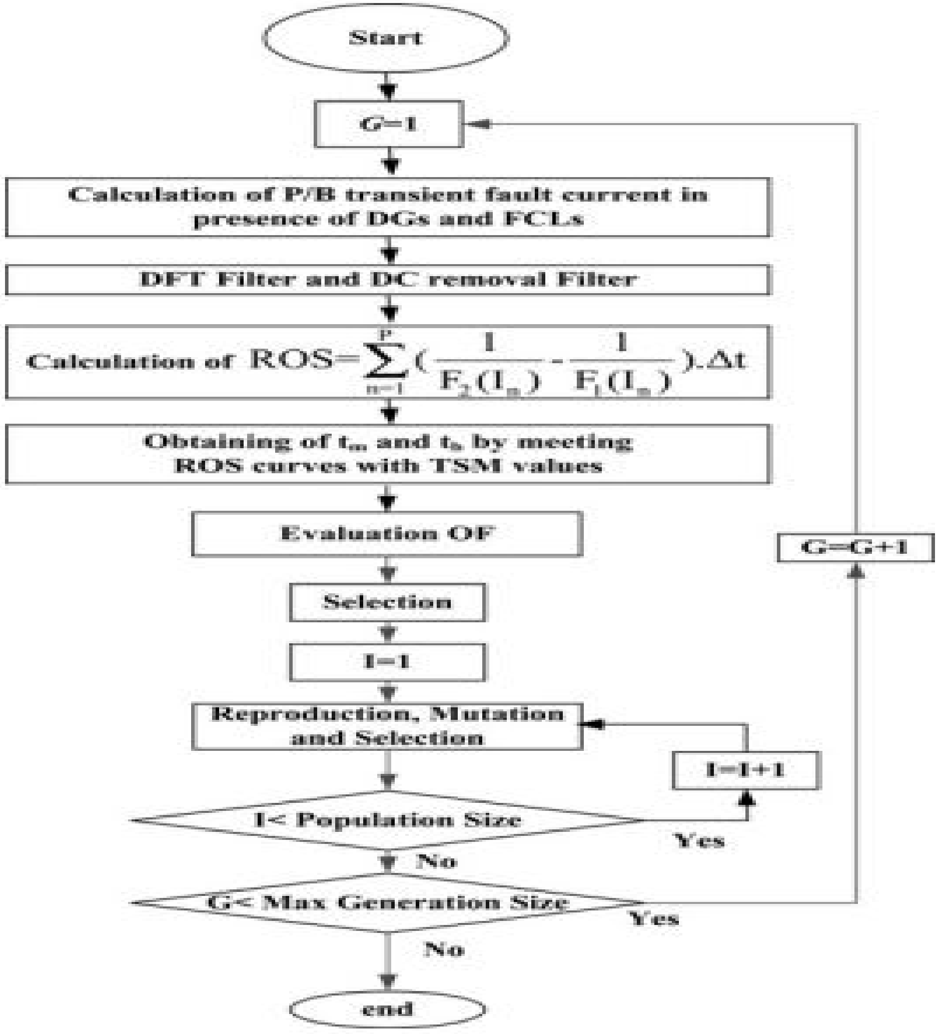
$$\text{OF} = \alpha_1 \sum (t_i)^2 + \alpha_2 \sum (\Delta t_{mb} - \beta_2(\Delta t_{mb} - |\Delta t_{mb}|))^2$$

$$\sum_{n=1}^{p}\left(\frac{1}{F_2(I_n)} - \frac{1}{F_1(I_n)}\right)\Delta t$$

$$\Delta t_{mbk} = t_{bk} - t_{mk} - \text{CTI}$$

Some Example Results of Microgrid Protection (Using FCL)

- ✓ Protection of Microgrid Considering Transient Behavior (Relay, DG and FCL)



Flow diagram of GA application in new coordination method

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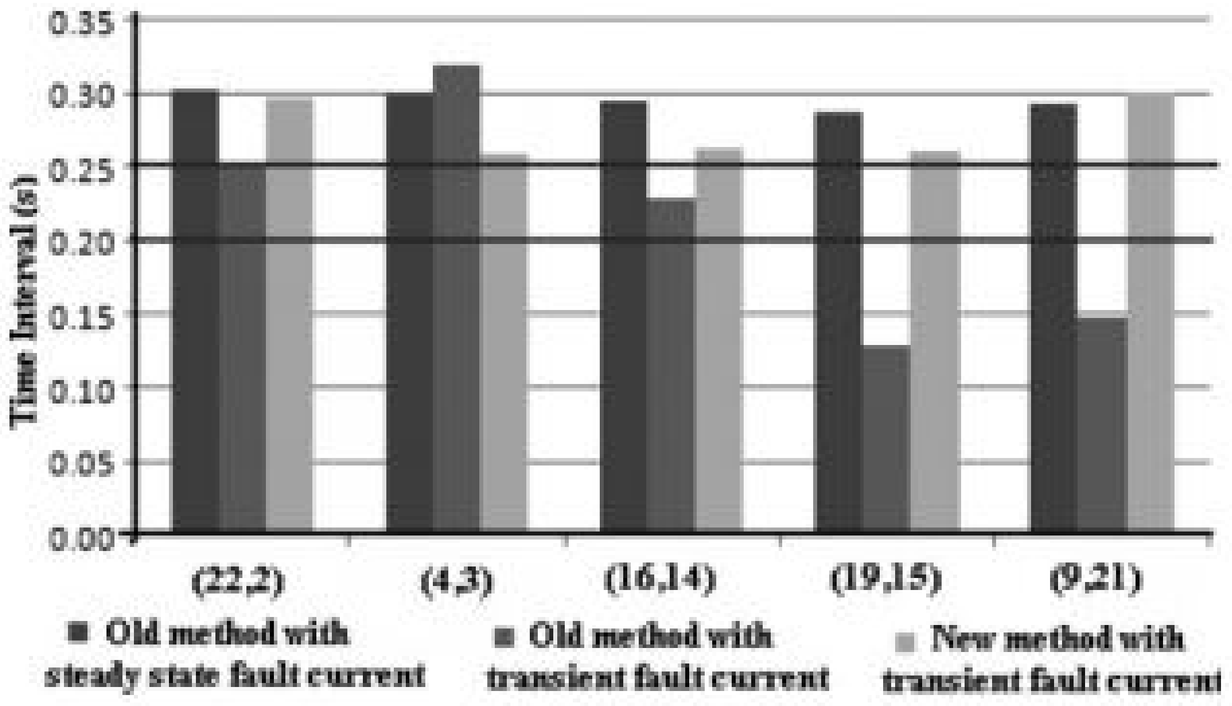
Some Example Results of Microgrid Protection (Using FCL)

- ✓ Protection of Microgrid Considering Transient Behavior (Relay, DG and FCL)



Time intervals of new method in comparison of old method

Discussion

- Most presented methods cannot cover all operational topologies of microgrid because of using offline calculations.
- Necessity in a method for microgrid protection which can adapt dynamic changes of these networks and guarantee speed and selectivity of protection system lead us to adaptive protection.
- Considering advantages of decentralized structure over centralized structure in adaptive protection, using online multi-agent protection methods is the most appropriate method to respond microgrid topology uncertainties.
- The issue which can challenge multi-agent protection methods is uncertainty in the probability of correct operation of agents and communication links.
- It is proposed that adaptive protection plans be developed in a way that enables them to make global decisions. [3,20]

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