GE Power Management

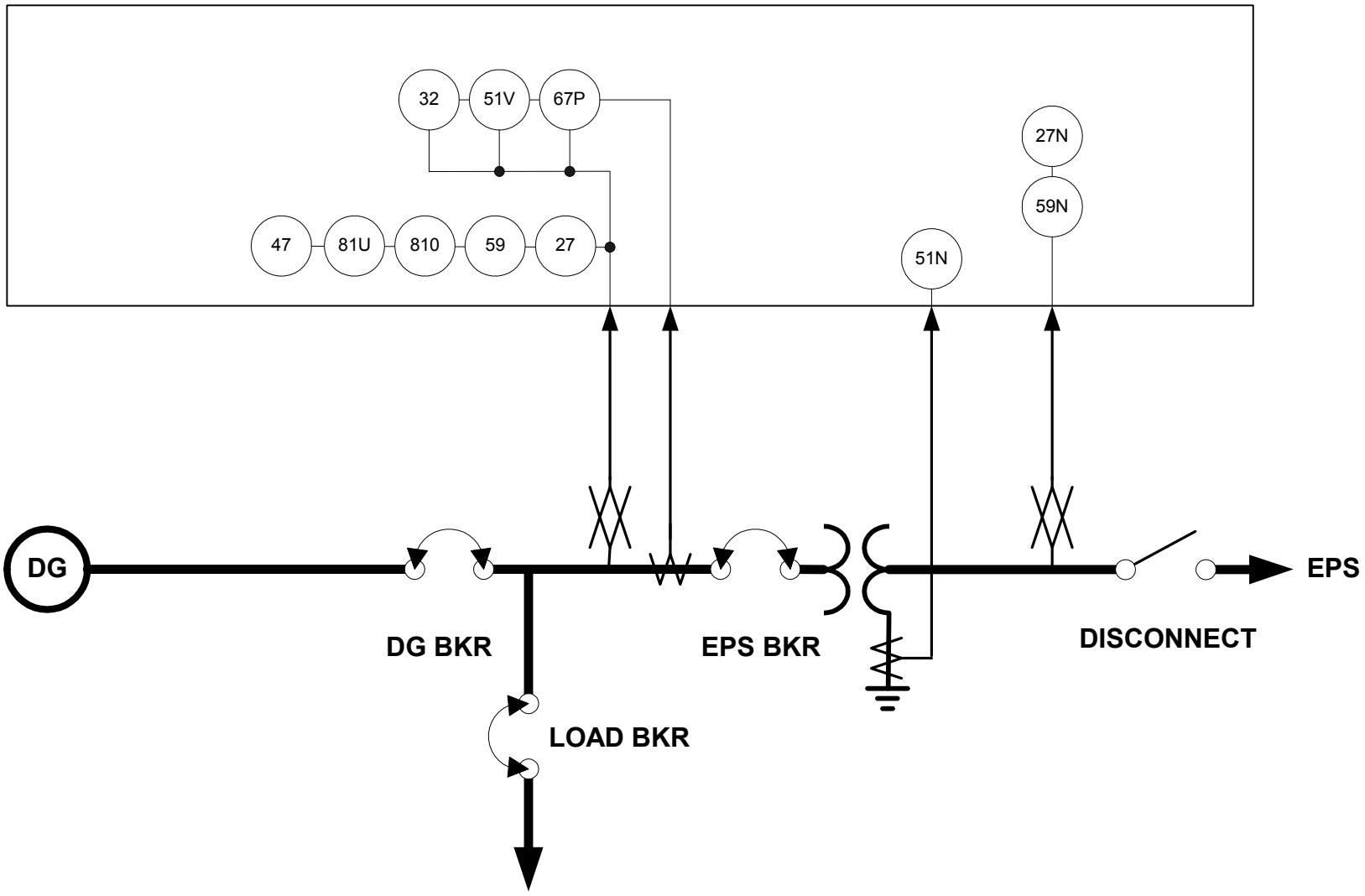
Generator Protection Needs in a DG Environment

Introduction

- **Protection**
- **Monitoring & Control**
- **Anti-islanding**
- **Communications**

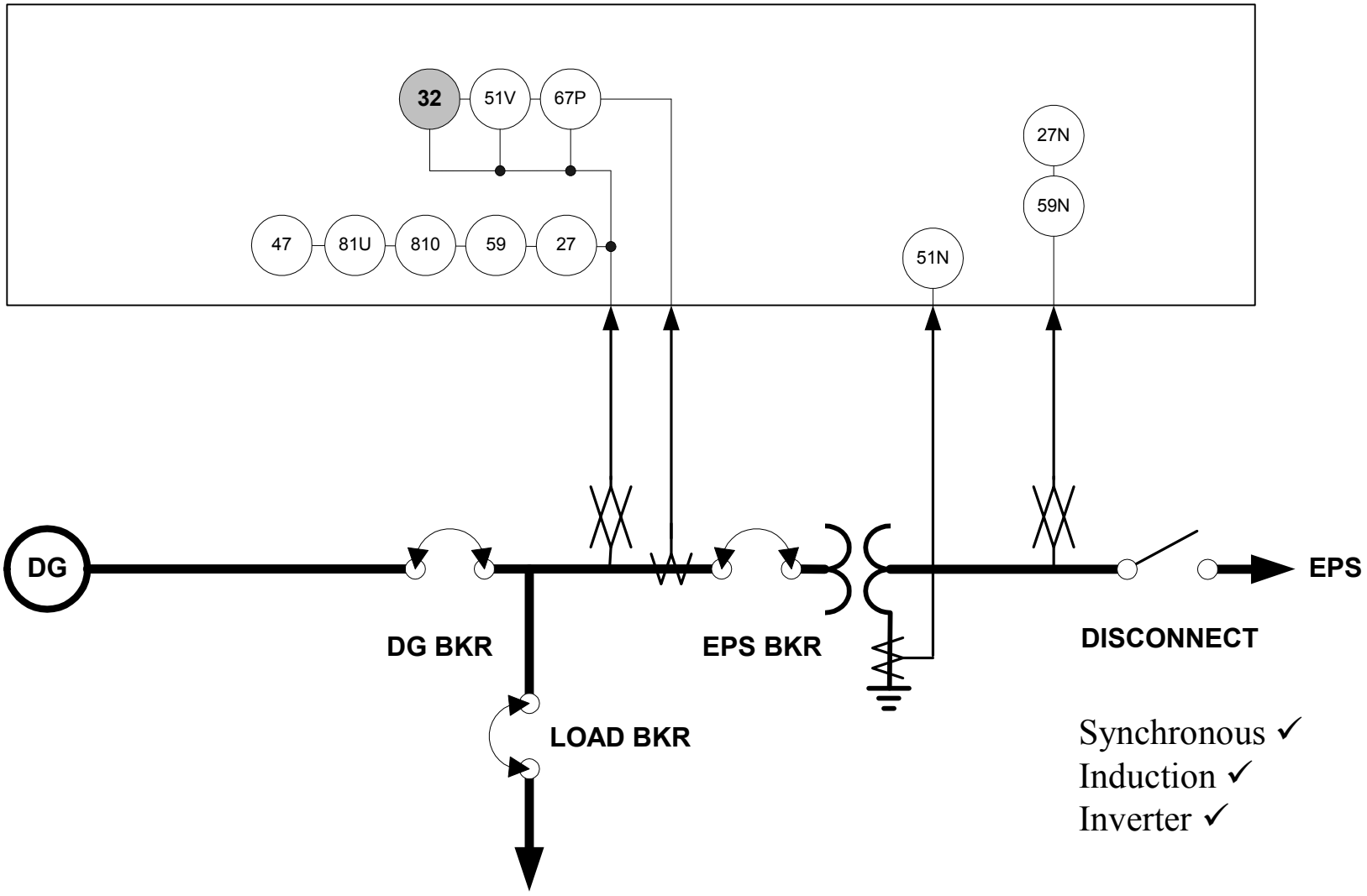
Protection

- **EPS Protection:**



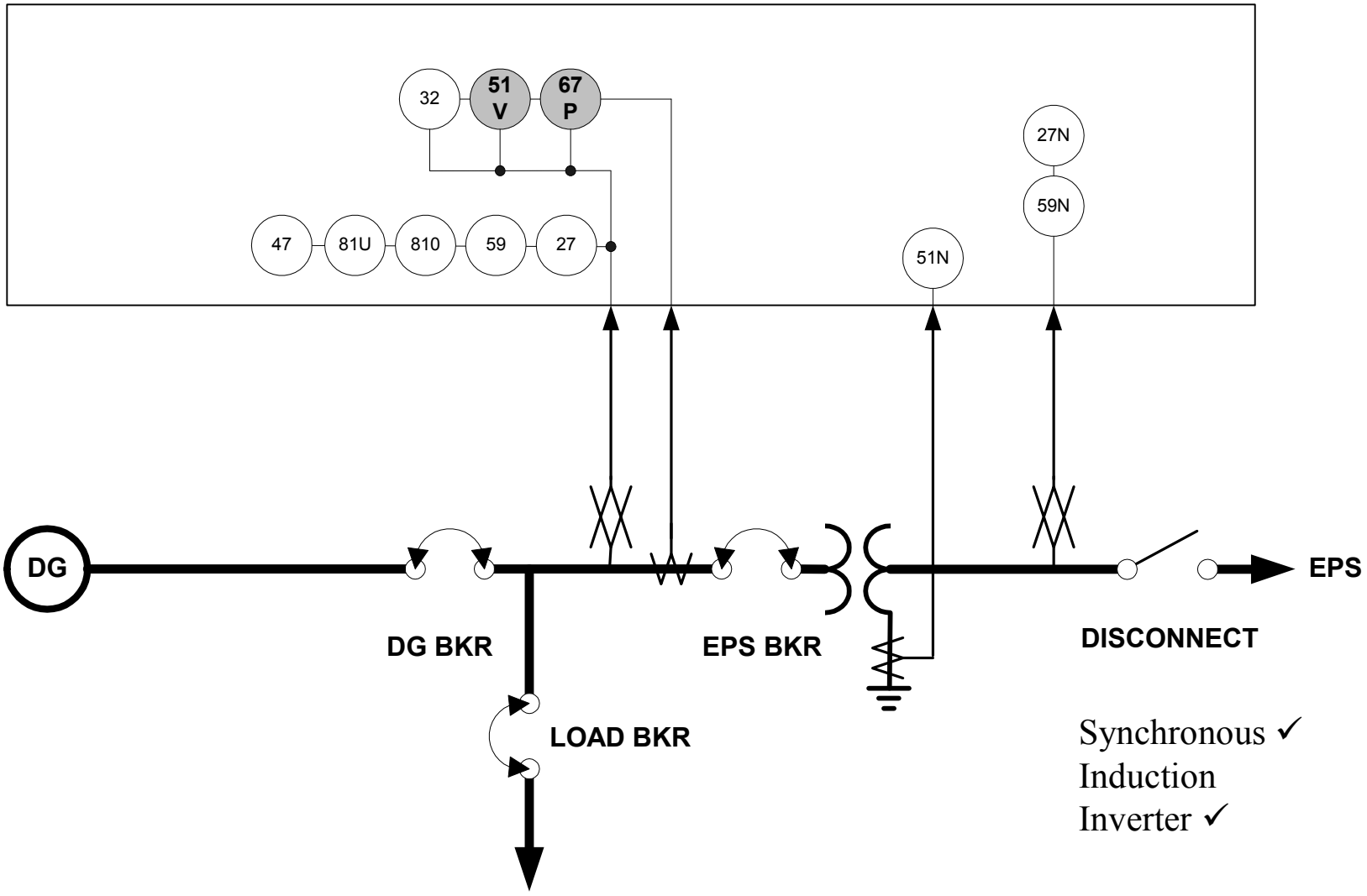
Protection

- **Forward Power:**



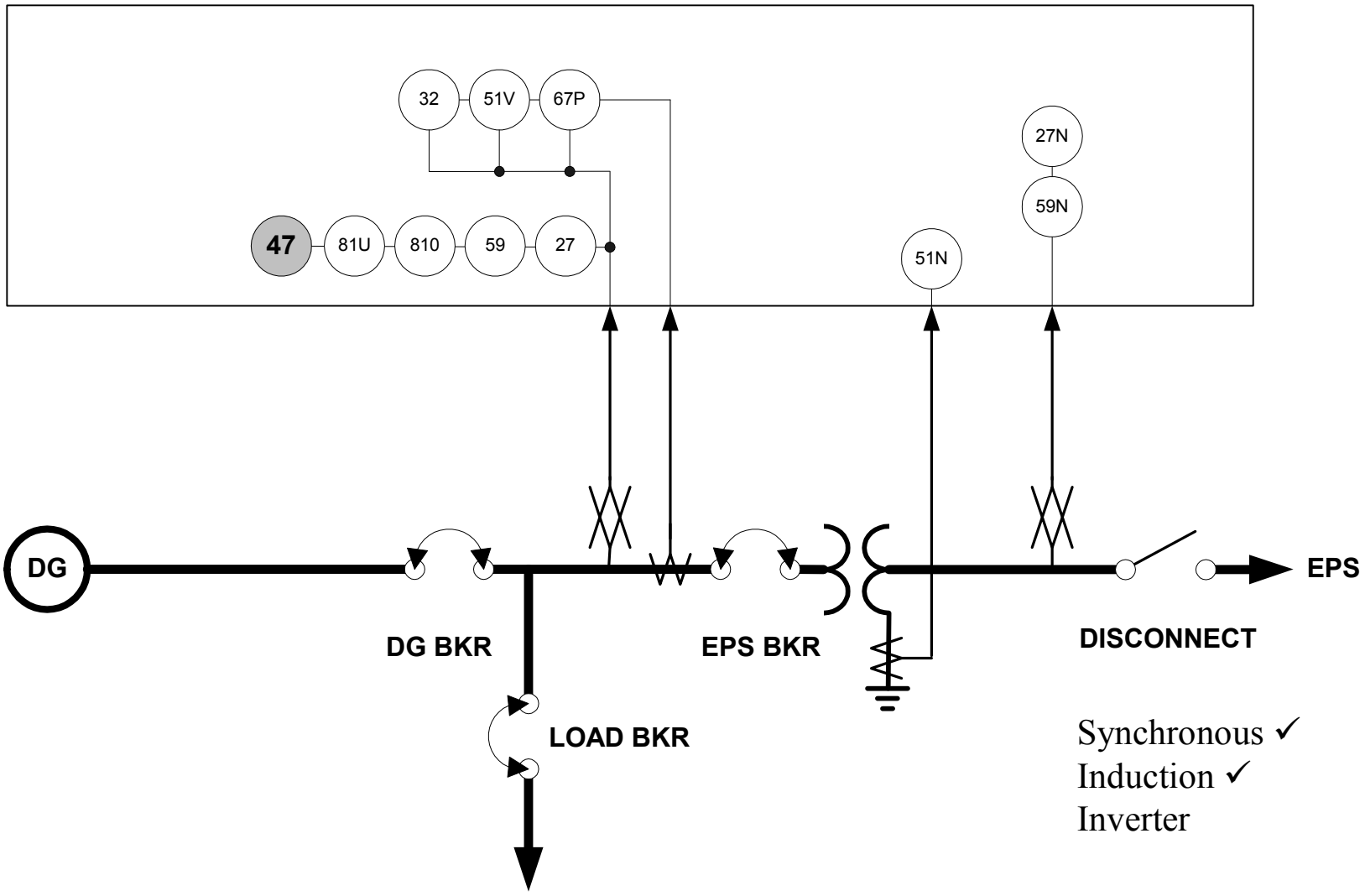
Protection

- **Phase Faults:**



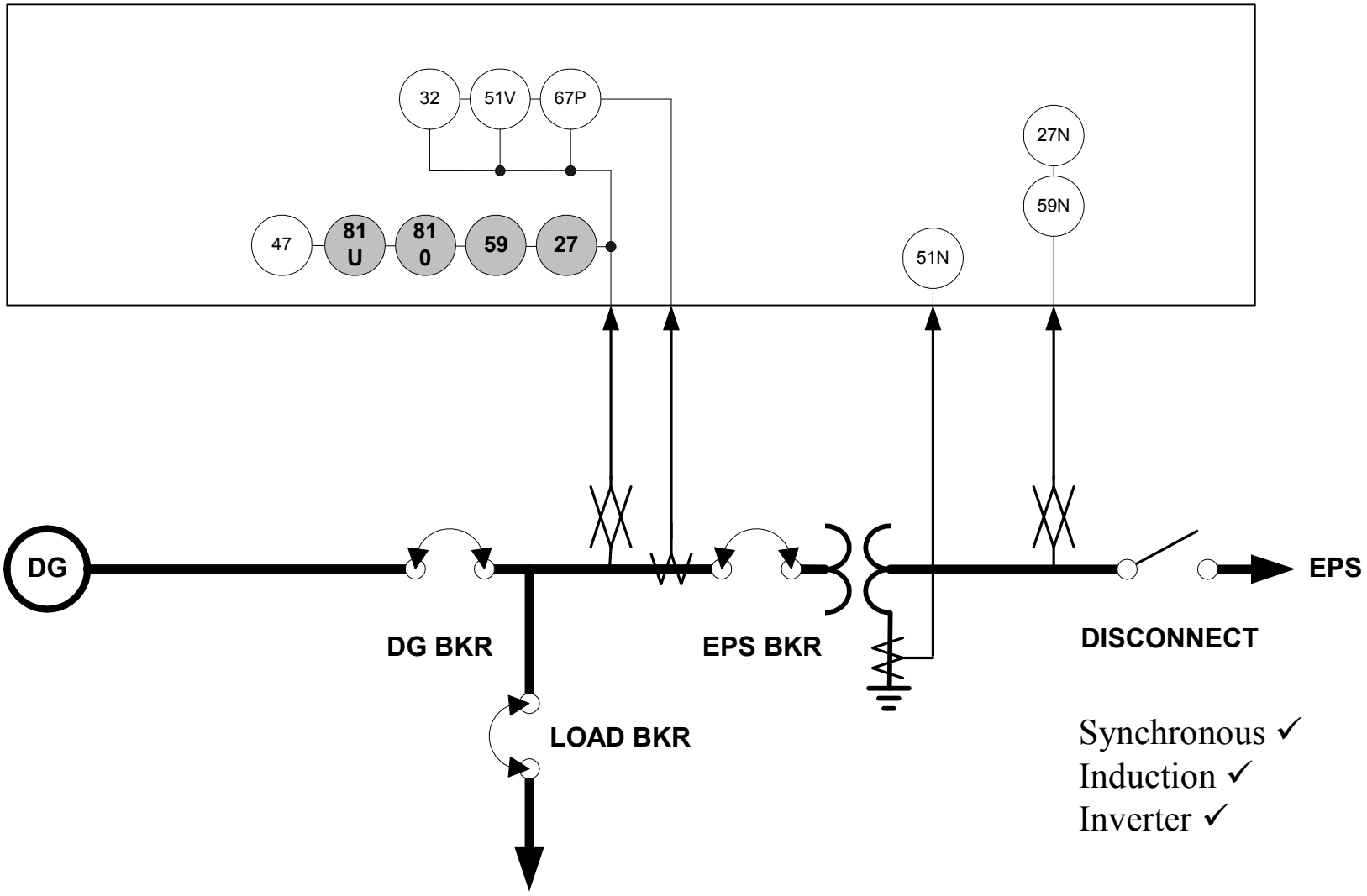
Protection

- **Reverse Phase:**



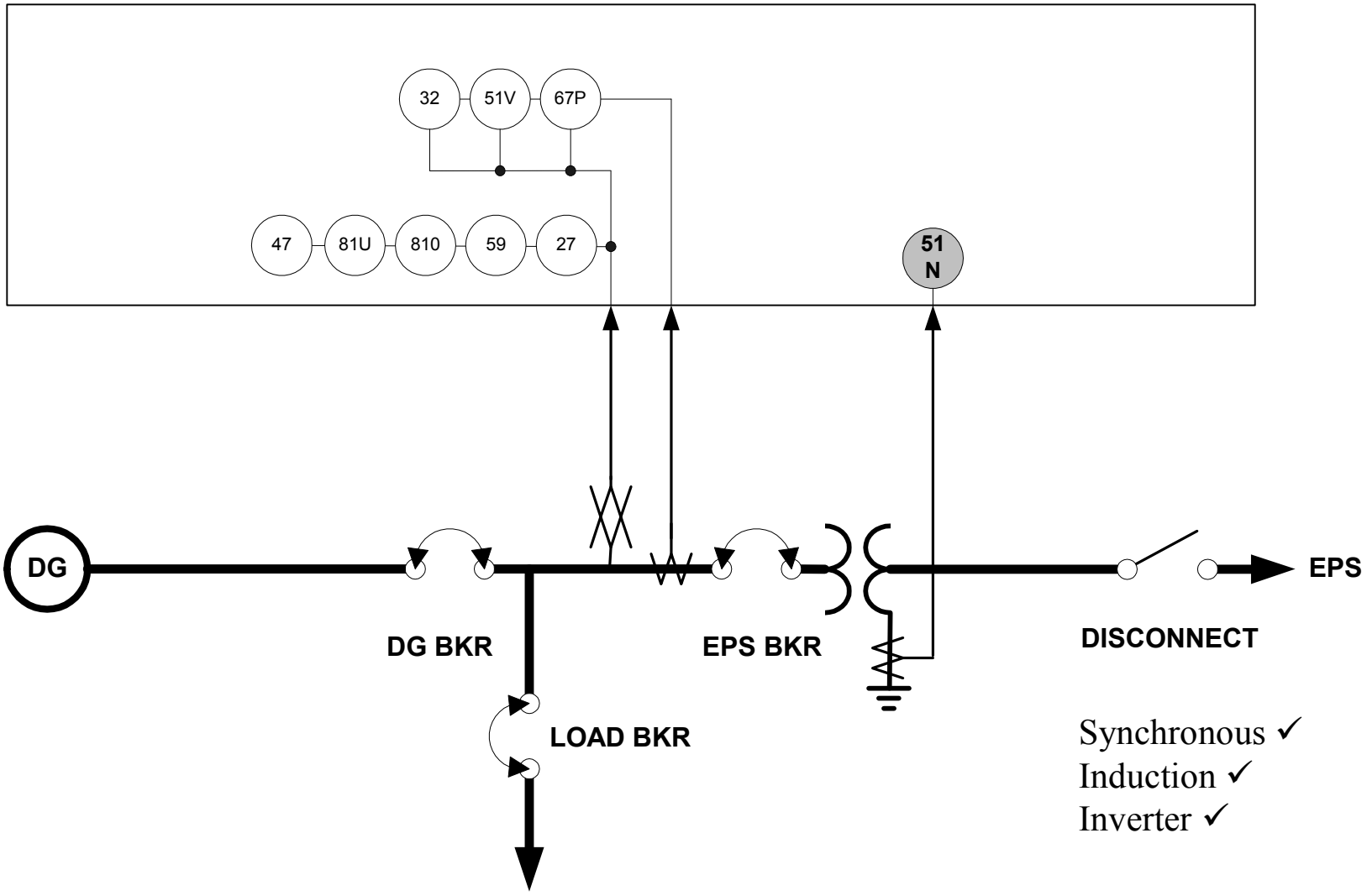
Protection

- **Abnormal Voltage & Frequency:**



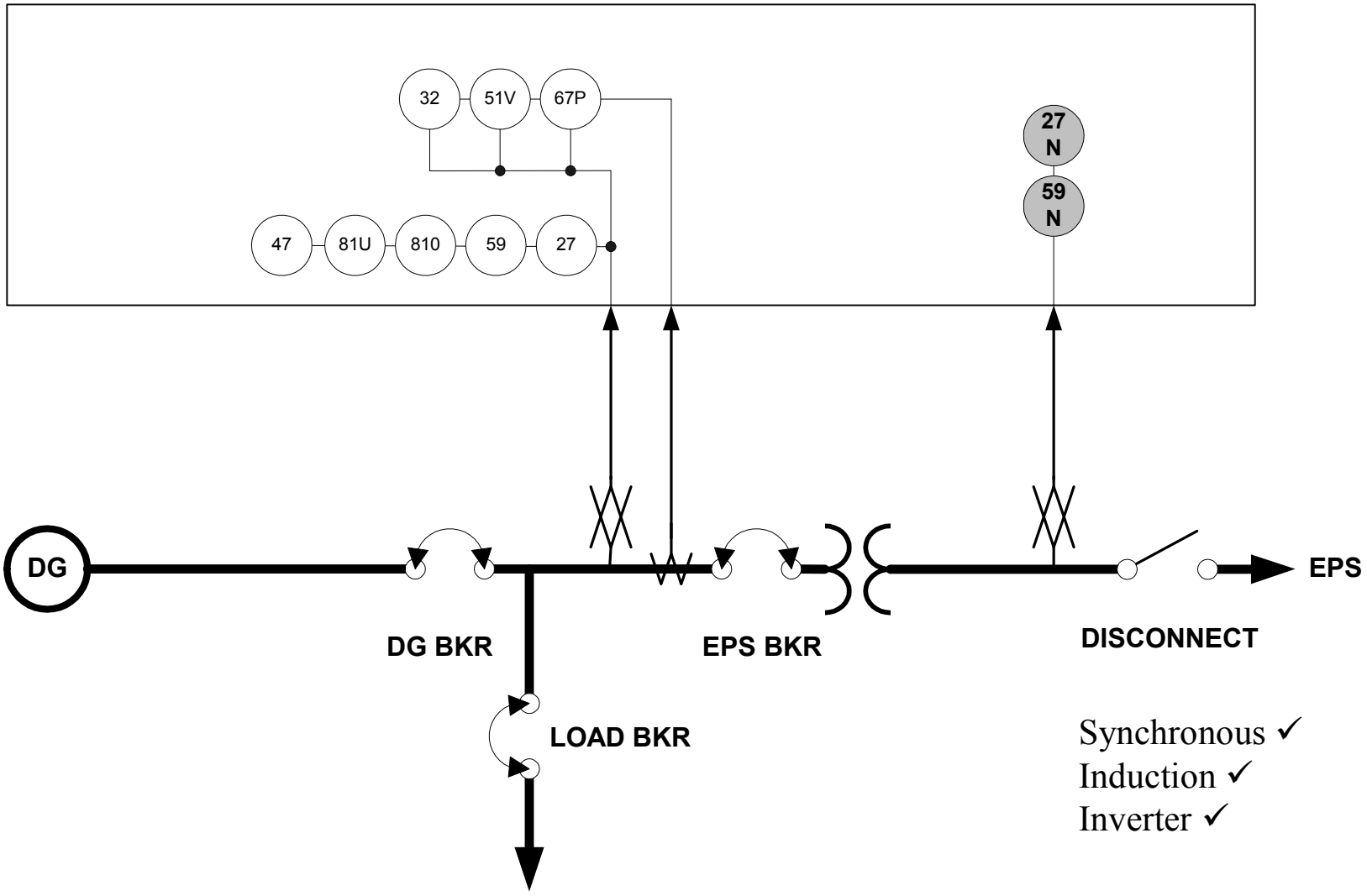
Protection

- **System Ground Faults:**



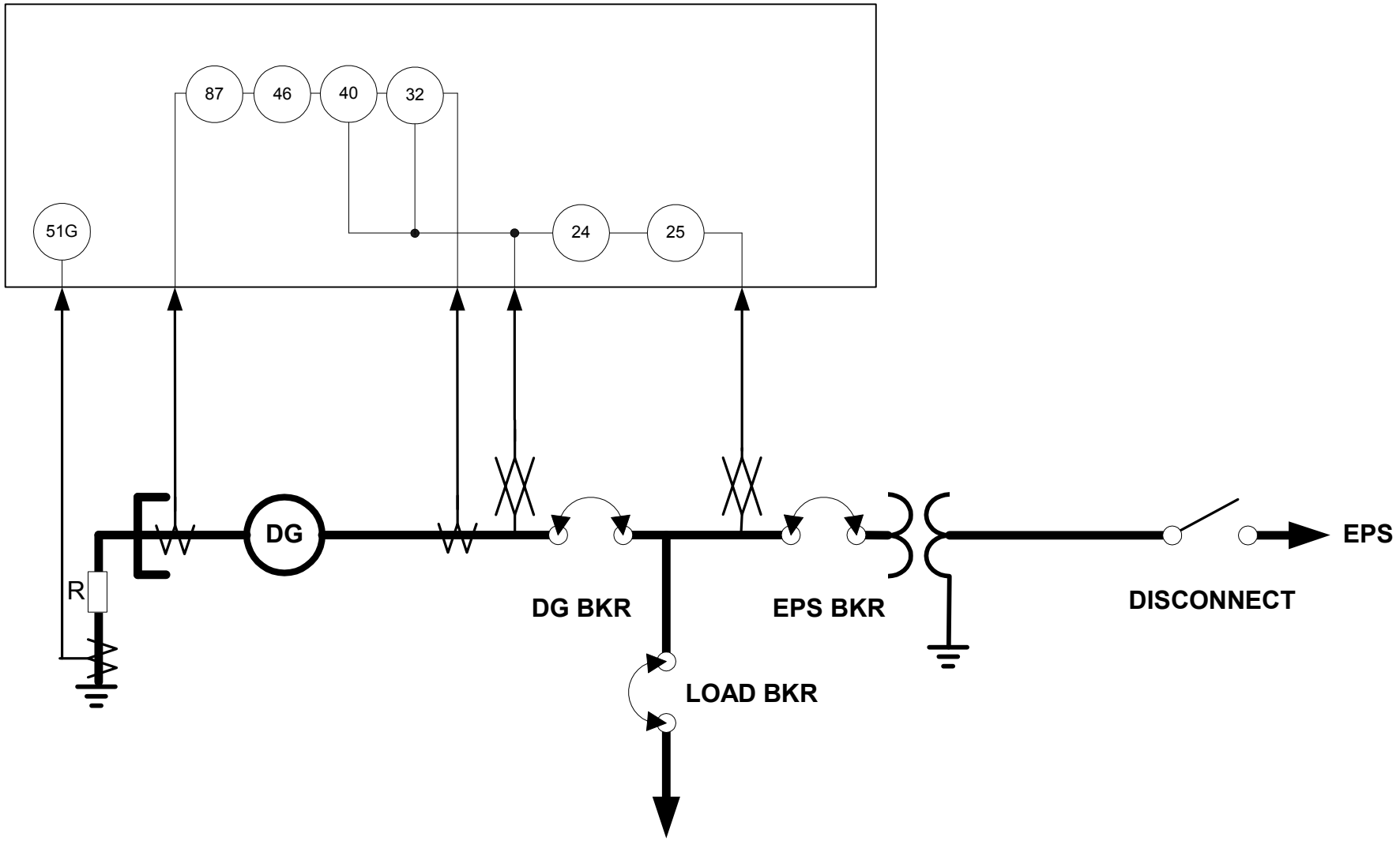
Protection

- **System Ground Faults:**



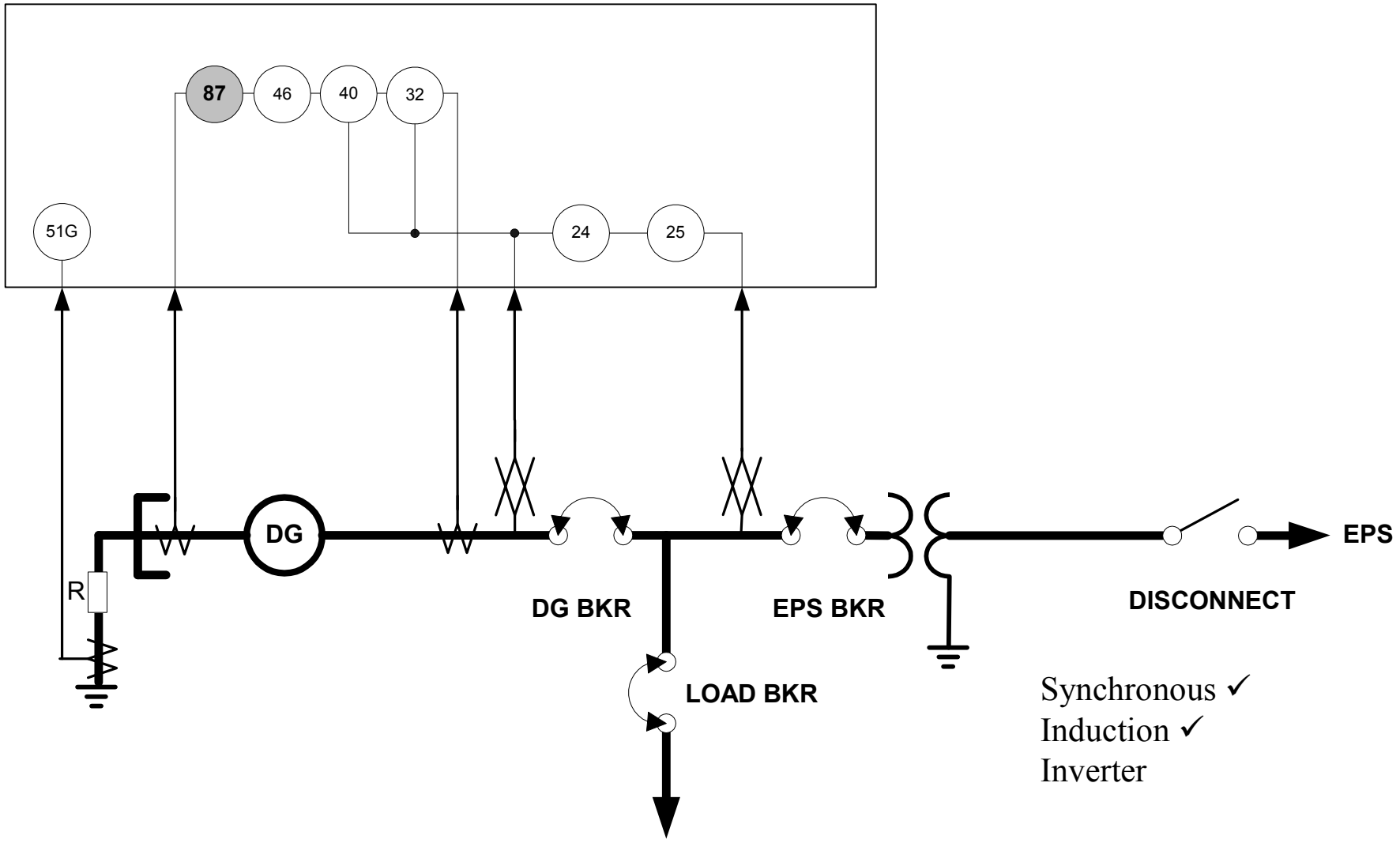
Protection

- **DG Protection:**



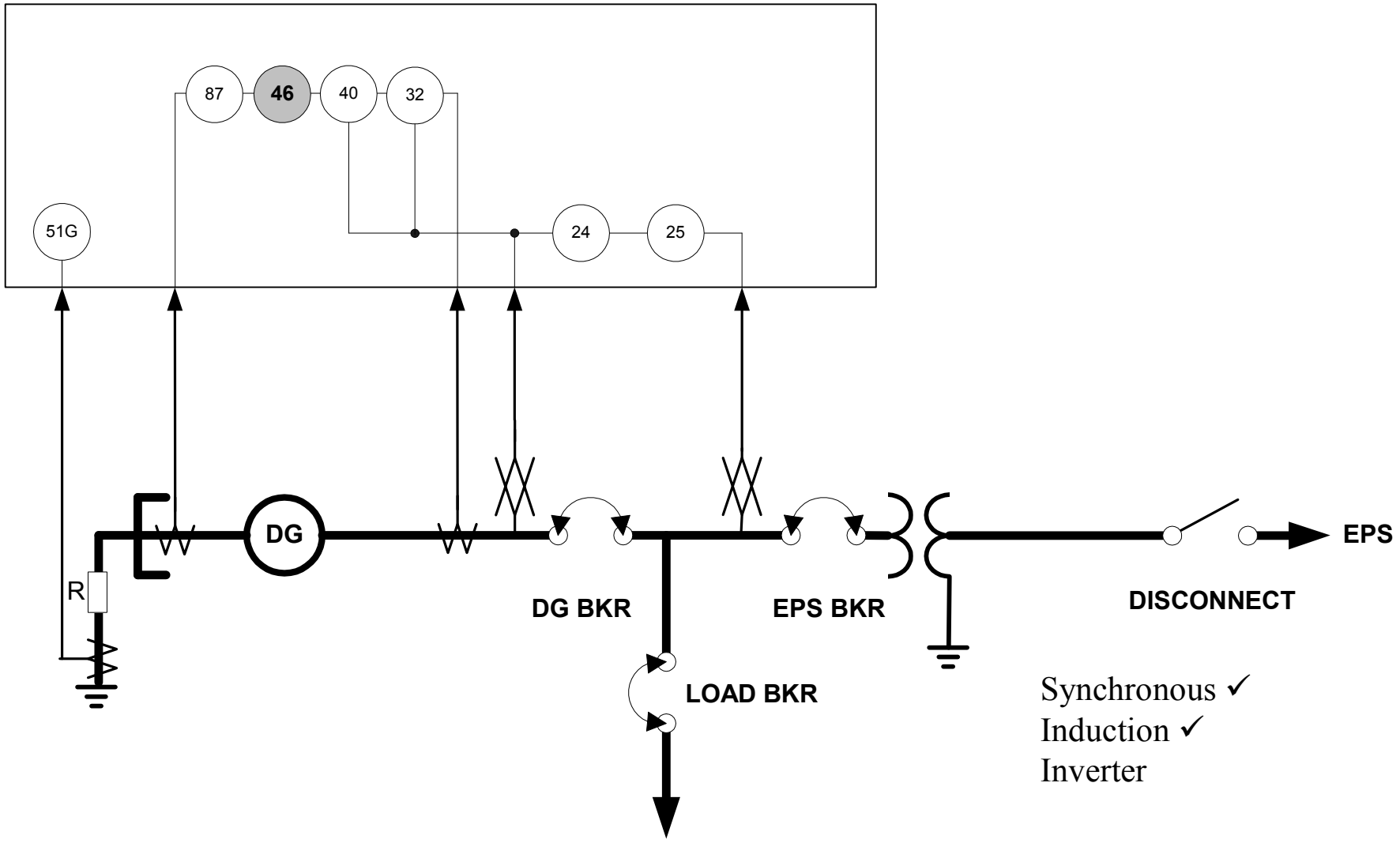
Protection

- **Stator Differential:**

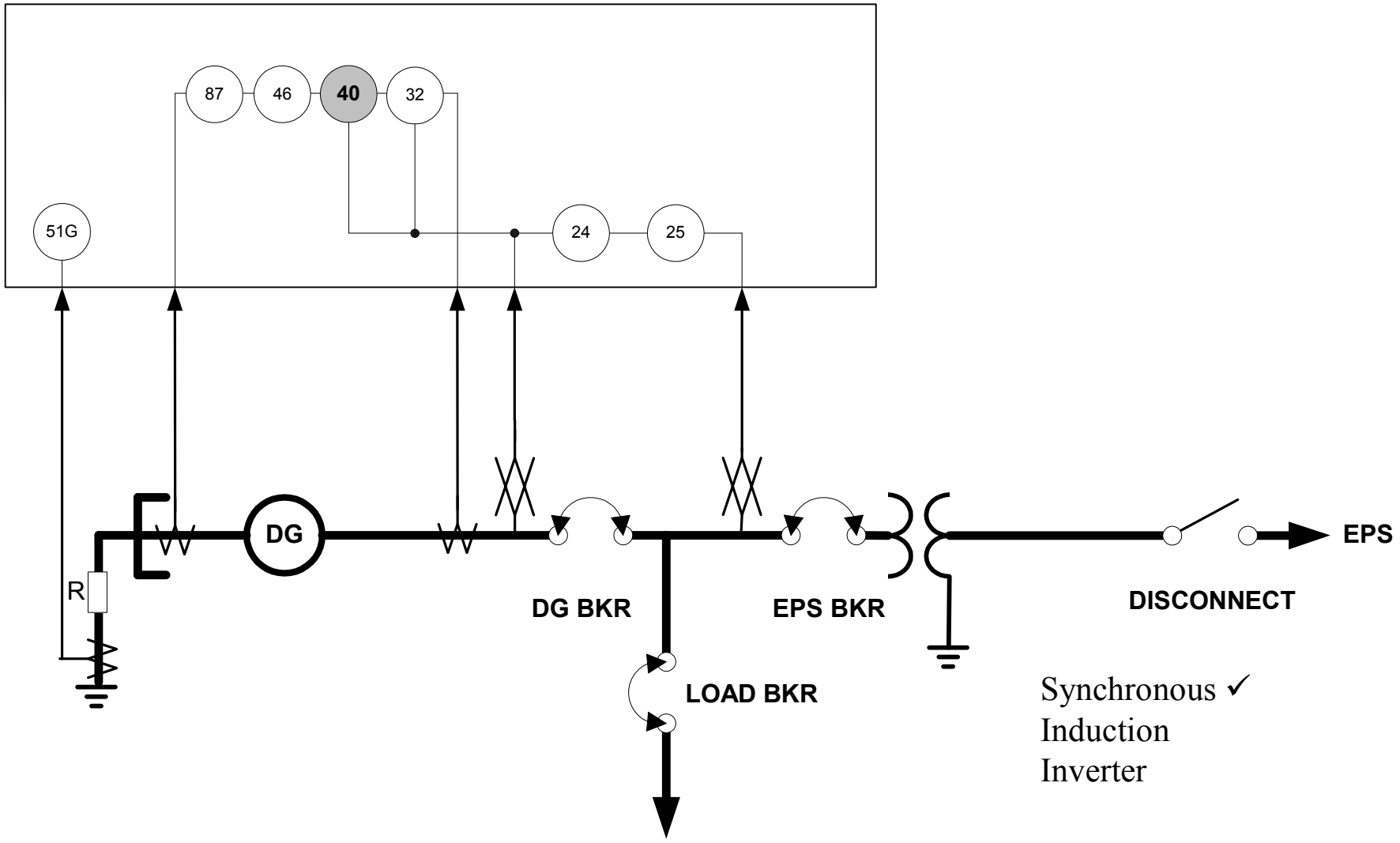


Protection

- **Generator Unbalance:**

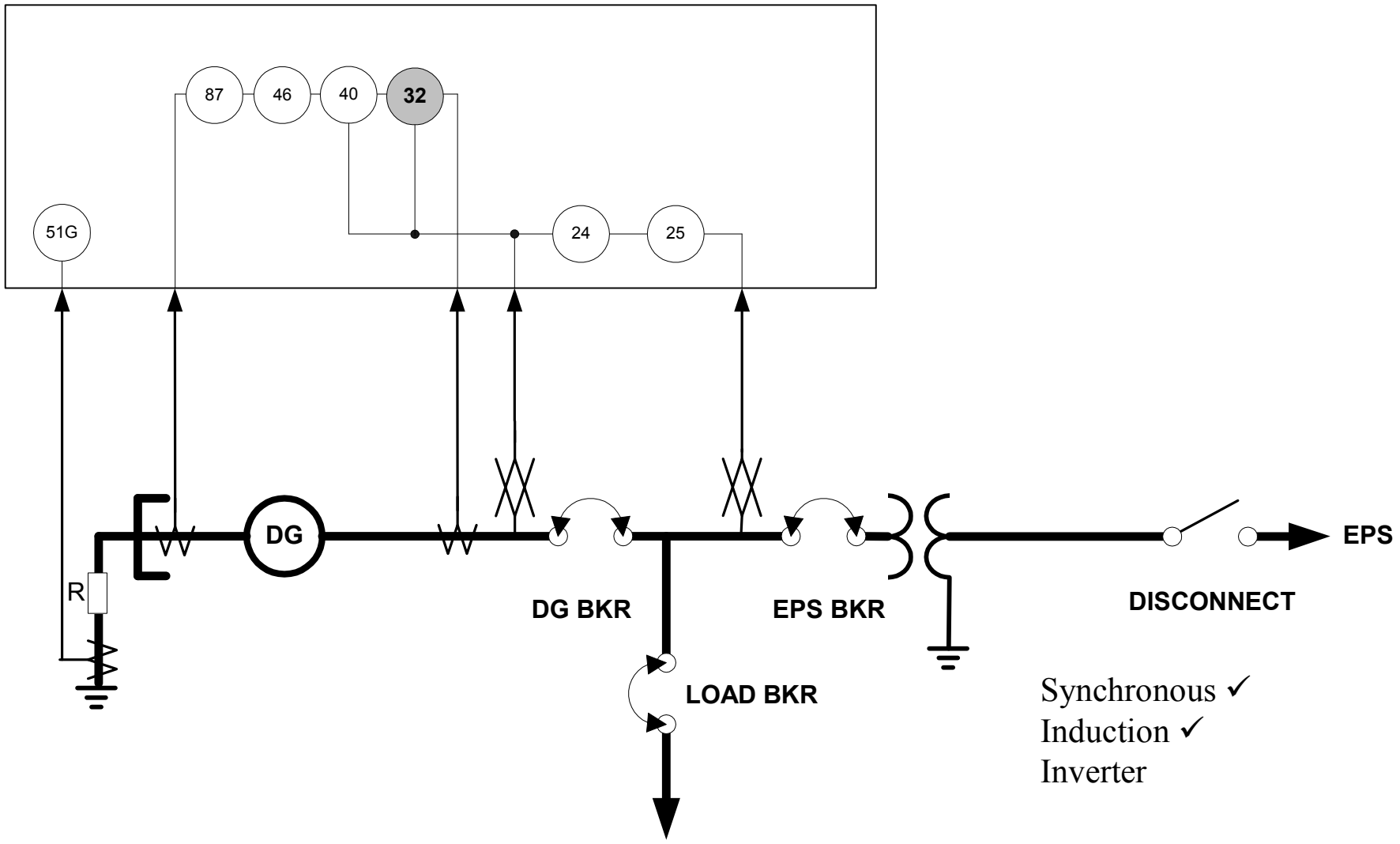


- **Loss of Excitation:**



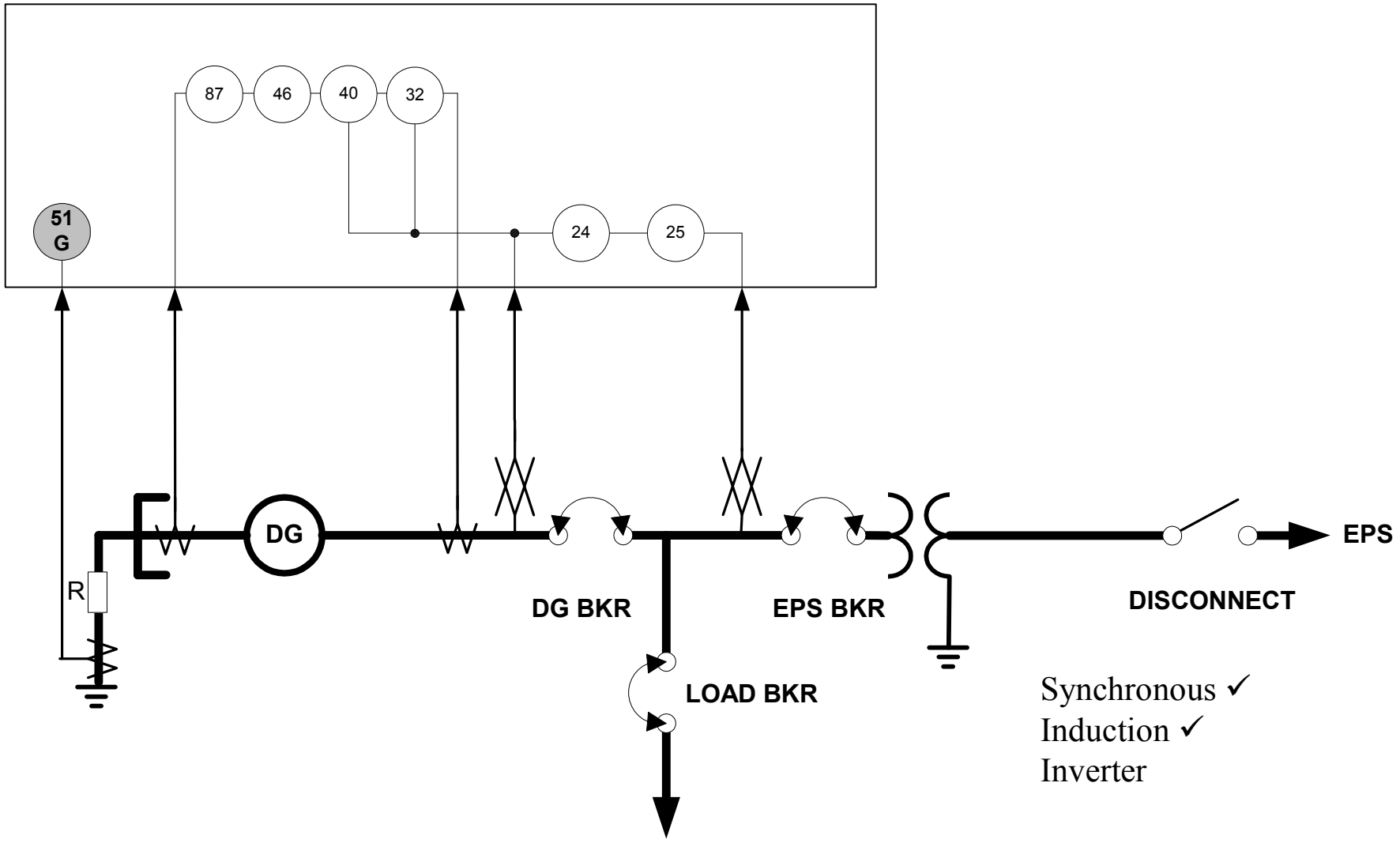
Protection

- **Reverse Power:**



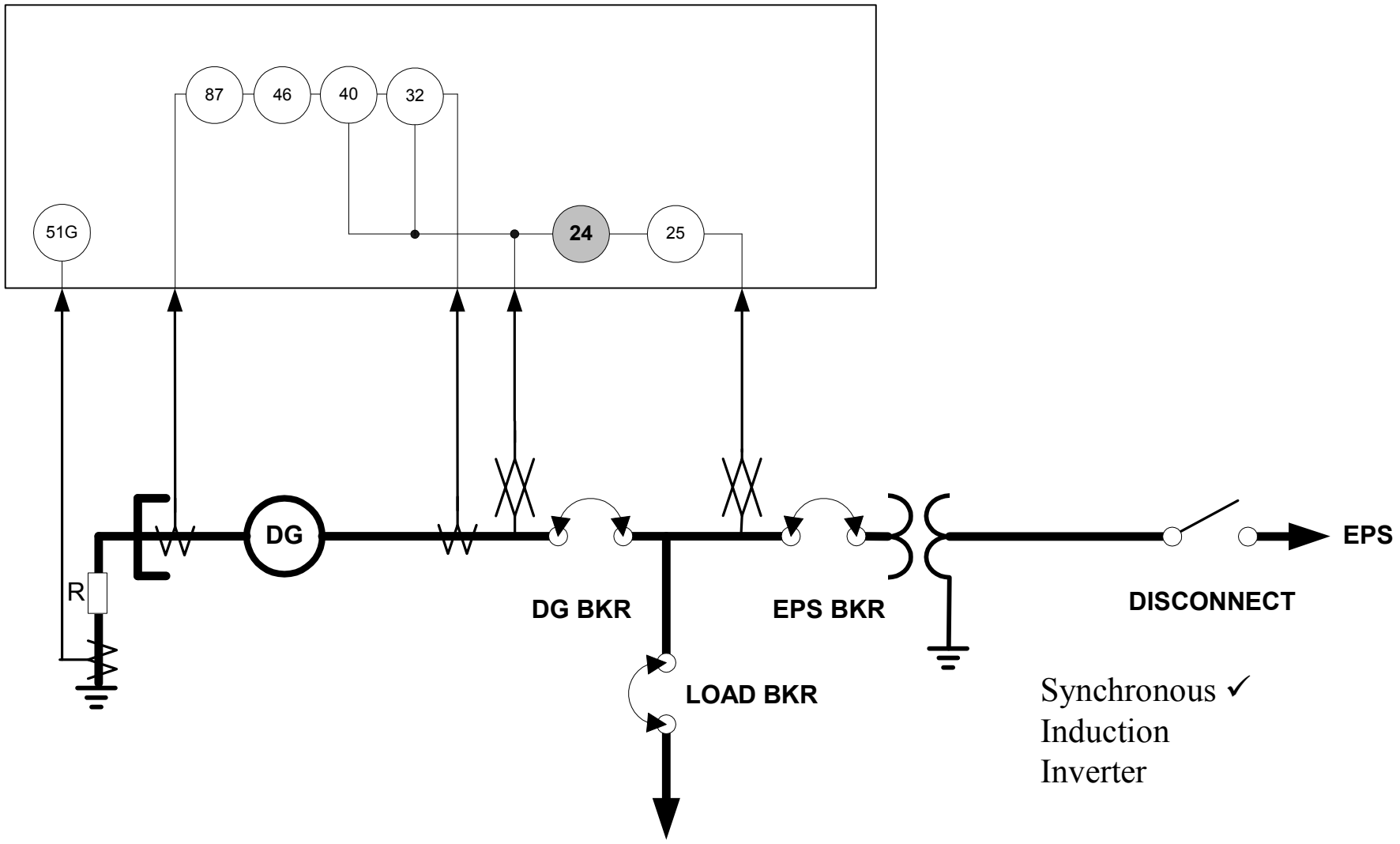
Protection

- **Generator Ground Faults:**



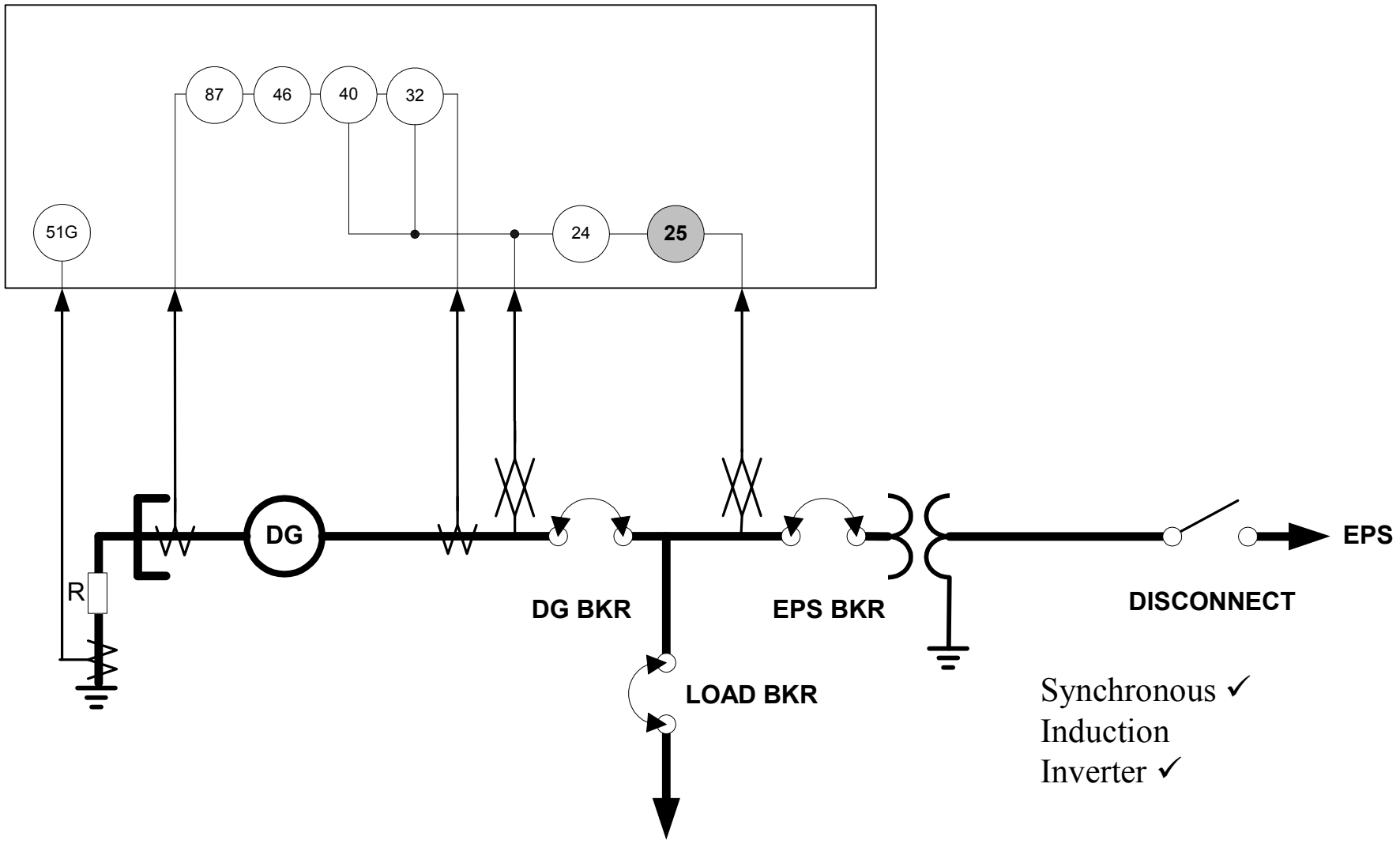
Protection

- **Over-Excitation:**



Protection

- **Synch-Check:**



Monitoring

- Metering
  - Voltage
  - Current
  - Real/Reactive Power
  - Energy
- Power Quality
  - Voltage & Current Harmonics
  - Power Quality Statistics
- Status
  - Breaker Position
  - Sequence of Events
- Oscillography/Data Logger

Control

- Local Interface
  - Easy access to protection settings.
  - Display of voltage, current, energy, power factor.
  - Display of protection target information, breaker and disconnect status.
  - Control actions such as manual trip & close.
- Programmable Functionality
  - Interlocking
  - Auto-synchronizing
  - Auto-restoration

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  - Control actions such as manual trip & close.
- Programmable Functionality
  - Interlocking
  - Auto-synchronizing
  - Auto-restoration

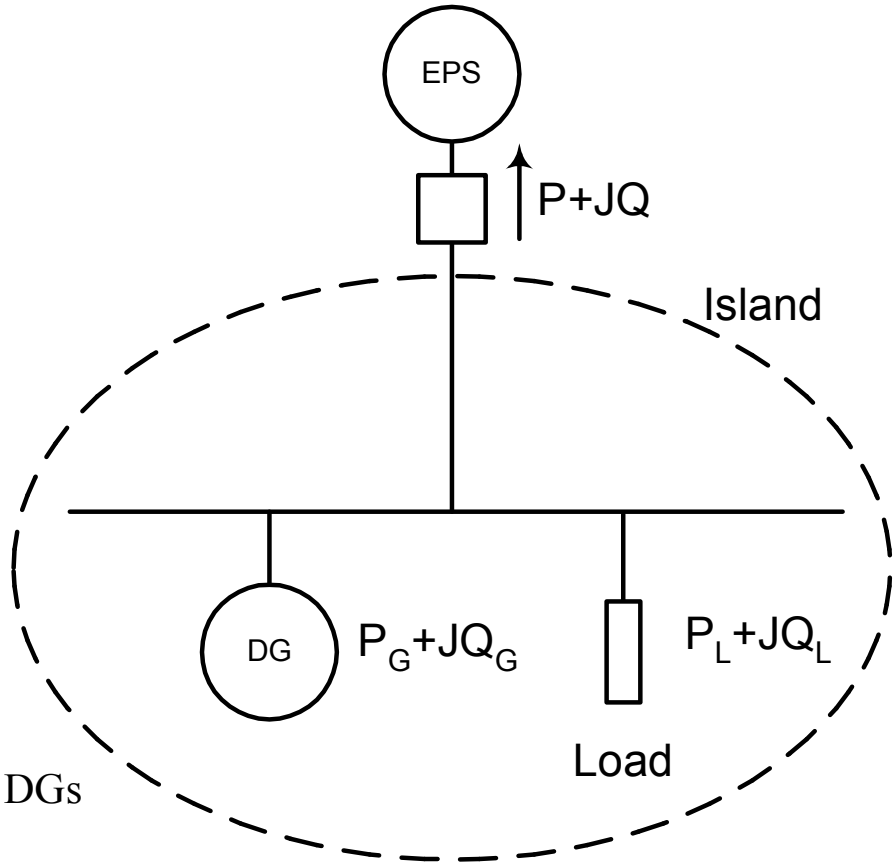
Summary

- **Due to the variety of possible implementations of distributed generation, a broad array of protective elements may be required.**
- **In addition to protection there is an opportunity to integrate a host of additional functions.**

Survey of Methods

Anti-Islanding (Passive)

- **OF/UF, OV/UV:**



Advantages

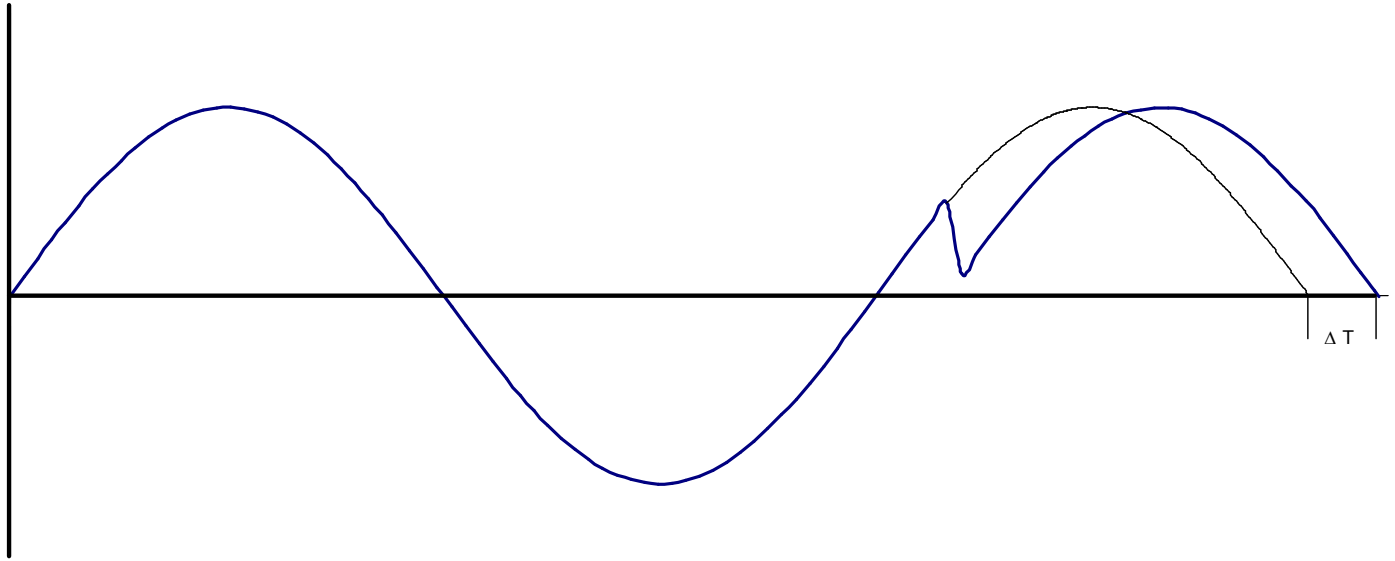
- Applicable to conventional DGs

Disadvantages

- Tripping time may be long for small mismatch
- Fails when P+jQ = 0

Anti-Islanding (Passive)

- **Voltage Vector Jump:**



Advantages

- Can operate more quickly than voltage/frequency protection
- Secure for single phase faults
- Applicable to conventional DGs

Disadvantages

- Can be difficult to set
- Fails when P+jQ = 0

Anti-Islanding (Passive)

- **Rate of Change of Frequency:**

Advantages

- Can operate more quickly than voltage/frequency protection
- Applicable to conventional DGs

Disadvantages

- May be difficult to reliably discriminate between an islanding event and a system disturbance.
- Fails when P+jQ = 0

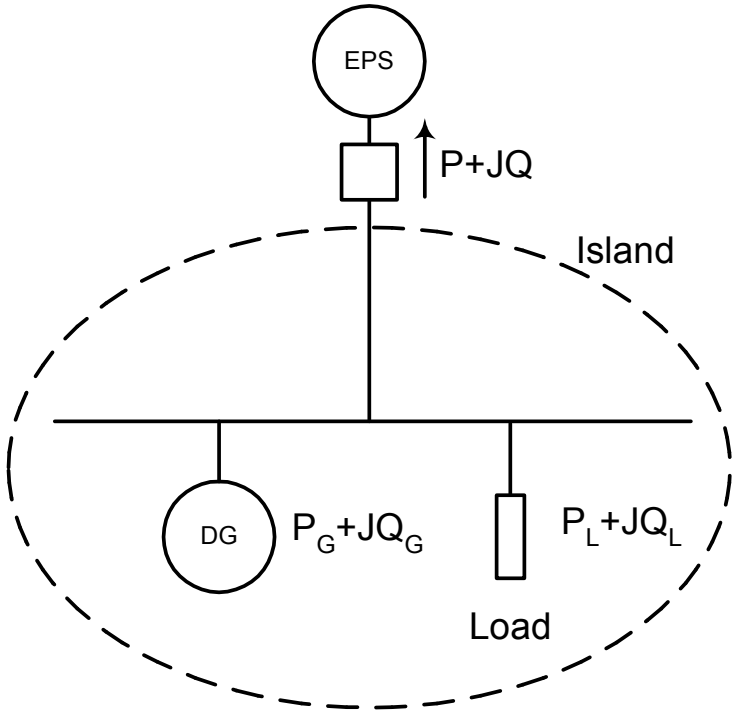
Anti-Islanding (Passive)

- **Rate of Change of Power:**

$$\Delta P_G = \Delta P_L \cdot \frac{H_G \cdot S_G}{(H_G \cdot S_G + H_{EPS} \cdot S_{EPS})} \quad \textit{Connected to EPS}$$

$$\Delta P_G = \Delta P_L \quad \textit{Islanded}$$

Where H is the inertia constant and S is the capacity



Advantages

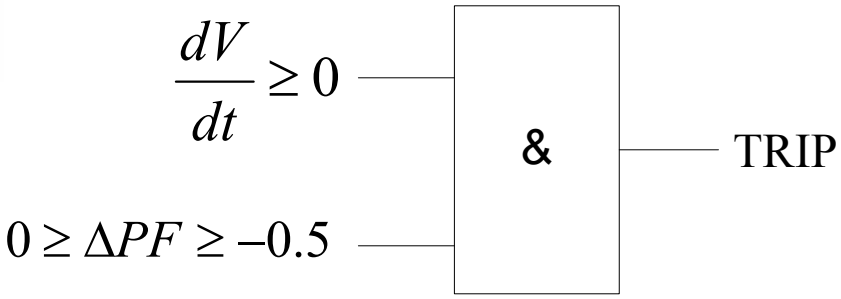
- Can operate more quickly than voltage/frequency protection
- Stable for single phase faults
- Applicable to conventional DGs

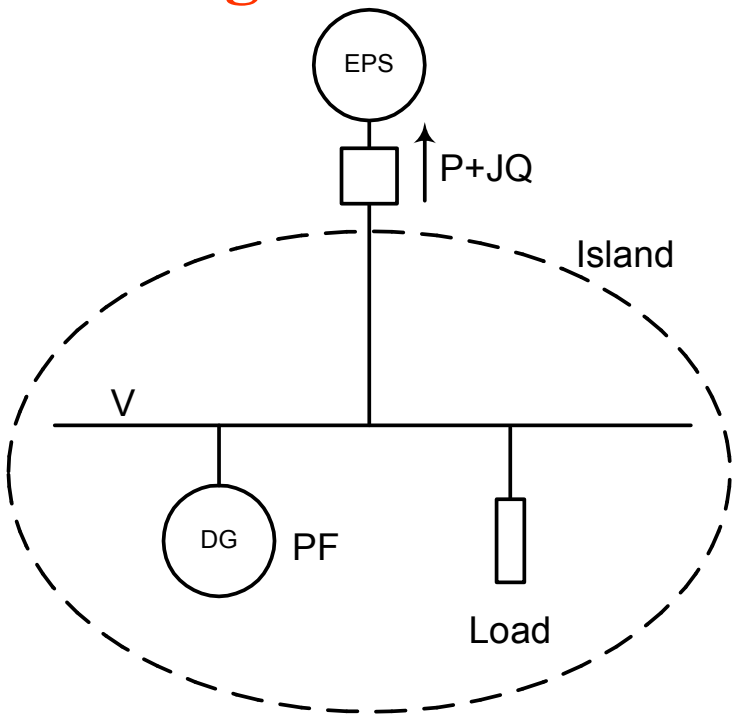
Disadvantages

- Fails when P+jQ = 0

Anti-Islanding (Passive)

- **Rate of Change of Voltage & Change in PF:**





Advantages

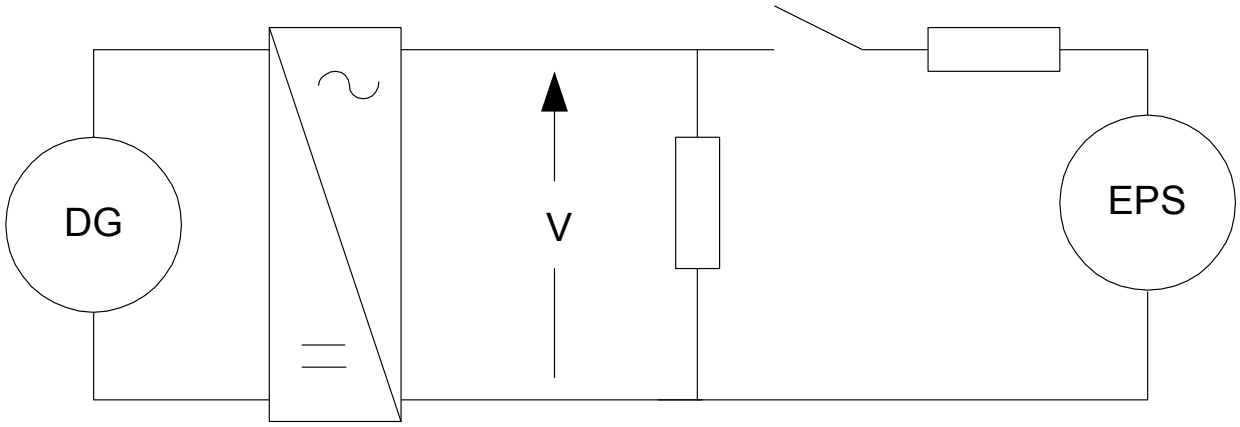
- Can operate more quickly than voltage/frequency protection
- Stable for system disturbances
- Applicable to conventional DGs

Disadvantages

- Fails when P+jQ = 0

Anti-Islanding (Passive)

- **Voltage Harmonic Monitoring:**



Advantages

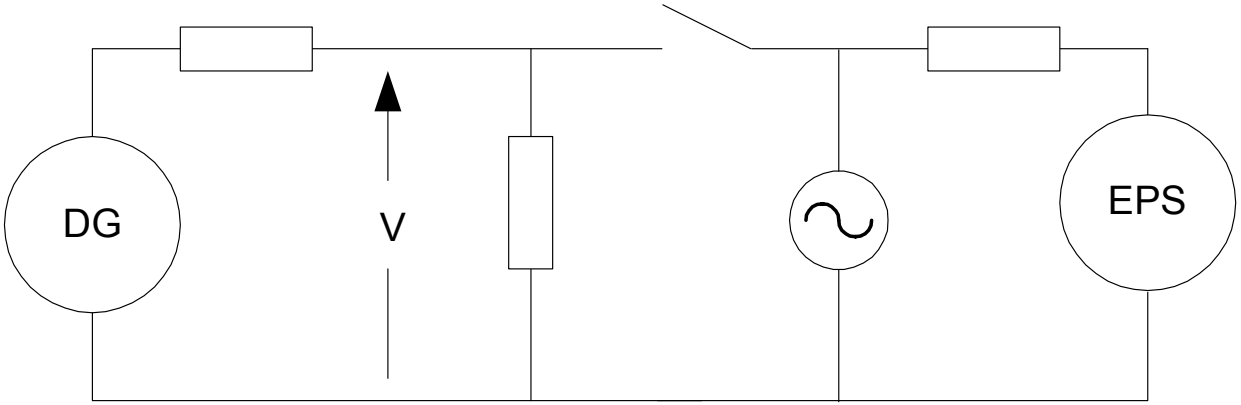
- Can operate when P+jQ = 0

Disadvantages

- Load may filter the harmonic content
- Could be affected by transient phenomenon
- Only applicable for inverter-based DGs

Anti-Islanding (Active)

- **High Frequency Signal:**



Advantages

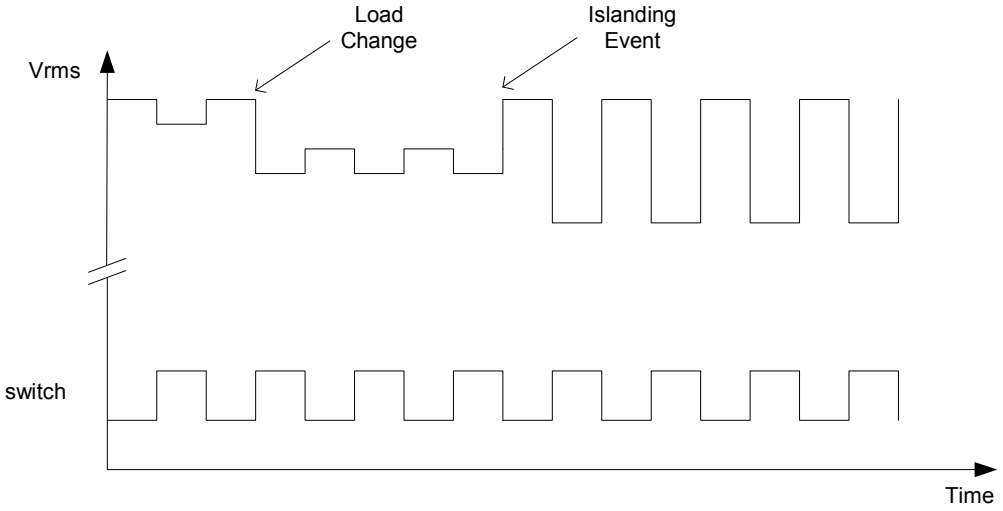
- Can operate when P+jQ = 0

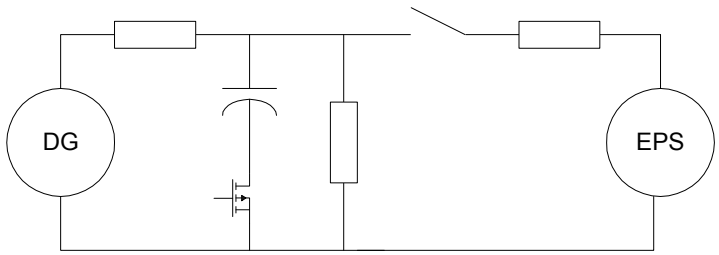
Disadvantages

- Requires the installation of a transmitter into the EPS.
- High frequency signals can be attenuated by series inductance.
- Impacts power quality.

Anti-Islanding (Active)

- **Impedance Switching:**





Advantages

- Can operate when P+jQ = 0
- Applicable to conventional DGs

Disadvantages

- May impact on power quality
- Multiple units require synchronized switching

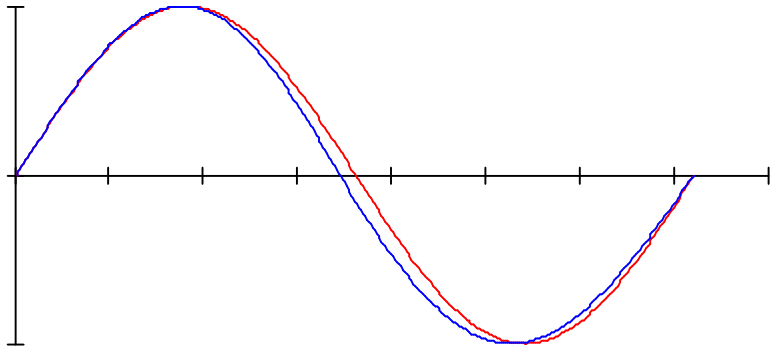
Anti-Islanding (Active)

- **Assymetrical Waveform:**

$$\partial f = \partial P_G \cdot \frac{K_G \cdot K_{EPS}}{(K_G + K_{EPS})} \quad Connected\ to\ EPS$$

$$\partial f = \partial P_G \cdot K_G \quad Islanded$$

$$Where \quad K = \frac{\partial f}{\partial P} \quad P - F\ Characteristic$$



Advantages

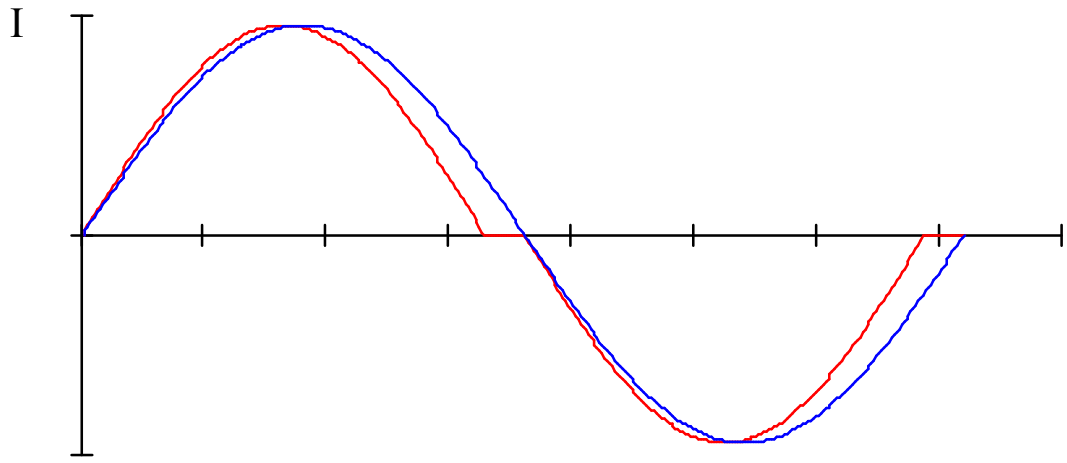
- Can operate when P+jQ = 0

Disadvantages

- Only applicable for inverter-based DGs

Anti-Islanding (Active)

- **Active Frequency Drift - Sandia Frequency Shift:**



Advantages

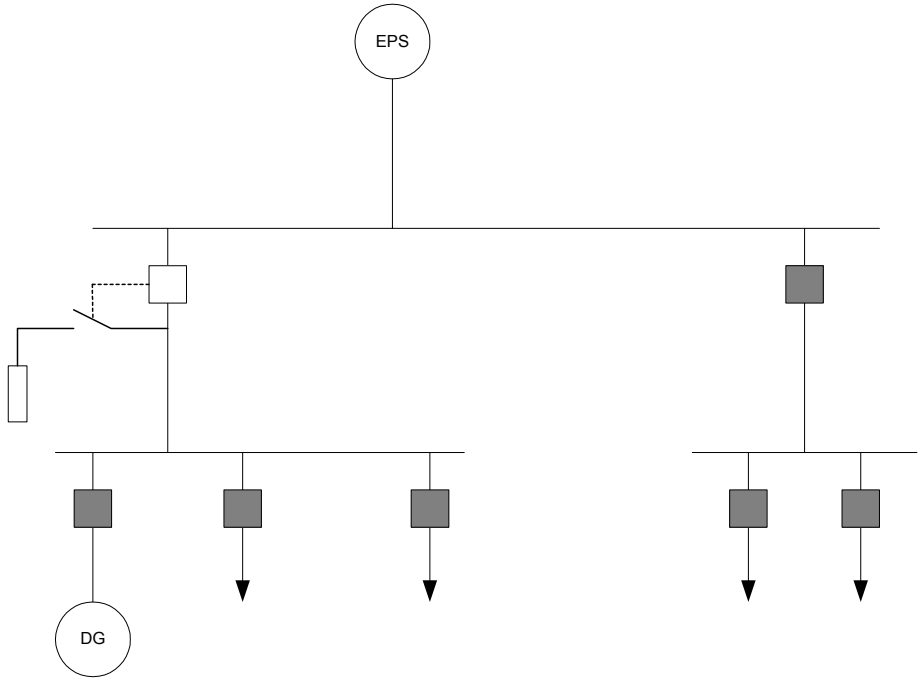
- Can operate when P+jQ = 0

Disadvantages

- Only applicable for inverter-based DGs

Anti-Islanding (Active)

- **Impedance Insertion:**



Advantages

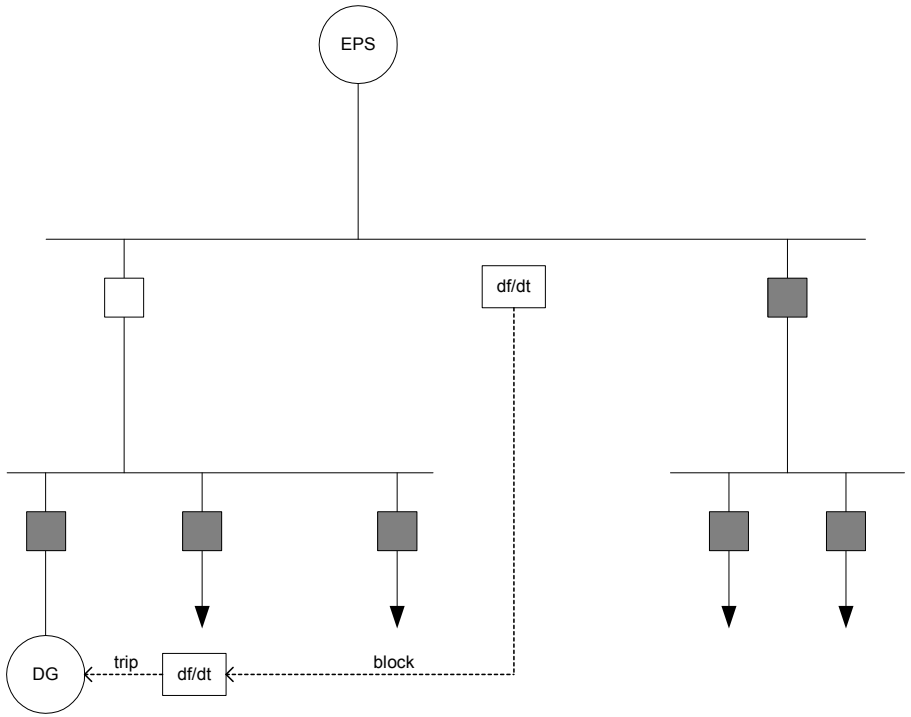
- Can operate when P+jQ = 0
- Applicable to conventional DGs
- No impact on power quality

Disadvantages

- Coordinated operation of breaker and impedance switch
- An impedance bank must be located at all locations where an island can occur

Anti-Islanding (Active)

- **Comparison of Rate of Change of Frequency:**



Advantages

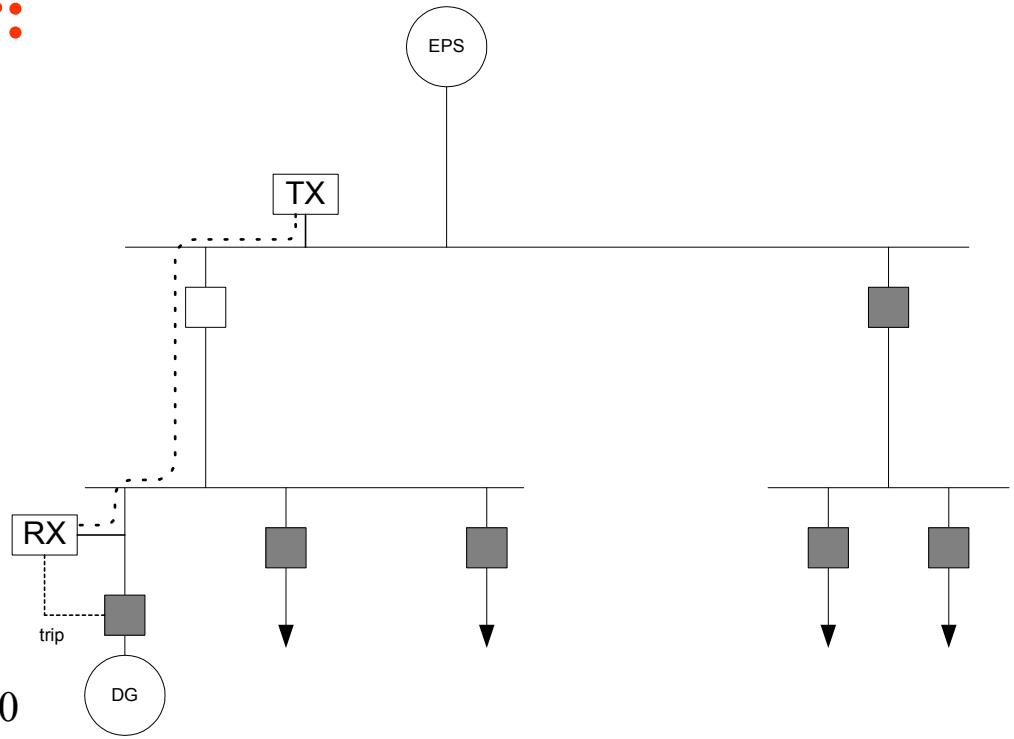
- More secure than ROCOF
- Applicable to conventional DGs

Disadvantages

- Requires communication channel
- Fails when P+jQ = 0

Anti-Islanding (Active)

- **Power Line Carrier:**



Advantages

- Can operate when P+jQ = 0
- Applicable to conventional DGs
- No impact on power quality

Disadvantages

- Requires installation of transmitter and receiver equipment.
- Transmitter must be very reliable
- May mal-operate during a system fault

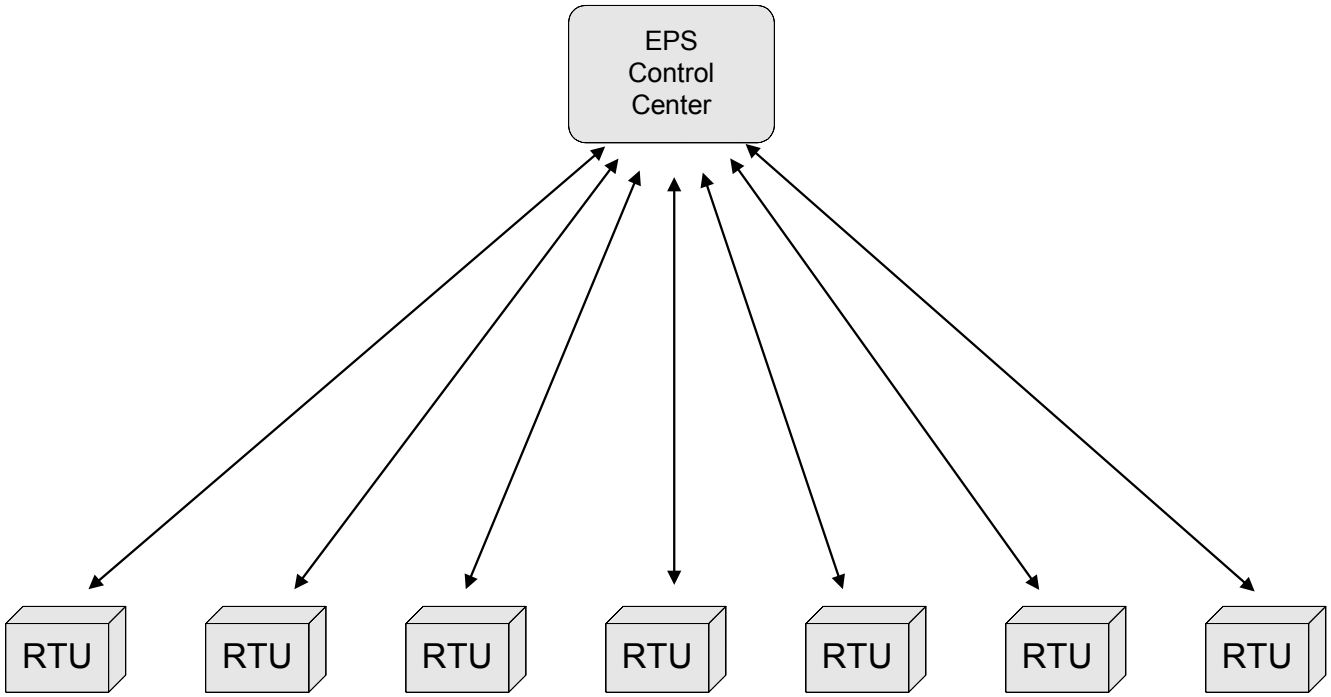
Summary

- **Most passive schemes cannot guarantee fast operation as the power flow across the breaker approaches zero.**
- **Many active schemes can quickly detect an island even when the power flow through the breaker is zero prior to islanding.**
- **Of the these schemes several are applicable only for inverter-based DGs.**
- **The remaining schemes have power quality or security issues.**

Areas For further study

- **How is the security of these schemes impacted as the penetration of DG increases?**
- **How is the dependability of these schemes impacted as the penetration of DG increase?**
- **How do each of the schemes impact on power quality as the penetration of DG increases?**

Communications



Advantages:

Secure

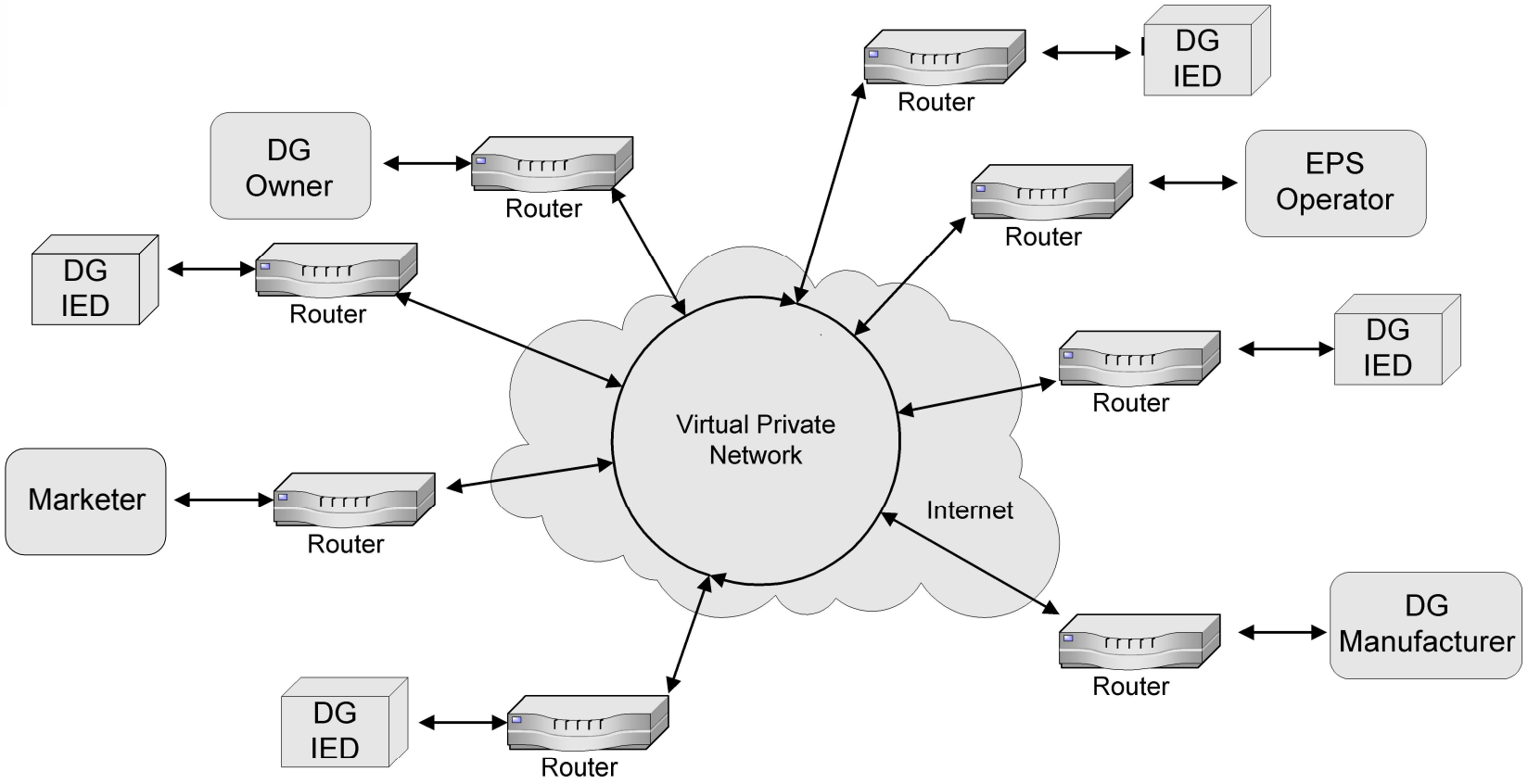
Reliable

Disadvantages:

Expensive to build and maintain.

Vertically integrated (not well suited for sharing of information).

Internet Topology

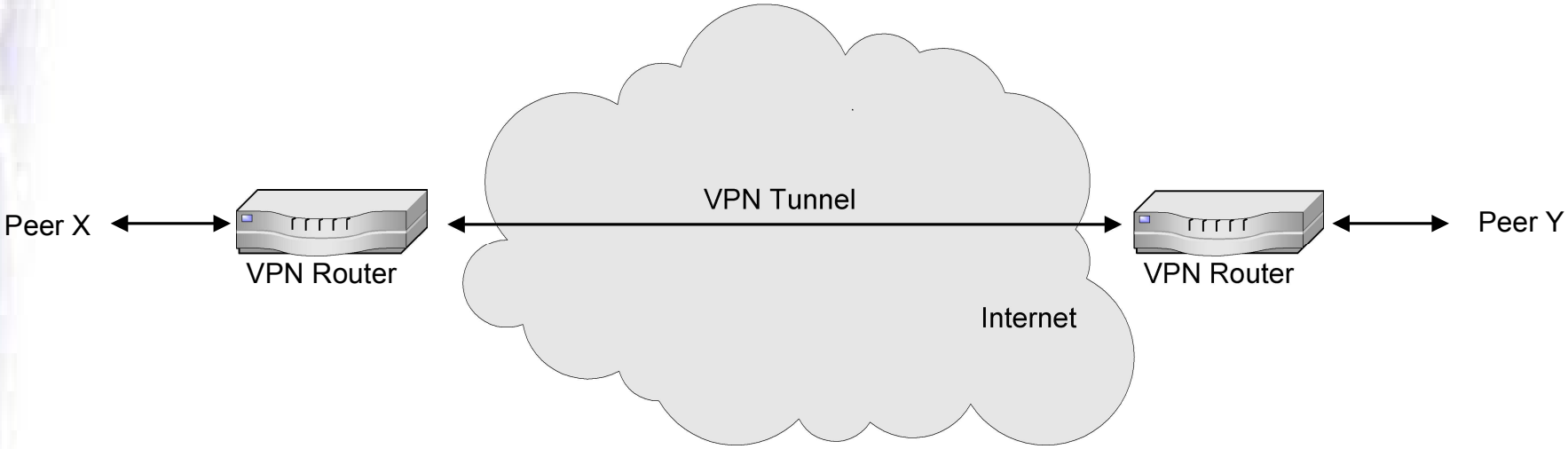


IPSec

IPSec is a set of open standard protocols designed to address the following security issues:

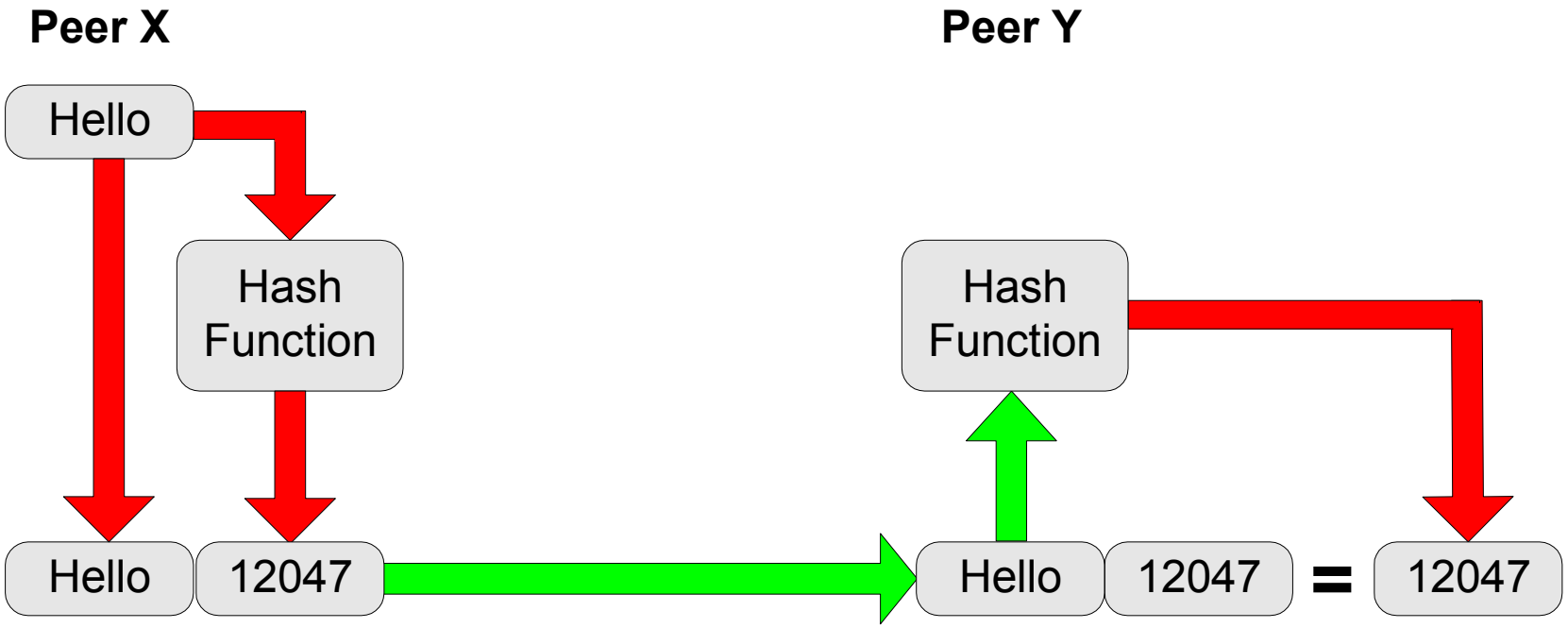
- **Confidentiality - Prevents unauthorized access to information as it is transferred across a public data network.**
- **Authenticity - Confirms the identity of the sender and receiver of the information.**
- **Integrity - Checks that information has not been altered during transmission**
- **Anti-playback - Ensures that a data transaction is only carried out once unless there is authorization for retransmission.**

VPN Tunnel



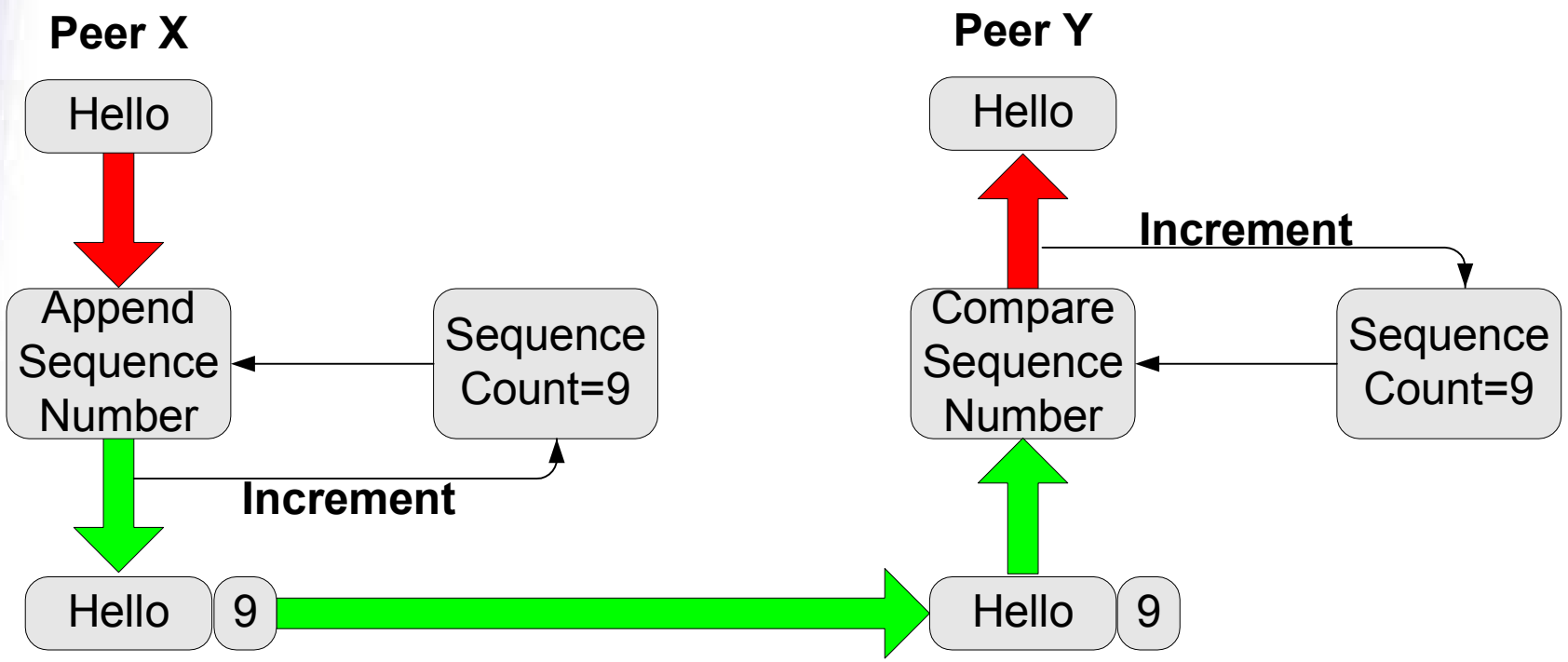
Authentication using pre-shared keys or public key cryptography
Agreement on encryption algorithms
Generation of Session Keys

Integrity



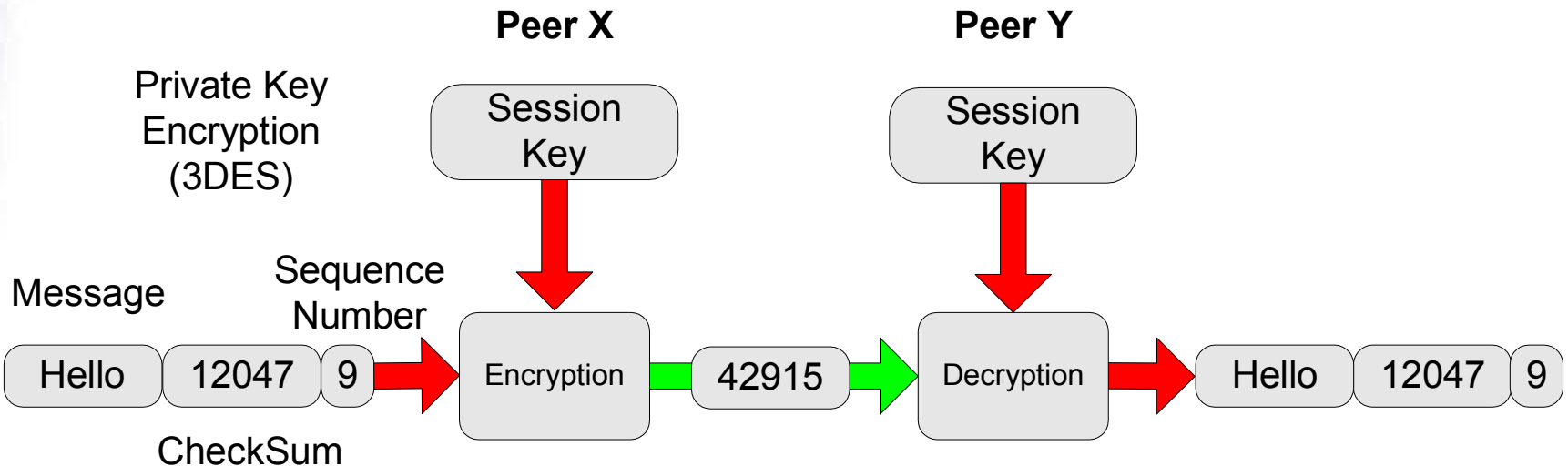
A hash function can also be used to verify that a message has not changed while in transit from X to Y. A checksum of the message is created by X. This message is appended to the message. Both the message and the checksum are sent to Y. Y now takes the message and puts it into the same hash function. If the checksums agree then the message has not been altered.

Anti-replay



Protection from resent messages can be obtained by attaching a sequence number to each transmitted message. After the message is sent, the sequence counter is incremented. At the receiving end, the sequence number is compared with the sequence counter. If the values do not agree then the message is rejected.

Complete Sequence



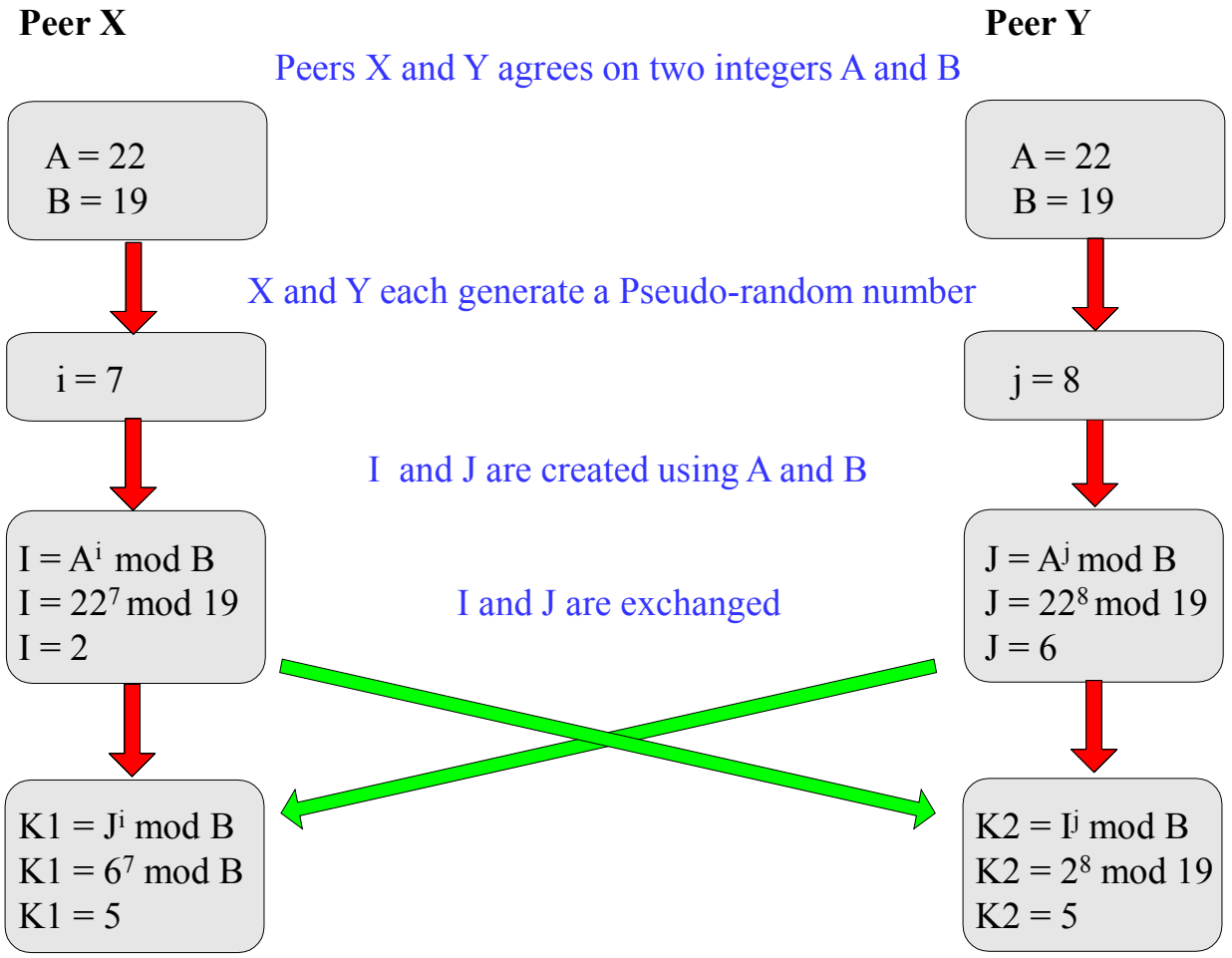
Summary

- **A VPN can provide a secure method of connecting DGs to DG stakeholders over the internet.**
- **IPSec specifically addresses the issues of authentication of users, integrity of data, anti-replay, and confidentiality.**
- **IPSec is an open framework which utilizes public domain algorithms that have withstood the test of time.**

Conclusions

- **The overall cost effectiveness of a DG implementation will be increased by integrating more functionality into the DG IED.**
- **Further investigation is warranted to compare the effectiveness of anti-islanding methods for various system topologies and operating conditions.**
- **The communication capabilities of the DG IED should support the application of new networking strategies.**

Internet Key Exchange (Diffie-Hellman)



Authentication

- Pre-shared Keys
- Public Key Encryptyion
- Digital Signatures

Authentication using Public Key Encryption (RSA)

Choose two large prime numbers P & Q

P = 7 Q=11

Calculate N & ϕ:

Choose E such that 1 < E < N and E and ϕ are relatively prime: *(Relatively prime means that E and ϕ have no prime factors in common)*

E = 7

The factors of ϕ are 1,2,3,4,5,6,10,12,15,20,30, and 60.

The factors of E are 1, 7

Find D such that D·E - 1 is evenly divisible by ϕ.

The public key pair is (E,N) or (7,77)

The private key pair is (D,N) or (43,77)

$$N = P \cdot Q$$

$$N = 77$$

$$\phi = (P-1) \cdot (Q-1)$$

$$\phi = 60$$

$$D = \frac{X \cdot \phi + 1}{E}$$

$$D = \frac{X \cdot 60 + 1}{7}$$

$$43 = \frac{5 \cdot 60 + 1}{7}$$

$$D = 43$$

Authentication using Public Key Encryption (RSA)

The algorithm for encryption is

$C=T^E \bmod N$

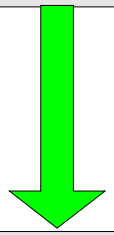
Where T is the plain text

The algorithm for decryption is

$T=C^D \bmod N$

Where C is the cipher text

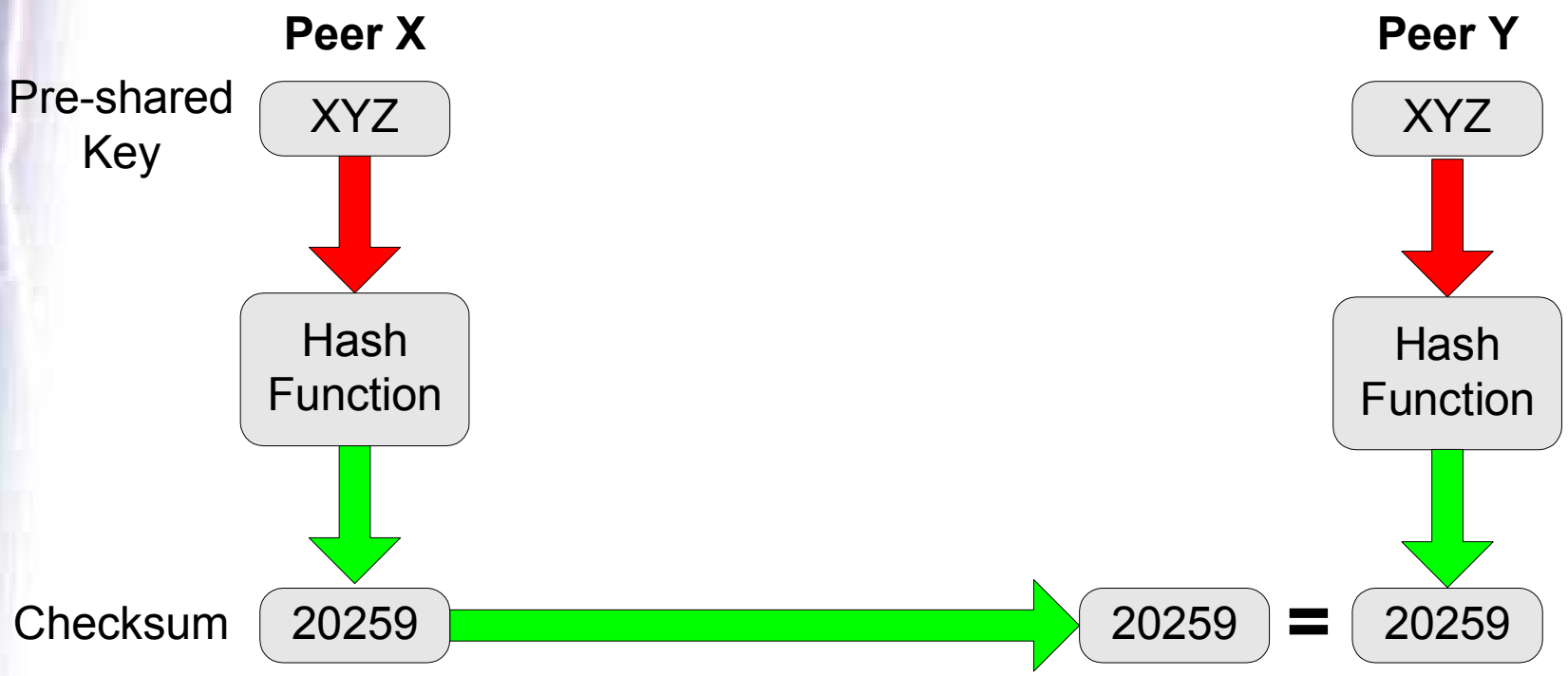
$$T = 2$$
$$C = 2^7 \bmod 77$$
$$C = 51$$



$$C = 51$$
$$T = 51^{43} \bmod 77$$
$$T = 2$$

If Peer X wants to authenticate Peer Y, X encrypts a message with Y's public key and sends the encrypted message to Y. If Y can successfully decrypt the message then Y proves he is the owner of the private key .

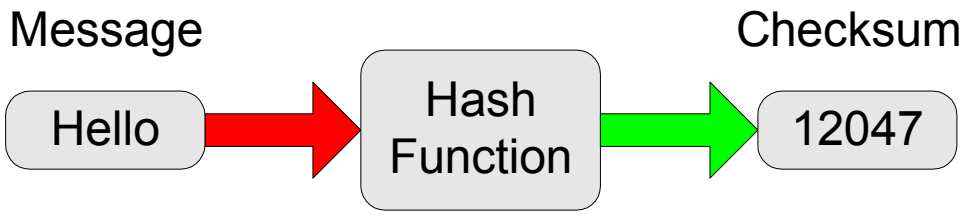
Authentication using Pre-shared Keys



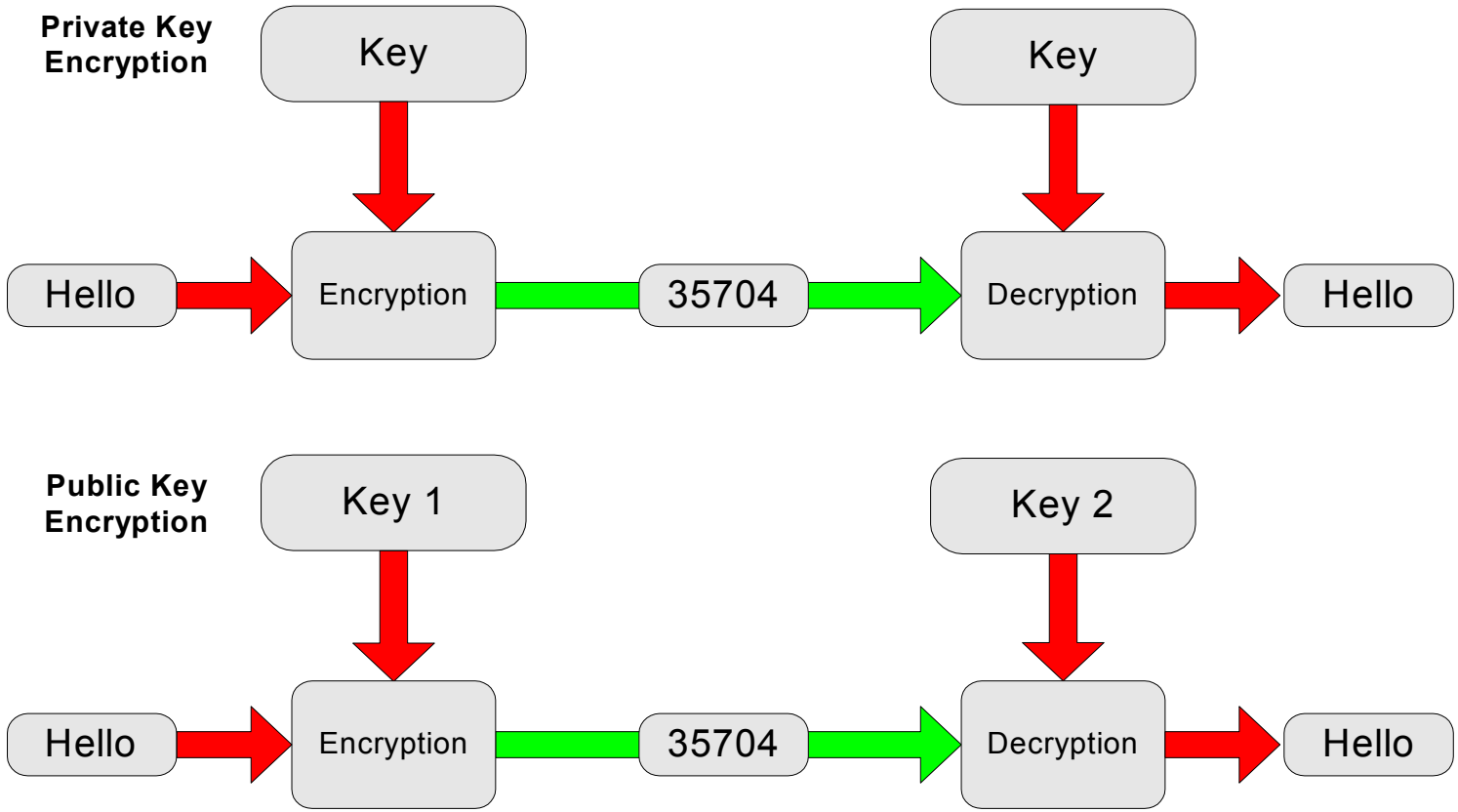
If Peer X wants to authenticate Peer Y, X creates a checksum using the pre-shared key and sends the checksum to Y. If Y can successfully reproduce the same checksum then Y proves he has the same key .

Secure Hash Function

- Properties
  - Input can be any length
  - Output is a fixed length
  - It is relatively easy to compute the checksum
  - The function is one-way
  - The function is collision free



Encryption


Private Key Encryption
Key
Key
Hello
Encryption
35704
Decryption
Hello
Public Key Encryption
Key 1
Key 2
Hello
Encryption
35704
Decryption
Hello