Generator Earthing

by
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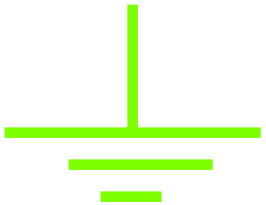
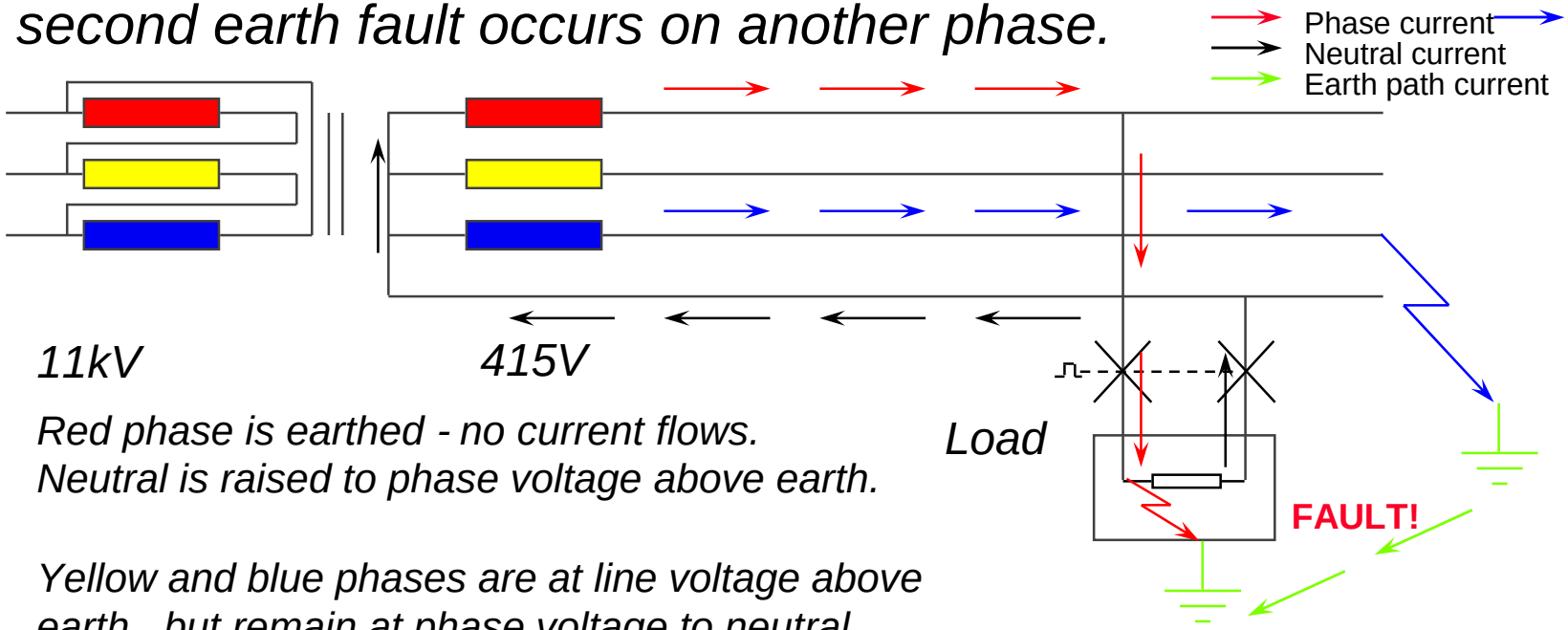
Why earth at all?



- Provides a reference for system voltages
  - Avoids ‘floating’ voltages
  - Prevents insulation stress
- Allows single earth faults to be detected
  - Earth fault current is sensed
  - Current magnitude used to trip protection devices
  - EEBADS (Earthed equipotential bonding and automatic disconnection)
- Prevents ‘touch’ voltages on adjacent components
- Provides means of referencing 3-wire non-connected systems - e.g. during H.V. synchronising
- Legal requirement in UK distribution systems

Neutral not earthed

- *Cannot detect a single earth fault by overcurrent unless a second earth fault occurs on another phase.*



Red phase is earthed - no current flows.
Neutral is raised to phase voltage above earth.

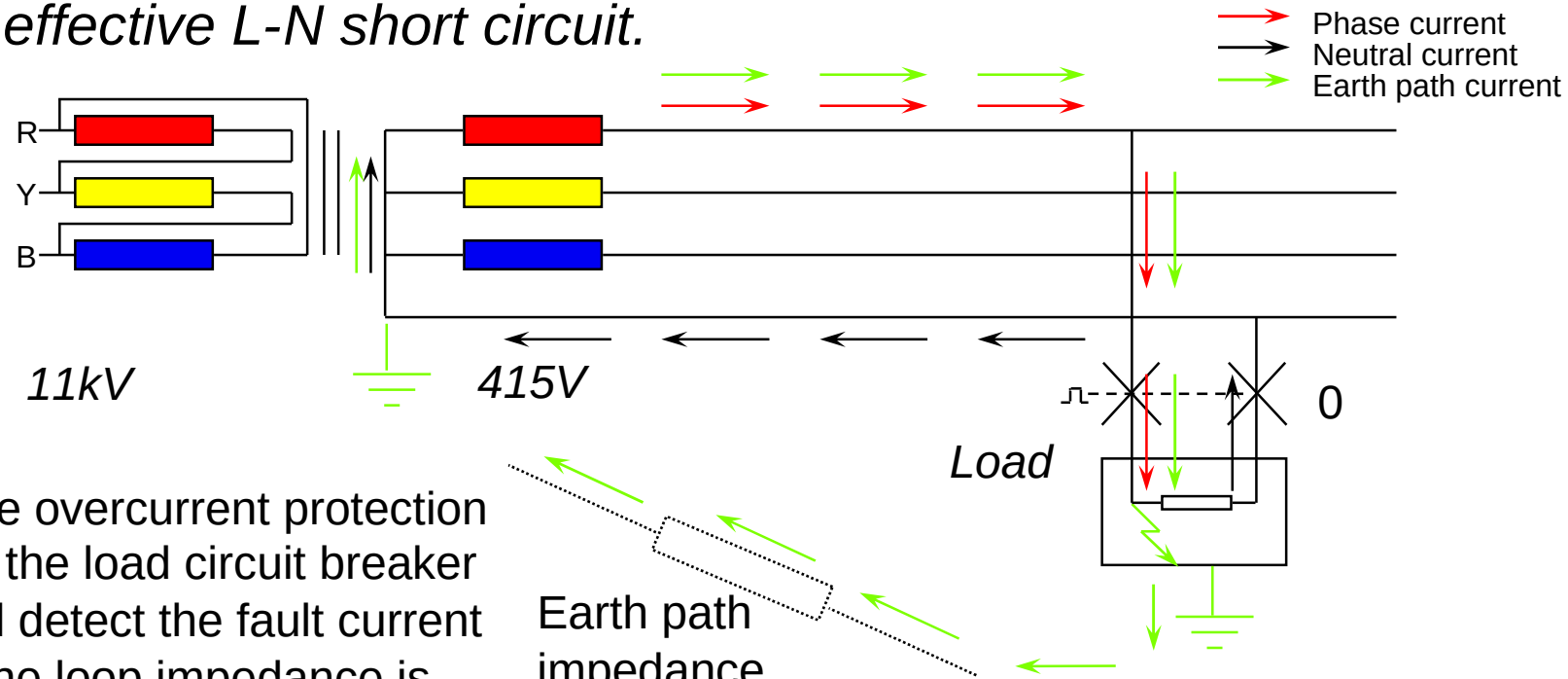
Yellow and blue phases are at line voltage above earth, but remain at phase voltage to neutral.

Fire risk if grounding contact is loose - arcing - due to cable capacitance currents to earth.

Shock hazard if person provides the earth connection - capacitance current.

Neutral earthed - EEBADS

- *Fault current flows through the earth path - producing an effective L-N short circuit.*

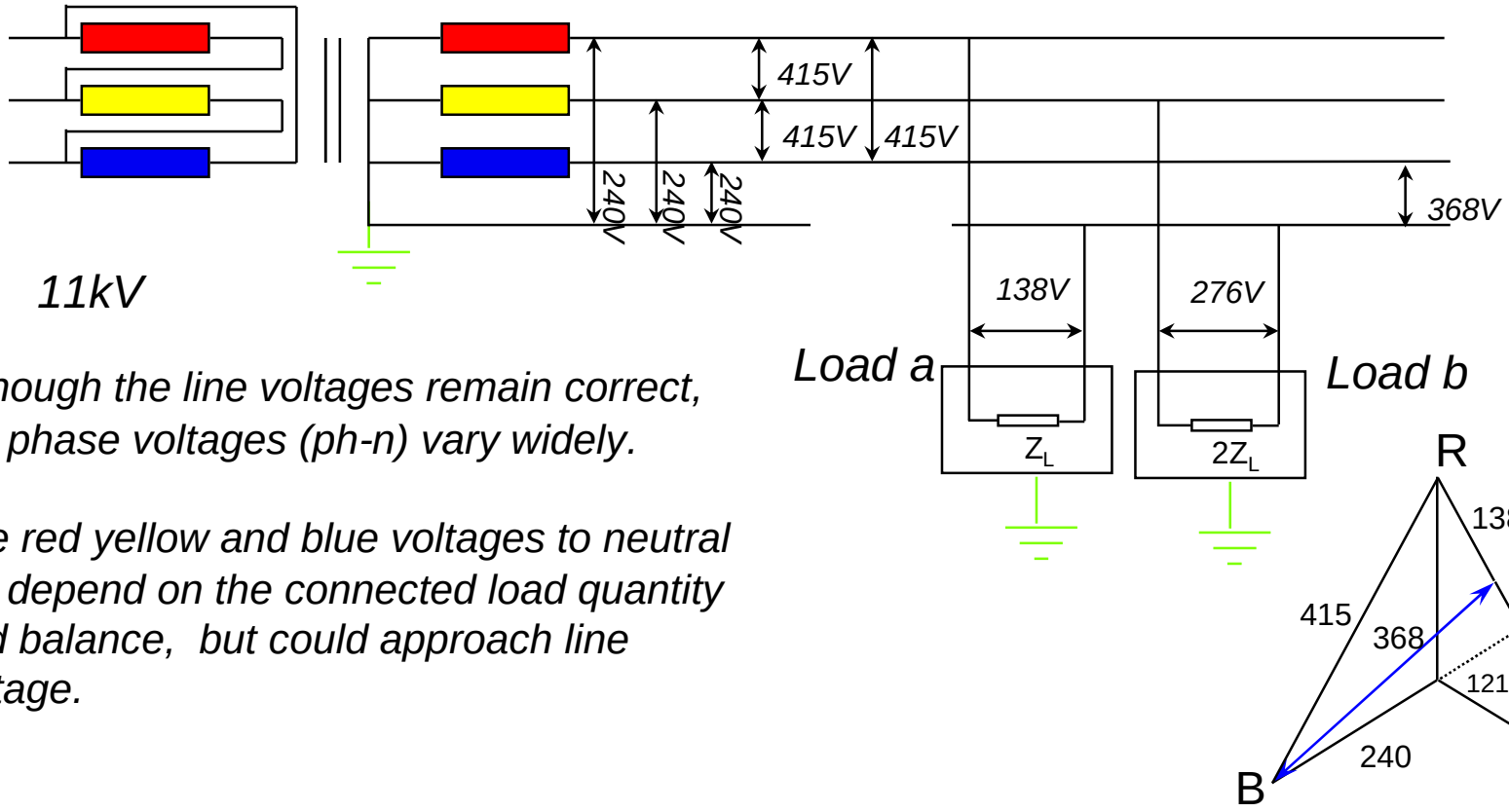


The overcurrent protection on the load circuit breaker will detect the fault current if the loop impedance is low enough to allow sufficient current to flow.

The loop impedance can be lowered by including more conductors in the earth path - e.g. cross bonding.

Broken neutral

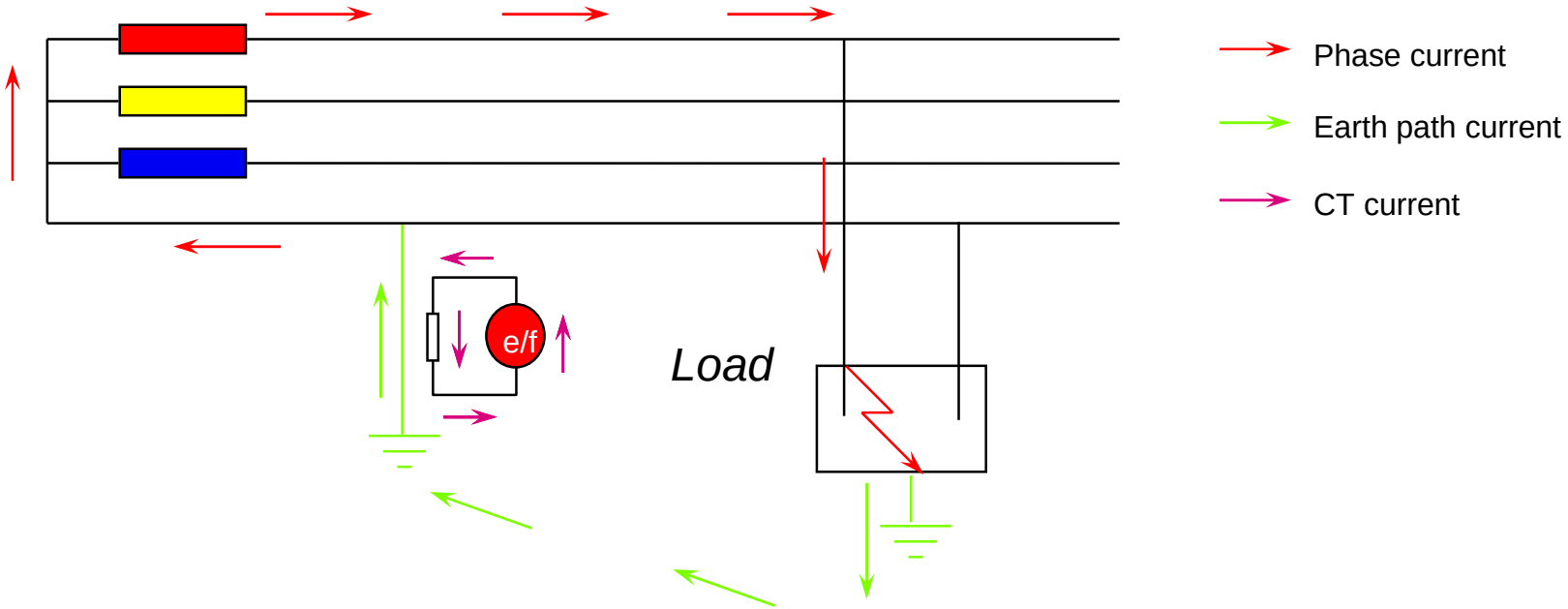
- *A serious problem:*



Although the line voltages remain correct, the phase voltages (ph-n) vary widely.

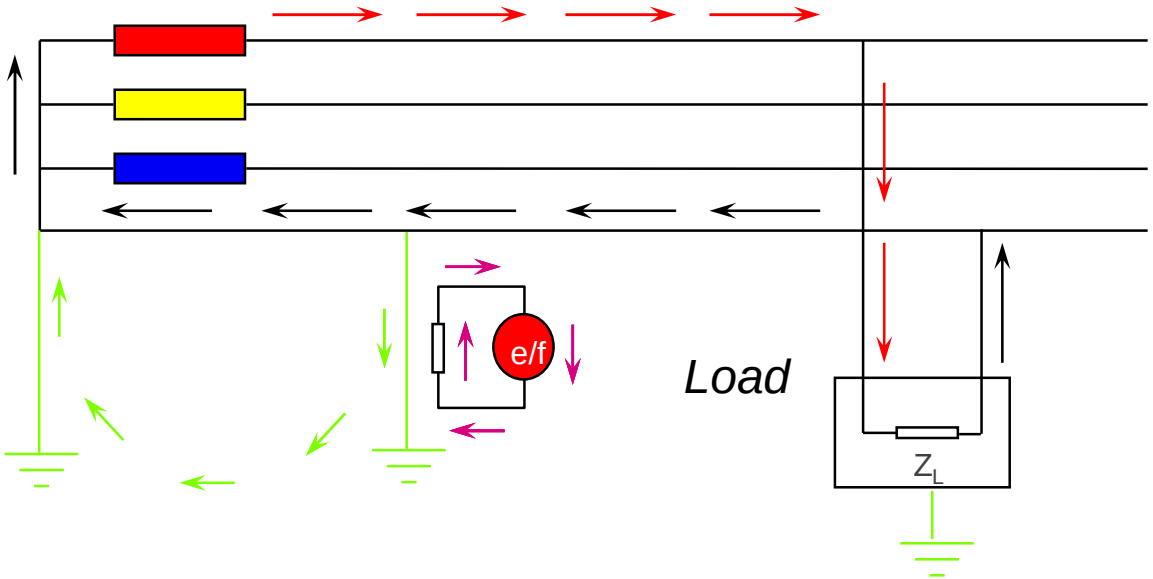
The red yellow and blue voltages to neutral will depend on the connected load quantity and balance, but could approach line voltage.

Unrestricted earth fault protection



- Sensing CT is located in the neutral earth link.
- Protection is by simple current sensing relay and will respond to any current flowing in the earth path.
- The whole system is protected.
- There is no selectivity - other than provided by the relays themselves.

Effect of multiple earthing - 1



Phase current

Neutral current

Earth path current

CT current

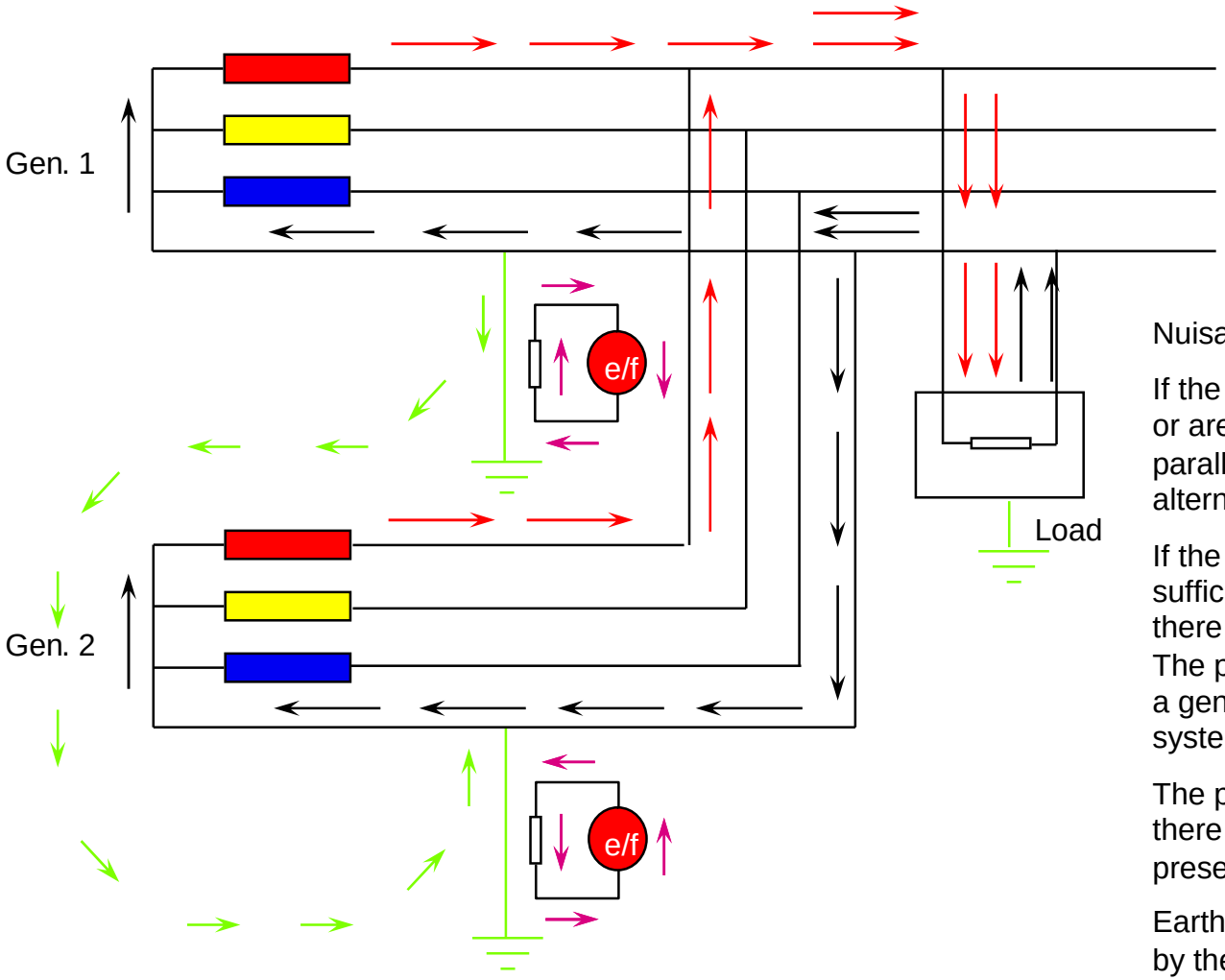
EFFECT OF LEAVING ALTERNATOR NEUTRAL EARTH LINK IN PLACE.

Nuisance tripping

Neutral current has an alternative route, through the earth path, resulting in protection operation on load imbalance.

- Unrestricted earth leakage protection is simple but is not without problems.
- The key requirement for unrestricted earth leakage protection to be effective is that the neutral must be bonded to earth at one point only.
- If this is not the case, protection will be unreliable, leading either to nuisance tripping, or failure to operate when required.

Effect of multiple earthing - 2



Phase current

Neutral current

Earth path current

CT current

Nuisance tripping

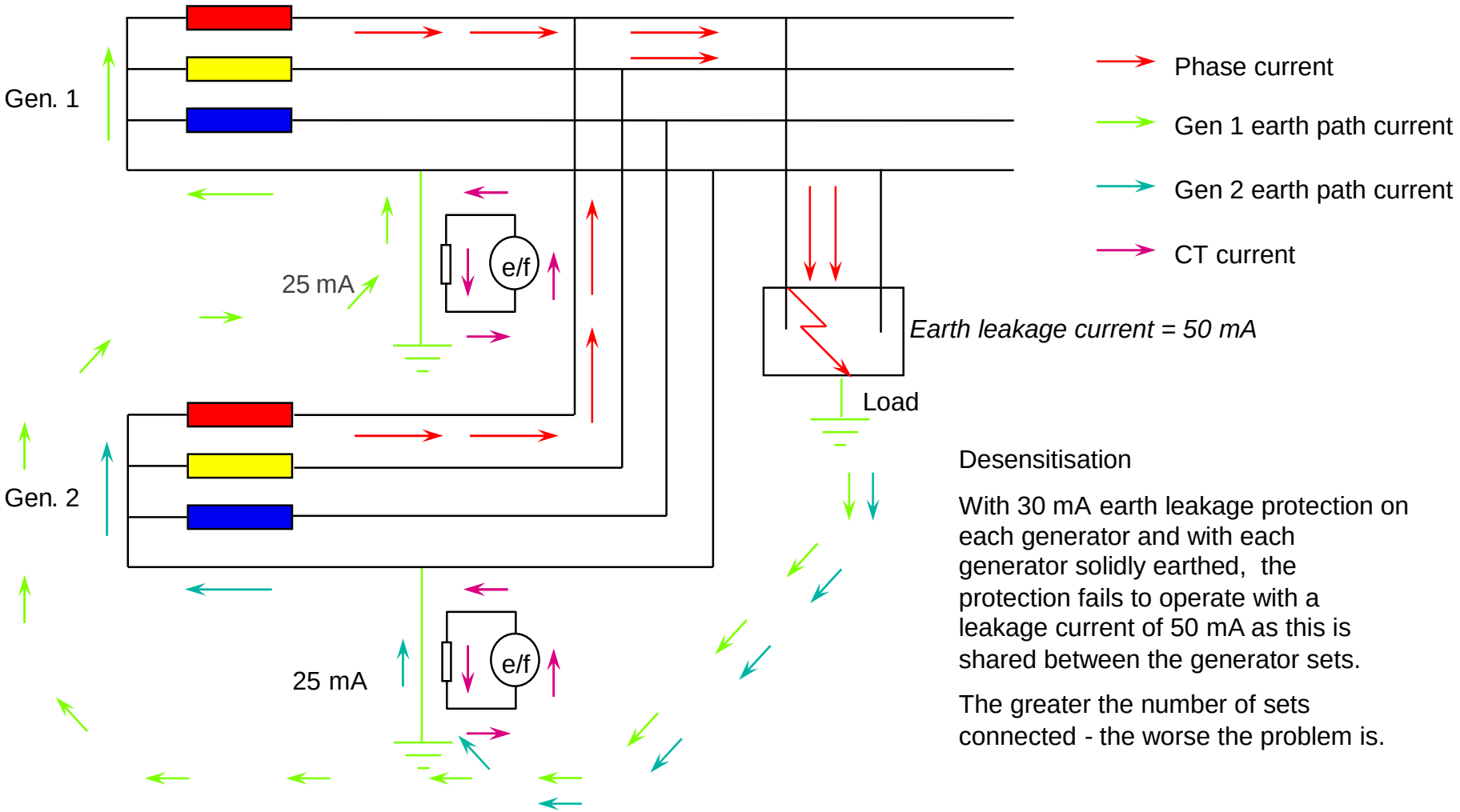
If the generators are not equally sized or are not sharing load equally, the parallel earth paths will provide an alternative route for the neutral current.

If the earth fault protection is sufficiently sensitive it will trip, although there is no earth fault on the system. The protection may operate every time a generator is brought onto the system.

The problem will be accentuated if there is significant 3rd harmonic present.

Earth fault protection is desensitised by the parallel path...

Effect of multiple earthing - 3

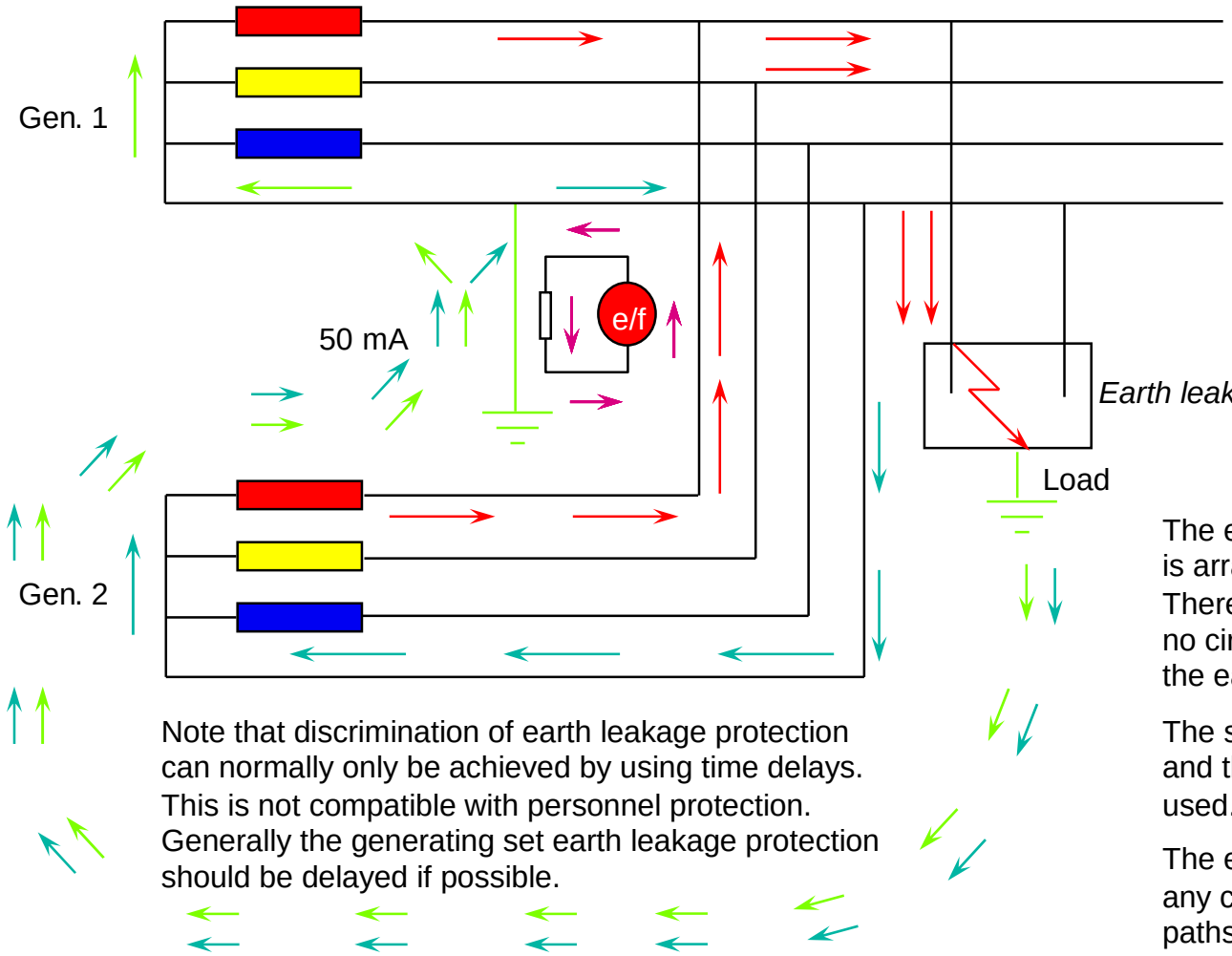


Desensitisation

With 30 mA earth leakage protection on each generator and with each generator solidly earthed, the protection fails to operate with a leakage current of 50 mA as this is shared between the generator sets.

The greater the number of sets connected - the worse the problem is.

Single point earthing



Phase current

Gen 1 Earth path current

Gen 2 Earth path current

CT current

Earth leakage current = 50 mA

Note that discrimination of earth leakage protection can normally only be achieved by using time delays. This is not compatible with personnel protection. Generally the generating set earth leakage protection should be delayed if possible.

The earth leakage protection on Gen. 1 is arranged to intertrip both generators. There are no shared current paths and no circulating current therefore exists in the earth path.

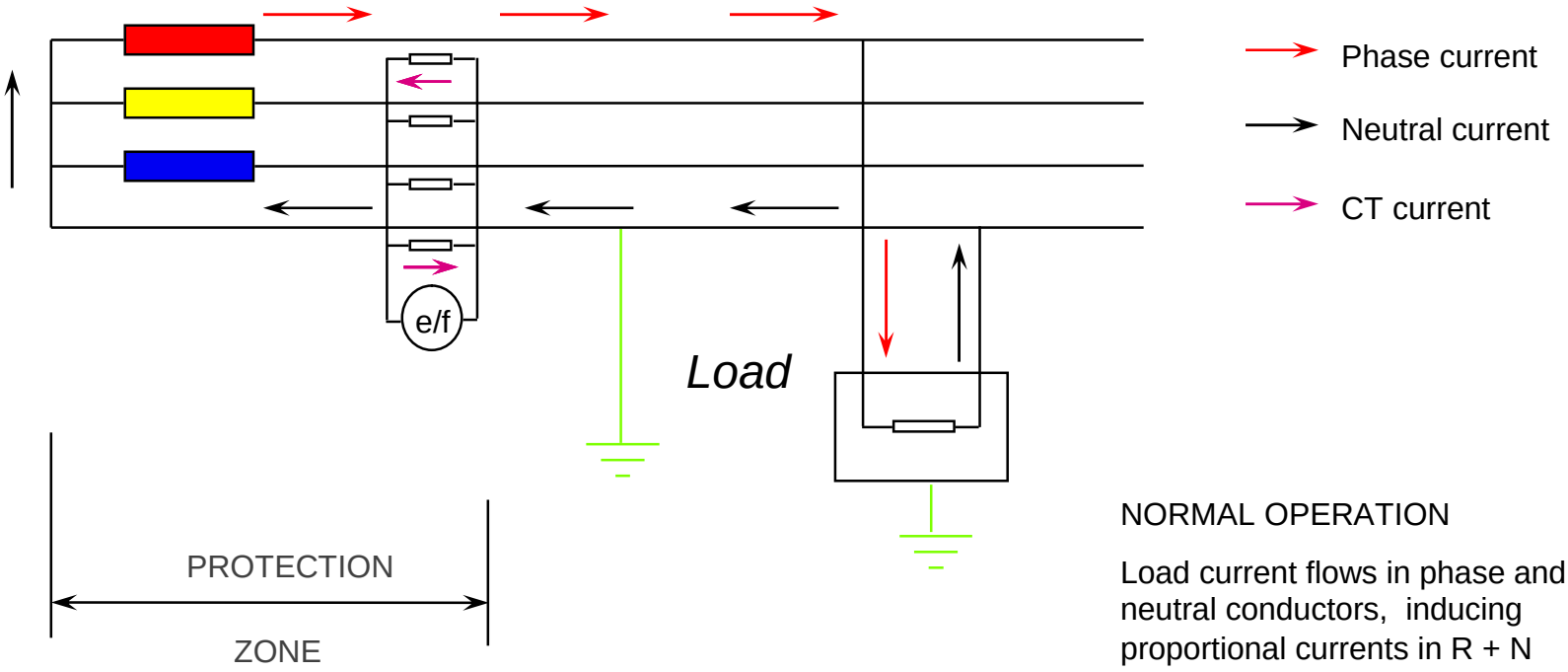
The set neutrals are interconnected and three pole circuit breakers are used.

The earth leakage protection ignores any circulating current in the neutral paths.

Unrestricted earth fault protection

- Unrestricted earth fault protection - summary
  - ADVANTAGES
    - Simple to apply
    - Provides protection for all earth faults on the generator, switchgear and system
    - Can give good level of personnel protection throughout the system
  - DISADVANTAGES
    - Discrimination is difficult on current - time delays must be introduced
    - Source will often trip at same time as downstream protection
    - Blackout situation may be more dangerous than the original earth fault
    - Difficult to apply to generators in parallel unless single point bonding scheme is adopted
      - Generators cannot be identically constructed
      - Intertrip must be arranged
  - MAIN USE
    - Back-up high-set protection for main, submain and distribution board faults
    - Sensitive protection (e.g. personnel) to be provided at final distribution stage

Restricted earth fault protection



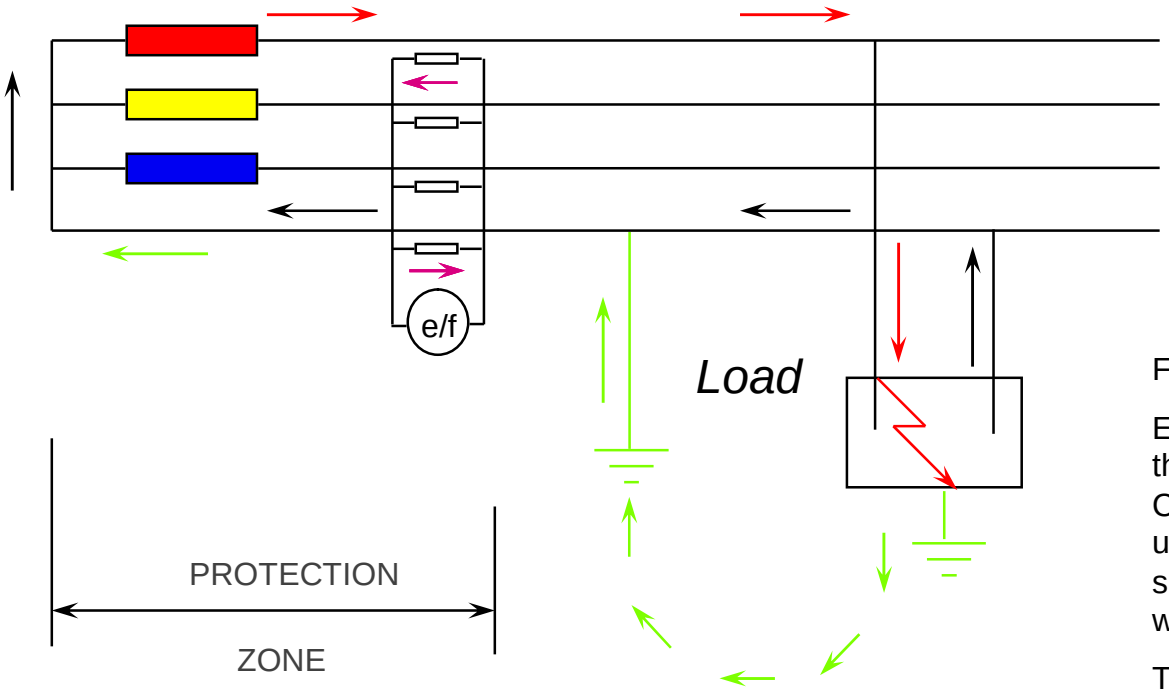
NB: Neutral MUST NOT be earthed within the zone.
Multiple earthing is permissible *outside* of the zone.

NORMAL OPERATION

Load current flows in phase and neutral conductors, inducing proportional currents in R + N CTs.

Currents circulate in the CT loop and no spill current flows through the relay.

R.E.F. - fault outside zone



Zone is defined by position of neutral earth link relative to the CTs.

Phase current

Neutral current

Earth path current

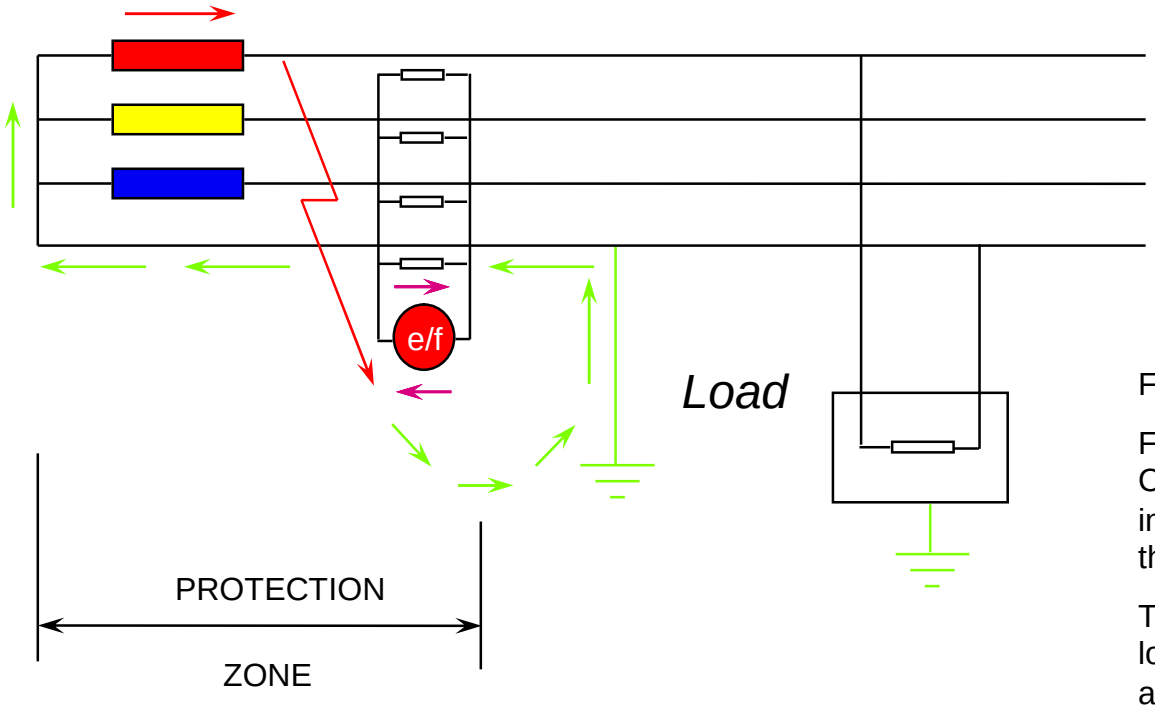
CT current

FAULT OUTSIDE OF ZONE

Equal currents are induced in the R phase CT and the neutral CT. A circulating current is set up in the CT pilot wiring but no spill current enters the relay, which is insensitive to this fault.

This type of protection relies on the integrity of the CT wiring and the accuracy of the CTs. Any variations in CT tolerances will result in instability to the through fault condition and will cause nuisance tripping.

R.E.F. - fault inside zone



Phase current

Earth path current

CT current

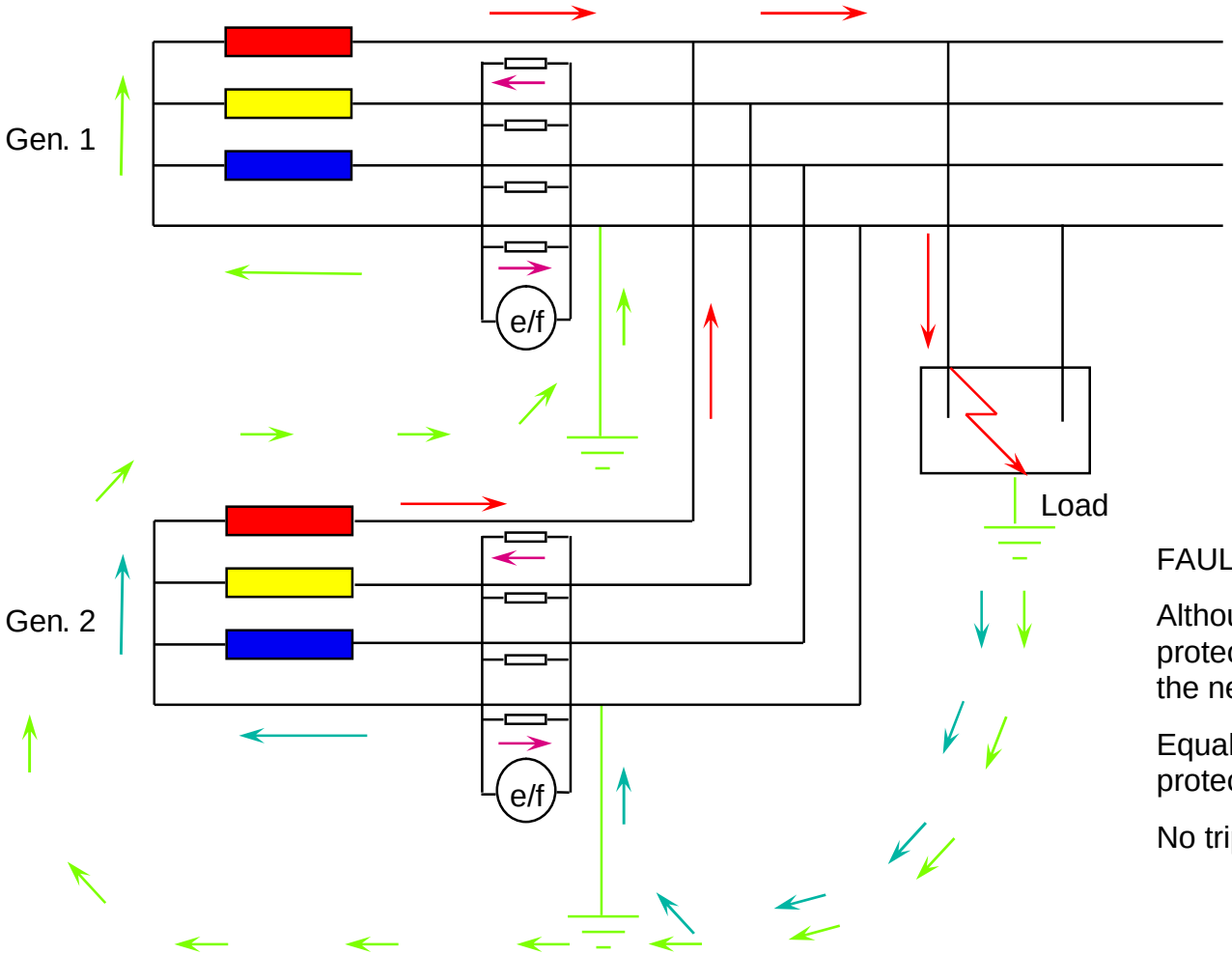
Zone can be arranged to incorporate interconnecting power cables to remote switchgear if required.
Note that no loads can be supplied between the windings and the CTs.

FAULT INSIDE ZONE

Fault current is induced in the N CT but not in any other CT. The induced current therefore flows through the relay.

The setting of the relay can be low - governed only by the accuracy class of the CTs and relay and the degree of protection required, since restricted earth fault protection is not required to discriminate with downstream protection.

R.E.F. - sets in parallel - 1



Phase current

Gen 1 Earth path current

Gen 2 Earth path current

CT current

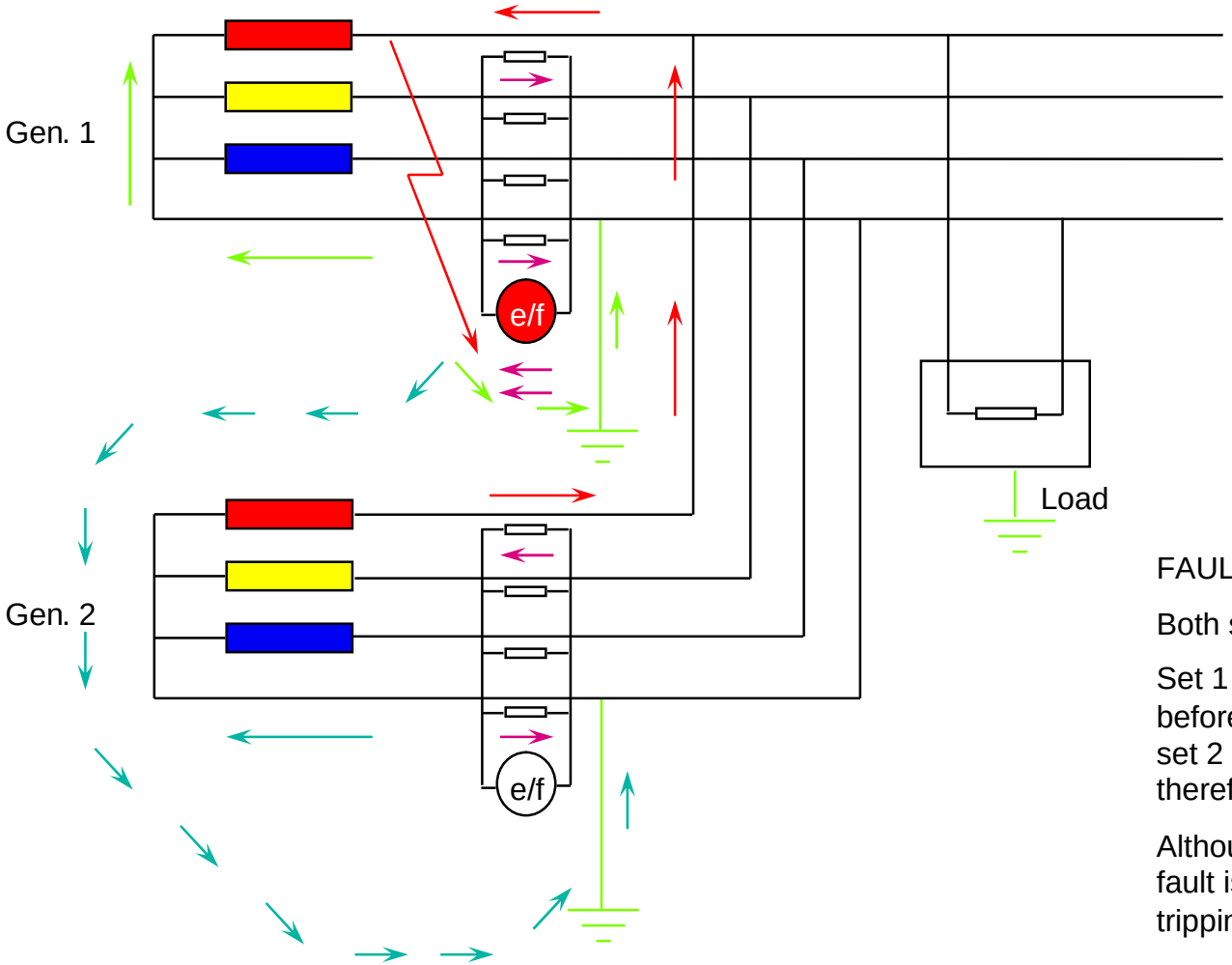
FAULT OUTSIDE OF ZONE

Although multiple earthing exists, protection is stable due to positioning of the neutral earth links.

Equal currents are induced in both sets protection systems' R/N CTs.

No tripping occurs.

R.E.F. - sets in parallel - 2



Phase current

Gen 1 Earth path current

Gen 2 Earth path current

CT current

FAULT ON ONE SET

Both sets provide current into the fault.

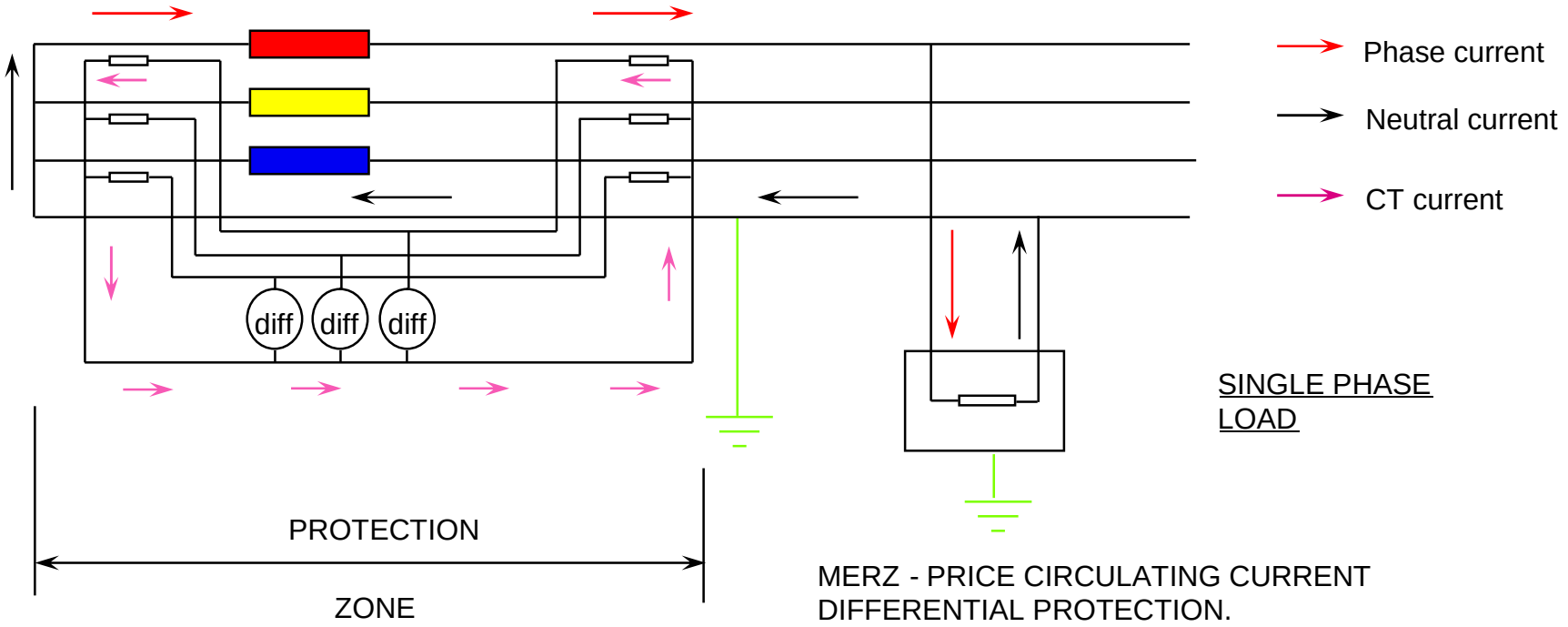
Set 1 current is induced in the N CT as before, but in this case, current from set 2 is induced in opposition and therefore aids tripping.

Although set 2 contributes current, the fault is outside of the set 2 zone and no tripping therefore occurs.

Restricted earth fault protection

- Restricted earth fault protection - summary
  - ADVANTAGES
    - Not affected by faults outside of the protected zone (through faults).
    - Easy to discriminate protection
    - Less risk of nuisance tripping
    - Can be set to low levels, reducing damage to alternator or cables in event of fault
    - Can be set for instantaneous operation - reducing the possibility of touch voltages, etc.
  - DISADVANTAGES
    - Insensitive to phase - phase faults in alternator windings.
    - Needs special CTs for best stability to through faults (Class X)
    - Care needed when wiring to ensure that CTs are orientated and wired correctly.
  - MAIN USE
    - Zone protection for alternator and transformer windings

Differential protection - 1



Typical relay setting 5% of rated current (reflected to CT secondary side).

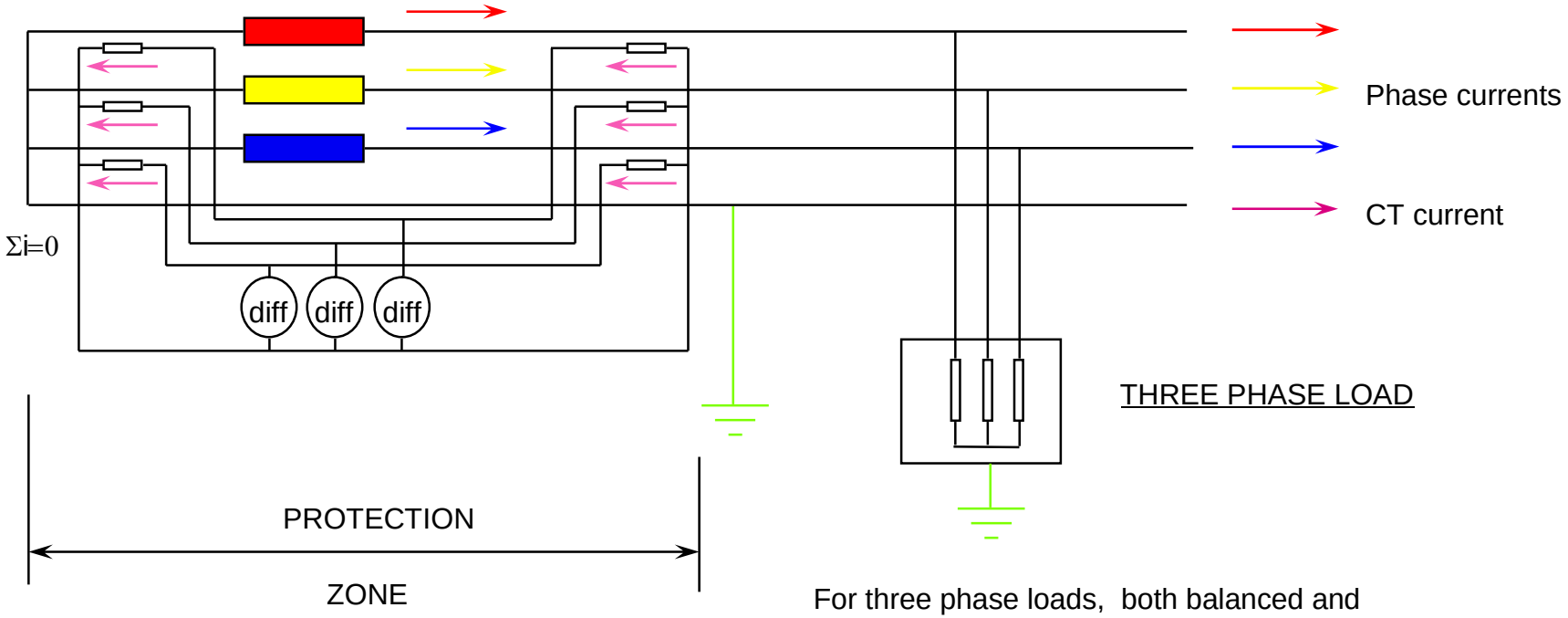
MERZ - PRICE CIRCULATING CURRENT DIFFERENTIAL PROTECTION.

A development of restricted earth fault protection that is able to cover both line-earth and line-line faults.

Under fault-free conditions, equal currents are induced in the line-end and neutral-end CTs. No current flows in the sensing relay.

The location of the neutral - earth link is not important.

Differential protection - 2

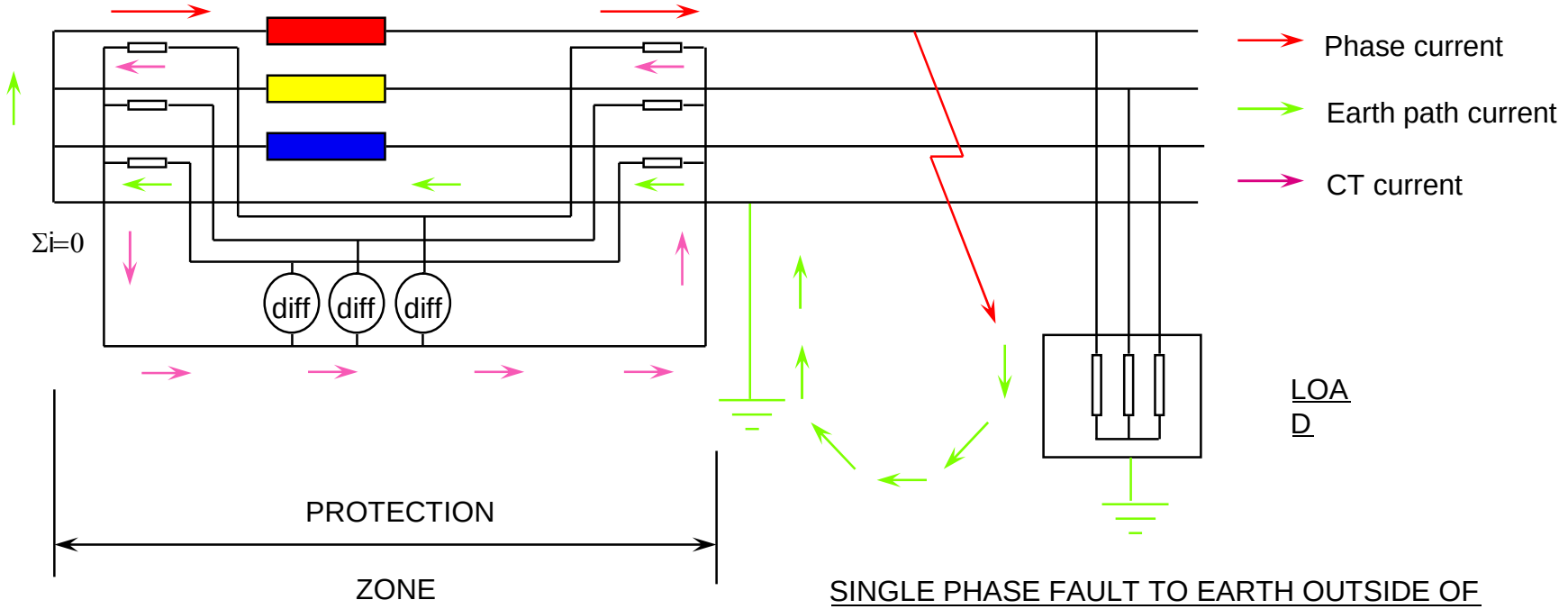


CT accuracy and correct wiring connections are of paramount importance. Class X CTs should be used and pilot resistors may be needed to balance the pilot impedances if, as is usual, the relay is mounted closer to one set of CTs than the other.

For three phase loads, both balanced and unbalanced, the line currents will always summate to zero, provided that there is no alternative path, e.g. earth fault.

It is imperative that there is no parallel path for neutral current through the earth path if the earth point is inside zone, otherwise nuisance tripping will result in cases of unbalanced loading.

Differential protection - 3

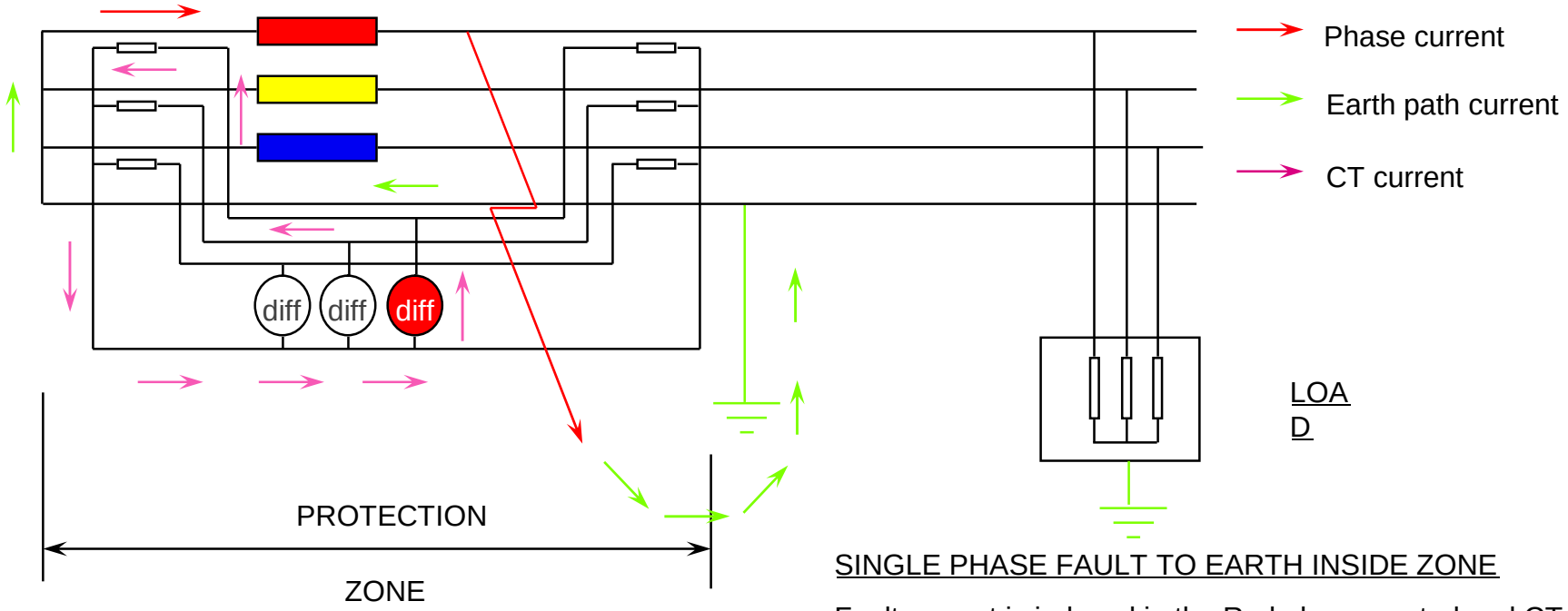


SINGLE PHASE FAULT TO EARTH OUTSIDE OF ZONE

Fault current is induced equally in both red phase CTs and circulates in the pilot loop.

No current flows in the sensing relay circuits and the protection is thus insensitive to this type of fault.

Differential protection - 4



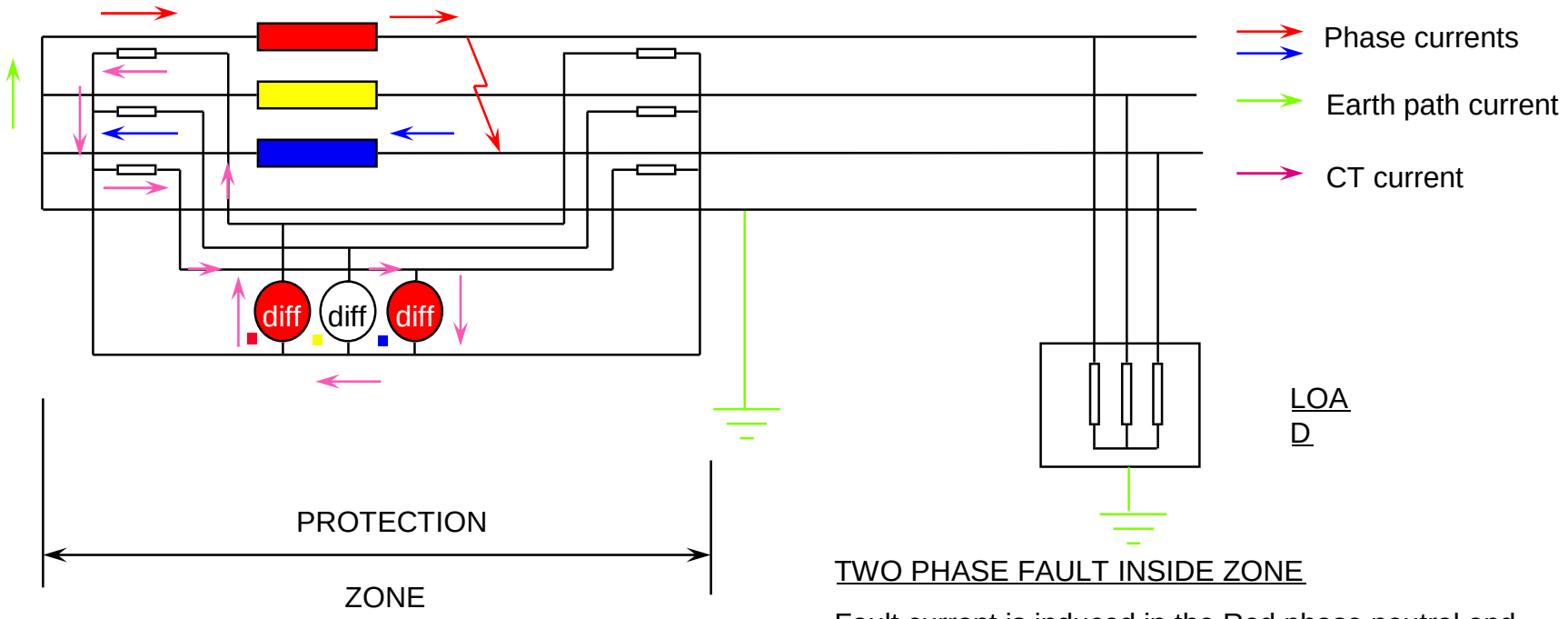
For high voltage sets, the effects of an earth fault in the stator pack or terminal box may be severe. Differential protection, correctly installed will prevent the fault building up and will localise the damage.

SINGLE PHASE FAULT TO EARTH INSIDE ZONE

Fault current is induced in the Red phase neutral end CT but not in the corresponding Red phase line end CT. Load current is not shown and summates to zero in the loops

Induced current circulates in the relay circuit and the protection operates, usually instantaneously. To ensure rapid collapse of fault current, the protection should be arranged to de-excite the alternator, since run-down times may be lengthy particularly on large machines.

Differential protection - 5



Owing to the cost of installing differential protection, it is not normally applied to LV machines below 2MVA or HV machines below 1000kVA

TWO PHASE FAULT INSIDE ZONE

Fault current is induced in the Red phase neutral end CT and in the Blue phase neutral end CT but not in the corresponding line end CTs.

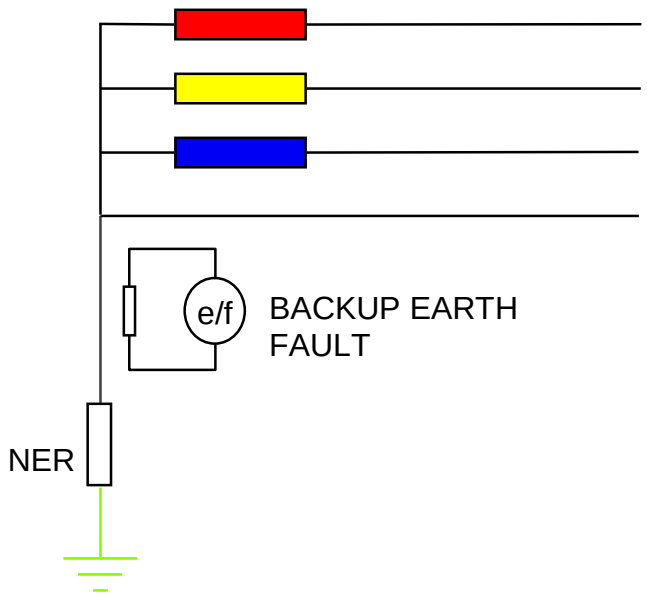
Induced current circulates in the red and blue relay circuits and the protection operates.

Differential protection - summary

- ADVANTAGES
  - Sensitive
  - Senses both line-line and line earth faults
  - Zone protection eliminates discrimination problems
  - Ability to annunciate which phase(s) have faulted
- DISADVANTAGES
  - Relatively expensive
  - Will often require balancing resistors in CT pilots, which are bulky
  - Complex to connect - particularly if star-delta transformers are involved or if a generator and unit transformer are to be protected (biased differential)
  - Prone to connection errors, which can be difficult to find
  - Requires special CTs (Class X)
- MAIN USES
  - Earth and interturn fault protection of high voltage or large low voltage alternators and transformers

Back-up earth fault

- Used to protect neutral earthing resistors or to provide back-up in event of protection failure.



•Resistor is normally sized to pass full rated current (generally the full load current of the largest set on the system) for either 10 or 30 seconds.

•The backup protection should be set to trip the system if the rating of the resistor is exceeded.

•Note that the presence of an NER does not alter the configuration of the protection, but does alter the settings and reduces the discrimination that can be achieved further down the system.

•Backup earth fault is another form of unrestricted earth fault and must be accounted in the discrimination scheme.

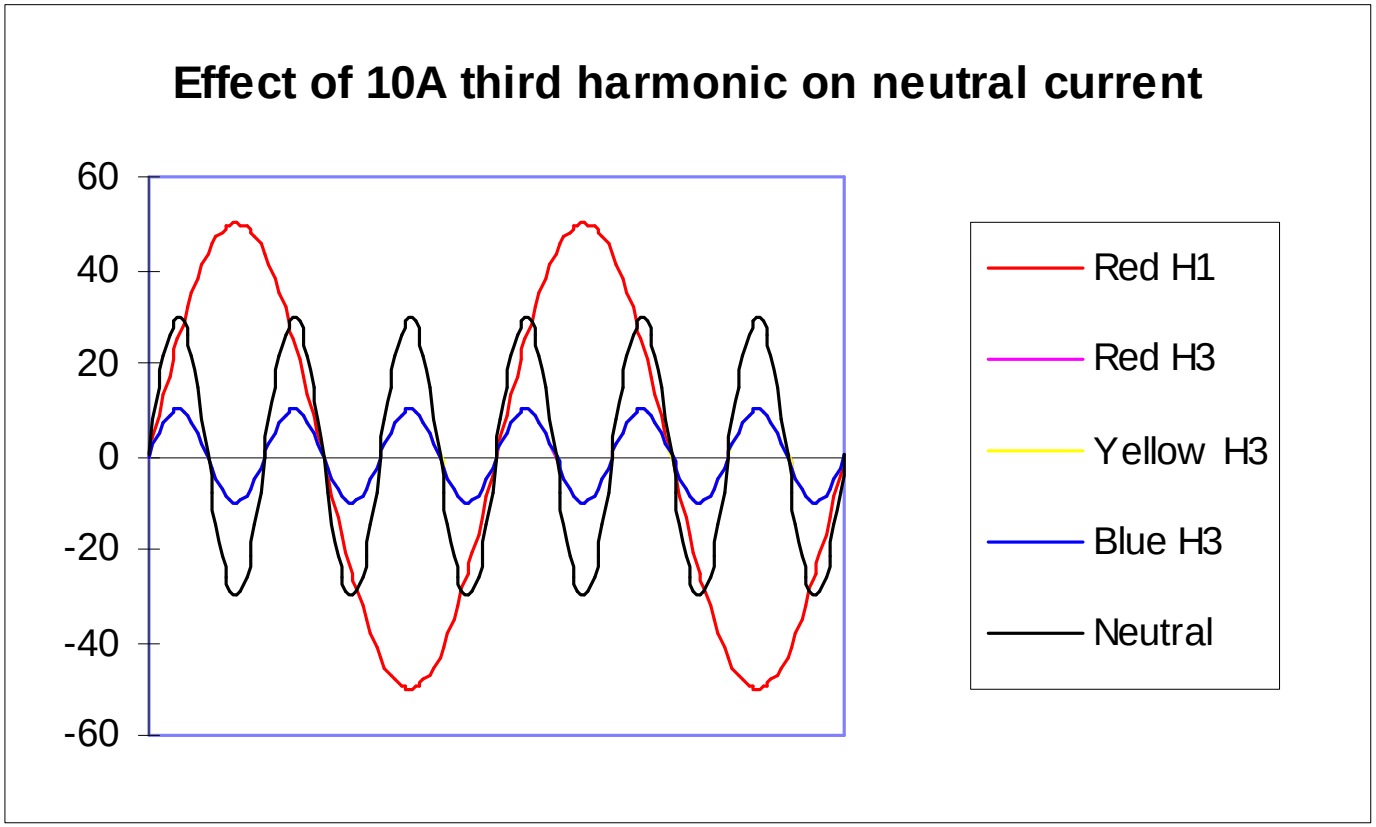
Earthing the generator - 1

- Single generator
  - LV set must have neutral earthed
  - May be possible to interconnect with supply utility company earth
  - Should have own earth system as well - in case of loss of supply system earth (e.g. fractured cable)
  - Maximum recommended impedance 20Ω
    - Actual value will depend on the circuit breaker protection settings
    - If CB setting range cannot be achieved - earth leakage protection
      - e.g. If earth resistance is 1 Ω maximum current on LV set is 240A, with 20 Ω, 12A. - not sufficient for any set main circuit protection
      - Using 300mA earth leakage protection allows a maximum earth impedance of 800 Ω
      - Using 30mA protection allows a maximum earth impedance of 8000 Ω, although this would normally be excessively high.
    - All extraneous conductive parts must be bonded together and earthed

Earthing the generator - 2

- Parallel generators
  - LV system must have neutral earthed - not necessarily individual sets
  - Parallel neutral must be rated for 3rd Harmonic currents between sets as well as system.
  - Sets should not use earth path for neutral interconnection
    - Risk of 3rd harmonic currents disturbing telecommunications
  - Set and mains neutral earth should not be paralleled when in parallel with mains
    - May result in loss of mains through tripping of S.E.F. protection
    - Will desensitise overall earth fault protection if present
  - Care should be taken not to inadvertently parallel neutral through the earth path on incompatible sets.

Understanding 3rd Harmonics

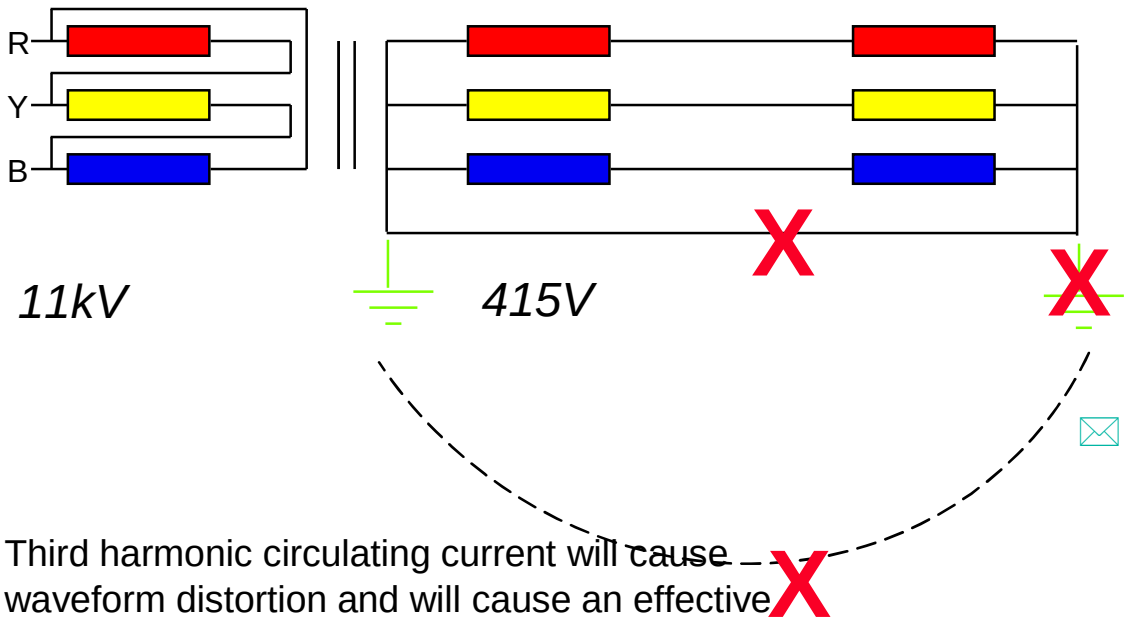


3rd harmonics are a distortion of the load current waveform - effectively other currents at higher frequency (150Hz in this case), are added to the fundamental (H1).

They are caused mainly by switched mode power supplies (PCs) and discharge lighting

These currents add in the neutral - giving rise to possibility of neutral current exceeding line current.

Avoiding 3rd harmonic problems



Third harmonic circulating current will cause waveform distortion and will cause an effective variance between the average value of the waveform (most AVRs) and the RMS (most meters).

Voltage regulator will appear inaccurate.

- Avoid connecting two star windings together:
  - Generator should be connected to a delta wound step up transformer LV winding
  - HV step down transformer should have delta HV winding + star LV
- If you *have* to connect two star windings together:
  - Try to avoid connecting the neutral as well as the phase conductors. Take the neutral from the source.

Summary

- In this presentation we have discussed:
  - The importance of a neutral connection
  - What happens if the neutral becomes disconnected
  - Unrestricted earth fault protection
  - Restricted earth fault protection
  - Differential protection
  - Back-up earth fault protection
  - Waveform distortion
- Remember - this presentation is not exhaustive. Individual systems must be evaluated on their merit.
  - The supplier of the equipment, as a professional, and the customer are jointly responsible for ensuring the safety of the system and the people who use it.