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ACHIEVING REDUNDANCY USING CONFIGURATION EXCHANGE THROUGH GOOSE COMMUNICATION IN SUBSTATION

by

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SUMMARY

Backup protections are used in substations to overcome equipment failure or fault detection failure. In UHV substations, major power plants and critical substations, the cost of failure out-weigh the cost of redundancy. There are different backup principles. In some of the backup protection schemes, relay operates after a time delay and protected device or system is subjected to stress until the back- up time. In some of the back protection schemes, the same protection element is duplicated. In other backup protection schemes, same protection principle of different manufacturers is used. For proof of concept, different protection principle and different manufacturers are also used. In all these back up schemes, IED configuration has to be done manually twice.

This paper explains how configuration can be achieved using Peer-Peer, Master-Slave and Slave-Master arrangement. It explains how using health status between IEDs can be used to co-ordinate configuration exchange. It also explains, how in case of communication failure, the setting/configuration can be exchanged between redundant IEDs. The redundant IEDs function in parallel using setting/configuration exchange through GOOSE to achieve the overall objective of protecting the power system. This redundancy scheme can also be extended to multiple set of protection devices provided they are configured using the above arrangements.

KEYWORDS

Protection, Redundancy, Configuration exchange, GOOSE (Generic Object Oriented Substation Events), IED (Intelligent Electronic Devices), CB (Circuit breaker), VT (Voltage Transformer), CT (Current Transformer), DO (Data Object), LN (Logical Node)

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1. PROTECTION ARRANGEMENT IN POWER SYSTEM

In time delayed back up protection as shown in Figure 1, where source G (generator) and fault F is depicted. In case of fault the Relay 3 fails to trip then Relay 1 trips as back-up protection after a set time delay. This protection scheme used is a radial scheme, where time graded zones are defined and each relay operate after specific time delay. In this scheme of back-up protection, should breaker at Station B fail to trip, either due to protection non-operation or breaker failure, the power system is subjected to the fault till the protection at Station A clears the fault. In order to reduce this delay, quite often redundancy protection is the norm in important power systems especially for EHV systems. In redundancy schemes as shown in Figure 1, Relay 3 and Relay 3_R both operate simultaneously, backing up each other, without any addition time to trip. Since both redundant IED has to have same configuration, it is important to have setting/configuration exchange between the IED using IEC 61850 Analog GOOSE. With exchange of settings/configuration automation is possible.
In the redundancy scheme of Station B, (Figure 1), the current and voltage measurements (from CT, VT) are shown connected to both main and redundant relays. In EHV systems and above, duplicated CT core and VT winding is the norm. SAMU (Stand Alone Merging Unit) may also be used to as shown in Figure 2 which uses IEC 61850 9-2.

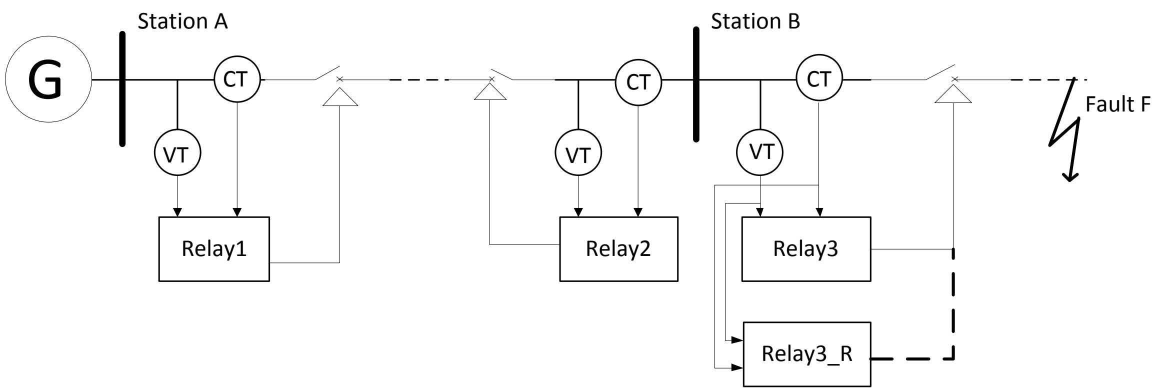

Figure 1: Protection arrangement in sub-station

2. REDUNDANCY SCHEME

In the proposed redundancy scheme, the two redundant IEDs function as Peer- Peer, Master – Slave and Slave-Master.
Peer-Peer configuration: In Peer (Active) – Peer (Follower) configuration, both IEDs function in parallel. If a setting/configuration is changed in any IED then they are synchronized using Analog GOOSE. The circuit breaker operation is controlled from either of the two IEDs. The trip signals from both the Peer are connected to CB.

Master- Slave configuration: In Master-Slave configuration, the Master IED sends its health information to the Slave continuously. If the Slave IED receives bad health signal from the Master, the Slave IED takes control of trip signal to the circuit breaker (Slave's trip signal is connected to CB*).In case of communication failure between the IEDs, then both Master and Slave operate as Peer-Peer. In case of any change in setting/configuration in Master or Slave IED, the parameter value is communicated with each other using Analog GOOSE.

Slave – Master configuration: In Slave-Master configuration, the Slave sends its health information to the Master continuously. When the Master receives bad health information from Slave, then Master takes control of CB (Master's trip signal is connected to CB*). In case of communication failure between the IEDs then both function as Peer-Peer. In case of any change in setting/configuration in Master or Slave IED, the parameter value is communicated with each other using Analog GOOSE.

*Note – In both Master-Slave or Slave-Master configurations, the trip signals from both master and slave IEDs are physically connected to the CB, but the logical connection is decided based on the health status.

The redundancy scheme is as shown in Table 1

Table 1 Configuration scheme.

Mode	Setting/ Configuration exchange	Health Signal communication	During IED failure[1]	Health Communication failure[2]
Peer – Peer	Configurable / Partial configurable/ Not configurable	Not required	Both trip signal connected to CB	Both operate in parallel
Master-Slave	Configurable / Partial configurable/ Not configurable	Master-> Slave	When Master fails, Slave trip signal is connected to CB	Both operate as Peer-Peer
Slave-Master	Configurable / Partial configurable/ Not configurable	Slave-> Master	When Slave fails, Master trip signal is connected to CB	Both operate as Peer-Peer

[1] IED failure is a condition defined by failure in operation (measurement failure etc.).But it is still able to send health signal
[2] Communication failures is a condition defined by failure in communication channel, failure in communication sending and communication receiving

The complete redundancy arrangement can be seen in Figure 2. The merging unit can be used as suggested. The measured values are sent to the IEDs using IEC 61850 9-2 especially when redundant protections are used. The configurations between the redundant IEDs are exchanged using Analog GOOSE. If other communication protocols are used then a protocol translator can be used. The trip coil is usually duplicated for redundancy.

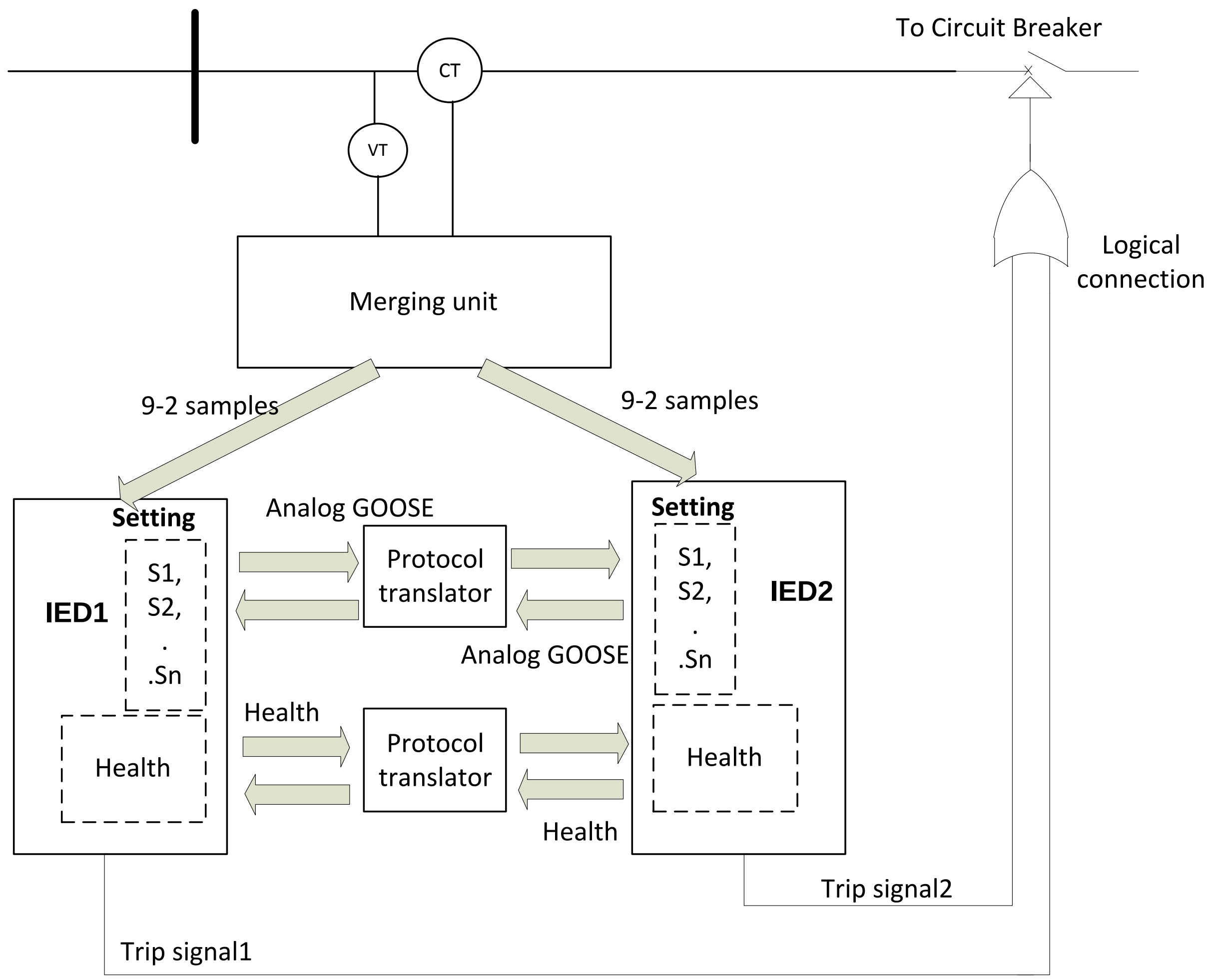

Figure 2: Backup protection scheme in sub-station

3. CONFIGURATION EXCHANGE:
   Each setting/configuration parameter of the IED is mapped as output in Analog GOOSE. These values are broadcast to the other IED. The redundant IED will also receive this information and update its setting/configuration values as shown in Figure 3

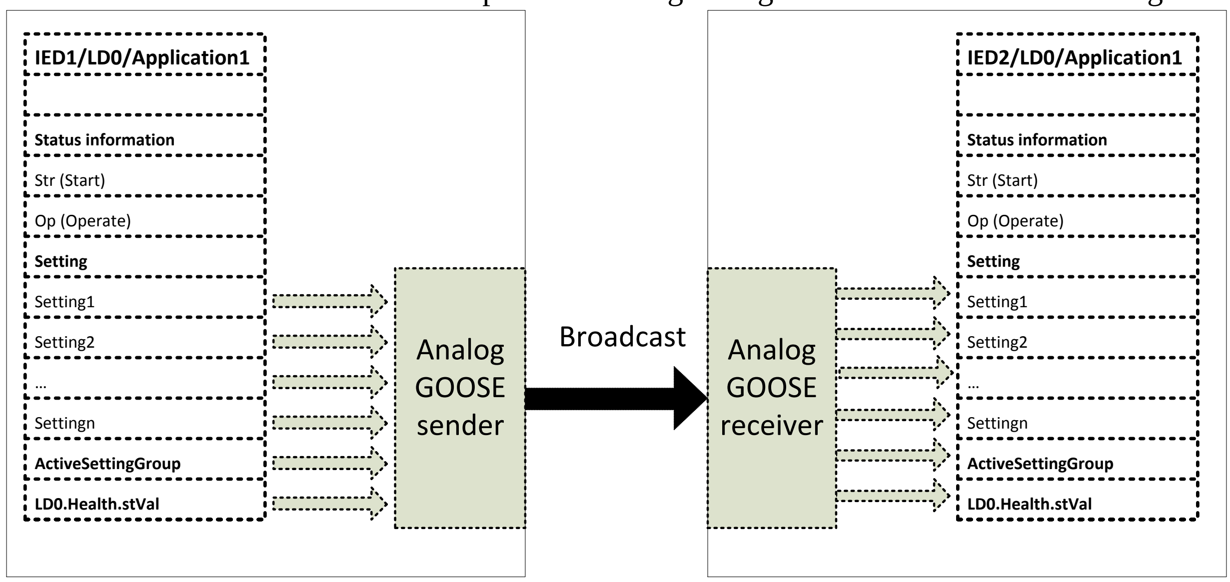

Figure 3: Mapping of setting/configuration to Analog GOOSE communication

4. ACKNOWLEDGE FUNCTIONALITY:

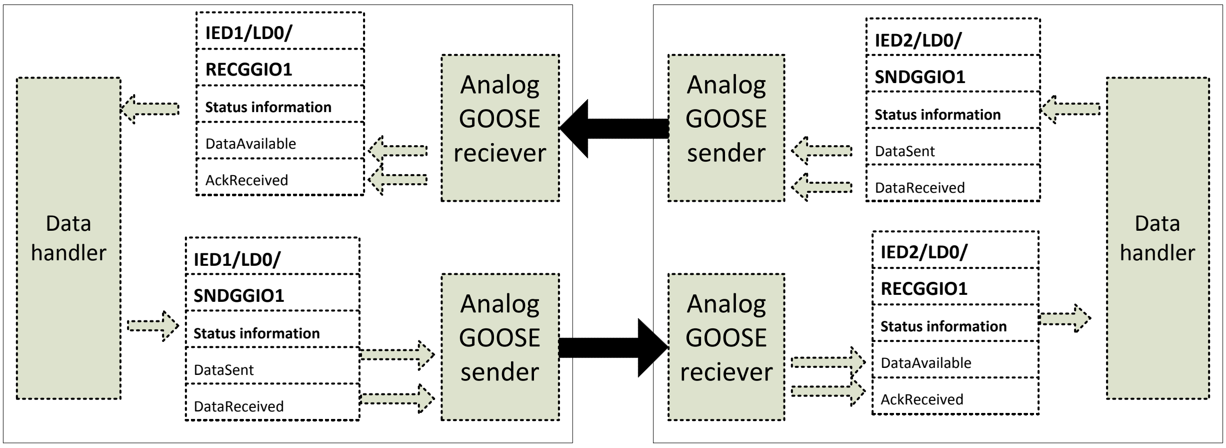

Figure 4: Acknowledge functionality

Referring to Figure 4, whenever a change in setting/configuration in IED1 is initiated, and the updated information is broadcasted and SNDGGIO (Send block) will set the **DataSent** status high which remains until it is committed. This is received by RECGGIO (receive block) by IED2 by the **DataAvailable** DO. This configuration exchange is handled by **Data handler**. The IED2 will send **DataRecieved** information using **Analog GOOSE sender** block using SNDGGIO LN. The **DataRecieved** information will remain high until **DataSent** status is low. This communication is done periodically. During this time **Data handler** in IED2 will not allow setting/configuration change. The IED1 will receive acknowledgment using **AckReceived**. Once **AckReceived** is low then Data handler assumes setting/configuration exchange cycle is over. In brief **DataSent** is mapped to **DataAvailable** and **DataRecieved** is mapped to **AckRecieved .**

Note: The **DataSent, DataAvailable, DataReceived** & **AckRecieved** are example data objects defined for describing in this paper and are not part of the standard DO

5. DIFFERENT BACK UP PROTECTION SCHEME

We can categorize redundancy into 4 different principles based on the possible scenarios for setting/configuration is exchange. Different back up protection schemes are categorized below:

a. Same protection principle with same manufacturer

b. Different protection principle with same manufacturer

c. Same protection principle with different manufacturer

d. Different protection principle with different manufacturer

a. Same protection principle with same manufacturer

In this scheme, same protection principle is used and IEDs of same manufacturer are used.

For example in case of short circuit detection a simple over current protection can be used. Since each of setting/configuration is available in the redundant IED, configuration exchange is simple. The redundancy operation principle is shown in Table 2. The configuration exchange between the IEDs is shown in Figure 5. Trip signal (Operate) from IEDs are connected to Trip circuit separately and they are “OR”ed and then connected to circuit breaker.

Table 2 Configuration scheme for same protection principle with same manufacturer

Mode	Setting/ Configuration exchange	Health Signal communication	During IED failure	Health Communication failure
Peer – Peer	Configurable	Not required	Both trip signal connected to CB	Both operate parallel
Master-Slave	Configurable	Master-> Slave	When Master fails, Slave trip signal is connected to CB	Both operate as Peer
Slave-Master	Configurable	Slave-> Master	When Slave fails, Master trip signal is connected to CB	Both operate as Peer

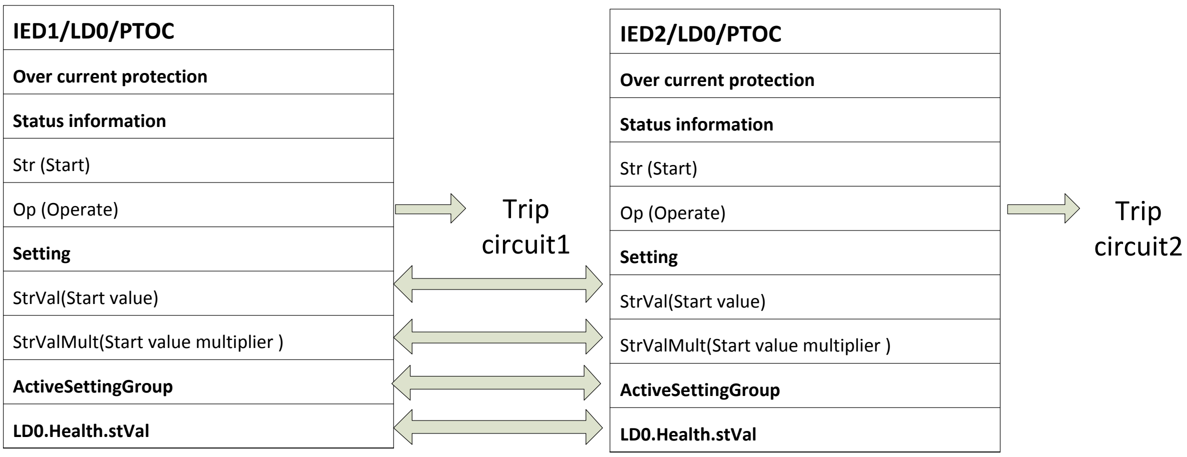

Figure 5: Configuration exchange between same IED manufacturer and same protection principle

b. Different protection principle with same manufacturer

In this scheme, different protection principle is used but IEDs of same manufacturer are used for redundancy. For example in case of short circuit detection an over current protection can be used to detect short circuit in generators. As a backup to this protection principle under impedance protection is used. Each of setting/configuration is not same in both the protection application. The redundancy operation principle is shown in Table 3. The configuration exchange between the IEDs is shown in Figure 6. Trip signal (Operate) from IEDs are connected to Trip circuit separately and they are “OR”ed and then connected to circuit breaker.

Table 3 Configuration scheme for different protection principle with same manufacturer

Mode	Setting/ Configuration exchange	Health Signal communication	During IED failure	Health Communication failure
Peer – Peer	Not configurable[1]	Not required	Both trip signal connected to CB	Both operate parallel
Master-Slave	Not configurable	Master-> Slave	When Master fails, Slave trip signal is connected to CB	Both operate as Peer
Slave-Master	Not configurable	Slave-> Master	When Slave fails, Master trip signal is connected to CB	Both operate as Peer

1) None of the setting/configuration can be exchanged using Analog GOOSE as there are no similar settings between IEDs

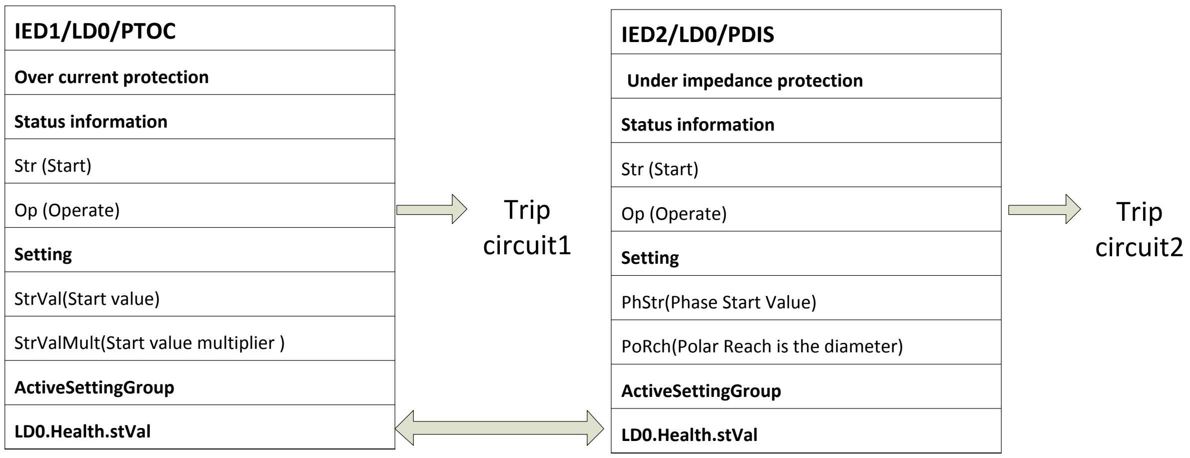

Figure 6: Configuration exchange between same IED manufacturer and different protection principle

c. Same protection principle with different manufacturer

In this scheme, same protection principle is used and IEDs of different manufacturers are used. For example in case of short circuit detection, a simple over current protection can be used. All the setting/configuration may not be similar between the IEDs. This makes configuration exchange a little complex. The setting/configurations that are available in both the IEDs are configured in Analog GOOSE communication. For example StrVal (start value) setting is available in both IEDs. This is mapped in Analog GOOSE. Others which are not available are not mapped. For example StrValMult (start value multiply) is not mapped in Analog GOOSE. The redundancy operation principle remains is shown in Table 4. The configuration exchange between the IEDs is shown in Figure 7. Trip signal (Operate) from IEDs are connected to Trip circuit separately and they are “OR”ed and then connected to circuit breaker.

Table 4 Configuration scheme for same protection principle with different manufacturer

Mode	Setting/ Configuration exchange	Health Signal communication	During IED failure	Health Communication failure
Peer – Peer	Configurable/ Partial configurable[1]	Not required	Both trip signal connected to CB	Both operate parallel
Master-Slave	Configurable/ Partial configurable	Master-> Slave	When Master fails, Slave trip signal is connected to CB	Both operate as Peer
Slave-Master	Configurable/ Partial configurable	Slave-> Master	When Slave fails, Master trip signal is connected to CB	Both operate as Peer

1) Few of setting/configuration can be exchanged using Analog GOOSE, only similar settings between IEDs

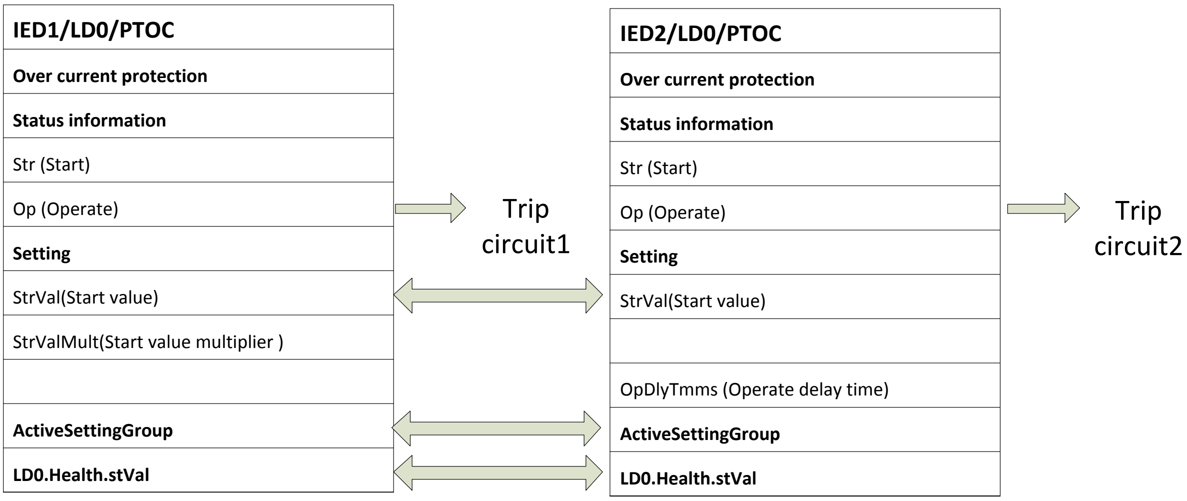

Figure 7: Configuration exchange between different IED manufacturer and same protection principle

d. Different protection principle with different manufacturer

In this scheme, different protection principle is used and IEDs of different manufacturers are used. For example in case of short circuit detection an over current protection can be used to detect short circuit in generators. As a backup to this protection principle under impedance protection is used. Each of setting/configuration need not be mapped as they have no relation in the other IED configuration. The redundancy operation principle is shown in Table 5. The configuration exchange between the IEDs is shown in Figure 8. Trip signal (Operate) from IEDs are connected to Trip circuit separately and they are “OR”ed and then connected to circuit breaker.

Table 5 Configuration scheme for different protection principle with different manufacturer

Mode	Setting/ Configuration exchange	Health Signal communication	During IED failure	Health Communication failure
Peer – Peer	Not configurable	Not required	Both trip signal connected to CB	Both operate parallel

Master-Slave	Not configurable	Master-> Slave	When Master fails, Slave trip signal is connected to CB	Both operate as Peer
Slave-Master	Not configurable	Slave-> Master	When Slave fails, Master trip signal is connected to CB	Both operate as Peer

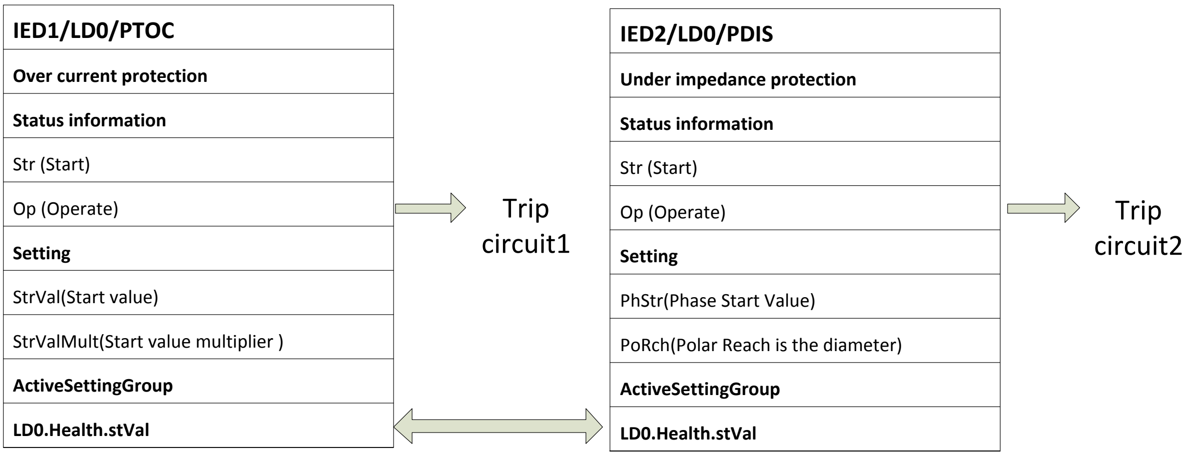

Figure 8: Configuration exchange between different IED manufacturer and different protection principle

6. SOLVING RACE AROUND CONDITION:
Whenever there is change in setting/configuration in IED1, the updated information is broadcasted and SNDGGIO (Send block) will set the **DataSent** status high. This is received by RECGGCIO (receive block) by IED2 by the **DataAvailable** DO. The IED2 will send **DataRecieved** information using **Analog GOOSE sender** block using SNDGGIO LN. The IED1 will receive acknowledgment using **AckReceived**. But IED1 will not wait to receive **DataAvailable** signal for it to commit its setting/configuration change. In case of communication failure both the IED1 will try to send **DataSent** signal but will not wait to receive **DataAvailable** signal. The change in setting/configuration is also committed. When the communication resumes between the IEDs both the IEDs initiate setting/configuration exchange. This will cause a race around condition when both the IEDs are sending **DataSent** signal. This condition could also happen during normal condition when setting/configuration exchange is initiated simultaneously in both the IEDs. This problem can be solved by assigning priority to any one of the IEDs. In Master-Slave or Slave-Master configuration, the setting/configuration change in Master will override over Slave IED. The Slave IED with lower priority will accept the **DataSent** signal and stop sending its **DataSent** signal. It will accept the new setting/configuration value and will update its SCL file. The IED with higher priority will ignore **DataSent** signal from the other IED. It will continue to set **DataSent** signal high till some period of time. There are more solutions to race around condition, but are beyond the scope of this paper.
Note – The Data objects (DO) used here are only for explanatory purposes and may not be part of the standard.

7. CONCLUSION

With this configuration exchange arrangement, it is possible to automate porting of setting/configuration from one IED to another IED in a redundant protection scheme. Thanks to IEC61850 Analog GOOSE which will greatly improve the reliable operation of the power system without manual intervention. This leaves a huge scope also for automation in redundancy with respect to relay co-ordination. The paper opens up possibilities of automating the system configuration, which may be considered one of the first few steps involved in evolving to next higher level of automation in systems including self-healing grid systems. However with further work on redundancy with multiple protection systems, more secure protection can be evolved.

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