

## Generator Protective Relays

# Application Notes on Generator Protection Schemes

## *Single Line Diagram Examples*

### 1. Introduction

The application notes provide selected single line diagrams for the SIPROTEC 4 generator protection device 7UM6, as well as the necessary supplementary devices 7UT6 and 7SJ6. They are intended to support the application engineer during the design phase. To limit the number of variants typical terminations were selected.

If the user requires support for protection refurbishment, then a single line diagram (drawn manually is sufficient) that describes the configuration of the plant must be created. The most important information is the position of the instrument transformers, their specification (rating, ratio, accuracy limit factor, distance from protection cubicle for calculation of the burden) and general plant/switchgear data.

In particular, to determine the earth fault protection concept, information regarding the connected system is required when generators are connected to the busbars directly.

The scope of protection is reflected on the one hand by the total cost and on the other hand by the strategic importance (availability, minimisation of damage) of the plant. Accordingly, there is no universally applicable standard for the scope of protection. The recommendations of the Electrical Engineering Councils may be used as a guide.

In table 1 the basic scope of protection is described in an exemplary manner. It shows the trend, whereby the scope of protection increases with increased machine rating.

Protection	ANSI	Generator – Rated Power (MVA)			
		< 5	5 - 50	50 - 200	> 200
Stator earth fault 90 %	64, 59N, 67N	X	X	X	X
Stator earth fault 100 %	64(100%)			X	X
Differential	87G, 87T	o	X	X	X
Overcurrent time	50, 51V	X	X	o	o
Impedance	21			X	X
Interturn fault				X	
Rotor earth fault	64R	o	X	X	X
Unbalanced load	46		X	X	X
Underexcitation	40	o	X	X	X
Out of step	78				X
Stator overload	49	X	X	X	X
Rotor overload	49R				X
Overvoltage	59	X	X	X	X
Frequency $f >$	81	X	X	X	X
Frequency $f <$	81		X	X	X
Reverse power	32	X	X	X	X
Undervoltage	27	Y	Y	Y	Y
Overexcitation (U/f)	24		o	X	X

Table 1: Scope of protection (o= optional, Y= pump storage power station (motor/ phase shift operation))

Furthermore the user's history (protection concepts used in the past, and experience gained from system faults) plays an important role in the layout of the device concepts. The numerical devices with

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their multi –functionality have great advantages in this respect. By scaling the functions packaged in one device, different requirements can flexibly be satisfied, while still maintaining a certain degree of standardisation for various applications and terminations.

### 2. Basic Redundancy Concepts

The design layout of protection systems is largely determined by redundancy considerations. The n-1 principle is the basis for numerous design decisions. This ensures that the failure of a single component is managed, and does not lead to the total break-down of a system. This principle is however not always applied. In small plants a trade-off between redundancy and costs takes place. In practice the following strategy is common-place:

#### **a) No Redundancy:**

In figure 1, the basic concept is shown. If the protection component fails – e.g. the self monitoring picks up – then a further operation without risk is not possible. The overall availability (minimising the plant-down time) can be increased with appropriate servicing (spare devices, service contracts etc.). This plant design may be applied to generators with small rating.

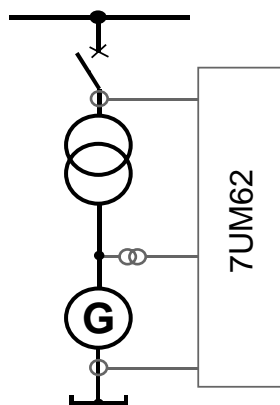


Figure 1: example : no redundancy

#### **b) Partial Redundancy:**

At least two protection devices are employed, as shown in Figure 2. The protection devices/function mix is selected so that the plant may remain in service when one of the two devices has failed. Certain restrictions must however be accepted. The protection devices are for example connected to the same instrument transformer. The burden imposed by the protection is negligibly small in this case.

The same applies to the auxiliary supply, as both devices are connected to the same supply and the circuit breaker usually only has one trip coil.

Substantially more time is available for the repair. The repair may be scheduled to coincide with a planned plant maintenance cycle.

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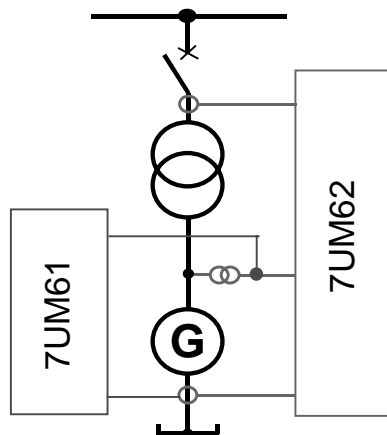


Figure 2: Example: Partial redundancy

**c) Complete redundancy**

Redundancy considerations are in the foreground of the design concept in this case. All essential components are duplicated. As shown in figure 3, the redundancy starts with separate instrument transformers e.g. current transformer cores, continues with the protection devices and the trip signal, which is routed via separate auxiliary supplies to the switch gear, utilising two trip coils. The protection functions may on the one hand be duplicated in the protection devices, on the other hand, supplementary protection functions with different measuring techniques are desirable. Typical examples are the short circuit faults and the earth faults.

Earth faults without short circuit current may be detected on approximately 90% of the protected zone by means of residual voltage measurement. A totally different measuring technique - using an injected signal (20 Hz) in the stator - provides protection on 100% of the protected zone.

The same is possible for short circuit protection. The main protection is provided by current differential protection, providing fast and selective protection. Impedance protection supplements this, while also providing back-up protection for system faults with corresponding grading settings.

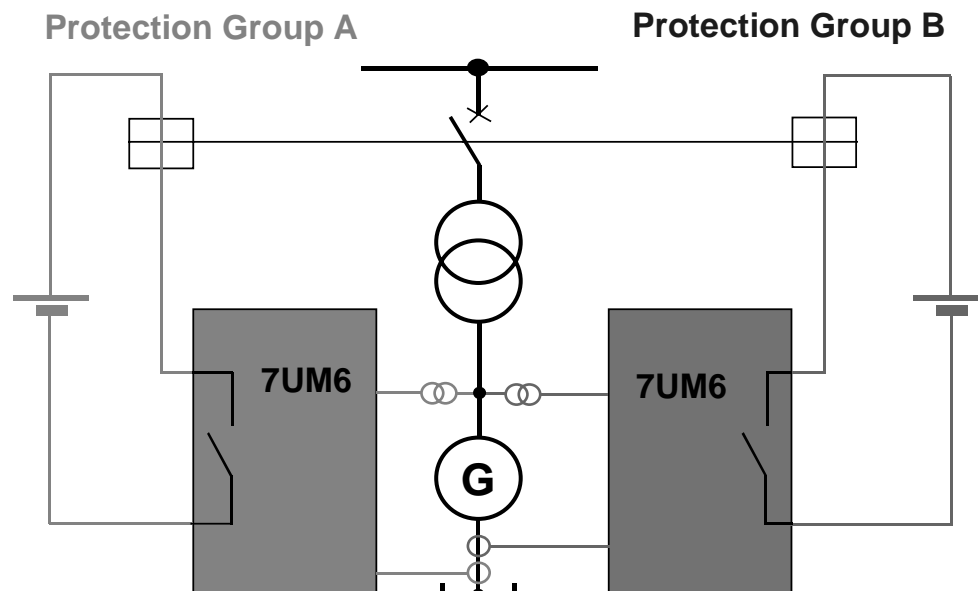


Figure 3: Example: Complete redundancy

**Tripping arrangement**

Generator protection, other than usual protection systems, must trip different switchgear depending on the nature of the fault. Its number is largely dependent on the plant configuration. Usually larger units have the most switchgear to be operated. Unique tripping arrangements are necessary with hydro generation.

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The fundamental principle is shown in Figure 4. The switchgear that has to be operated is shown on the one side and on the other side the protection functions that provide the initiating protection functions can be seen. The tripping program/concept depends on the recommendations/experience as well as the operating conditions. In this respect there are two philosophies. Via a tripping matrix (with digital technology a software matrix) the individual tripping program is defined and the switchgear is operated directly. The other variant, typical in the USA, reduces the tripping to two programs: e.g. only the generator is isolated, and the isolation of the generating unit. The switchgear is operated via lock-out relays. The protection only requires a limited number of tripping contacts for this purpose.

The attached single line diagrams also contain a typical tripping arrangement.

- **Generator Breaker**
- **Excitation Breaker**
- **Turbine Rapid Shut Down**
- HV Network Breaker
- Auxiliary Supply Breaker 1
- Auxiliary Supply Breaker 2
- Aux. Supply Changeover
- SEE/SFC, Unit-trafo
- SEE/SFC, Aux.-Trafo
- Reserve
- Special Trips for Hydro Stations (e.g. brake)

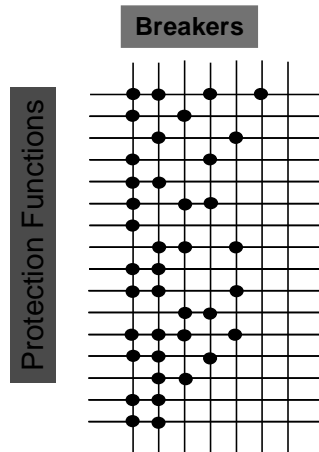


Figure 4: Protection tripping via matrix

### 3. Single - Line Diagram for small generators (< (5- 10)MW)

7 protection application examples for small generators are referred to in the annexes. Only one protection device is used, due to cost considerations. Redundancy is neglected. At the low end ranging from 0,5 to approximately 3 MW the 7UM61 for example provides adequate functionality. If current differential protection is required, the 7UM621 can be employed. The decision up to which size generator a protection concept without redundancy can be used is generally based on cost criteria (whereby consequential costs must also be considered).

The multi functional protection devices also satisfy all the protection demands of a 10 MW machine. In the following, the different attachments are described. The heading corresponds to the attachment name.

#### **7UM61\_LV\_1.pdf**

The attachment refers to a low voltage generator. To connect the voltage to the measuring input a voltage transformer is required. The voltage transformer requirements set by the protection are minimal. The burden in the voltage circuit amounts to approximately 0,3 VA, so that a voltage transformer rated burden of 1 VA is sufficient. The class CL 1 is recommended.

The basic function mix (MLFB- position 14 = A) is sufficient for the scope of functions.

The AND gate in the tripping matrix indicates that the underfrequency protection f1 must be blocked via an auxiliary contact of the generator circuit breaker. A binary input is available for this purpose.

For the settings, the device manual provides information with descriptions of the individual protection functions.

#### **7UM61\_MV\_1.pdf**

A generator that is directly connected to a medium voltage busbar is shown. To achieve reliable earth fault protection, a primary resistor is connected in the star point to produce earth currents. To prevent operation in the event of earth faults on the busbar, two core balance current transformers are

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connected to the protection in parallel. In addition, the neutral displacement voltage is used as a release criterion (recommended setting, Address 0150 non-directional with U0&I0). During start-up (open generator circuit breaker), monitoring of the neutral displacement voltage on its own is sufficient. This state may be defined in the protection device via binary input. The protection function then automatically changes to neutral displacement voltage (refer to 1. AND-gate in the matrix). The remaining terminations correspond to the common standard.

The standard function mix (MLFB- position 14 = B) is recommended for the scope of protection functions.

### ***7UM61\_MV\_2.pdf***

In general, the layout corresponds to the attachment 7UM61\_MV\_1.pdf, the difference being the earth fault protection. To obtain the necessary residual earth current, an earthing transformer is connected to the busbar. For selective fault clearance, a directional earth fault protection is used. The earth current is measured via core balance CT and the displacement voltage is derived from a broken delta winding on the voltage transformers.

### ***7UM61\_MV\_3.pdf***

This attachment describes a unit consisting of a generator and unit transformer.

For rapid clearance of faults in the transformer, an impedance protection is employed. Therefore full scope of protection is required ((MLFB- position 14 = C).

The earth fault protection is now implemented by evaluation of the neutral displacement voltage. This is derived from the neutral earthing transformer. If the displacement voltage on the secondary of the neutral earthing transformer can be greater than 200 V, it must be divided (see device manual).

The rotor earth fault protection is implemented by means of earth current measurement (function sensitive earth current detection). Via the coupling device the rotor is injected with a system frequency AC voltage.

The relevant non-electrical signals from the unit transformer are introduced via binary input. For tripping the function "external trip coupling" is used.

### ***7UM621\_LV-2.pdf***

This attachment describes the application of a large low voltage generator. The current differential protection ensures rapid clearance of short circuits.

The rotor earth fault protection in this case is provided by the protection function „Rotor earth fault protection (R, fn)". The resistance measurement is obtained with the driving voltage (UE) and the current flowing in the rotor (IEE1). Greater sensitivity is achieved in this manner. Implementation of UE must be set in (Address 0223 UE connected to Rotor). The protection function output is routed as an alarm via the tripping matrix.

The basic function mix (MLFB- position 14 = A) is recommended for the protection scope of functions.

### ***7UM621\_MV\_4.pdf***

This attachment shows a generator that is connected directly to the busbars, which utilises an earthing transformer also connected to the busbar, to obtain earth currents. Short circuit protection is provided by differential protection. Earth faults are detected by directional elements in this case. The earth current is measured via IEE2 and the displacement voltage, derived from voltage transformers connected in broken delta configuration, is measured via input UE.

The rotor earth fault protection is obtained with the "sensitive earth" current protection function. The measured value is obtained via the IEE1 input. This must be set accordingly during configuration of the protection function (Address 0151 with IEE1). With regard to the tripping, only an alarm is provided.

The basic function mix (MLFB- position 14 = A) is recommended for the protection scope of functions.

### ***7UM621\_MV\_5.pdf***

In the generator unit configuration, the differential protection covers both the generator and the transformer. The required vector group adaption is achieved in the protection. In addition, a restricted earth fault (REF) is provided. It utilises the input IEE2 and the current transformer on side one. For this

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application, the zero sequence voltage release in the REF must be switched off. (Address 2103: REF Pickup of U0 Release must be set to 0 ). If back-up earth fault protection is required for the system, an additional device 7SJ4 (SIPROTEC easy) must be used. The tripping is routed to the 7UM62 via binary input.

The rotor earth fault protection is obtained with the “sensitive earth” current protection function. The measured value is obtained via the IEE1 input. This must be set accordingly during configuration of the protection function (Address 0151 with IEE1).

The stator earth fault protection is implemented with the displacement voltage detection. The voltage from the neutral earthing transformer is connected to the protection input UE for this purpose.

The basic version (MLFB- position 14 = A) is recommended for the protection scope of functions. If in addition an impedance protection is required as back-up for system faults, as well as an earth fault protection for faults close to the system star point (Criteria 3. Harmonics in the displacement voltage) then the version Standard (MLFB- position 14 = B) should be used. If earth current differential protection is required, then MLFB - position 15 = C must be selected.

### **4. Single - Line Diagrams for average size generators (10 – 50 MW)**

The attachments show three example applications for the protection of average size generators. The examples apply the partial redundancy according to figure 2, whereby at least two 7UM6 devices are employed.

#### ***7UM6-Redundancy\_1.pdf***

With direct busbar connection the redundant configuration was applied with stringent cost limiting measures. Accordingly separation of the current transformer cores was neglected and the most cost effective version of the two 7UM6 devices was selected.

The main protection is a 7UM621. The principal protection scope and the connection are identical to the example 7UM621\_MV\_4.pdf and therefor the corresponding comments can be checked there. The back-up functionality is provided by a 7UM612. This also provides sufficient in and outputs for input signals and alarm outputs. As the underexcitation and load unbalance protection should also be redundant, the standard scope of functions (MLFB- position 14 = B) must be used.

The neutral current is looped through accordingly. No problems are to be expected in this regard, as the burden of the protection devices is negligibly small. The voltage connection (phase-ground voltage and displacement voltage) are connected to the voltage transformer in parallel.

#### ***7UM6-Redundancy\_2.pdf***

This version of direct coupling to the busbar employs 2 7UM621 devices. In this case, the spare parts issue (amongst others) plays a role (identical parts). The protection functions are duplicated. The current measurement is done with separate current transformers or current transformer cores. Furthermore, a cable connection to the switchgear is assumed. The device F11 provides the differential protection of the cable including the generator. In device F21, the differential protection is solely provided for the generator.

The stator earth fault protection via the earth current differential connection (input IEE 2) is provided with additional release criteria – displacement voltage (input UE).

The rotor earth fault protection is implemented with the sensitive earth current function (input IEE 1). The allocation of IEE 1 must not be overlooked during the configuration. Only one alarm annunciation was provided.

For the underexcitation protection, the excitation voltage was also coupled via the input TD 3. Fast tripping can be achieved in the event of detected underexcitation and for failure of the excitation voltage.

Notes regarding the further protection functions can be found in the device manual.

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The basic scope of supply (MLFB- position 14 = A). fulfills the protection requirements. If the starting protection is required, (e.g. the ANSI market), then the option standard (MLFB-position 14 = B) must be selected. In this way, impedance protection will also be available as additional back-up protection. The connections will not change. The tripping matrix must be expanded accordingly.

### ***7UM6-Redundancy\_3.pdf***

In this unit configuration, a greater rating of the generator unit is assumed. Therefore the scope of protection is extensive. 2 7UM621 devices are employed :

- F11: Scope of function standard (MLFB – position 14 = B); and in addition for the earth current differential protection (MLFB – position 15 = C).
- F12: Scope of function standard (MLFB – position 14 = B)

The F11 provides overall current differential protection for short circuits. It includes the generator and the transformer. In F21, it is exclusively for the generator. Back-up protection is provided by the impedance protection. It protects the generator, the transformer as well as parts of the network. In addition, the F11 device includes overcurrent protection. This should be allocated to the HV current transformer, thereby providing an additional back-up protection for the network. According to the protection co-ordination, a definite time or inverse time protection characteristic should be selected (refer to manual). The function I>> was chosen in the example.

Assuming effective earthing of the transformer, restricted earth fault (REF) protection was additionally included in F11. The sensitive earth current function (definite time stage) is implemented as back-up earth fault protection.

A dual concept is employed for stator earth fault protection. The displacement voltage across the burden resistance of the neutral grounding transformer is measured via input UE by F11. At the same time the 100% stator earth fault protection via third harmonic is provided in F11. If sufficient third harmonic is available at the generator, then this function may be activated (refer to manual). Monitoring of the displacement voltage is also done in F21. In this case it is calculated from the phase-ground voltages.

The rotor earth fault protection is allocated to device F21. The computation of the rotor earth resistance is done by evaluation of the measured voltage (input UE), and the rotor earth current (input IEE1). In power system data 1 the corresponding allocation of the voltage input UE (Address 0221 UE CONNECTION: **UE Connected to Rotor**) must be done for this function to operate. The alarm stage is output as an alarm while the tripping stage RE<< is used to shut down the generator.

The remaining protection functions are duplicated as far as possible. The excitation voltage is measured for the implementation of the underexcitation protection (refer to manual).

### **5. Single – Line Diagram for large generators (> (50 – 100 MW))**

Hereunder a sample solution for a large generating unit is proposed. In essence this differs from the above examples in the plant design and scope of protection. The generating unit additionally has an auxiliary transformer and generator circuit breaker. The three protected objects (generator, unit and auxiliary transformer) already define the allocation of protection devices. Complete redundancy is consequently strived for (refer to figure 3). This implies stringent separation, starting with the instrument transformers, continuing with the protection devices and finally ending with the tripping. The auxiliary supply is also duplicated.

The following notes exclusively refer to the protection concept and the instrument transformer connections. This explanation should be viewed as a suggestion.

The required notes have been summarised in attachment **Large Unit.pdf** . Page 001 describes the fundamental concept including the tripping matrix. Page 002 shows the same protection concept. Only the tripping arrangement was changed, showing a variant with lock-out relays. Page 003 describes a solution only protecting the generator, if for example the generator is provided as packaged solution. The following notes apply to page 001 and are structured according to the three protected objects.

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### **Generator:**

Two 7UM622 devices are applied for the protection. The maximum hardware version was selected due to the signals that must be input and the number of trip signals that must be output.

#### *Short circuit protection:*

The device F11 includes generator differential protection and an impedance protection function. The impedance protection provides back-up protection for the transformers as well as the system. The device F21 includes the impedance protection. It additionally assumes the back-up protection of the generator in case F11 fails. The overcurrent protection provides the excitation transformer protection. For this purpose the overcurrent protection functions must be allocated to side 1 during the configuration.

#### *Stator earth fault protection:*

In this case 100% stator earth fault protection is implemented with injected 20 Hz voltage in the starpoint. The required accessories can be recognised in the neutral earthing transformer. The measured quantities are routed to the inputs UE and IEE1 of the device F11. Alternatively the displacement voltage measurement is also provided in the device, as this function is also available. If an independent measured solution is required, this can be achieved by calculation of the displacement voltage with the measured phase-ground voltages. For this purpose the voltage input must be set accordingly. (Address 0221 UE CONNECTION: **UE Connected to Loading Resistor**). At the same time it is recommended to block the protection functions when the fuse failure monitor picks up. The corresponding annunciation may be routed to the blocking input of the protection function via CFC. In device F21 the displacement voltage is measured on a broken delta winding of the voltage transformers, thereby providing an independent back-up mode.

#### *Rotor earth fault protection:*

With large machines, a sensitive rotor earth fault protection is of great value. For this purpose, the technique using an injected low frequency square wave voltage (1-3Hz) is recommended. The control device 7XT71 must be housed in a protection cubicle in the immediate vicinity of the protection device. The protection function is implemented with device F11. The measured quantities are derived with transducers (TD 1 and TD 2). This function may in principle also be done in parallel with device F21. This was however neglected as a transducer input (TD 1) was reserved for the DC voltage protection. This is required for gas turbines with starting converter.

#### *Remaining protection functions:*

The further protection functions are duplicated as far as possible. This includes the reverse power protection, underexcitation protection (with excitation voltage measurement via TD 3), unbalance load protection, out of step protection, frequency protection, over voltage protection, starting protection (on stationary machine) and the fuse failure/circuit interruption of the voltage transformer secondary.

#### Scope of function:

- F11: Version Full (MLFB- position 14 = **C**) as well as (MLFB- position 15 = **B**)
- F21 Version Full (MLFB- position 14 = **C**)

### **Unit Transformer**

The main protection function is the three winding differential protection achieved with F13 (7UT613). In addition, an earth current differential protection on the high voltage side is provided for increased sensitivity during single phase faults. Furthermore, the earth current stage is used as back-up protection for earth faults in the system. If the device fails, a Buchholz protection as well as an impedance protection (F11 and F21) will assume the back-up protection functionality.

Signals from the Buchholz protection are derived via an independent path. The binary inputs of device F22 (7UM612) are used for this purpose. In addition, this device provides the back-up protection functionality on the high voltage side. The sensitive earth current stage operates for earth faults. The pick-up thresholds as well as the time grading must be co-ordinated with the system. The overcurrent protection is employed as back-up protection for the system or transformer. The I>> - stage may be made directional towards the transformer. The pick-up threshold must be set above the inrush. Alternatively, a delay must be introduced when the system CB is closed. The I> - stage is the back-up



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protection for the system and must be co-ordinated accordingly. For the system condition "closing of system CB while generator CB is open" a delay of this function is also required. The displacement voltage (calculated from the phase-ground voltages) is used for alarm purposes.

Alternative devices such as a pure overcurrent protection 7SJ6 or a distance protection 7SA6/ 7SA522 may also be applied. This amongst others depends on the protection requirements.

### ***Auxiliary supply transformer***

In this application, a three winding transformer is assumed. The required three winding protection is provided by F23 (7UT613). At the same time, a earth current differential protection (REF) is implemented for the two low voltage windings that are Y connected low voltage windings.

Back-up functionality is provided by device F12 (7UM612). The main inputs are also routed via this device. The overcurrent protection provides back-up protection for short circuits in the auxiliary supply transformer or auxiliary supply circuit. Both the I> and I>> - stages may be used for this purpose. The sensitive earth current stage provides the back-up protection for earth faults on the low voltage side (1 A CT's are a pre-requisite).

The second earth current back-up function is achieved with the earth current input of the 7UT613 (F13).

The short circuit protection on the low voltage side (back-up protection of the auxiliary supply in-feed) is generally housed in the medium voltage bays and is therefor not further elaborated on here.

Device F12 also provides the sensitive earth fault protection (important when generator CB is open) as well as the usual over excitation protection.

### ***Tripping arrangement***

On the right hand side the corresponding trip signals of the individual devices are summarised. The AND-gates designate the switching state dependent blocking or release conditions. For this purpose, the available logic inputs of the protection functions may be used. The allocation to the binary inputs (routing) must be fixed during the engineering stage. This applies to F11 as well as F21.

Optional input of non-electrical signals on the devices F12 and F22 are indicated. The pick-up threshold of the binary inputs should be selected to the highest value. If interference signals are possible in old plants, a shunt resistor (10 k $\Omega$  / 5 W) must be applied to the binary input to shunt the interference signals. Interference quantities may also be minimised by routing the initiating signal with different cables.

The 7UT613 does not have sufficient potential free contacts for large generating units. Therefor an auxiliary relay was introduced for each output to provide contact multiplication (refer F13 and F23). The time critical trip signals are routed from the protection device directly to the switchgear (e.g. system CB or generator CB). The other signals are routed via auxiliary relay. The small delay is uncritical, especially since the signals to the switchgear are also routed via auxiliary relay in the event of a hardware matrix. The same applies to the lock-out relays.

For the concept on page 2, only 2 tripping programs (segregated for generator (partial shut-down) and transformer (total shut-down))are implemented. The initiating signal for the switchgear is routed via lock-out relay (86-G, or 86-T). The switchgear that will be operated is indicated in the legend at the bottom.

## **6. Signalling**

The necessary scope of annunciations has been the topic of many discussions, particularly with regard to older plants. In this respect the multi-function devices give rise to the situation where the device has too many functions and too few contacts for individual alarms.

The integrated software matrix or the programmable CFC logic allow annunciations to be combined.

Therefor, only those alarms that are essential for plant operation (e.g. also for emergency operation) should be routed via contact. All the events necessary for clarification of protection operation are stored in the protection device and will not be lost, as battery back-up is ensured. These may be retrieved with the operating program DIGSI (also from remote).

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In new plants, the information transfer via serial interface should be consequently applied. In the control system, substantially more protection annunciations are then available – these may be customised for the operating personnel if required. A communication solution to the power station control system may for example be provided by the PROFIBUS DP.

A further advantage is provided by the transfer of selected operational measured values. This achieves a saving of transducers on the one hand, while on the other hand a read-out of the operational measured values in the protection is an indirect "external test". If the values make sense, then the entire measuring circuit (instrument transformer – protection device – communication) is in order. A saving in secondary testing is possible (reduce the test to non monitored plant sections) or increase the test cycle period.