Module concept Siprotec 7UM85

Flexible and scalable devices for generator protection

Digital protection devices are state of the art. They are constantly enhanced to provide reliable protection for different system designs with only few components. Siemens offers a new device concept with the Siprotec 7UM85 generator protection. It is characterized by its modularity and flexibility regarding hardware and software and can thus be adapted to a wide range of requirements.

Climate change and the decreasing availability of resources have led to a rethink of power generation. Renewable energy like solar and wind power, hydropower and biomass are increasingly used. For a reliable supply with power, however, conventional generation units like gas turbine, hard coal-fired and brown coal power stations remain necessary. The turbine-powered synchronous generator is therefore still the dominating power generation unit, with a broadening product portfolio.

Solar power systems, for example, feed their generated power to the grid using inverters. Wind farms use two different concepts: Firstly, the generation using double fed induction generators, with the slip controlled by an inverter, and secondly using synchronous machines. Due to the different frequencies, the power is supplied to the grid with an inverter. Synchronous generators are also used for hydropower and biomass, yet they are substantially smaller than those used in brown coal power stations.

This article provides information on the electrical protection of synchronous generators and power plant units. Digital protection equipment has been in use for more than two decades. Technological development has led to more powerful processors and more memory capacity. This means that a lot more protection functions can be implemented in a device. And, that the protection tasks can be fulfilled with fewer devices.

Flexible communication is another technology trend. Ethernet-based protocols like IEC 61850 or Profinet are used to exchange data with control equipment and can perform flexible control tasks. This communication will extend to sensor level - for example with the process bus compliant to IEC 61850-9-2.

Figure 1.
Device view:
Basic module with expansion modules

The required protection functions are determined by the size of the system and also by economical aspects. Support for the specification of the scope of protection is given in [1]. In addition, the rules for network connection [2], [3] must be observed. They describe the required behavior of the generation units connected to the grid for different load and fault situations.

Device technology trend

The different generation unit sizes lead to the requirement for scalable hardware. This can be implemented in different kinds of ways, for example with different device classes or with housing technology that can expand the hardware with pluggable circuit boards.

Siprotec 5 from Siemens has chosen another approach and has created a module kit **(Figure 1)**. The base module (1/3 x 19" wide) with a powerful dual core processor with extensive memory is a key element. It is suitable for the protection of small generation units. When it is necessary to record and process considerably more measured variables and binary inputs and outputs, the device can be supplemented with expansion modules (1/6 x 19" wide). This enables the user to put together the suitable hardware for the generator protection application at hand.

The housing design in **Figure 1** is particularly worth mentioning. The cooling fins with their enlarged surface ensure that heat dissipation out of the device is significantly improved. At the same time, the encapsulated modules improve the electromagnetical properties.

Flexible communication is guaranteed by pluggable communication modules with electrical and optical interface design.

Ethernet-based versions are state of the art - with 100 Mbit trending towards 1 Gbit. The plug-in modules are located on the rear side of the device **(Figure 2)**. These modules can run different protocols that are selected and configured during engineering. For generator protection applications, these are, for example, the Ethernet-based protocols PROFINET and IEC 61850.

Figure 2. Plug-in communication modules

To fulfil the multitude of different generator protection tasks the respective protection functions are required. Their scope depends on the system design and size (see remarks in [1]). While previous devices had a fixed function scope or the functions could only be selected using order codes, Siprotec 5 uses a new concept. The protection device for generator protection applications - 7UM85 - has the basic protection functions. These are suitable for small systems. If additional functions are required, the user can select them from the library during engineering **(Figure 3)**.

This concept ensures a high level of flexibility. When ordering the device, the user selects a function point class with a defined quantity of function points. If functions from the library are used, the number of available function points decreases. If functions that require function points are deleted, on the other hand, function points are made available again. These can then be used for other functions.

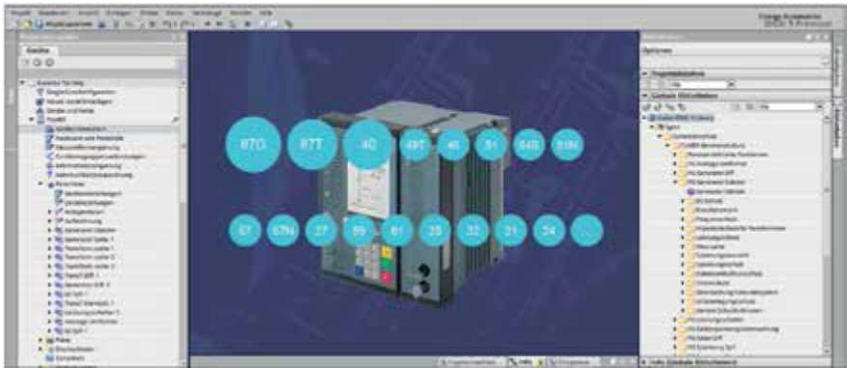

Figure 3. Additionally loadable protection functions ensure high functional flexibility

More function points can be ordered any time, if required. The user will receive a file and can easily update his device.

Particularities when using generator protection

Generation plants typically have different designs. These must be taken into account when developing the device technology and the protection functions.

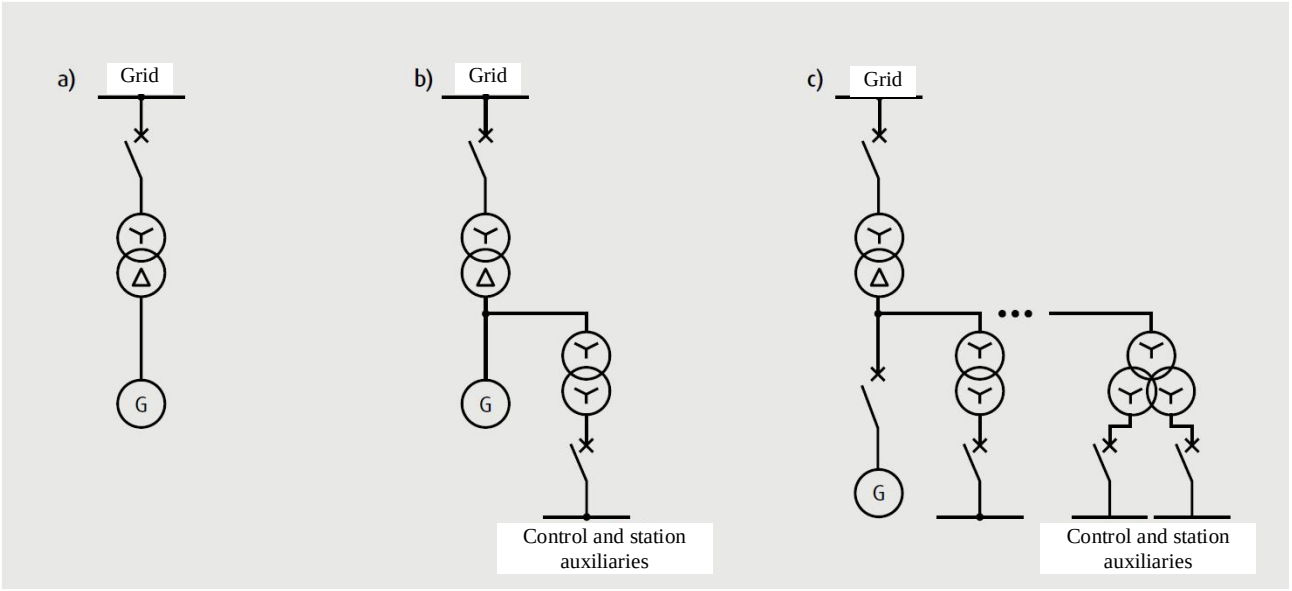

Figure 4. Different unit connections

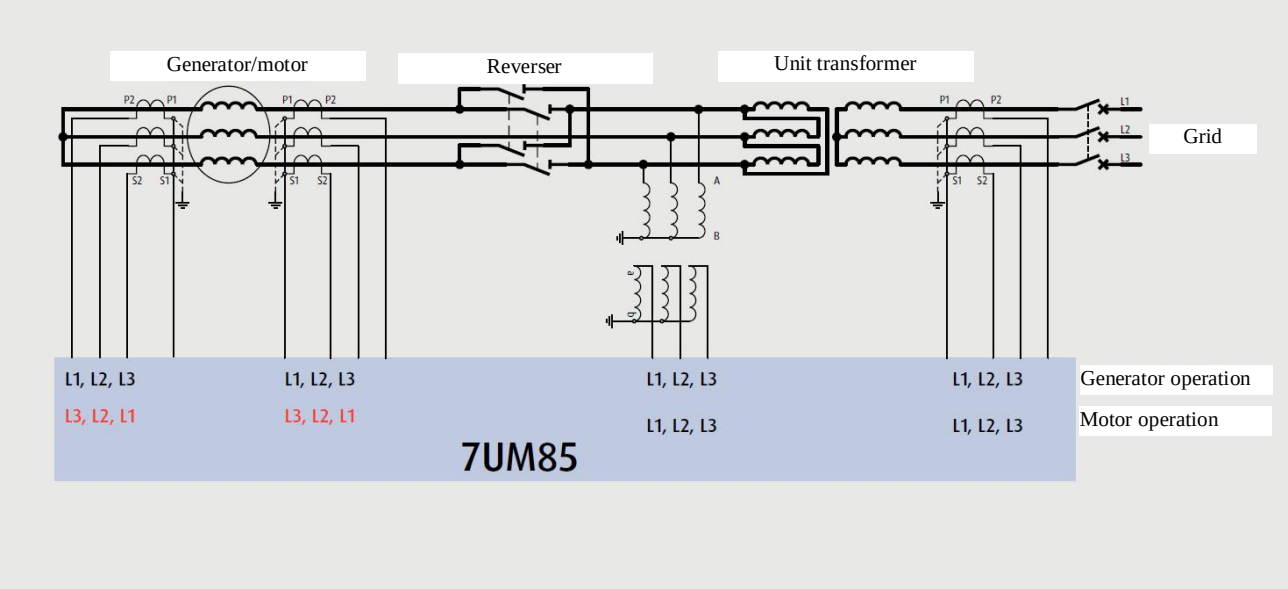

Figure 5. Changing the phase sequence for pumped-storage power plants

There are basically two basic versions: busbar and unit connection. In case of the busbar connection, several generators supply one common busbar. This kind of connection is used in industrial plants. The galvanic connection of the generators leads to particularities in the design of the stator ground fault protection. A unit connection is always a combination of generator and unit transformer. This means the generator is galvanically isolated from the grid supply. This concept has different implementations **(Figure 4):** The implementation in **Figure 4a** can mainly be found in smaller generation units, the variants in **Figures 4b** and **4c**, on the other hand, are used in larger power plant units.

The variant in **Figure 4c** with generator circuit breaker offers a high level of flexibility. In case of a short-circuit in the generator, it will be separated from the grid with the generator circuit breaker. In addition, the control and station auxiliaries can be supplied by the unit transformer in case of maintenance work.

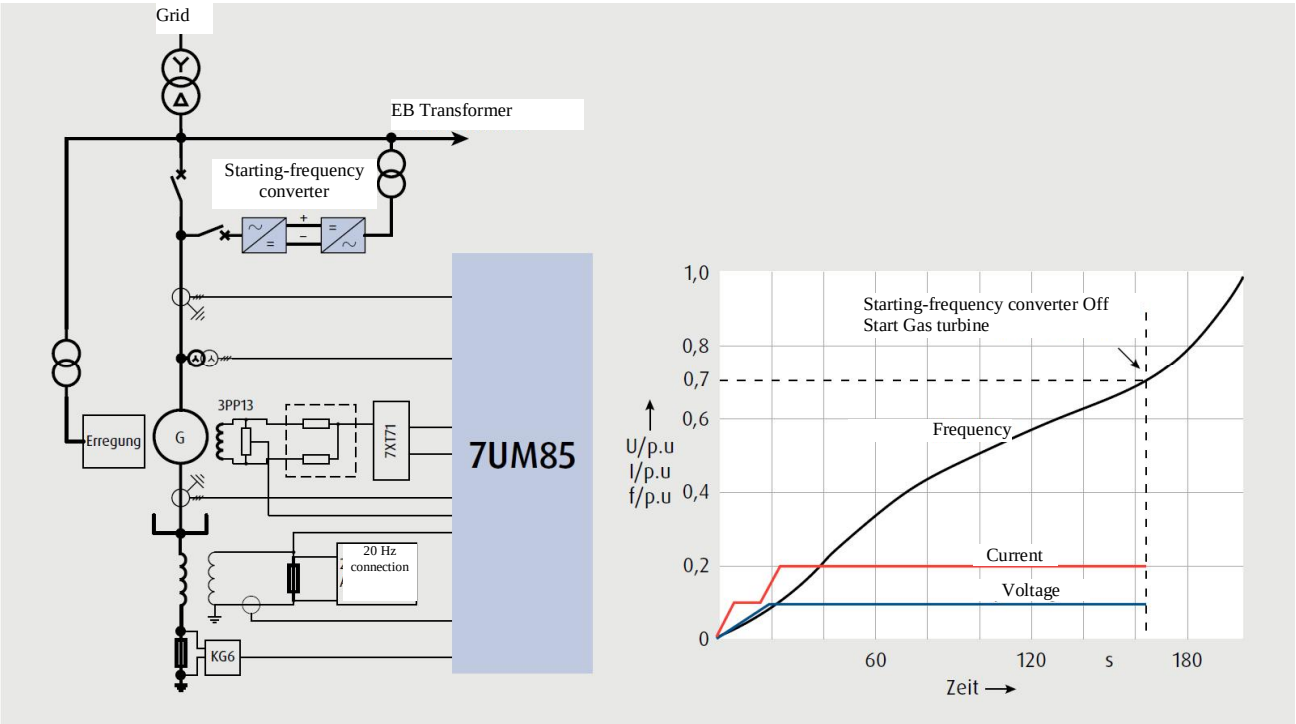

Figure 6. Starting up a gas turbine power plant unit

Two of the many particularities that have to be considered when it comes to the device equipment will be presented below.

Changing the phase sequence

Pumped-storage power plants have the advantage that they can provide electrical energy relatively quickly. But they can also be used as an additional load for a short time. During pump operation, the generator will then work as a motor. This is achieved with a coupling or by changing the phase sequence. The switch for changing between the two phases is located between the generator and the unit transformer **(Figure 5)**. This means that during motor operation, the phase sequence on the motor side is L3, L2, L1 while it remains L1, L2, L3 on the transformer side.

This particularity was considered during development of the SIPROTEC 5 protection devices and the measuring points can be adapted to the phase sequence automatically. Until now, different devices had to be used for each operating mode.

Adapting the sampling frequency

Among others, gas turbine power plants are discussed as a replacement or supplement for nuclear power units. This type of plant design has an additional particularity. **Figure 6a** shows a typical plant configuration. The starting-frequency converter supplies the generator, creates a phase rotation depending on the frequency and brings the connected turbine up to the respective speed. At approx. 70% of rated speed, the turbine is ignited and further accelerated until it attains its rated speed - rated frequency. Then, the generator is brought to the rated voltage and synchronized with the grid with a paralleling device. **Figure 6b** shows the curves of the typical variables voltage, current, frequency. As the frequency curve shows - increase of speed with time -, the protection equipment must adjust to the wide working frequency range during the startup procedure. To achieve a high level of measuring accuracy even in case of significant deviations from the rated frequency (for example f_{rated} = 50 Hz), SIPROTEC 5 devices have powerful sampling frequency tracking implemented (operation range from 10 to 80 Hz). This means the sampling frequency of the measured-value acquisition/processing is automatically adapted to the current generator frequency.

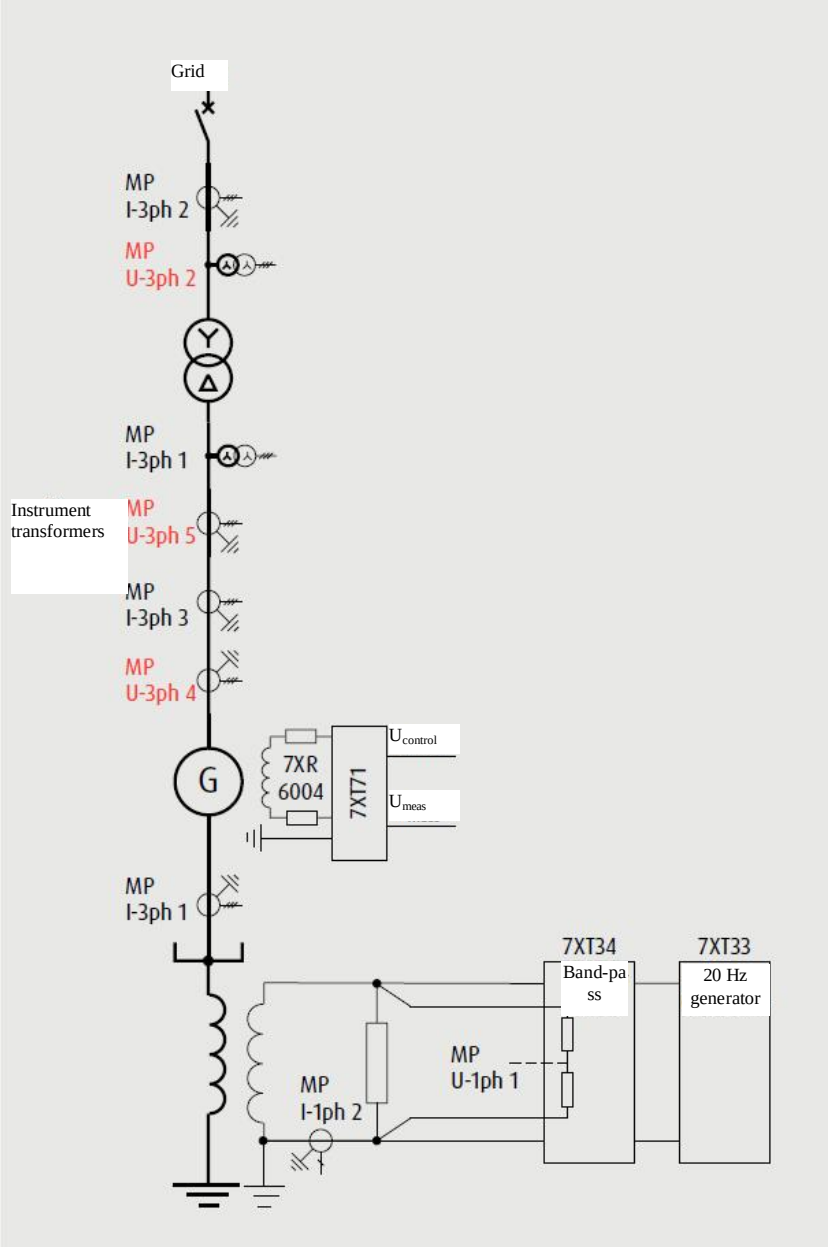

Figure 7. Single-line diagram

The number of sampled values per cycle of the generator frequency therefore remains constant. This means the used digital filters have ideal transmission properties. Startup overcurrent protection is provided for low frequencies (from about 2 Hz).

Example of use

From the multitude of application options, the use of the Siprotec 5 generator protection 7UM85 is shown using an example with the simplest type of unit connection. To show the possibilities of the new device technology, the protection scope was expanded.

It is suitable for a power plant unit with a higher power rating - for example approximately 100 MVA. For smaller power ratings, the scope of hardware and functions can be reduced accordingly.

To avoid errors and misunderstandings, the plant design should be done with a single-line diagram. It shows the typical primary components, the number of voltage and current transformers and their positions. The single-line diagram for the example is shown in **Figure 7**. You can see the combination of generator and unit transformer, the high-voltage circuit breaker, the voltage and current transformers and the installation position of the current transformers.

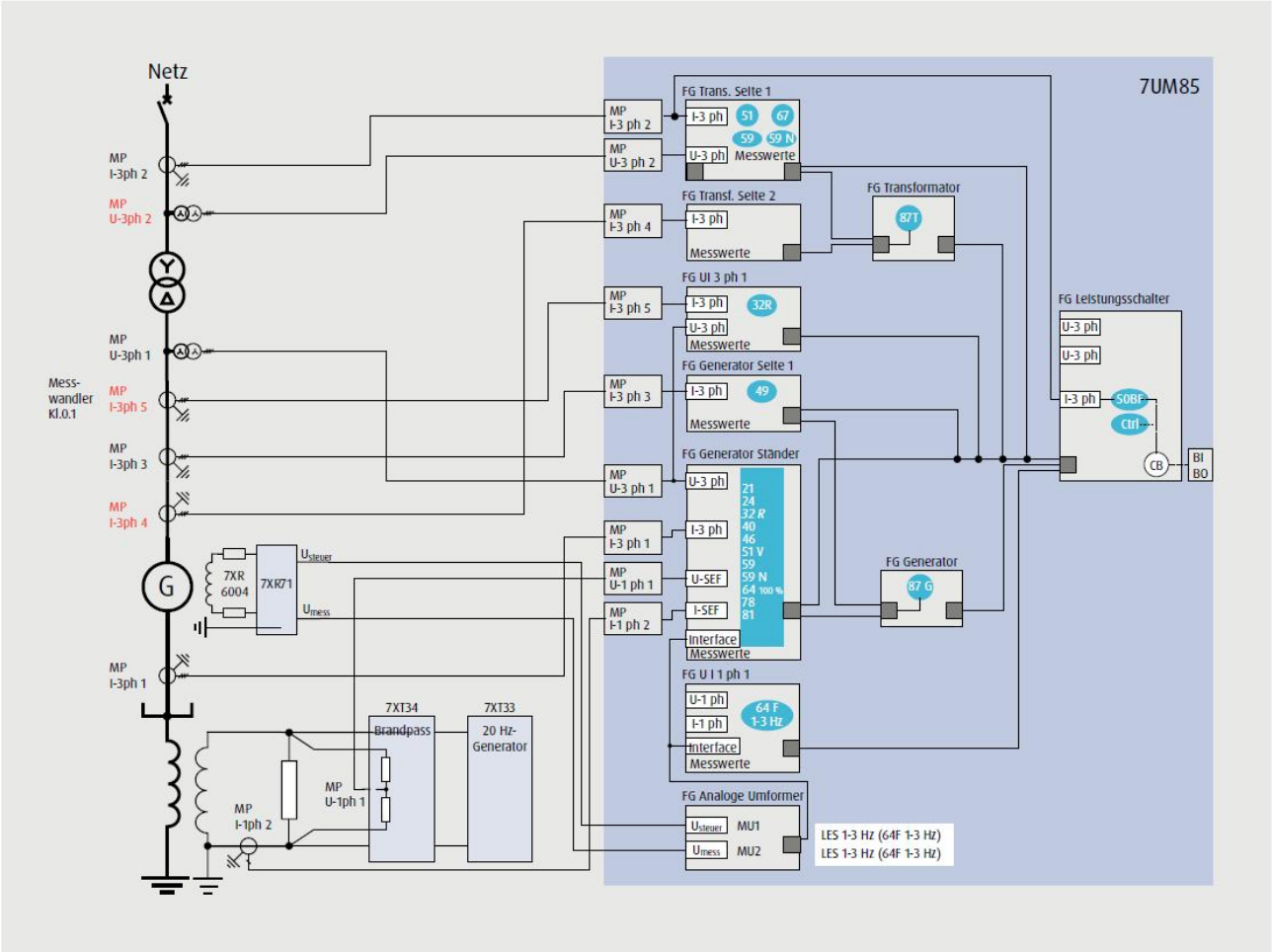

Figure 8. Functional structure of the application example

The individual measuring points are numbered and are marked with the symbol MP.

Application templates are provided (see 7UM85 Device Manual [4], chapter 4.2) to simplify the use of the application. It is recommended to start DIGSI 5 engineering with a predefined application template and to modify it accordingly. From DIGSI V7.80, the user can save his application template and use it as a starting point for new projects. This reduces engineering work and costs.

Figure 7 shows those measuring points that have to be expanded by the recommended application template "Generator unit connection advanced 8U 16I" [4]. An instrument transformer is used in measuring point MP I-3ph5 to which the reverse-power protection has to be connected. The advantage of the instrument transformer - for example Cl. 0.2 - is the significantly lower angle error - for example around 10 min. - compared to typical Type P protection-class current transformers (5P, <60 min.) or PR (5PR, <60 min.). The angle error of the protection device is negligible thanks to the factory calibration of the input transformer. When connecting the instrument transformer, it is not necessary to calibrate the reverse-power protection connected to the grid in over- or underexcited operation of the generator ([4] chapter 10.23 Reverse-power protection).

Then, the differential protection for the unit transformer and generator has to be connected to different cores. The variant used in the application template - common CT core - can be used for smaller power units. In addition, the voltage on the upper-voltage side of the transformers is to be monitored as well and a 100% stator ground-fault protection with 20-Hz injection is to be provided. This is connected to the neutral transformer with load resistor in the neutral point. The 1-3 Hz measuring principle ([4] chapter 6.44Rotor earth-fault protection - 1-3 Hz) is to be provided as rotor ground-fault protection. The accessories required for this are shown in the single-line diagram. The alterations from the application template must be taken into account when selecting the hardware. An expansion module with an IO210 is required, for example.

The basic scope of the required hardware components is determined by the transformer type, the necessary binary inputs and outputs and fast measuring transducers. An online configurator offers detailed support for the selection, guiding the user through the configuration steps.

The result of the configuration is the product code for the configured 7UM85 –in case of the example: P1L54472. This is an unambiguous code for the device. The result of the configuration can be saved as a PDF file and used as a basis for DIGSI 5 engineering and documentation.

Important properties of the example device are:

- Flush-mounted housing, version 5/6 x 19" - a basic module with large display and three expansion modules
- 18 protection type current inputs and two sensitive current inputs - one is used for the 100% stator ground fault protection
- Seven voltage inputs
- Four fast measuring transducer inputs
- 23 binary inputs and 24 binary outputs
- Auxiliary voltage 60 - 250 V DC, 100 - 230 V AC
- One communication plug-in module Type ETH-BA-2EL, 2 x electrical Ethernet
- 325 function points

For initial applications, we recommend drafting the functional structure visually. To do this, the applications templates from the device manual can serve as examples. The functional structure of the 7UM85 and the connection to voltage and current transformers is shown in **Figure 8**. The measuring points (MP) are shown as input interfaces on the left side. They have to be connected to the respective voltage and current transformers. The selected template now has to be expanded by the measuring points marked red. The connection of the measuring points with the transformers - the assigned connection terminals - via routing matrices is done in DIGSI 5.

Figure 8 also shows units labeled FG (function group). A function group is a "container" that holds the interfaces required for the measuring points and among the function groups. If a protection function is loaded to a function group, it will automatically connect to the interface. DIGSI checks if it is admissible to load the function to the selected function group.

To ensure the reference to the application, names relating to the protection object have been assigned for the function groups. They can be edited by the user. The typical structures for the connection of function groups have to be followed. Transformer differential protection, for example, requires the function groups FG Transformer Side and FG Transformer. Generator differential protection also requires an FG Generator Side, but it can also use the FG Generator Stator processing the current from the neutral point current transformer.

The circuit breaker is controlled by FG Circuit Breaker. This function group contains the functions required for controlling the circuit breaker including reading back the switch position. The function group can run the functionality breaker failure protection or a synchro check - as release for the manual synchronization - or a one-channel paralleling function. We recommend using a separate, two-channel paralleling device (7VE63, 7VE85 in preparation) for larger generation units.

As mentioned above, the 1-3 Hz rotor earth-fault protection as an interface requires fast measuring transducer inputs (10 V version). These can be found in FG Analog Units and can be configured there. The protection function accesses the relevant measuring transducers via interface.

The universal FG VI-3ph was supplemented for the reverse-power protection mentioned above and is connected to the measuring transformer via measuring point MP I-3ph5. Both FG Generator Stator and FG VI-3ph process the voltage of measuring point MP V-3ph1.

The many protection functions used are represented by ANSI symbols. The numbers describe a protection function. Examples for this are:

- 87T: transformer differential protection
- 87G: generator differential protection
- 40: underexcitation protection
- 78: out-of-step protection
- 81: frequency protection

Further details can be found in [1].

The selected structure achieves a high level of flexibility for the area of application. During engineering, the user can draw on a comprehensive manual [4] which offers descriptions of the individual functions and detailed setting instructions.

Summary

Digital protection devices are state of the art when it comes to generator and unit protection. They have been proven to be successful for two decades. The continuously increasing performance of microelectronic components like processor, memory and communication interfaces lead to the constant further development of protection equipment.

The aim of this development is to provide reliable protection for different system designs using only few components. This is true not only for the flexibility of the hardware design, but also the software functionality. With Siprotec 5 as an example, the 7UM85 generator protection was used to present a new device concept. It is characterized by its modularity and flexibility regarding hardware and software and can thus be ideally adapted to a wide range of requirements. Thanks to the powerful communication, the system is ready for connection to transformers outside the installation concept and to the process bus technology. This is a further step towards consistently digital technology.

References

[1] VGB-Standard Electrical Generating Unit Protection. VGB-S-025-00-2012-11-DE, first edition 2012, ISBN 978-3-86875-403-2, VGB Powertech Service GmbH, Essen.

[2] Technical requirements for the connection and operation of customer installations to the high voltage network (TAR high voltage) VDE-AR-N 4120, draft 2017, VDE-FNN, release in 2018, VDE-Verlag, Berlin.

[3] Technical requirements for the connection and operation of customer installations to the extra-high voltage network (TAR extra-high voltage). VDE-AR-N 4130, draft 2017, VDE-FNN, release in 2018, VDE-Verlag, Berlin.

[4] Siprotec 5 generator protection 7UM85 from V7.50, manual, www.siprotec.com

Dr.-Ing. habil.
Hans-Joachim Herrmann,
Principal Key Expert Protection, Energy Management Division, Digital Grid, Protection Relays, Siemens AG, Nuremberg

>>hans-joachim.herrmann@siemens.com

>>www.siprotec.com