Simulation of industrial decoupling devices

E. Lerch, P. Zaherdoust
Siemens AG
Erlangen, Germany

G. Bizjak
University of Ljubljana
Ljubljana, Slovenia

Abstract

Planning and commissioning of industrial decoupling devices are very demanded task. With the help of digital simulation programs structure and functioning of such decoupling devices can be determined and verified. In this paper different ways of modelling the protection relays are shown together with a description of decoupling device modelling. As illustrations of successful use of digital simulations in this field some examples of simulations of existing industrial decoupling devices are shown.

Key words: digital simulation, industrial plants, decoupling devices, protection

1. Introduction

Planing and commissioning of the industrial networks is today practically impossible without the help of digital simulation programs. As these networks consist of a large number of low and high voltage motors, generators, reactive power compensation devices and other elements, their dynamic behaviour is very important for the proper planing. Especially the knowledge of the dynamic behaviour of the industrial plant, which can only be obtained with the digital simulations, important for planning of protection devices.

One such important protection device is the so called decoupling device. Its task is to protect sensitive load from power supply interruption. Such loads are connected to the internal save plant part together with the in–plant generators. The internal system is connected to the rest of in–plant network or/and to the utility network through the circuit breaker equipped with the decoupling device. In case of a fault outside of the internal area, which could cause serious power supply problems, the decoupling device disconnects the internal plant from the fault. This disconnection should be fast enough to assure a smooth transient and stabile stand–alone island operation of the internal system supplied by in–plant generators.

Such a decoupling device normally consists of different protection relays (e.g. undervoltage, under– and over–frequency, over current, direction,...) and additional logic and time delay elements. For the determination of needed protection relays and their settings extended simulation studies of the dynamic behaviour of the industrial network have to be made.

2. Modelling of protection relays

The protection relays can be presented in digital simulation programs in 3 ways. Models can represent only the functioning of the relays or their complete structure. Numerical relays can also be considered by implementation of the total signal processing software of the original relay if C–source are available and interfaces can be defined. The first way of modelling is the simple and so more frequently used.

2.1. Modelling of relays functioning

The protection relays are in most cases represented in the digital simulation programs only with its main functions. These are settings at which a relay becomes active and time settings. To reach better accuracy of the model, also the transfer function of the measurement device can be represented. In the digital simulation program NETOMAC [1] special mathematical–technical blocks are used to represent the protection relays in this way. On figure 1, an example of undervoltage relays in shown.

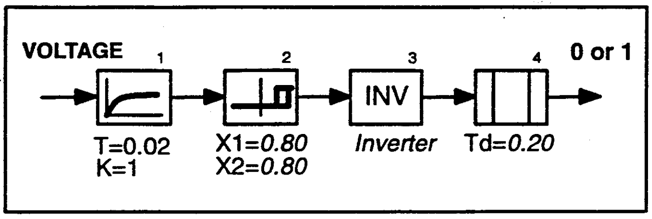

Figure 1: Typical function model of an undervoltage relay

Block 1 represents the transfer function of the measurement device. This is normally the first order time delay function with appropriate time constant (approx. 20 ms). In the block 2 the under–voltage setting is defined in per–unit value (e.g. 80% of nominal voltage). This block is active if the voltage is above this value, so the next block (3) is an inverter. In this way the relay becomes active if the voltage is below the setting value. The last block (4) represents the time delay of the relay. The output is a binary signal to activate the decoupling device.

In the similar way as the presented undervoltage relay is modelled also the functioning of the other relays can be represented. The models have to be made so, that their behaviour is as close to the behaviour of the real relays as possible.

2.2. Modelling of the relay structure

The second way of representing the protection relays is the modelling of its structure. The relay model in this case consists of models of all analog elements and the representation of digital filters and algorithms. Such models are much more complicated and extended, but represent the behaviour of the relays more accurate. This second–stage modelling is mainly used for fault–analysis /2/.

2.3. Use of original software

The third way of representing espcially numerical protection relays is the modelling of its hardware–structure including the analog/digital–converters and using the original software of numerical relays. With such a model every decision of the original relay can be comprehended.

This third–stage modelling is especially used during development and design tests.

3. Model of decoupling device

Decoupling device models consist of a protection relay model combined together with proper logical blocks (like 'and', 'or', 'inverter'). The active output of the complete decoupling device is used as an opening command for the coupling circuit breaker. One example of such decoupling device is shown on figure 2.

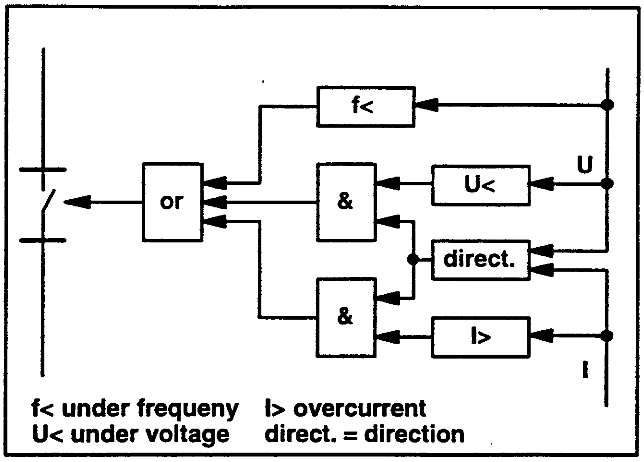

Figure 2: Structure of the decoupling device

The set of included protection relays depends on the possible conditions, which can occur in network during the faults. Most frequently included are under– and/or overfrequency relay, undervoltage relay and overcurrent relays for all in–plant generators. The frequency relays are normally directly used to disconnect a coupling circuit breaker and other relays are combined with the direction relay. With the direction relay the of the fault can be located to be inside or outside the area.

This structure of decoupling device has to provide, that in the case of serious fault outside the internal area, this area will be disconnected from the faulty network. For the frequency relay, this condition is not necessary as the relatively small industrial plant network cannot change system frequency.

Time delay settings of protection relays have to provide, that the increase area will be decoupled fast enough to stay stabile. On the other hand this decoupling should not be to often If the fault in the outside network is cleared by other protection devices very fast, (first time zone of relay setting) disconnection is not needed and can even have negative consequences.

With help of digital simulations all needed settings of used protection relays can be defined and tested. Also different combination and structures of decoupling devices can be considered before the real equipment is ordered and installed.

4. Simulation of decoupling device example

To show the behaviour of the decoupling device models, the simulations of operation of decoupling devices from an existing chemical plant were made. From figure 3, where the one pole scheme of the existing plant is shown, in can be seen, that two decoupling devices are used.

The first decoupling device couples the utility network with the in–plant network and second is installed between the internal area with very sensitive loads and the rest of the in–plant network , so called external area. Both decoupling devices have to work co–operatively to prevent the power supply shortcuts in the internal area. In case of a fault in the utility network, the first decoupling circuit–breaker has to disconnect and the total in–plant network goes in stand alone operation. In case of a fault in the external area the second decoupling device has to save the internal area but the first circuit–breaker has to stay closed, so the utility network can support the voltage recovery after the fault is cleared. From the same reason, in the case of a fault in the internal area, both circuit–breaker has to stay closed. In this way, the short circuit capacity of the utility network can be used for fast reaccelerations of in–plant motor loads.

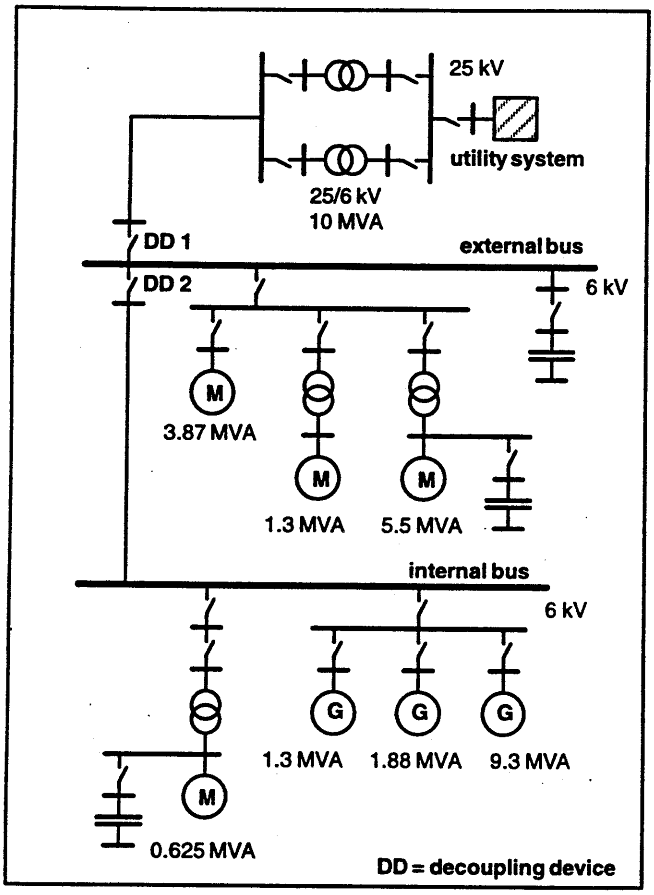

Figure 3: Chemical plant with two decoupling devices in operation.

4.1. Structure of used decoupling devices

In the mentioned chemical plant, to this day a grown concept of protection and of decoupling devices was used. The structure of this decoupling devices is shown on figure 4. The decoupling device 1 consists of "or" combined outputs of three relays. The first is a combined of under– and overfrequency relay set to a 1 Hz difference from nominal value. As such large frequency deviations need very severe faults, this relay has no additional time delay. The second is a under voltage relay set to 80% of nominal value and delayed for 200 ms. The third signal is a generator overcurrent signal from decoupling device 2 and should signal very distant faults, where voltage drop is less than 20%.

The decoupling device 2 has "or" combination of two relays. The first is a undervoltage relay set to 40% of nominal voltage and delayed for 350 ms to allow decoupling device 1 to operate at first. This second is the already mentioned combination of generator overcurrent relays, delayed for 3,5 seconds. Both relays are combined with a direction relay which observes the direction of power flow through the circuit breaker 2.

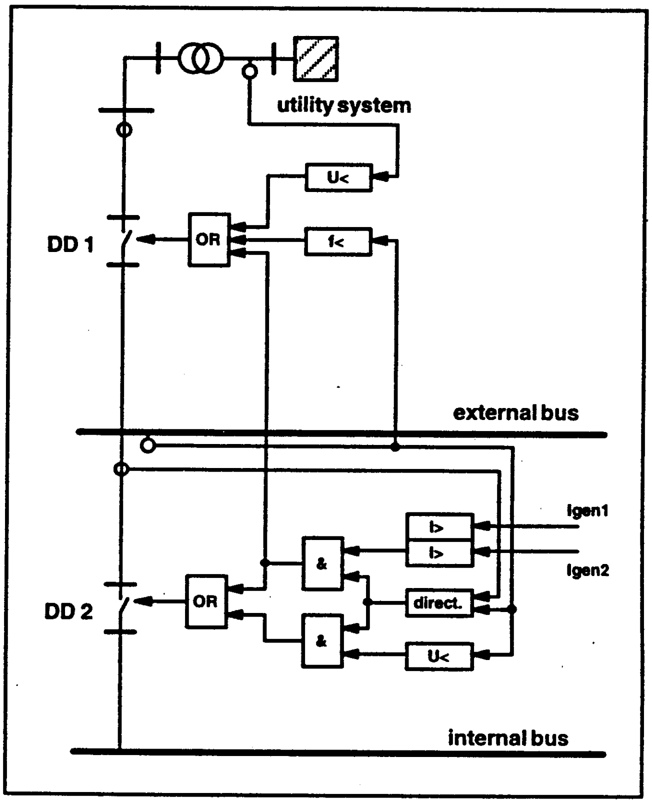

Figure 4: Structure of the basic decoupling devices

With simulations, which were made to show the behaviour of both old decoupling devices, it was found out, that this concept does not fulfil all necessary criteria as it will be shown later. Varying a large number of fault scenarios a new concept was developed and it is shown on figure 5.

The main difference is in the decoupling device 1, which in new concept also includes a direction relay. Its output is combined with outputs of undervoltage and generator overcurrent relays. In this way a better recognition of the fault place can be achieved. The output of a frequency relay is used directly as such large frequency changes can cause only large disturbance in the utility network. The other modification, which results in a very significant improvement is inverted output of direction relay of decoupling device 1 used to block an operation of decoupling device 2. With this measure, the operation of decoupling device 2 caused by a fault outside the in–plant network is prevented. In this way the external area on the in–plant network will never stay without both suppliers: utility network and in–plant generators connected to internal area. The difference in the operation between old and new concept is shown in the following examples.

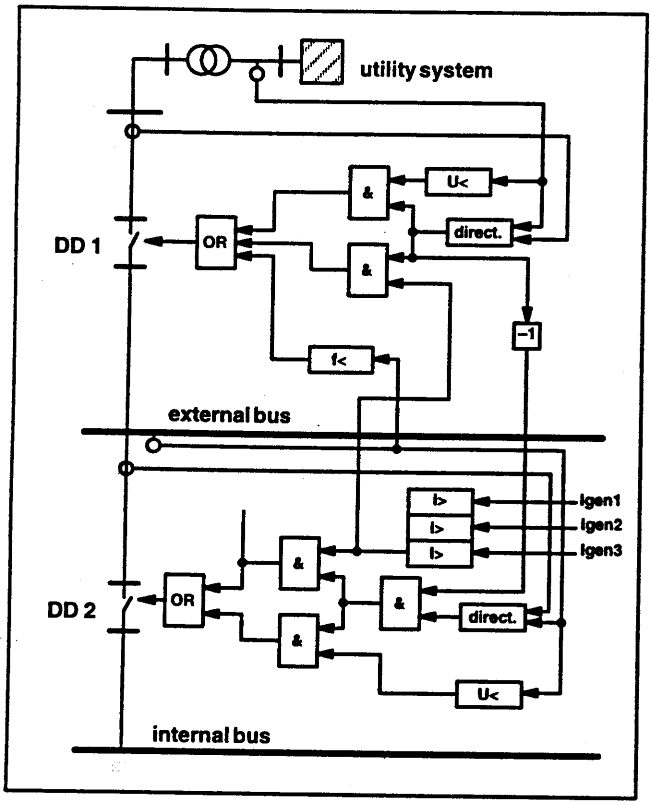

Figure 5: Decoupling devices according to the new protection concept.

Settings of relays were also derived with digital simulations. Frequency relay of the decoupling device 1 is used without time delay as 1 Hz diference to signal very severe faults. The time delay settings of fast undervoltage relays are chosen in such a way, that the decoupling device is slower as the primary protection relays, which have to clear the fault in a first place. On the other hand, if they fail, the decoupling device has to be fast enough to prevent in–plant generators to lose synchronism. The generator overcurrent relays of the decoupling devices have to work at very distant faults, which causes very small voltage drops. In such case, the generators will operate overloaded and can be disconnected by own overcurrent relays. To prevent this unwanted action, the time delays of decoupling device's overcurrent relays have to be shorter as of the generator's overcurrent relays.

4.2. Simulated cases

To show the basic protection and decoupling concept and also the difference between old and new decoupling devices, three most illustrative short circuit faults are simulated. First, short circuit in utility network outside the in–plant network. Second fault is a short circuit fault in the 6 kV external network. As last case, the fault in the internal area network was simulated.

To assure an unbreakable power supply of the in–plant load in the case of severe fault in a utility network, the decoupling device 1 has to open its circuit breaker. For the same reason, the decoupling device 2 has to stay closed as all in–plant generators are connected to the internal network. From the simulation results on figures 6 and 7, where voltages of all three main bus–bars are shown, it can be seen that both (old and new) decoupling devices work properly. As during a short circuit fault voltage recovers very lowly, the undervoltage relay after set time delay of 200 ms gives order for disconnection of circuit–breaker 1. The circuit–breaker 2 stays closed as the undervoltage relay of decoupling device 2 has larger set time delay as relay in decoupling device 1 or as the decoupling device 2 is blocked if the directional relay in decoupling device 1 point to the fault outside. Approximately 2,3 seconds after disconnection, all in–plant motor load successfully restarts and voltage of the factory network stabilizes at nominal value.

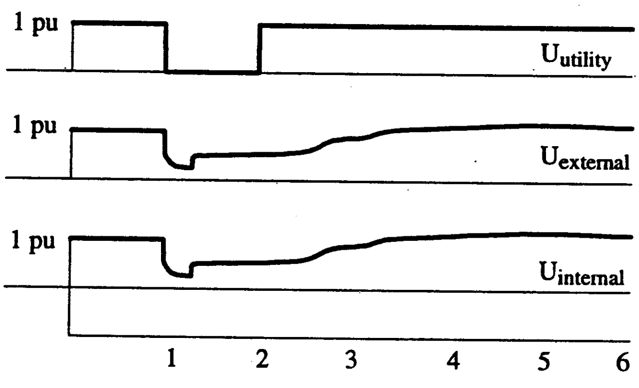

Figure 6: Main busbar voltages at fault in **utility network** old decoupling devices

While in the first simulated case both, old and new, decoupling devices show same behaviour, they act in the second case (fault in the external area) totally different. Decoupling device 1 opens circuit–breaker 1 after 200 ms time delay of under voltage relay. As the fault is in the external area, it is not cleared with this action so undervoltage relay of decoupling device 2 disconnects also circuit–breaker 2 some 100 ms later. After that a voltage of the internal busbar recovers very fast, but the external area stays without power supply (figure 8).

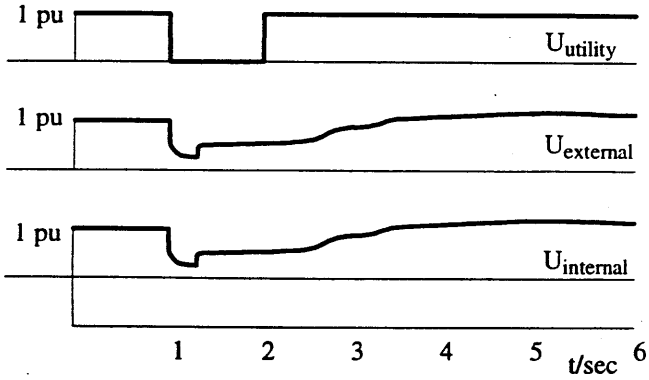

Figure 7: Main busbar voltages at fault in **utility network** new decoupling devices

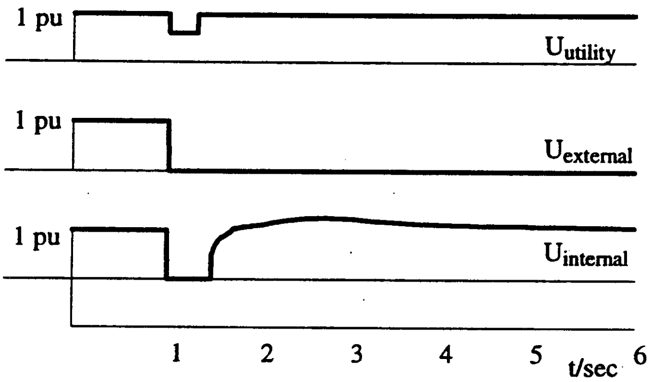

Figure 8: Main busbar voltages at fault in **external area** old decoupling devices

Observing the action of new decoupling devices, we can see, that the under–voltage relay of decoupling device 2 react at the same time as in the old device and opens the circuit–breaker 2, so saving the internal area load. But decoupling device 1 does not react as its direction relay spots fault inside the in–plant network. The external area stays connected to the utility network and the load can reaccelerate immediately after fault is cleared.

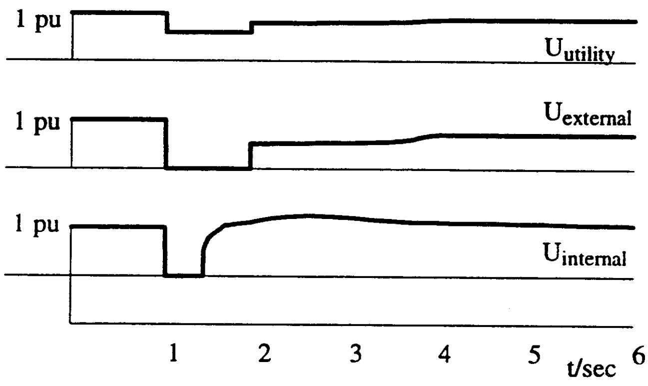

Figure 9: Main busbar voltages at fault in **external area** new decoupling devices

A similar action of old decoupling device can also be observe in the third case, where short–circuit fault in the internal area was simulated. As the decoupling device 1 is not equipped with a directional relay, it disconnects the circuit–breaker 1 after 200 ms due to the action of under–voltage relay. With this action the in–plant network goes into stand–alone operation. After the fault is cleared motor–load reacceleration depends only on the available reactive power of the generators. So the reacceleration process can take up to five seconds as it is shown on figure 10.

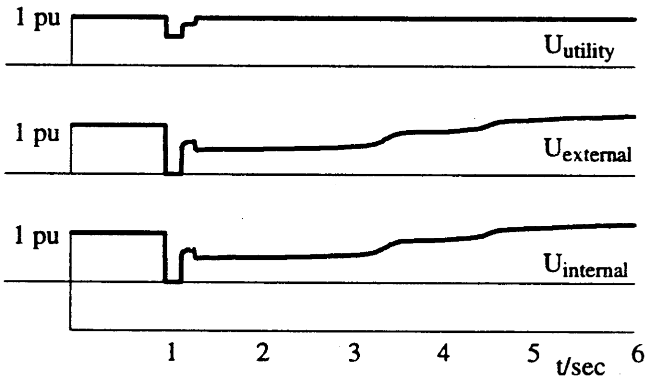

Figure 10: Main busbar voltages at fault in **internal area** old decoupling devices

With the use of new decoupling devices this unwanted action is prevented and the plant network stays connected to the utility network. The large amount of reactive power needed for the motor load reacceleration can so be taken from the utility network and voltage recovers in less than one second.

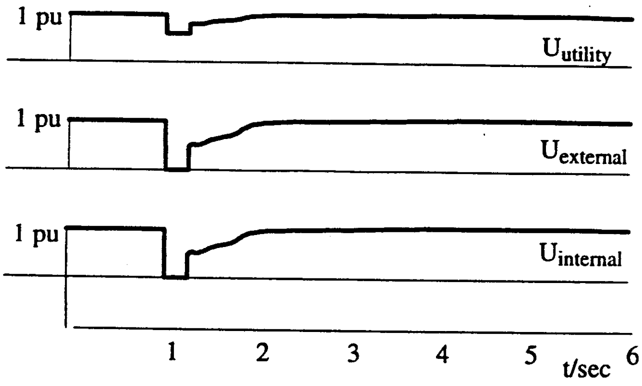

Figure 11: Main busbar voltages at fault in **external area** new decoupling devices

5. Conclusions

Determination and verification of proper concept and structure of decoupling devices are very difficult. As shown in this paper, digital simulation programs and suitable models of protection relays are very helpful tools for this task. With the help of digital simulations different structures of decoupling devices can be tested on large numbers of possible faults and transients in the network. The structure of decoupling devices can be changed and tested very easily.

Additional confirmation of successful use of digital simulations in industrial decoupling device projects was given by comparison of simulations with measurements on a finished decoupling devices This comparisons showed very good agreement between simulated and measured behaviour of either single protection relays or complete decoupling device.

6. References

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