# ADVANCED SYSTEM PROTECTION METHODS DUE TO HIGHLY FLUCTUATING INFEEDS FROM DISTRIBUTED ENERGY RESOURCES

Nils SCHAEFER
ISET e.V. – Germany
nschaefer@iset.uni-kassel.de

Thomas DEGNER
ISET e.V. – Germany
tdegner@iset.uni-kassel.de

Timo KEIL
Uni Erlangen – Germany
keil@eev.eei.uni-erlangen.de

Johann JAEGER
Uni Erlangen – Germany
jaeger@eev.eei.uni-erlangen.de

## *ABSTRACT*

*Fluctuation of load and generation from distributed energy resources may impact the system protection in distribution networks. The aim of this research work is to determine in how far short-term peak loading conditions restrict the ability of a protection relay to distinguish between load and fault case. Suitable network scenarios are analysed in order to address this new challenge for the system protection.*

## 1. INTRODUCTION

Distribution networks of tomorrow will have to meet the challenge of allowing the integration of more and more distributed energy resources (DER) without reducing security of supply. Concerning this matter, in the field of system protection manifold problems do and will arise since many DER are based on fluctuating renewable energy resources like wind or solar radiation [1], [2].
An increasing rate of installed DER capacity often results in higher loadings of equipment [3], as previous distribution networks have commonly been designed for a central power supply with unidirectional power flow. For reasons of economy often only minor structural modifications or extensions of equipment are carried out when connecting DER. As a consequence short-term fluctuation of the power infeed from DER (e.g. caused by a gust of wind or sudden clouding of solar panels) combined with special load conditions can cause temporary peak loadings of distribution lines or transformers. These peak loadings and overcurrents respectively usually do not endanger the considered equipment but may lead to false tripping of protection relays. The aim of this research work is to determine in how far short-term peak loading conditions restrict the ability of a protection relay to distinguish between load and fault case.

## 2. FLUCTUATION OF LOAD AND INFEED FROM DISTRIBUTED ENERGY RESOURCES

Both load and generation from DER based on renewable energy resources are subject to fluctuations which shall be characterised in the following.

### 2.1 Fluctuation of load

For fluctuation of load there are enormous differences. Loads can be classified according to consumer group (e.g. domestic, agricultural, commercial and industrial), season, geographical latitude and time of day. The German BDEW (former VDEW et al.) has set up 1 domestic (see Fig. 1), 2 agricultural and 6 commercial / industrial load profiles.

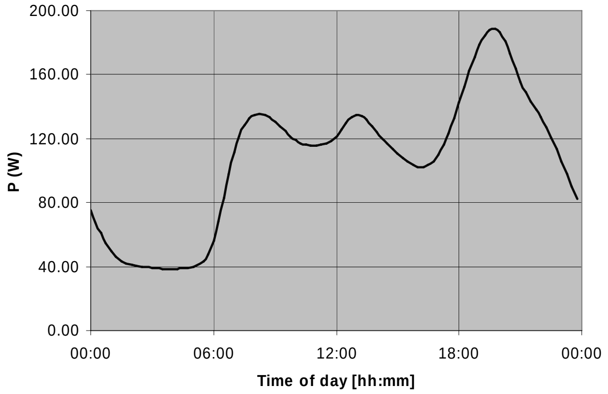

Fig. 1: Domestic load profile (working day, winter) for an annual consumption of 1,000 kWh

These day profiles give 15-min average values for the different customer groups based on an annual consumption of 1,000 kWh (separately for working day / weekend and summer / transition time / winter). On the basis of these profiles the load modelling in this paper is performed.

### 2.2 Fluctuation of infeed from distributed energy resources

Regarding infeed from DER based on renewable energy resources there are long- and short-term fluctuations which are to be considered here more closely. Long-term fluctuations in terms of photovoltaic systems occur according to the shift of day and night, the actual season and dominating weather conditions. Clouding of single or multiple solar panels cause short-term fluctuations. Regarding wind power plants days of still air and stormy or windy days lead to long-term fluctuations, while short-term fluctuations may be caused by, for instance, a gust of wind. In Fig. 2 the instantaneous electric power values of a stall controlled wind power plant with an asynchronous generator and a rated power of 1 MW are given. It can be seen that maximum values of up to 145 % of rated power are reached. For a wind speed of 16 m/s the average value of the maximum values lies at about 125 % of rated power. Combined heat and power (CHP) units are not subject to short-term fluctuations, but long-term fluctuations. The primary energy resource (e.g. biogas) can be stored and electricity generation can be timed. Small-scale hydropower plants do not underlie short-term fluctuations and they hardly depend on long-term fluctuations (only seasonal).

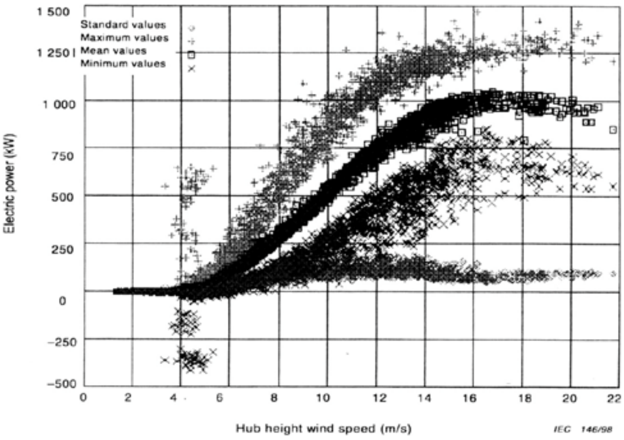

Fig. 2: Instantaneous power values of a stall controlled wind turbine ($P_{rated}$ = 1.0 MW) [4]

## 3. SYSTEM OPERATION AND PROTECTION PRACTICES IN DISTRIBUTION NETWORKS

Distribution networks comprise low (LV, up to 1 kV) and medium voltage (MV, up to 60 kV) networks. LV networks are usually designed and operated in a radial structure. System protection in LV networks is most often simply realised by means of fuses. Communication links and remote controlled circuit breakers are normally not applied. The design of MV networks is mostly performed by meshed or ring network structures, while the operation is mostly done with open rings, also establishing a radial structure. In case of network disturbances the faulty network section is separated and customers at the remote end of the defective feeder may then be supplied by closing the disconnector at the disconnecting point of the ring. For system protection in MV networks definite and inverse time overcurrent and distance protection relays are in use. In case of a high DER penetration and/or closed ring operation directional overcurrent or even distance protection has to be applied to guarantee selective and reliable protection functioning.

## 4. CASE STUDY PERFORMED

This chapter firstly gives some details on the case study investigated in this paper. Secondly, it deals with the modelling of the case study, before it ends up with summarising the results.

### 4.1 Description of the considered distribution network

For the modelling described in this paper a 20-kV-distribution network in Germany is considered. It comprises a town of about 15,000 inhabitants with its rural surrounding. The network is mainly operated in a closed ring structure, while it also has some radial feeders. The infeed is given from the 110-kV high voltage level at a central substation by a 25-MVA transformer. Moreover there are several DER (i.e. CHP units, wind power plants and small-scale hydropower plants) feeding in at LV and MV level.

### 4.2 Modelling and considered case studies

The network is modelled using the network calculation software PSS™SINCAL. In this paper a long radial MV feeder with several DER is considered in detail. 11 wind power plants, 2 small-scale hydropower plants and 1 CHP unit are connected to the feeder. The DER units are all modelled by PQ-controlled synchronous generators. They are directly coupled to the MV grid, neglecting any applied converters and the LV/MV transformers.

The DER units, representing wind turbines, are set to a high power infeed of 1.25 $P_{rated}$, which corresponds to the facts given in section 2.2. Furthermore the fluctuation of wind power can be demonstrated by selected measurement data from ISET (see Fig. 3). In Fig. 3 the power infeed from a wind power plant with a rated power of $P_{rated}$ = 600 kW is shown. As can be seen in the diagram the power output exceeds 1.1 $P_{rated}$ (with a maximum of 1.23 $P_{rated}$) over a period of about 300 ms, which lies in the range of relay tripping times of only a few hundred milliseconds.

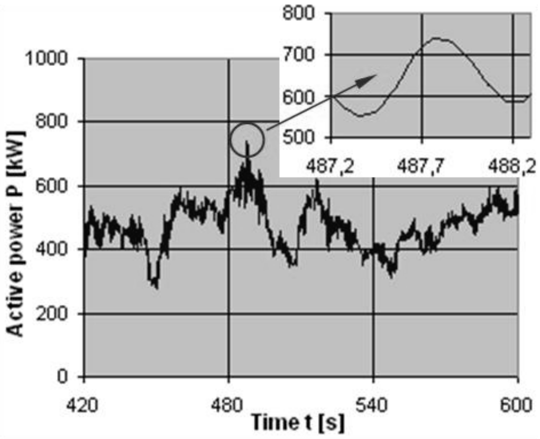

Fig. 3: Power output of a stall controlled wind power plant with asynchronous generator ($P_{rated}$ = 600 kW, sampling rate = 10 Hz) [5]

The system protection applied on the considered feeder is based on definite time overcurrent relays with direction determination function. The pick-up value ($I_{pick-up}$) of the low set element (I>) of the overcurrent relays is set to 1.2 times rated current ($I_{rated}$) of the different line sections. The drop-off value is considered to be 95 % of the pick-up-value. The tripping times are graded as shown in Fig. 4 below.

By assigning the discussed peak values of DER infeed and the load profiles to the DER units and the loads respectively, different operational network scenarios are created. Simulations along the time axis are performed and extreme conditions can be found for peak values of DER infeed and minimum load of only 10 to 20 % nominal consumption. The resulting peak loading conditions within the time-dependent profile calculations are analysed in terms of reliable functioning of the protection systems.

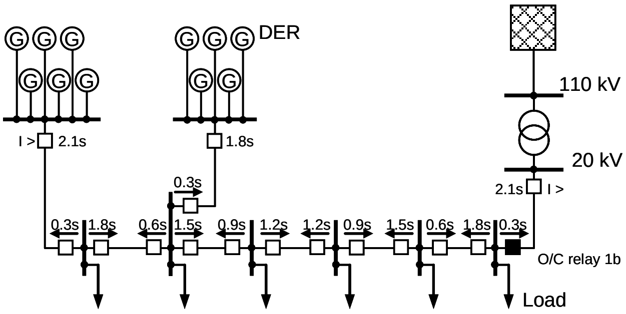

Fig. 4: Considered feeder with I> grading times of the directional overcurrent relays

## 4.3 Results

The simulations performed reveal that under certain conditions one line section of the considered feeder (20-kV cable, 3 x 50 mm², $I_{th}$ = 0.185 kA) is loaded up to 130 %. This value has been reached for an assumed DER infeed of 1.25 $P_{rated}$ combined with load conditions of 10 % nominal load.

The low set element of the overcurrent relay “O/C relay 1b” (see Fig. 4) does not trip, as the peak values of DER infeed only occur for a very short time of about 100 ms (compare Fig. 3). Due to the short-term fluctuations the pick-up value ($I_{pick-up}$) of the low set element is reached only temporarily. The measured current always falls below the drop-off value (i.e. 95 % of $I_{pick-up}$) again, before the set grading time of 300 ms has passed. After reaching $I_{pick-up}$ the low set element of the overcurrent relay would only trip, if the measured current permanently exceeded 0.95 $I_{pick-up}$ during a period of 300 ms or more.

## 5. CONCLUSION

According to the results discussed in the last paragraph, it may be required to install overcurrent relays with overload element. The low set element I> in the considered case study is set to a very low tripping value of only 1.2 $I_{rated}$, acting as a kind of overload protection. However, the low set element does not reveal the above-mentioned peak loading conditions, which might endanger the functional integrity of the installed cable in the long run. By introducing overcurrent relays with a separate overload element, possible overload conditions can be detected, due to the monitoring and recording of thermal images.

Otherwise under extreme conditions of DER infeed or in case of repowering of wind parks, the highly dynamic infeed of DER may trip low set elements of overcurrent relays. In that case extensions of equipment may be required and/or protection coordination has to be revised (maybe here overload elements have to be added, too).

Discussing one of the effects of high DER penetration, this paper points out that installation of DER has to come along with an adequate adaptation of the system protection. The pick-up protection facility has to be advanced by enhanced evaluation methods (separate overload functionality instead of using the low set element I>). The authors show, how future distribution networks may face challenges of protection malfunction originating from fluctuating conditions of generation and load.

## ACKNOWLEDGEMENTS

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