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A probabilistic load shedding concept considering highly volatile local generation

Ines Hauer [a,*], Martin Wolter [b], Martin Stötzer [a], Marc Richter [a], Zbigniew A. Styczynski [a]

[a] Otto-von-Guericke Universität Magdeburg, Germany
[b] 50 Hertz Transmission GmbH, Germany

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ABSTRACT

Automatic load shedding is the ultimate countermeasure against imbalance in a power system and can effectively help preventing large blackouts. Taking into account a high penetration of renewable energy sources (RES) in the distribution grid, a clear distinction between load and generation at the PCC becomes increasingly more difficult. For that reason an adaptation of frequency relay parameters and their locations of installation are necessary. In Europe this is rest on a multi-step plan based on values such as the yearly peak load. In this paper a novel probabilistic method for automatic load shedding is presented that uses the average values instead of peak values for load shedding. Its applicability is verified by a dynamic power system model that was developed to compare the classical and novel probabilistic load shedding principle. The method is verified using data from a German TSO.

Introduction

Since RES is mainly integrated in the distribution grid, a high amount of loads can by supplied locally in periods of high wind speeds and/or solar radiation. When this happens, the transmission system operator (TSO) has to feed less power into the distribution grid which leads to a decreasing vertical system load over the UHV/HV transformers.

In power system areas with a high penetration of wind energy systems and photovoltaic systems, which are characterized by a highly volatile character, the vertical system load becomes negative in special weather conditions and a power feedback from the distribution grid into the transmission grid takes place.

The resulting changes in the power system structure are new challenges, especially regarding the current protections schemes, since they are mainly designed for a unidirectional load flow from the transmission to the distribution level. This aspect plays a decisive role in cases of the under frequency load shedding (UFLS). If an active power imbalance due to a disturbance in the electric power system exceeds the available primary reserve, the frequency decreases and the automatic load shedding is the ultimate countermeasure to avoid a collapse [15]. Therefore a reliable operating load shedding is essential for a secure network operation. However, the frequency relays that are installed in the distribution grid do not distinguish the load flow direction. They simply switch off the subordinate power system independent of the current generation situation in that branch. Therefore, in this case, the disconnection of generation units will worsen the imbalance problem and has to be avoided.

Many different algorithms regarding adaptive load shedding schemes have been proposed in the past. An overview of these methods is given e.g. by Xu et al. [31]. Mohd Zin et al. [17] give a comparison of the under-frequency static and dynamic load shedding concept, while nowadays static load shedding concepts are applied in the power systems due to simplicity. However, most of the methods discussed in literature propose dynamic or adaptive load shedding concepts, where for example an adaption of load shedding amount, load shedding speed or relay setting according to the rate of change of frequency is calculated for example in [2,4,29]. Safarian and Sanaye-Pasand [23] offer an interesting combined under frequency/under voltage load shedding scheme, where the load shedding decision is made locally in an adaptive way taking into account combinational events. However, they take a fixed total amount of power in the load shedding stages, since they do not consider an increasing distributed generation or changing distribution grid conditions. A further adaptive under voltage load shedding scheme is proposed by Otomega [20].

The publication of [13] suggests using the PMU measurement also for adaptive load shedding. Furthermore [21] present a frequency gradient based load shedding approach. In a further

* Corresponding author at: Universitätsplatz 2, 30106 Magdeburg, Germany. Tel.: +49 3916711649; fax: +49 3916712408.

E-mail address: ines.hauer@live.de (I. Hauer).

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Nomenclature

P	active power flow over a transformer
P_{inst}	installed capacity
$P_{act}(v)$	power feed of a generation unit – in per unit – depending on the wind velocity v
YAV	yearly average value
YPV	yearly peak value
MAV	maximal monthly average value
r	percentage of load that has to be shed off totally in the stages $r = 10–15\%$
$L_{SH;K}$	load that is actually available for load shedding
f_N	nominal frequency
$\Delta f_{dyn.}$	maximum dynamic frequency deviation
f_{stat}	steady state frequency deviation
SRL	self-regulating load
S	apparent power
SP_K	load shedding switch probability in the load shedding stage K
s_G	generator static
T_t	generator time constant
T_{res}	time constant of the system

publication [22] provides an approach for frequency trajectory forecast usable for adaptive load shedding. These adaptive approaches as well as the proposal of [25] require the wide use of communication links and a high amount of system information, which is not available in current power systems.

Other approaches such as [10] discuss also the volatility of renewable integration in the context of an intelligent micro grid structure. In [30] the use of intelligent energy management for ripple control is analyzed. Tascikaroglu et al. [24] discuss this problem locally in the context of virtual power plant operation. In the paper of [11] is suggested to use the PTDF method for simultaneous shedding of generation and load and [14] proposed a method which allows to enlarge the concrete transmission line in the case of overloading.

Lot of works have been dedicated to the economic aspect of load dispatch. Manda et al. [16] gives a useful overview on this subject.

All proposed approaches analyze the power system without a high penetration of volatile renewable energy, and if the volatile energy is taken into account (e.g. in [30] the balancing has been shown only in the local environment.

The literature has also shown some systematic proposals for dynamic security assessment based on decision trees, i.e. by Voumvoulakis et al. [27] or defence plans by Mollah et al. [18]. The approach proposed in this paper also starts with the currently applied load shedding concept in Europe.

The applied load shedding schemes are normally based on different stage plans that are calculated for special reference values. In Europe the stage plan according to the ENTSO-E policy 5 handbook [6] is applied. The reference value for the stage plan is the yearly peak load. In regions with a high amount of RES the occurrence of the peak load scenario is becoming increasingly rare, since days without a renewable power feed in are seldom. For that reason it is useful to define a more realistic reference value – namely, the **yearly power flow average value** – for the load shedding.

Obviously an average value is smaller than a peak value which leads to a lower amount of load that will shed in case of an under frequency problem. For that reason a comparison of both load shedding principles is necessary to investigate how much of the necessary load – according to the stage plan – can be shed off and to what extent the new load shedding principle can be applied in the future. For that investigation the German TSO 50 Hertz Transmission provided data about the vertical power flow over all of its UHV/HV transformers in the supplied area. Using statistical and probabilistic algorithms the reference values and the switchable load in the distribution grids were determined. To compare both load shedding concepts a dynamic power system model for the investigated region as well as special weather scenarios were designed.

According to this, the paper is organized as follow. First of all, the two investigated load shedding concepts are presented in 'Proposed load shedding concepts'. The data basis for the whole analysis is given and the example system is shortly introduced in 'Data analysis'. 'Probabilistic data analysis' introduces the mathematical background for the probabilistic data analysis using special examples. The power system modeling concept with the modeling of the transmission and distribution grids as well as their parameterization is the content of 'Power system modeling'. Finally, the results of the dynamic load shedding simulations are discussed in 'Dynamic simulations of the load shedding principles' before a conclusion finishes the paper.

Proposed load shedding concepts

System frequency is a global indicator for the system balance. A small frequency deviation, for example between 49.8 Hz and 50.2 Hz, compensates the primary and secondary control in the system. If the balance disturbance exceeds the available reserve, the frequency will leave its stability limits. In case of under frequency an automatic load shedding, which starts from 49 Hz according to the stage plan, will be activated to bring the frequency back within its limits. In the German power system the following 5 stage plan (Table 1) is applied according to the ENTSO-E guidelines in policy 5 [6] and the German transmission code [26]. The common reference value for load shedding implementation is currently the yearly peak load (YPL) that has been measured at the UHV/HV transformers in the electrical power system at a certain day in the year. The yearly peak load represents the day with the highest vertical system load in the year so that it is used as the worst case for a load shedding scenario. According to these values the TSOs determine the reference value for each DSO related to their power purchase from the TSO at the reference time. The DSO has to install the frequency relays in such a way that the required percentage of the YPL reference value will shed in each stage (e.g. 10–15% in stage 2).

Normally, the frequency relays are installed in the medium voltage level, while branches connecting generation units to this voltage level are not equipped with them.

Taking into account the increasing percentage of RES, which highly influence the vertical system load, a change in this procedure is necessary. Therefore a technical recommendation from the German forum network technology/network operation in the

Table 1
Load shedding stage plan for Germany.

Stages	Measure
Stage 1: 49.8 Hz	Alarm, pump shedding
Stage 2: 49.0 Hz	Loadshedding l0–15%
Stage 3: 48.7 Hz	Load shedding 10–15%
Stage 4: 48.4 Hz	Load shedding 15–20%
Stage 5: 47.5 Hz	Disconnection of generation