LV MICROGRID SUPPLIED BY DIESEL GENERATOR AND PV

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ABSTRACT

This paper deals with operational tests of diesel generators (DG) to the E.ON Distribuce, Inc. distribution system (DS) in the Czech Republic used to providing the supply to separated part of the network during planned interruptions. Frequency and voltage conditions were analyzed regarding to the EN 50160 based on measurements performed within such microgrid. This paper discusses the issues associated with the renewable energy sources (RES) penetration in isolated microgrids. Lastly, resulting recommendations are presented for optimal operating reserve of diesel generator and RES protection relays settings as well, regarding the voltage, power and frequency stability of island network.

INTRODUCTION

Distribution area of E.ON Distribuce in the Czech Republic (operated by the E.ON Distribution, Inc.) supplies around 1.5 million customers, most of them connected to the low voltage. Electricity market liberalization increases notably the pressure for introduction of fees applied in case of insufficient SAIDI (average duration of interruption) as well as SAIFI (average number of interruptions) parameters. The Czech Energy Regulatory Office introduced the target values of SAIDI/SAIFI for all three regional distribution system operators (PDS) in the Czech Republic, which should be achieved to 2020. For example, SAIDI parameter should be improved for 5 percent per year. The fine is specified for PDS if these requirements are not achieved. Diesel generators can be utilized for improving SAIDI or even SAIFI in some cases. Usage of auxiliary power sources to supporting continuous operation of separated network is suitable particularly for planned interruptions which allow better preparation of auxiliary power sources. Figure 1 and Figure 2 show the potential improvements of SAIDI and SAIFI based on the data from 2016.

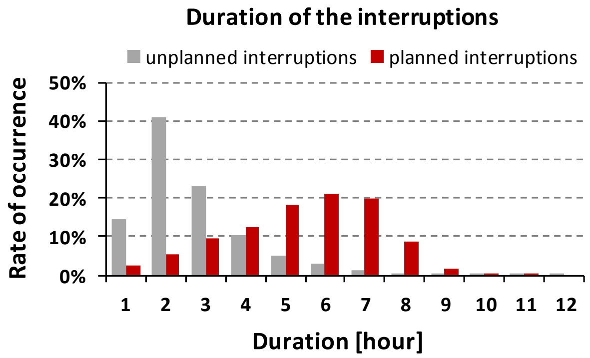

Figure 1: Duration of interruptions

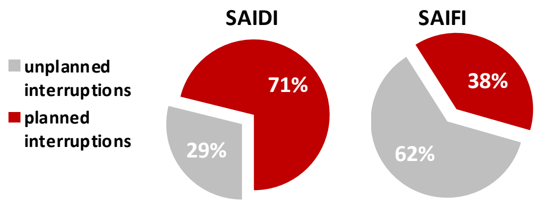

Figure 2: Rate of planned interruptions on the overall level of power continuity indicators

MICROGRID PARAMETERS

Given network, operating in parallel with DS is supplied from single 22/0.4 kV distribution transformer of 160 kVA. Some 45 consumers connected to the LV are supplied through mixed lines (overhead and cables) about 1.8 km long. PV 4.92 kW is connected 410 m downstream off distribution transformer station (DTS).

Parameters of given diesel generator

Caterpillar GEP 100 diesel generator was used during the planned power interruption. This agregate was not equipped with synchronizing unit. Subsequently, the main DTS breaker was opened and main diesel generator breaker was closed. The folowing Table 1 shows the diesel generator prameters [1].

Table 1: Diesel generator parameters

Caterpillar GEP 100 400/230V			
Engine data		Generator data	
Maximal Power [kW]	87	Maximal Power [kW]	72
Nominal speed [rpm]	1500	Type	Self-excited, brushless
Cylinder config [-]	In-line 6	Nominal frequency [Hz]	50
Governor type	Mechanical	Nominal voltage [kV]	0.4 /0.23 kV

Diesel generator provides the frequency regulation through the volume of fuel injected to the engine. Regulation of voltage to 230 V nominal at generator terminals was made by synchronous machine exciter as depicted on Figure 3.

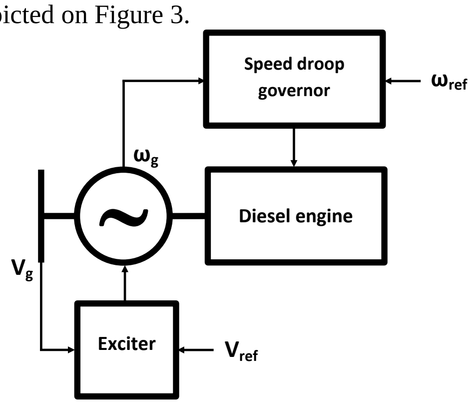

Figure 3: Diesel generator control scheme

MEASURED DATA ANALYSIS

Measurement was made at DG, LV load about 500 m off DTS, at load with installed PV 410 m off DTS at load at the end of the LV line, 580 m off DTS. P, Q, U, I values were recorded with 1 s interval.

Analysis of frequency in isolated microgrid

The relation between supplied active power and network frequency was analyzed based on the measurements, see Figure 4.

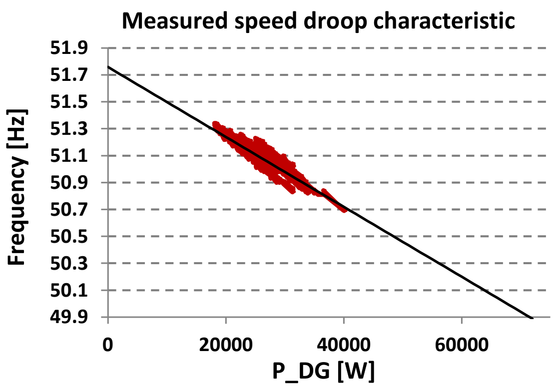

Figure 4: Measured speed droop characteristic

Data points correspond to the linear function. Regulating function can be defined as follow [2], [8]:

$$Droop\ \% = \frac{No\ load\ speed - Full\ load\ speed}{No\ load\ speed}$$

Evaluated droop in this case is 3.6 percent. That means that 1 percent change of aggregate rpm corresponds to the 27.8 percent change of active power of generator, i.e. 20 kW. Figure 5 shows histogram of isolated microgrid power frequency.

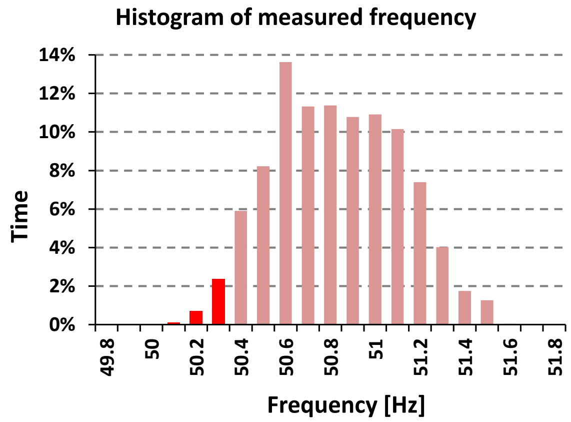

Figure 5: Histogram of measured power frequency

Figure 6 depicts the time profile of power frequency measured in microgrid as well as the time profile of given PV active power. The chart clearly shows that the PV is connected to the microgrid only when frequency is below 50.3 Hz.

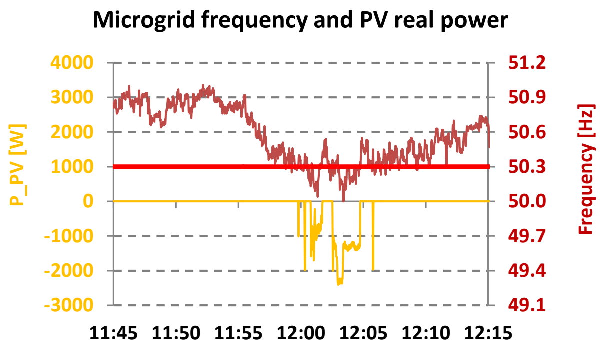

Figure 6: Connecting of PV on power frequency of microgrid dependency

PV disconnection was caused by PV over-frequency protection. PV frequency protection setting was in compliance with Distribution Code [3]. Requirements for protection settings used within this document are listed in Table 2. The microgeneration setting is in compliance with EN 50438 standard [7].

Table 2: Protection relay settings [3]

Parameter	Maximum tripping time [s]	Limits for tripping
overvoltage	0.2	230 V + 15 %
undervoltage	0.2	230 V + 15 %
overfrequency	0.2	50.5 Hz
underfrequency	0.2	49.5 Hz

According to the evaluation published in [5], most of the PVs use frequency protection threshold set close to the nominal value. Frequency protection settings of PV in DS in the Czech Republic is shown on Figure 7.

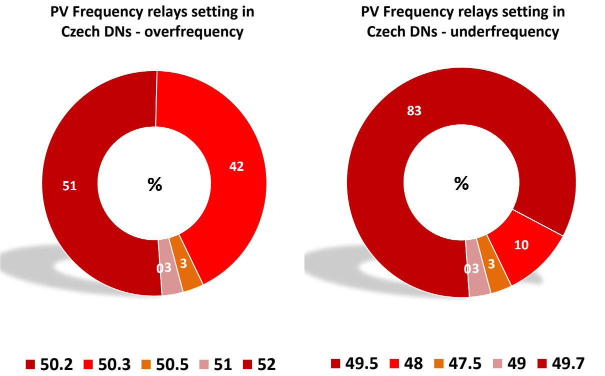

Figure 7: Evaluation of frequency protection setting of PVs in DS in the Czech Republic

Power quality characteristics evaluation

Power quality characteristics are defined in EN 50160 standard [4]. Given microgrid was operated for few hours only and that the standard defines ten-minute values for continuous phenomena, not enough data was available. Therefore one second measured values were used. IEC/TS 62898-2 Ed.1 standard [9] specifies that power quality parameters defined by relevant standards can be violated within island network (with no connection to DS) once consumers are informed that such violation may occur.

Power quality characteristics were not violated at any point of measurement within microgrid. Figures 8 to 12 depict histograms of measurement evaluations.

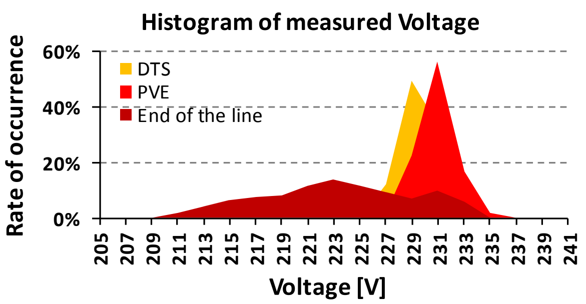

Figure 8: Histogram of measured voltage, phase L1

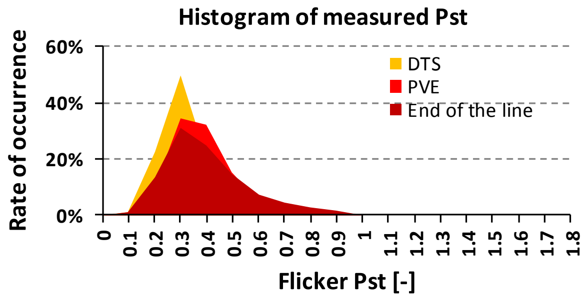

Figure 9: Histogram of measured Pst

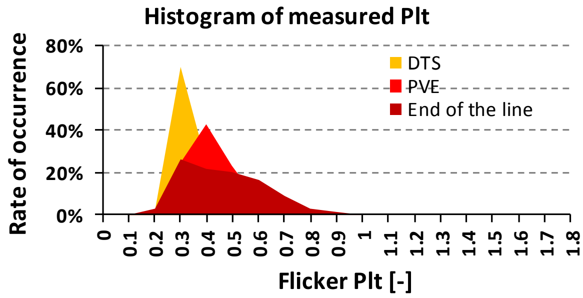

Figure 10: Histogram of measured Plt

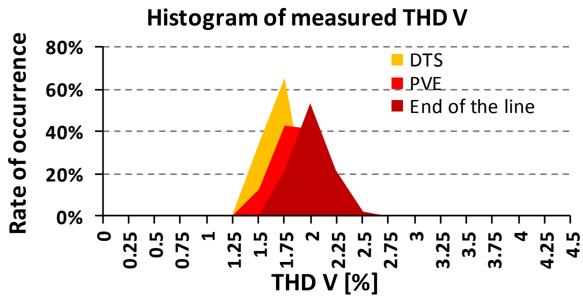

Figure 11: Histogram of measured THD

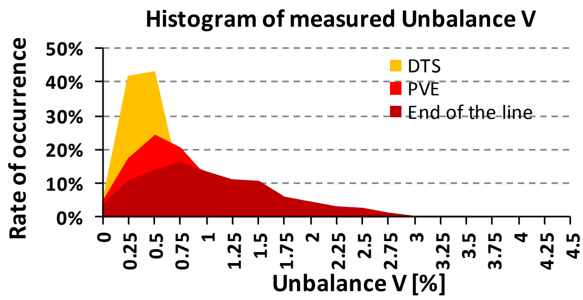

Figure 12: Histogram of measured voltage unbalance

SELECTION OF DIESEL GENERATOR WITH SUITABLE PARAMETERS

Setting of suitable parameters for diesel generator is affected mostly by the loads in network and power of RES. Load characteristic (linear, non-linear, motors and their ramp start characteristics), required reactive power and time profile of total load should be considered as well. Various frequency protection settings of RES can be expected within DS because of year of installation. In this case, If an isolated network is supplied by diesel generator RESs are operated in PQ mode (very the same to the parallel operation with DS). Autonomous regulations could be activated by values variation (such as voltage and frequency). Manufacturer software can be utilized to selection diesel generator suitable for required load characteristics as well as above mentioned factors. For example, above mentioned diesel generator can be overloaded up to 30 percent of (overfrequency) or 50 percent (underfrequency) for short time, as listed in literature [8]. The temperature of winding and insulations (growing with duration of overload and square of the current) is limiting factor. Stable operation and ability to withstand steep load changes is affected by parameters setting as well as setting of time constants of exciter, voltage regulation and diesel generator rpm regulation settings. System of rpm regulation was identified based on measurements and information acquired from vendor. The system of rpm regulation diagram that can be used for dynamic model is shown on Figure 13.

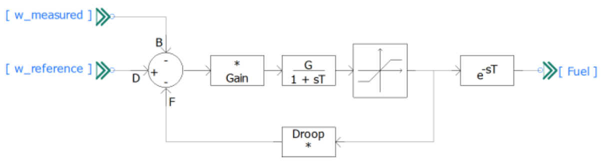

Figure 13: Speed droop of fuel control system

According to the vendor the generator can be over-sped (125 percent to 150 percent of rpm) e.g. during large load shedding. Inertia of diesel generator is another subject that needs to be identified for the generator dynamics. Table 3 provides additional generator parameters that are useful for modelling the dynamics.

Table 3: Generator reactance and time constants

Parameter	Value	Parameter	Value
Xd	3.48 pu	Xq	2.09 pu
X´d	0.13 pu	X´´q	0.098 pu
X´´d	0.077 pu	t´´	10 ms
t´d	0.2 ms	t´do	2712 ms

CONCLUSION

This paper deals with operational testing of diesel generators within E.ON distribution system in the Czech Republic. Diesel generators can be utilized as backup power source, providing the power continuity during disturbances or interruptions caused by planned maintenance. This paper focuses first and foremost at the power quality monitoring (in compliance with EN 50160 standard) i.e. voltage and frequency which can be used for future modelling of DG power requirements as well as evaluation of relation between frequency and active power input variation. For wider usage of backup power sources and in addition to the technical specifications, economical or legislative issues need to be addressed. These issues include for example:

- Regional distributors are not allowed to be producers and charge the cost for power generation.
- Economic incentive (compensation for lowering SAIDI and SAIFI indicators) is not sufficient enough to cover the costs. Additionally, these costs are not authorized to be justified yet.
- Nondiscriminal usage of backup power sources based on the number and duration of expected interruption (SAIDI, SAIFI) or risk of exceeding specified limits of distribution interruption.

In response to Commission Regulation (EU) 2016/631 [6] we suppose the modification and validation of dynamic calculation models for the definition of conditions regarding the switching to island operation supplied by auxiliary power source including local sources and subsequent connection to DS without interruption.
Due to the economic reasons, DG deployment is reasonable for repeated long-term interruptions only.

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[6] Commission Regulation (EU) 2016/631 from 14. April 2016, defining Distribution Code regarding the requirements for connection of generating plant to the power system.
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[8] *Generator Systems-Application and installation guide*, Caterpillar company, USA, 2008
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