FAST AND RELIABLE POWER MEASUREMENT FOR ENERGY SOURCES TO ENHANCE DISTRIBUTION GRID STABILITY

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Abstract
This paper deals with measurement of fast active power for monitoring the renewable sources connected to a distribution grid. Fast measurement of active power is the key point of a reliable operation of the distribution grid. In past years we have observed increasing ratio of generated power from renewable energy sources. Renewable energy sources have specific behaviour under a specific weather condition. The term "specific behaviour" should be understood here as the oscillations of output power supplied to the distribution grid. This oscillation could be caused e.g. by wind gusts – wind turbine, or passing clouds – photovoltaics. Such kind of active power oscillation could lead to a large blackout. To prevent large blackouts, we have to perform fast active power measurement. This paper will disclose the method of the fast active power measurement and its application for monitoring the dynamic response of the distribution grid.

Key words: *renewable sources; distribution grid; power generation; blackout.*

INTRODUCTION

Electric power measurement is a general measurement being done in distribution grid monitoring. Any energy source needs a fast power measurement to monitor the operability and the stability of the distribution grid *(Madruga, Bernardon, Vieira, & Pfitscher, 2018; Milligan, 2018)*. Usual methods for measuring electric power are based on digital principle. However, it could be beneficial to use analogue signal processing for some application, especially if we want to investigate dynamic effects in the distribution grid related to the renewable sources. Distribution grid with certain penetration of renewable sources is in the middle of our interest. Renewable sources for instance PV cells (Photovoltaic) can be the source of instabilities for the distribution grid *(Chuang, Chang, Hsiao, Lu, & Yang, 2019; Fiedler, 2019)*.

Digital measurement is widely deployed. It is a part of complex monitoring systems delivered with hardware and equipped with SCADA (Supervisory Control and Data Acquisition) software or the like. Nevertheless, digital measurement has basic limitations. It goes about higher sampling frequencies and the equality of sampled value in a range of one sample. The requirement of higher sampling frequency is often achieved by raw estimation, which might be insufficient, e.g. for making measurements in the systems operating at 50 Hz – distribution grid.

Digital measurement is based on sampling of instantaneous values. The principle of digital active power measurement is that we measure voltage u(t) and current i(t) as a function of time. An instantaneous value of active power is then calculated from the instantaneous values of voltage and current *(Calleja, 2006; Sarkar & Sengupta, 2010)*.

Its median value for the selected time interval gives active power. Similarly, reactive power is determined as the displacement u(t) versus i(t) by 1/4 period. Typical problem of digital power measurement is how to set sampling frequency fs to respect higher harmonic trends expressing deformation of the voltage and current sine wave. We consider that the system frequency is fo is equal 50 Hz. Sampling frequency is as shown in equation (1), which is too low for most of the cases.

$$f_s = 20 \cdot f_0 = 20 \cdot 50 \; = 1 \; kHz \qquad (1)$$

Frequency 1 kHz cannot affect harmonic trends, especially if the semiconductor converters (commonly used for renewable sources – PVE, wind turbine) are used. There also appear errors of measured active power due to interference of the sampling frequency with the measured parameters. Choosing a higher sampling frequency e.g. 10 kHz and higher helps us to avoid all the problems mentioned above, but it

is resulting in higher hardware requirements *(Cataliotti, Cosentino, Di Cara, Lipari, & Nuccio, 2015; Cataliotti, Cosentino, Lipari, Nuccio, & Serazio, 2013)*.
Digital power measurement does not fit into the HW (Hardware) and SW (Software) of ordinary small PLC (Programmable Logic Controller). The solution leads to electrical power measurement on DSP (Digital Signal Processor) or programmable gate arrays. The measurement unit and its price range then contrast with a simple control system of the energy device itself.
Additional option for power measurement is the analogue method. It is a simple, cost-effective and reliable method, which is based on multiplication of analogue signal of voltage and current by analogue multiplier. After the multiplication we have to use an analogue filter. For instance, filtered signal can be connected to analogue input of common PLC (Programmable Logic Controller)*(Twigg & Hasler, 2009)*. The solution for three phases P, Q, U_{RMS}, and I_{RMS} it means 12 measured variables would cost $120. The frequency range is up to 50 kHz for each channel, if the maximum frequency is not limited by measurement transformers.
Besides digital and analogue methods, which are often used for such kind of measurements, are so called PMUs (Phasor Measurement Units). PMUs allow to measure various phenomenon within the distribution grid. PMUs have several disadvantages and the first one is the investment cost. PMUs are in current scale suited for distribution grid operators such as for WAMS (Wide Area Monitoring Systems). Although to use PMUs for monitoring simple gensets or RES operation is not cost-effective.
Second disadvantage is the measurement of hardware and software. PMUs use sophisticated data processing methods, but cheaper PMUs use nominal value of the frequency (50Hz) instead of actual frequency. To measure dynamic trends, we need fast and responsive measurements, which can be seen below. Collecting and monitoring of operational data for long term periods is not the aim of the proposed solution.
The aim of this paper is to demonstrate the functionality of designed wattmeter for fast active power measurement applicable for local traditional/renewable sources to investigate their dynamic behavior related to rotational inertia.

MATERIALS AND METHODS

Due to the above-mentioned drawbacks of digital active power measurement were designed and assembled wattmeter utilizing analogue measurement method. Designed wattmeter is designed for three phases. The main purpose of designed wattmeter is to investigate the dynamic behaviour of renewable sources and their influence on the distribution grid with special focus on the stability.
Wattmeter construction
The measuring board/wattmeter has 6 inputs and 3 outputs. The inputs are voltage and current signals of corresponding phases. The outputs are then active power signals or resulting total active power from three phases.
The main elements of the board are three analogue multipliers AD633 one per phase. They are serving for multiplication voltage and current signal to gain active power. In the Figure 1. can be seen the schematic of the designed wattmeter.

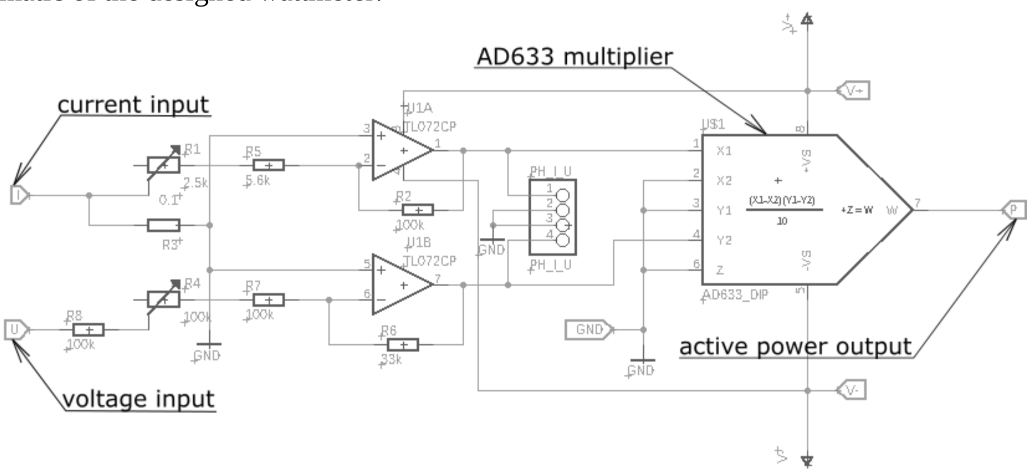

Fig. 1 Exemplary schematic of the designed wattmeter. Shown schematic corresponds to one phase measurement.

Wattmeter testing and calibration

The function of the designed wattmeter was tested and calibrated on the diesel genset with nominal power 1,3 MW. Nominal parameters of the genset are voltage 6.3 kV, 1000 rpm, 50Hz and cosϕ 0.8. Experimental measurement was done in Prague metro emergency power station in Radlicka station (line B). Testing conditions were chosen due to the variability under various testing states (power output, parallel operation etc.). The Figure 2A shows just the test condition. The designed wattmeter could be applied in the same manner for wind turbine or for photovoltaics cells.

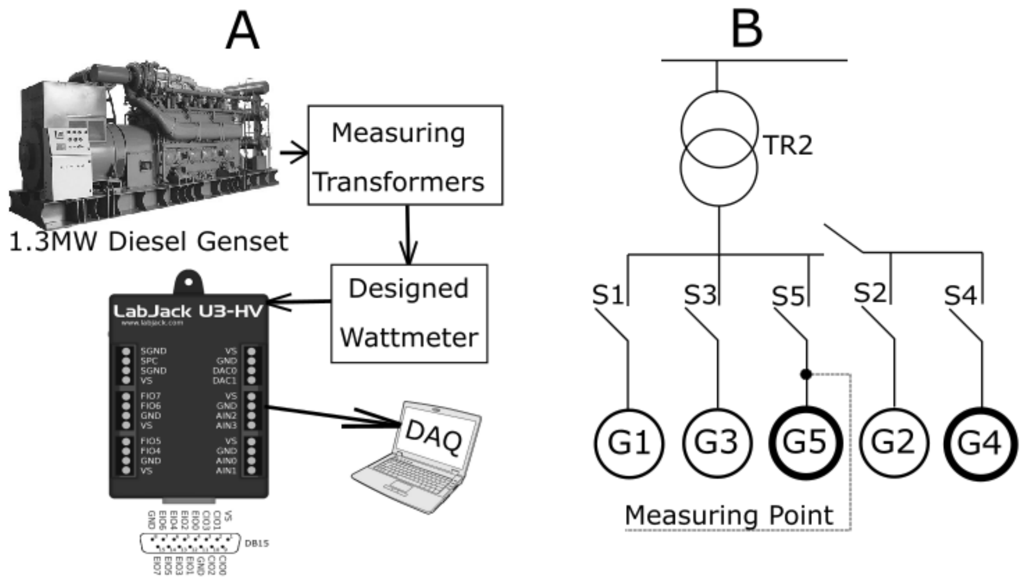

Fig. 2 A – Instrumentation arrangement, **B** – Location of the measuring point (G-generator, S-switch, TR-transformer).

In the Figure 2 we can see the instrumentation arrangement and location of the measuring points. Designed wattmeter was connected to the measuring transformers.

The current transformer has nominal current of primary winding 200 A and secondary winding 5 A. Maximal apparent power for primary and secondary winding is 10 VA. Nominal voltage on the primary winding is 6 kV and on the secondary winding is 0.1 kV. The voltage transformer has maximal load on the secondary winding 50 VA. Voltage transformers are in the set consisting of three transformers for each phase. They are connected in delta/star connection.

The measuring transformers are used also for operational measurement (monitoring). Analogue output from the designed wattmeter was then connected to the USB DAQ module LabJack U3-HV. Data was sampled with 10 kHz frequency.

Measured data was recorded by laptop equipped with LabJack software LJLogUD. Obtained data was then analyzed using MATLAB software. MATLAB analysis consists of filtering the data sets and selecting the sections closed to the phasing action of the gensets.

Statistical analysis to compare independent separate measurements was done using ANOVA method, results are shown in the Tab. 1.

Tab. 1 ANOVA test results

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.229474	2	0.114737	2.868421	0.017103	3.354131
Within Groups	1.08	27	0.04			
Total	1.309474	29				

Measurement comparison device was based on the same measuring transformers using measurement card connected to the SCADA system. The difference between reference measurement and designed wattmeter was maximally 10 %. However, the purpose of designed wattmeter is to diagnose and disclose possible failures of the power generation system, so the accuracy of 10 % is still tolerable.
The measurement was done using one wattmeter connected to G5 according to the Figure 2B. We have investigated the influence of two generators running in parallel operation. Testing condition was that G5 was synchronized to the grid (upper trends) and then synchronized with G4 (bottom trends). Measurement then monitored the influence of synchronizing G4 into parallel operation with G5.

RESULTS AND DISCUSSION

Following trends show the result of phasing G4 into parallel operation with G5. Phasing both generators was done under 100 kW load. To verify the functionality of designed wattmeter (monitoring of dynamic behavior of energy sources) we phased the G4 with slight phase displacement, so that it generated power impulse delivered to the distribution grid. Thus, on the top trend in each figure we can see dynamic response of the distribution grid to G5 phasing. Similar trends can be observed in the discontinuous power generation or lost of synchronism, which can be observed in renewable energy sources area (Madruga et al., 2018).
Connecting another genset G4 to electrical grid caused oscillation in the distribution grid, which needs to be regulated by various regulation mechanisms, e.g. frequency regulation (Milligan, 2018). This led to a visible response from already phased G5.
In the Fig.3 we can see first set of measurements on the G4 and G5 in parallel operation with 2s resolution, above we can see significant peak during synchronizing G5 causing the disturbances (disturbance is damped within 13 seconds), below is the response of already synchronized connected genset to the G4 connection. Based on this measurement we can conclude, that G4 is the source of irregularities, which cause fluctuation of delivered G5 power.

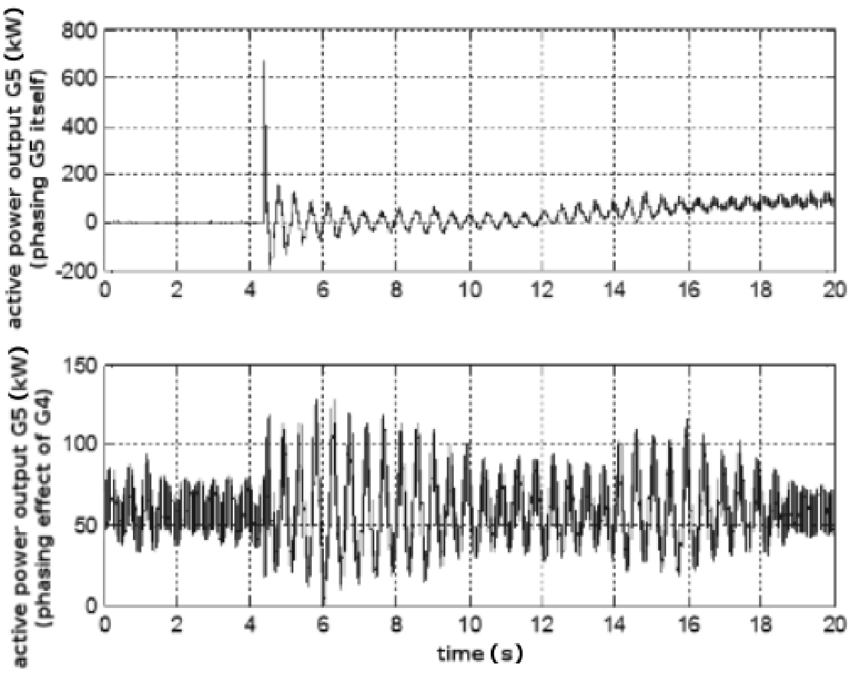

Fig. 3 Set of measurement of active power of G5 – plot with 2s resolution (upper –synchronizing genset to electrical grid, bottom – response of synchronized genset to synchronization event of 2nd genset.

In the Fig. 4 we can see similar trends like in the Fig. 3, but with 1s resolution. We can see significant fluctuations in the G5 power output. Shown state could be potentially dangerous, but we can observe that the damping factor is still high, so the fluctuations are lowered.

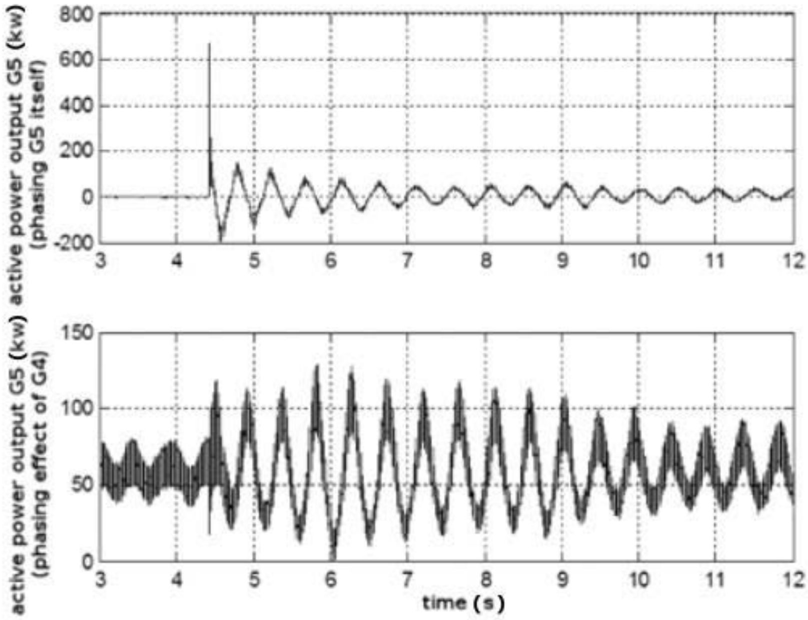

Fig. 4 Set of measurement of active power of G5 genset – plot with 1 s resolution (upper –synchronizing genset to electrical grid, bottom – response of synchronized genset to synchronization event of 2nd genset.

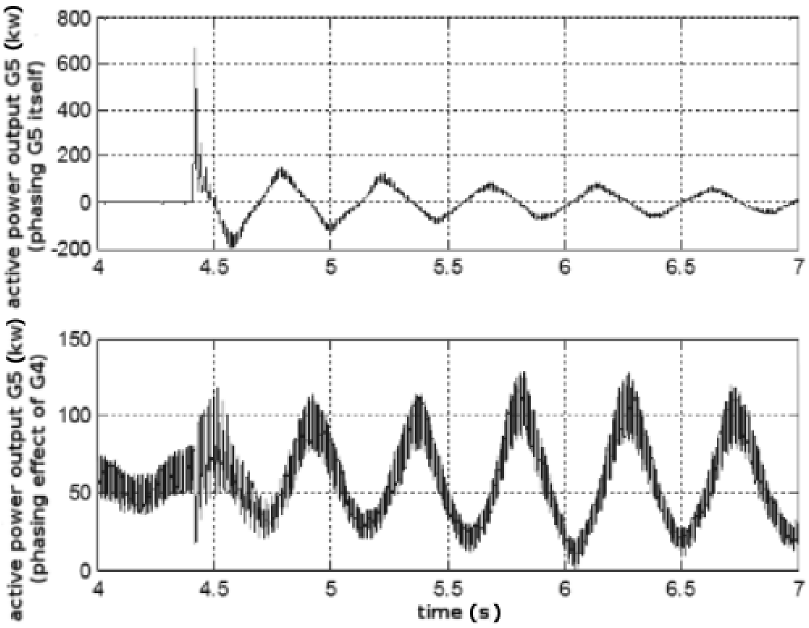

Fig. 5 Set of measurement of active power of G5 genset – plot with 0.5s resolution (upper –synchronizing genset to electrical grid, bottom – response of synchronized genset to synchronization event of 2nd genset

In the Fig. 5. we can see the trends with 0.5 s where damping factor is low, so the amplitude has growing trend. This is state is emergency and could lead to the breakdown of the gensets and to the interruption of delivered power.

CONCLUSIONS

The measurement with developed wattmeter proved that analogue method can provide very fast and reliable outputs. This is very important for monitoring of the energy sources with special regards to their dynamics.

Another point of interest is the accuracy of the measurement. We compared our data with standardized digital measurement done by operators. We achieved maximal error for approximately 10 % of measured value. The error is not satisfying, but main purpose of developed wattmeter is to monitor the dynamics, such as the dynamic response of the distribution grid, damping coefficient, etc. The dynamic response of the distribution grid can be used to find the correlation between the traditional energy power sources output and the renewable power sources output. This type of correlation can be used for distribution grid modelling.

The developed wattmeter will be further used for long term monitoring of the PV panels with focus on dynamic behaviour based on weather conditions (e.g. temperature, clouds…).

The methodology of fast active power measurement provides the values corresponding with the instantaneous torque magnitude according to the Park's equations. It means that foregoing method could be used to investigate mechanical irregularities. Developed wattmeter was used to discover the source of problems e.g. the genset's cylinder (combustion issues), mechanical defects (bearings) or to detect higher order of harmonic functions in the power output. Measured results were used to correct rotational speed regulation. The method is usable for monitoring of electromechanical systems and in comparison, with PMU is much cheaper and more reliable.

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