Measurement of electric power dynamic of the generators working in the distribution grid

Milan Daneček, Ivan Uhlíř

[1] *CTU in Prague, Faculty of Mechanical Engineering, Department of Instrumentation and Control Engineering, Technicka 4, 166 07 Prague 6, Czech Republic*

Abstract

This paper is focused in the application of fast analog wattmeter for a genset. This wattmeter was designed for application in a genset comprising an internal combustion engines. Fast and accurate measurement of electrical power is basic for stable and efficient genset control system. Designed wattmeter is eliminating the disadvantages of digital measuring. Digital measuring is utilizing sampling of instantaneous values of voltages and currents. This sampling can cause problematic signal processing in case of high sampling frequency.

Keywords: wattmeter, genset, analogue measurement, control system

1. Introduction

Electric power measurement is one of general measurement. Any generator producing electricity needs fast and accurate power measurement.

About 40 percent of electricity is consumed by industry; for this reason more efficient industrial appliances and equipment (e.g. high-efficiency motors and variable speed drives) are under continuous development [1].

However also for home appliances a reduction of the energy consumption is continuously demanded; energy efficiency rating is today supplied by the producer for every household electrical and electronic device [2 - 6].

Above mentioned appliances are closely related to the microgrid technologies. Researches of Microgrid have been developed promptly in recently years because of energy crisis and environmental concern. The microgrid should operate normally in grid-connected and transfer to islanding operation mode when a utility fault occurs. However, to stabilize the voltage and frequency on the AC bus during mode transfer is difficult for microgrid control [7].

Analog wattmeter is well suited for above mentioned applications for solving common problems in power measurement and in control systems. It can measure the power from very low values until very high values with accurate results.

Due to simple design is analog wattmeter very reliable. This advantage is very useful with regards to the application. Thus designed analog wattmeter is intended mainly for an industrial application in such a genset comprising internal combustion engines.

This paper will also describe real application and functioning proving the feasibility of designed wattmeter.

2. Motivation

Genset with internal combustion engines has often troubles with fast and accurate power measurement.

Here is one example of these difficulties. We did couple of validating measurements at genset with 1500kVA nominal electric power. This genset has 16 cylinders and use natural gas as a fuel see Fig. 1.

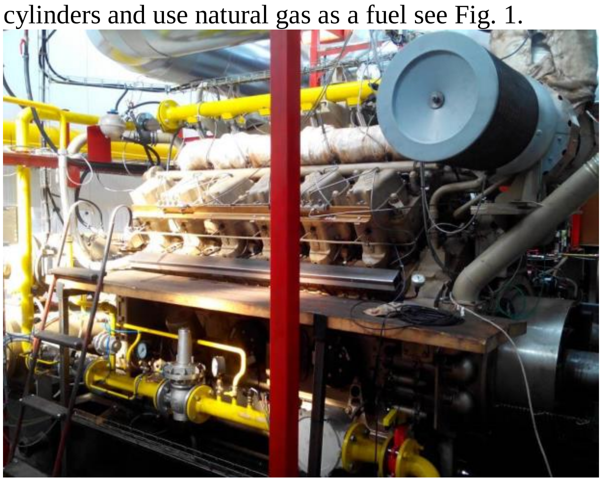

Fig. 1: Analyzed 1500kVA genset

In the described genset have occurred the problems with the excitation control strategy. Via reversible investigation was found that even the generator was connected and synchronized to the distribution grid the regulator was trying to control generator voltage. Logically it is impossible to control generator voltage as long as the generator is connected to the distribution grid.

During this investigation was also found, that the digital active power measurement was also out of real range. This opinion was confirmed by the direct measurement of the active power. For measuring was used double channel oscilloscope, which was connected to the genset switch box.

Trend measured by the digital way in the operator's room is shown in following Fig. 2.

* Author contact: milan.danecek@fs.cvut.cz

As is seen from the Fig. 2 the measured oscillations of active power doesn't give any sense.

At first, the amplitude within one minute period is 80kW. Secondly the active power trend is not smooth. This effect is probably caused by interfering between sampling frequency and phase frequency and also by higher harmonic functions.

Now we know how digital measuring work in practice. Now we will describe digital and analog measurement in detail.

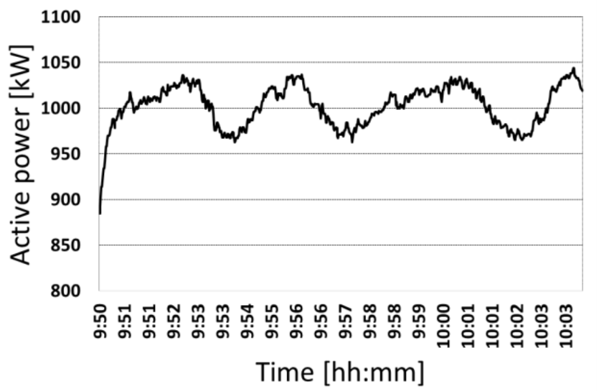

Fig. 2: Measured trend of analyzed genset active power

3. Measuring principles and their consequences

There are two basic methods to measure active power, reactive power, apparent power and cos φ. We can utilize digital measurement or analog measurement to measure above mentioned parameters.

3.1. Digital power measurement

Digital measurement is based on instantaneous values sampling. The method is digital measurement of electric power of voltage u(t) and current i(t) in the phase conductors. Instantaneous electrical power is calculated from instantaneous values of voltage and current [5 - 6].

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 f_s to respect higher harmonic progressions expressing distortion sine wave voltage and current of the frequency fo = 50Hz. Sampling frequency fs = 20*fo = 1 kHz is for most cases too low. 1 kHz cannot affect harmonic distortions, especially if semiconductor converters are used. There also appears variation of measured power due to interference of the sampling frequency with the measured parameters. To choose a higher sampling frequency eg. 10 kHz and above will help us to avoid all the problems mentioned above, but it is resulting in higher requirement for computer performance. Designed power measurement does not fit into the HW and SW of ordinary small PLC. The solution leads to rapid units to measure electrical power on DSP processors or programmable gate arrays. The measurement unit and its price range then contrasts with a simple control system of energy device itself.

3.2. Analog power measurement

Another option for power measurement is analog way. It is simple, cost-effective and reliable system, which is based on multiplication of analogue signal of voltage and current by analog multiplier. After multiplication we have to use an analog filter. Filtered signal is connected to analog input of common PLC control unit.

Price for one analogue channel for instance with analog multiplier AD663 and one quadruple operational amplifier costs $10. The solution for three phases P, Q, URMS, IRMS it means 12 measured variables will cost $120. The frequency range is up to 50 kHz for each channel, if the maximum frequency is not limited by measurement transformers. If the subscribed system is used signal interference cannot occur.

Class accuracy at the fundamental frequency of 50 Hz is achievable better than 1%, which is sufficient for the most energy measurement. Same way how to obtain P and Q is available to obtain the analogue URMS and IRMS values via u2 (t) and i2 (t) mean value after filtering and square root quad feedback of the operational amplifier. [2]

Measuring and displaying of cos φ value is often required by the customer or user, with invocation to the old habits of practitioners with insufficient theoretical basis. Variable cos φ is defined as the ratio of active power and apparent power, or as a cos phase shift between voltage and current:

$$\cos\varphi = \frac{\Sigma P_i}{\Sigma U_i I_i} \tag{1}$$

If electrical power will decrease to zero (eg. by reducing current consumption) cos φ becomes problematic variable, it will become indefinite value 0/0. In practice, this shows that even small errors of measurement voltage and current will cause large errors in the data of cos φ. The display shows nonsensical data, eg cos φ > 1. If the control strategy is controlled by a variable cos φ, then its control becomes unstable or even collapse. The solution is to modify the calculation of the apparent power in the denominator of the formula:

$$\cos\varphi = \frac{\Sigma P_i}{\sqrt{\Sigma P_i^2 + \Sigma Q_i^2}} \ , \tag{2}$$

where reactive power Qi is obtained by measuring either digital or analogue u (t) and i (t), similarly like P. In this adjustment for low current and electrical power can appear on the display. It should be clear, that the power factor for low electrical power output is not decisive.

4. Design of the wattmeter

As was mentioned above, designed wattmeter is working based on analog principle. The heart of the designed wattmeter are three analog multipliers AD663.

Each multiplier is desired to calculate power in one phase. Schematic design of analog wattmeter can be seen on Fig. 4.

By using the electrical scheme on the Fig. 4 the analog wattmeter prototype was constructed. This prototype include insulated output, power supply, current and voltage inputs and calibration trimmers. Detail construction can be seen on Fig. 3.

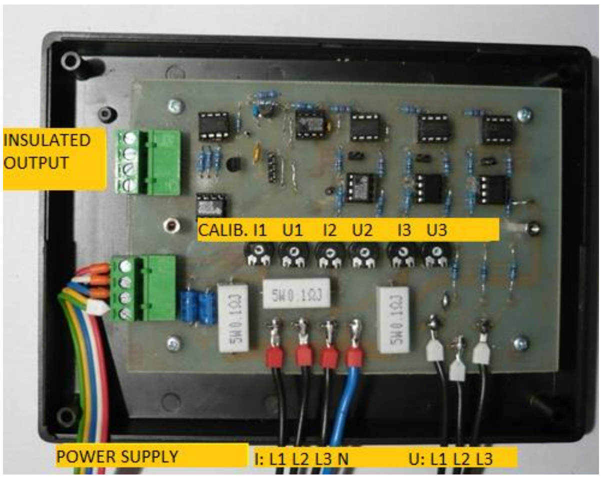

Fig. 3: The analog wattmeter prototype

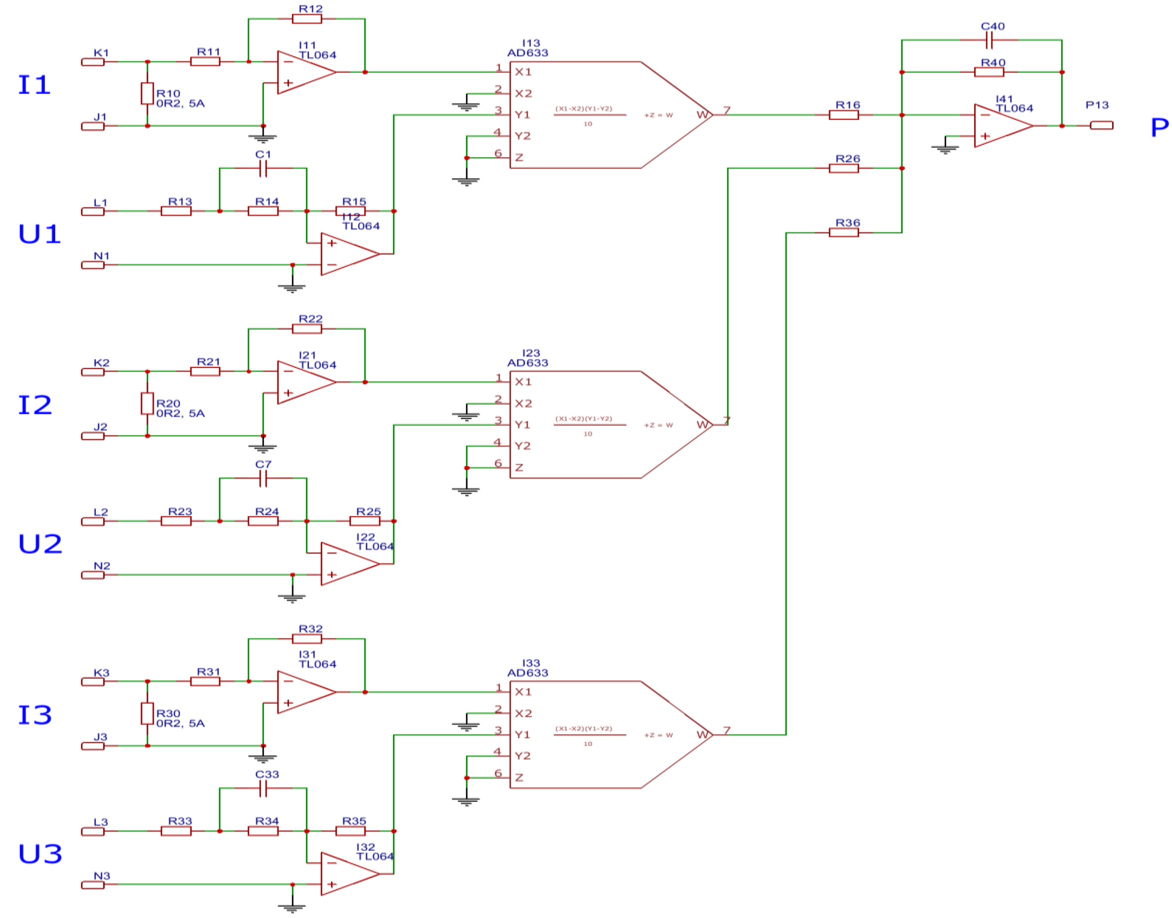

Fig. 4: Schematic design of the designed analog wattmeter

5. Practical testing and calibration

Designed analog wattmeter was tested and calibrated in the laboratory with 4kW – 230V – 50Hz synchronous motor. This motor was connected to the grid via 10kVA booster adjusting voltage from 400V to 230V. Used synchronous motor was actuated via DC dynamometer with cage power supply via controlled rectifier. Excitation with no load was 1.2A. Before connecting to the grid the voltage was equal. Frequency of the generator was about 0.5 Hz slower. The generator was connected in generating state.

There occurs an oscillations see Fig. 5 of active power with 0.4s period. These oscillations are given by an electromagnetic stiffness of the synchronous motor and inertial mass on its shaft. One segment on the screen is corresponding to 1V of the power converter output and to 4.5kW of active power.

For future applications, especially for genset control system is important that the active power trend seen on Fig. 5 is smooth. The active power trend doesn't include any interferences, which are obvious in digital measuring of electric power. There are no substantial interference of grid frequency in case of symmetrical phases of the appliance.

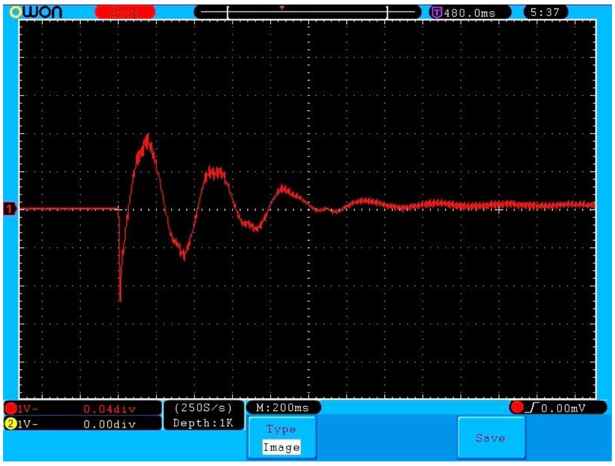

Fig. 5: Active power trend measured during first testing of the designed analog wattmeter

6. Future application of the developed wattmeter

Developed wattmeter provides very good and accurate data. This accuracy was validated during measurement in the emergency Prague metro genset. Said genset is equipped with 6 diesel engines each with nominal performance 1.2MW.

In this installation we proved and verified overall setup and optimization of designed wattmeter. This testing also proved the reliability and safeness of the developed wattmeter.

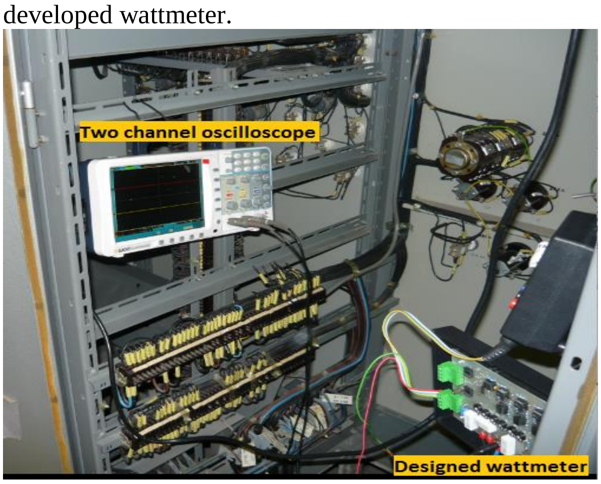

Fig. 6: Temporary testing on 1.2MW genset

7. Conclusion

This paper has showed the working principle and reliability of designed wattmeter.

By using realized wattmeter we can measure the properties of the generators working in the distribution grid, e.g. active power, reactive power, apparent power and cos φ. Analog method is characteristic with its measuring speed and high accuracy of measured properties.

Good results of analog wattmeter application also allows future application such an adequate measuring unit for genset instrumentation a control systems.

8. Acknowledgement

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* Author contact: milan.danecek@fs.cvut.cz