Measurement of electrical power for application in microgrid technologies

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Abstract
This paper deals with application of measurement methods for microgrid technologies. To optimize a control system accurate measurement of input variables is necessary. Very important variable is the electrical power, especially in connection to self-consumption. In some cases we can find, that our own electricity meter (verification measurement) differs about 30% in comparison with the measurement of electricity supplier. The main task for further distribution of available energy is to find sustainable method to measure electrical power with higher accuracy of data. This consumption of electrical energy will be one of the most significant inputs to control strategy for energy management in energy efficient buildings.

Keywords
electrical power, microgrid technologies, analogue multiplier, sustainability of energy sources

1. Introduction

Implementation of microgrid technologies helps energy production and energy consumption become more efficient. Microgrids combine various distributed energy resources (DER). Definition of microgrid is not connected to the size or to the amount of devices, it is about effectivity and cognitive communication between energy demand and energy production. Main parameter is that microgrid can operate like a standalone system and it can be also connected to the electricity grid. For implementation of the microgrid control strategy is necessary to measure electrical power of each device (nodes) in the system. This study is focused on usage of the microgrid technologies for energy efficient buildings and on design of sustainable and accurate measurement for implementation in microgrid technology.

1.1. What is a microgrid

Microgrid systems became discussed topic especially with development of renewable sources. Microgrid is a small scale electricity system with renewable energy sources, traditional energy sources, storages and with energy management systems in smart buildings, campuses etc. Use of microgrid technologies can help to the costumers to find the optimum for consumption and generation of electricity, heat and cold. Microgrid can operate independently without connecting to distribution grid (standalone systems) or it can be connected to the main electricity grid.

Microgrids have several kinds of advantages. For example: onsite energy consumption during peak power conditions, lowering stress on the transmission and distribution system. Integration of renewable sources in distributed energy resources could be also beneficial.

Main problem with microgrid systems is the price of installation. Basically microgrid systems contain renewable energy sources, which are still quite expensive in comparison with classical energy sources. For utilization of microgrid technologies is necessary to find sustainable systems to connect and operate device for energy production (gas turbine, PV cells, fuel cells etc.) and also for energy consumption (electrical appliances).

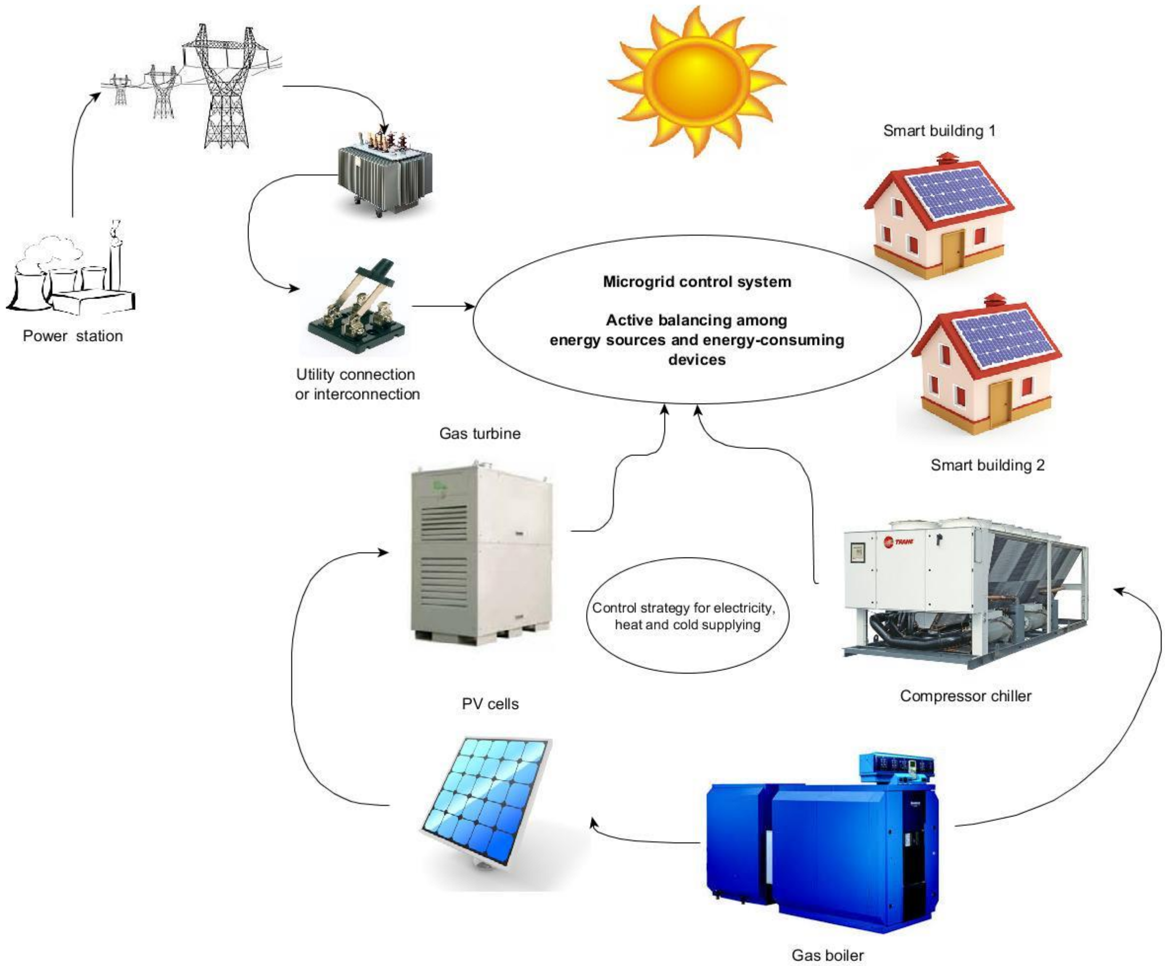

Figure 1: Microgrid structure

1.2. Motivation

Motivation for microgrid application is to save primary energy sources and to find optimal ratio between energy demand and energy production. Typical problem in pilot projects is how to find optimal control strategy. Control strategy itself is not complicated, the problem is how to find sustainable way to measure input variables. If we want to keep the investment price as low as possible we have to look for ways how to measure all input variables. Most important variable for monitoring the state of microgrid is electrical power. The best option how to monitor self-consumption is to put own electricity meter to every device (pump, fan, motors etc.). This solution is not cost-effective, especially because of the price of commonly used electricity meters. This is the main problem to be solved, find simple (cheap) but accurate method for electrical power measurement with regards to reliability.

2. Measurement of electrical power

Measurement of electrical power is starting point, which has very strong influence to the quality of chosen control strategy. We have several methods to measure active power, reactive power, apparent power or cos φ.

2.1. Digital measurement of electrical power

First method is digital measurement of electric power. It is based on sampling the instantaneous values of voltage u(t) and current i(t) in the phase conductors. Instantaneous electrical power is calculated from instantaneous values of voltage and current.

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. Hidden problem of digital power measurement is how to choose sampling frequency f_s to respect higher harmonic progressions expressing distortion sine wave voltage and current of the frequency f_o = 50Hz. Sampling frequency $f_s = 20*f_o$ = 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 gives 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.

2.2. Analogue measurement of electrical power

Nowadays analogue measurement of electrical power is already almost forgotten. It is simple, cost-effective and reliable system, which is based on multiplication of analogue signal of voltage and current by analogue multiplier. After multiplication we have to use an analogue filter. Filtered signal is put to analogue input of common PLC control unit. Price for one analogue channel for instance with analogue multiplier AD663 and one quadruple operational amplifier costs $10. The solution for three phases P, Q, U_{RMS}, I_{RMS} 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 U_{RMS} and I_{RMS} values via u^2 (t) and i^2 (t) mean value after filtering and square root quad feedback of the operational amplifier.

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:

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

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:

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

where reactive power Q_i 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.

3. Real influence of smart grid technologies?

The benefit of smart grid technologies is very obvious. In case we can optimize energy production with energy demand it will bring energy losses reduction. The problem is final price of electricity for common customer, because price for 1 kWh combine many factors. It is payment for power (payment for actually consumed electricity), regulated payments for electricity transmission and electricity tax.

Most important sector for the consumer is regulated payment for electricity transmission. It contains price for distribution, price for system services, price for support of electricity buyout and price for accounting activities of the Electricity Market Operator (EMO). In this sector is pointed smart grid technology. The real influence of smart grid technology to the final price of electricity is controversial. To utilize smart grid technologies will require huge budget of money to fit the distribution grid etc. So two basic questions came on. How will be covered/paid the fitting in distribution grid? It can be partly covered by customers specially to change common electricity meter for ’’smart’’ electricity meter and the rest will be dispersed to the final price of electricity. Second question is if the energy losses reduction will pay back (in the future, how many years?) the initial investment for research and utilization smart technologies in the distribution grid? We hope yes!

4. Conclusion

Analogue measurement of electrical power brings us sustainable way how to utilize microgrid technologies or smart grid technologies respectively. Considering the mass deploying of smart technologies is necessary to find cost effective technologies. Pilot projects in the field of smart grid technologies shows us that we still need research and development in the sector of smart technologies, to find cost-effective and efficient solution. Efficient solution means that the final price for electricity will be kept in appropriate range, so the benefit will be twice higher. We can decrease the energy consumption (primary sources) and we can save the environment while keeping electricity prices.

5. Acknowledgement

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Nomenclature

u(t), U	*voltage waveform, voltage*	*(V)*
i(t), I	*current waveform, current*	*(A)*
f_s	*sampling frequency*	*(Hz)*
f_o	*phase frequency*	*(Hz)*
P	*active power*	*(W)*
Q	*reactive power*	*(VAr)*
S	*apparent power*	*(VA)*
U_{RMS}	*RMS voltage value*	*(V)*
I_{RMS}	*RMS current value*	*(A)*
$\cos \varphi$	*power factor*	*(-)*

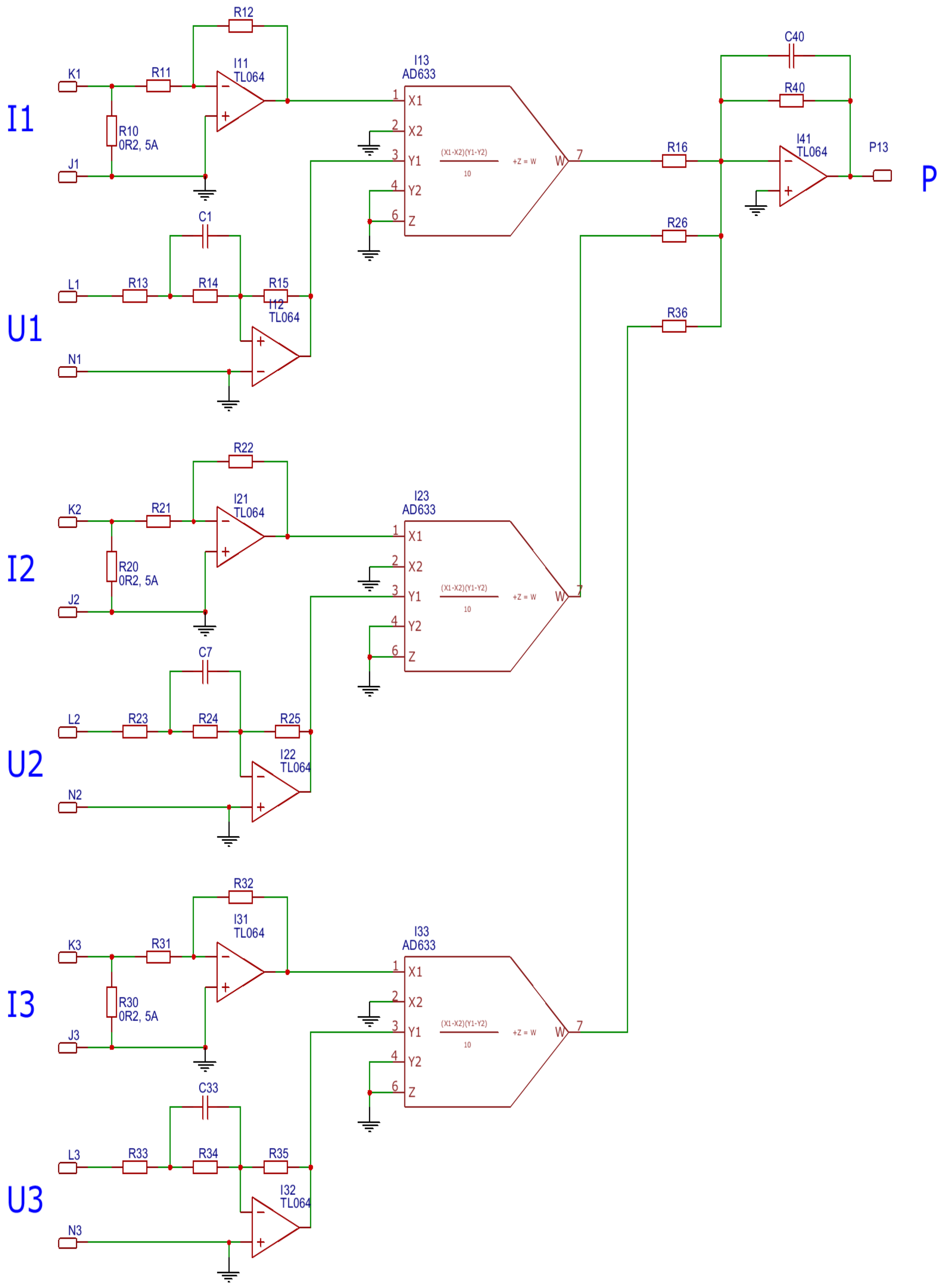

Figure 2: Scheme of analogue measurement of electrical power

6. References

[1] Alireza Zakariazadeh, Shahram Jadid, Pierluigi Siano, Smart microgrid energy and reserve scheduling with demand response using stochastic optimization, International Journal of Electrical Power & Energy Systems, Volume 63, December 2014, Pages 523-533, ISSN 0142-0615

[2] Waleed Al-Saedi, Stefan W. Lachowicz, Daryoush Habibi, Octavian Bass, Power flow control in grid-connected microgrid operation using Particle Swarm Optimization under variable load conditions, International Journal of Electrical Power & Energy Systems, Volume 49, July 2013, Pages 76-85, ISSN 0142-0615

[3] Di Zhang, Nilay Shah, Lazaros G. Papageorgiou, Efficient energy consumption and operation management in a smart building with microgrid, Energy Conversion and Management, Volume 74, October 2013, Pages 209-222, ISSN 0196-8904

[4] Hossam A. Gabbar, Abdelazeem A. Abdelsalam, Microgrid energy management in grid-connected and islanding modes based on SVC, Energy Conversion and Management, Volume 86, October 2014, Pages 964-972, ISSN 0196-8904,

[5] Yancheng Liu, Qinjin Zhang, Chuan Wang, Ning Wang, A control strategy for microgrid inverters based on adaptive three-order sliding mode and optimized droop controls, Electric Power Systems Research, Volume 117, December 2014, Pages 192-201, ISSN 0378-7796

[6] Canbing Li, Chi Cao, Yijia Cao, Yonghong Kuang, Long Zeng, Baling Fang, A review of islanding detection methods for microgrid, Renewable and Sustainable Energy Reviews, Volume 35, July 2014, Pages 211-220, ISSN 1364-0321

[7] Mariya Soshinskaya, Wina H.J. Crijns-Graus, Josep M. Guerrero, Juan C. Vasquez, Microgrids: Experiences, barriers and success factors, Renewable and Sustainable Energy Reviews, Volume 40, December 2014, Pages 659-672, ISSN 1364-0321

[8] Iván Patrao, Emilio Figueres, Gabriel Garcerá, Raúl González-Medina, Microgrid architectures for low voltage distributed generation, Renewable and Sustainable Energy Reviews, Volume 43, March 2015, Pages 415-424, ISSN 1364-0321