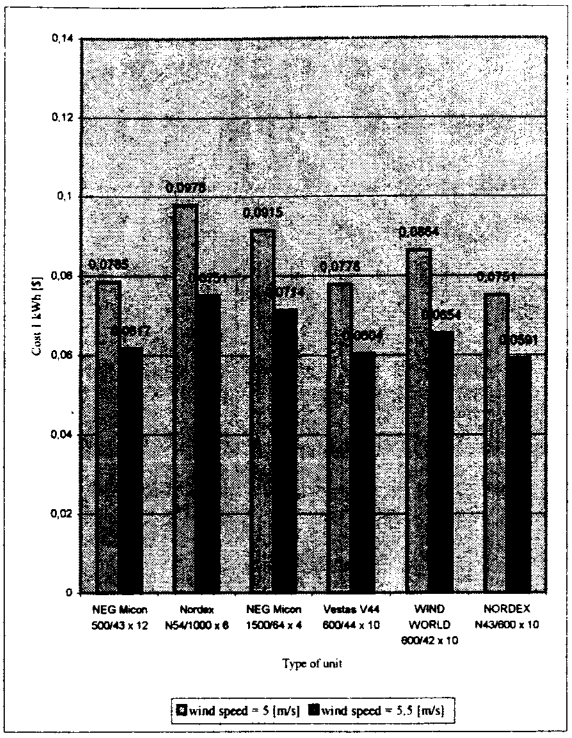

Fig. 9. Electricity cost per kWh for analised 6 MW wind farm (surface class = 1).

1. www.elektrownie-wiatrowe.org.pl 2. www.energy.sourceguides.com 3. www.euwinet.iset.uni-kassel.de 4. www.reisi.iset.uni-kassel.de/wind/ 5. www.uni-muenster.de/energie/wind 6. www.windpower.dk

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APPLICATION OF PHYSICAL MODELLING FOR AERODYNAMIC TEST OF FGD ABSORBER

1. Introduction

Belchatow Power Plant is the Polish and European largest lignite fired conventional plant. It consists of 6 power units of 360 MW capacity and 6 units of 370 MW capacity, which gives the total of 4380 MW installed capacity. There are 6 flue gas desulphurization plants based on lime-gypsum method installed at Belchatow Power Plant and another two ones are under realization.

Commencement of the construction of Belchatow Power Plant, which took place in 1975, was of a great importance both to the Polish power system and to the Power Plant itself, as its development perspectives were very promising. Six years later, on 29th December 1981 the 1st Power Unit was synchronized with the National Power Grid and the last one — on 12th October 1988, reaching the total of 4320MW capacity, as it had been originally planned.

Power generation equipment is arranged in the 700 m long and 100 m wide main building, so its total area equals 7 ha. The cubic capacity of the building is 6 million cubic meters and the total area of the whole enterprise is 900 ha. Arranged by the main building, the two 300 m tall stacks allow — at the high outlet velocity — to emit flue gases at the height of 0.5 km.

The annual energy production is 27 million kWh, which covers almost 20% of the whole country electricity demand. Annual lignite consumption supplied by the local mine reaches 33—37 million tons.

Since the first power units of the Belchatow Power Plant have been operated over 100 thousands hours, i. e. 70 % of the designed operation period, the suitable modernization plans has been already elaborated and approved. Its realization should result in the turbines life extension and efficiency increase and thus allow their operation for the next 15 years.

Belchatow Power Plant was designed in 70s. During that time the know-how within the scope of environment protection engineering was much poorer, environmental legislation was much more liberal than it is now and emission reduction technologies were at the early stage of their application in Europe.

Naturally, due to the production of huge amount of electricity and consumption of vast amount of coal, the Plant is also a major source of emission. The year 1989 was the worst in this regard. During the production of 28.2 million MWh of electricity the plant consumed 37.55 million tons of lignite, emitting to atmosphere 405,400 tons of SO_2, 77,000 tons of NO_x and storing over 4 millions tons of furnace wastes at the waste dump.

2. SO_2 reduction program at Belchatow Power Plant

The decisions taken in 1990 resulted in the realization of the first stage of the flue gas desulphurization plant construction. The tender procedure for delivery, erection and start-up of the flue gas desulphurization plant resulted in selection of Dutch company HTS E&E. On 15th June 1991 a contract was signed for construction of 4 flue gas desulphurization plants at power units Nos. 8, 10, 11, 12.

After successive commissioning of FGD (Flue Gas Desulphurisation) plants within the period September 1994 - September 1996, the first stage of installing these very crucial for SO_2 emission reduction plants was finished. At that time they enabled SO_2 emission reduction by 1/3 in relation to previous years.

Due to the worse coal quality (increased sulfur content in the fuel) another plant construction was necessary. In the second half of 1995 a tender specification was prepared, and in the beginning of 1996 a call for tender was announced for construction of flue gas desulphurization plants at power units No 5 and 6, which started the second stage of SO_2 reduction at Belchatow Power Plant. After detailed evaluation of submitted offers, RAFAKO's proposal was chosen and on 13th March 1997 a contract was signed for construction of two flue gas desuphfurization plants at units No 5 and 6.

The new plants at units 5 and 6 constructed in years 1997-2000 and delivered by RAFAKO S.A. operate according to similar wet lime-gypsum technology, which fulfills criteria of the Best Available Technique — BAT, as it is defined in just being introduced EU Directive, so called IPPC.

It is also another SO_2 emission reduction since 2000, equaling 50% in total in relation to primary total emission.

Aiming to prepare Belchatow Power Plant to more stringent national environment protection requirements, and having in mind European Union regulations, the decision to build another flue gas desulphurization plants at units 7 and 9 was taken. In 1999 another call for tender for the construction of flue gas desulphurization plants at units 7 and 9 was issued with strengthened requirements regarding new plants performance. Another two flue gas desulphurization plants at units 7 and 9 will be built after an offer submitted by RAFAKO S.A. was selected and the contract signed on 2nd June 2000.

In 2003 the last two flue gas desulphurization plants will be commissioned and since then 8 units will be equipped with the equipment, which is so vital for coal fired power plant, enabling it to reduce SO_2 by 2/3 in relation to the situation 10 years ago.

In this way, the minimum SO_2 reduction program implemented by Belchatow Power Plant will be finished, which is in line with SO_2 Reduction Program in Utility Power Sector accepted by government in 1996. SO_2 emission levels throughout years depending on burnt fuel are shown on the diagram (Fig. 1).

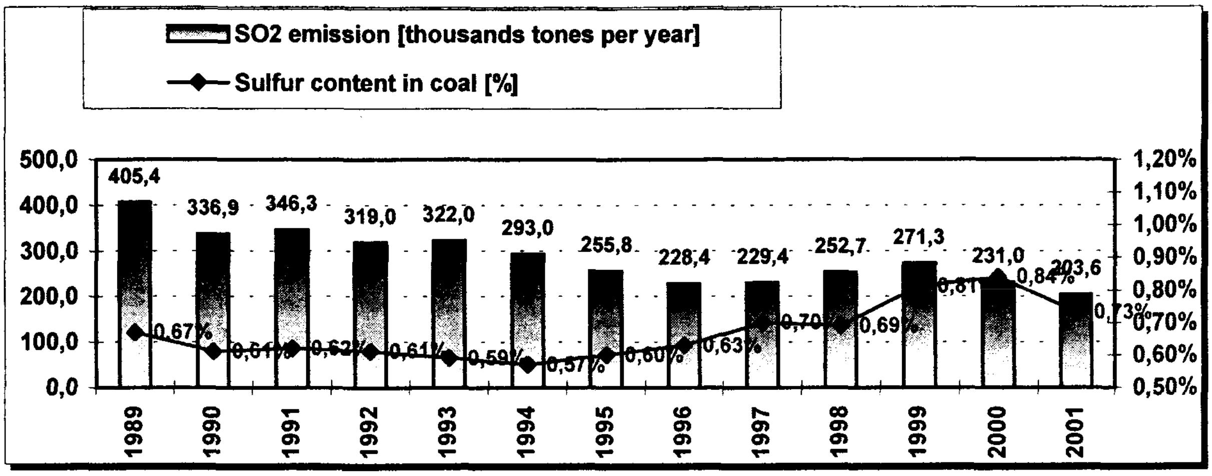

Fig. 1. Emission levels of SO_2

3. Aerodynamic studies of an absorber

3.1. General information

Open spray towers are already used for more than 25 years in FGD application on power plant boilers. Its technical and technological development was characterised by reduced dimensions of the absorber, optimisation of spray nozzle design and mist eliminator design. Despite all the developments too little attention was given to the aero- & hydrodynamics of gas and fluid flow in spray towers.

The first FGD plant on a power boiler fired with lignite was erected in Poland at Belchatow Power Plant. Various measurement of the SO_2 distribution at the absorber outlet had shown a quite unequal distribution what indicated unequal gas flow inside the absorber. Therefore it becomes necessary to analyse the gas flow distribution inside the absorber. Such studies were done on a physical model of the absorber. Typically physical models are make as a transparent constructions what enables visualisation of the gas flow with smoke or spark markers. Fluid dynamic studies of technological equipment (using air) do not take into account the influence of a dispersed phase component, in that case dust or liquid. These studies allow testing the main direction of gas flow, pressure drop as well as the space velocity distribution. In result it is possible to estimate and optimise various constructional versions of a tested device.

Power boiler flue gases cleaned in an ESP (Electrostatic Precipitator) are introduced into bottom part of an absorber by means of two fans. The desulphurisation processes in an absorber take place when flue gases comprising SO_2 come into contact (react) with counter flow sprayed milk of lime slurry. The $CaSO_3$ after oxidation forms gypsum crystals that are collected after hydro-extracting. The flue gas temperature at the absorber outlet is about 65°C and it is further increased of 10 degrees with hot air taken from air preheaters (Luvo).

There are considerable variations of sulphur content in the fired lignite which results in temporarily increase of SO_2 above the designed value of 4000mg/m^3 even up to 7000mg/m^3. In such cases the sulphur dioxide removal efficiency heavily deteriorates.

FGD absorbers in Belchatow Power Plant have four spray levels designed in such a way to evenly distribute the sprayed liquid across the entire absorber cross-section. In a case of simultaneous occurrence of unequal gas flow distribution in the absorber and SO_2 increase at its inlet the desulphurisation efficiency drastically drops down. The desulphurisation efficiency mainly depends on volumetric ratio of L/G and the contact time of gas with liquid. The volumetric ratio L/G represents the ratio of liquid (a suspension volume in dm^3) and gas phase (gas unit i.e. $1m^3$).

In order to solve all the FGD operational problems the Belchatow Power Plant ordered Politechnika Wroclawska to carry out aerodynamic model studies of one FGD absorber and elaborate recommendations to increase the FGD plant efficiency [1].

The layout of a power unit with FGD plant of Belchatow Power Plant is shown on Fig.2.

3.2. Model of the absorber

Gas distribution analysis were done on a physical model of absorber made in a scale of 1:20 [2]. A reliable model for hydrodynamics studies is when the Reynold's number for the model is greater than $Re \geq 10^4$; which guarantees absolutely turbulent gas flow in a model (so called range of self-modelling). It is important with the studies to fulfil the dynamic affinity criterion of the Euler number. This criterion enables transfer of hydraulic resistance from a real object to the model and vice versa. In order to obtain the proper picture of a gas flow in different FGD installation elements as absorber and gas ducts, it is possible to use the well known principles of gas flow movement in straight and combined gas ducts [3].

The absorber model has been made according to the design layout that is why those obtained results can be used as a base for optimisation of the flue gas desulphurisation process.

Table 1 gives the basic data of the FGD installation.

Table 1

Basic data of the FGD installation

Item	Description	Unit	Quantity
1	Absorber diameter	m	18,7
2	Absorber height	m	43,2
3	Number of spray levels	-	4
4	Flue gas volume (at STP condition)	m^3/s	472,2÷583,3
		m^3/h	$1{,}7 \cdot 10^6 \div 2{,}1 \cdot 10^6$
5	Water consumption	m^3/s	0,014÷0,033
		m^3/h	50÷120
6	Flue gas temperature at the absorber inlet	°C	125÷145 (150)
		K	398÷418 (423)
7	Flue gas temperature at the absorber outlet	°C	65
		K	338
8	SO_2 concentration of flue gas at the absorber inlet (at STP condition)	mg/m^3	2300÷4130
9	SO_2 concentration of flue gas at the absorber outlet (at STP condition)	mg/m^3	< 400

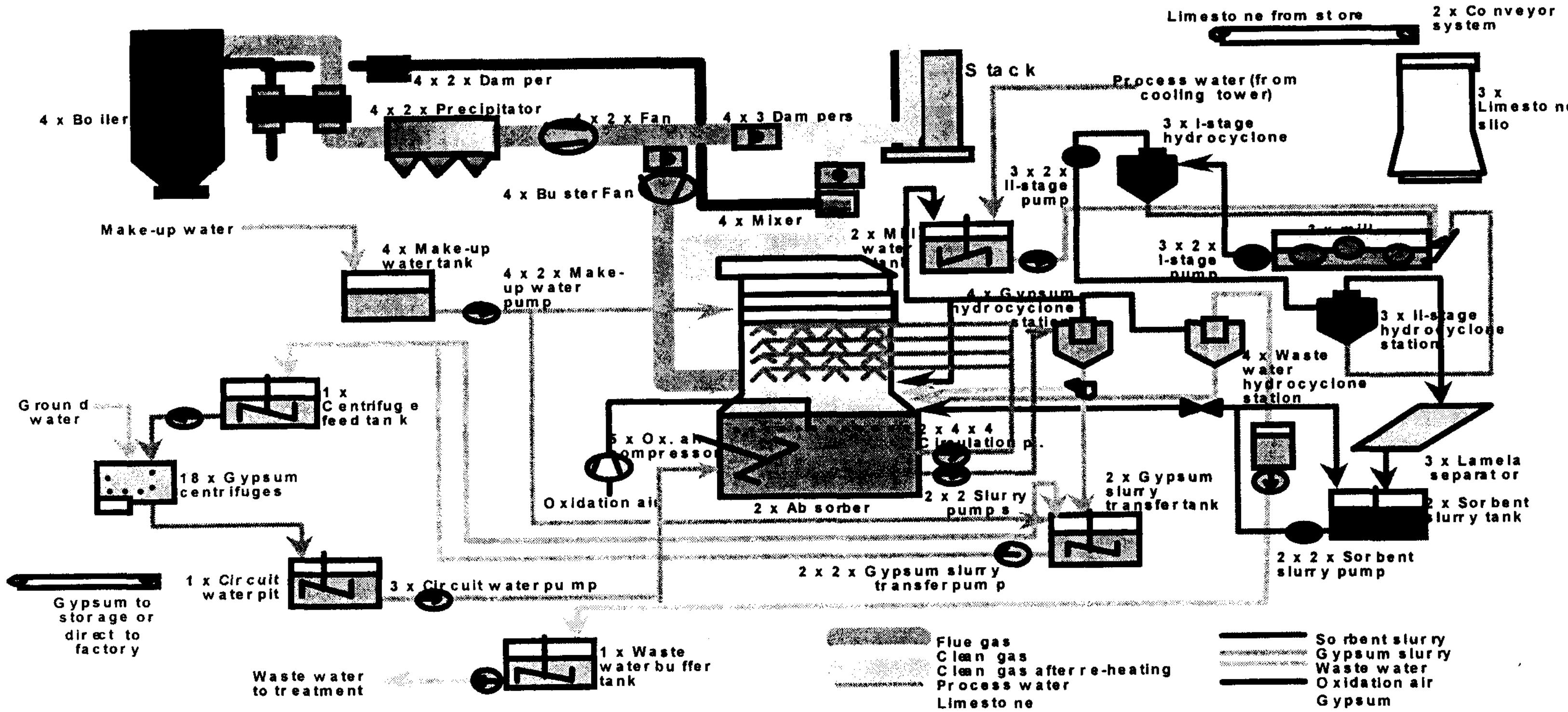

Fig. 2. Scheme FGD unit 8, 10, 11 and 12 Belchatow Power Station

3.3. Visualisation of gas flow

In those tests a spark marked visualisation technique has been used (with burning sawdust particles). Burning sawdust particles having very small inertia are moving along trajectories nearly approaching the flue gas flow movement. This technique enables not only observations of the gas flow but also makes possible camera recording of the observed phenomenon. The character of gas flow i.e. its main direction, recirculation spheres, as well as any flow perturbations due to the inner constructional elements can be easily identified.

The results of visualisation tests are pictures of gas flow inside the model shown on Fig. nos 3 & 4. The tests shown a quite unequal gas flow in the absorber cross-section. There were observed regions with high gas flow velocities as well as regions with back flow of the gas. On the base of visualisation tests it was found that the gas practically flows through a half of the absorber cross-section only when the other half is almost unused. It is the result of unfavourably configured inlet gas duct to the absorber, as shown on Fig. 3.

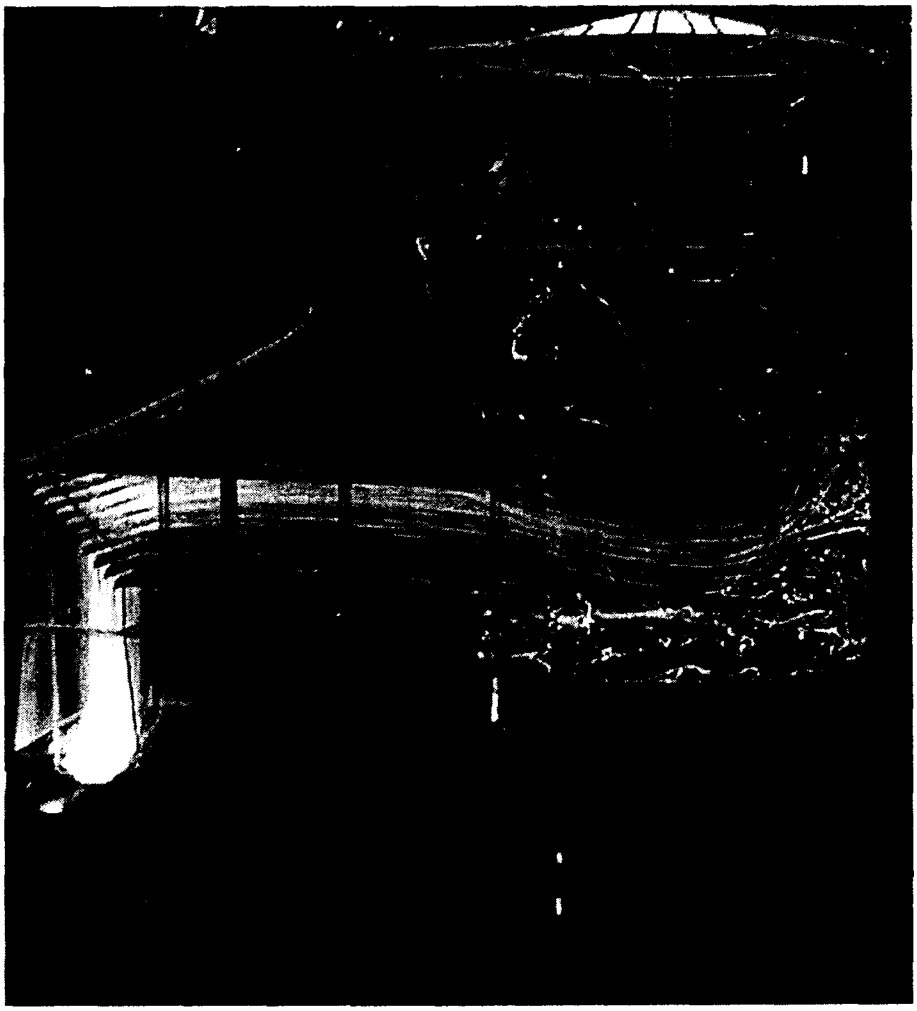

Fig. 3. Visualisation of the gas flow in the FGD absorber model

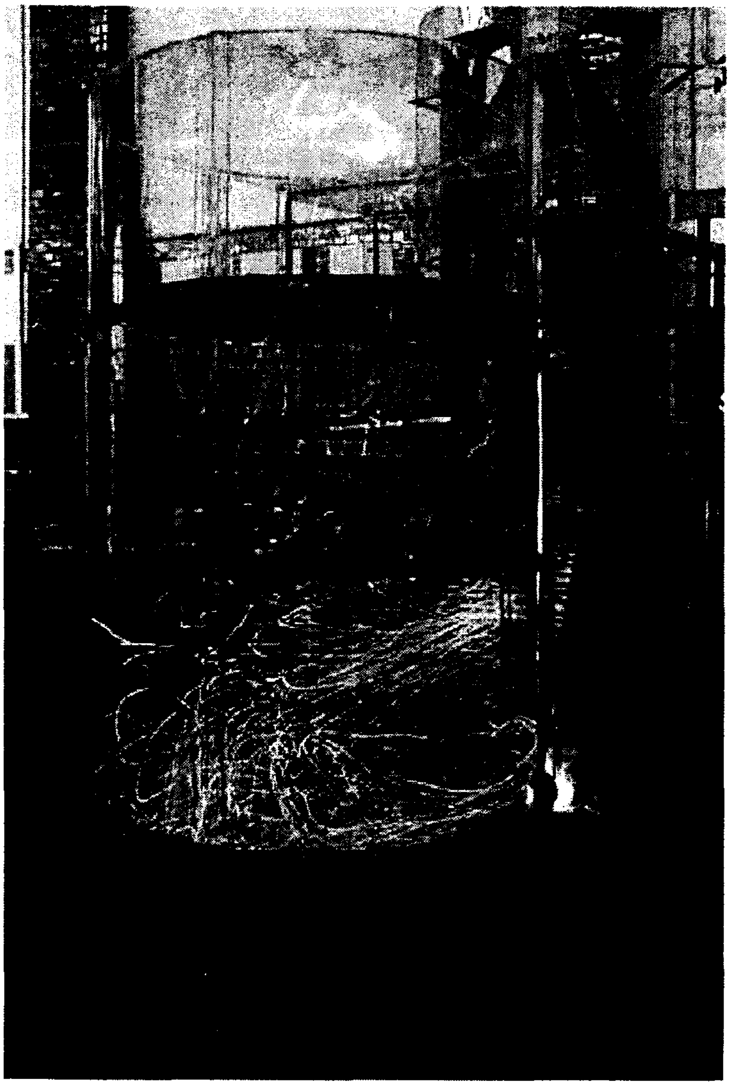

Fig. 4. Visualisation of the gas flow in the bottom part of absorber

4. Conclusions

Aerodynamic studies of FGD absorber gas flow pattern and visualisation of the gas flow makes it possible to evaluate the constructional design concept of the absorber from a aerodynamic point of view and to create a base for optimisation of its operation [4].

Test results of a gas flow character inside an absorber has shown that the commonly used assumptions of homogenous gas flow character in process models are not right.

The unequal gas flow results in unequal gas spraying with slurry. At the same moment, the contact time of a flue gas with slurry in high gas velocity regions is too short to secure a right course of SO_2 process reactions, as the SO_2 removal efficiency depends mainly on the ratio of L/G (liquid/gas) and contact time of liquid slurry with flue gasses.

The increase of absorber SO_2 removal efficiency is possible by modernisation of its spraying nozzle arrangement, implementation of high volume nozzles at high gas velocity regions and low volume nozzles at low gas velocity regions.

1. Jędrusik M., Gostomczyk M.A., Świerczok A., Nowaczewski E. Badania modelowe aerodynamiki reaktora do odsiarczania spalin, Materiały Konferencji Naukowo-Technicznej ENERGETYKA, 2002, 6—8 listopad 2003. — S. 279—284. 2. Gas flow model studies. IGCI Publication No EP-7, January, 1997. 3.

Idelcik J.E.: Aerogidrodinamika technologiczeskich aparatov, Moskva, 1983. 4. Baernthaler K., Ploder S., Weiss Ch., Maier H.: Low cost improvement for Spray Towers of the first generation — FGD Voitsberg 3 / Austria as an example, Austrian Energy & Environment, 15th Annual International Conference, September 14—18, 1998

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ЯКІСТЬ ЕЛЕКТРОЕНЕРГІЇ В ЕЛЕКТРИЧНИХ МЕРЕЖАХ З РОЗПОДІЛЕНИМ ГЕНЕРУВАННЯМ

Decentralized electric power generation is playing a more and more important role in power systems. Decentralized electric power generation or so called distributed generation (DG) can have a significant impact on the power flow and voltage profile in electrical network as well as on power quality indices. This requires a suitable means to analyze the influence of such technologies on the electrical networks. In this paper performance peculiarities of the electrical network including DG are considered.

1. Вступ. Під поняттям “розподілене генерування” розуміють роботу невеликих електричних генераторів, які приєднують або безпосередньо до розподільної мережі, або на стороні споживача, з потужностями, звичайно меншими від 10...15 МВт. Технології розподіленого генерування включають фотоелектричні генератори, вітрові турбіни, мікрогазові турбіни, генератори з двигунами внутрішнього згоряння [1, 2, 5, 7, 9]. Ці технології стрімко розвиваються і займають своє місце на ринку енергії. В Україні теж спостерігається ця тенденція завдяки розвитку енергетичного ринку, економічній привабливості когенеруючих джерел енергії, технологічним досягненням у використанні відновлюваних енергоносіїв. Передумовами розподіленої генерації є постачання споживачів електроенергією за зниженою собівартістю зі зниженими втратами порівняно з традиційним централізованим постачанням. Додатково місцеві ресурси, які включають відновлювані джерела енергії, можуть бути використані. Проте розподілене генерування може мати істотний вплив на режим електричної мережі та якість електроенергії, що важливим є і для споживачів, і для постачальників електроенергії. Цей вплив може бути або позитивним, або негативним, залежно від особливостей електричної мережі та характеристик генераторів [2].

Якість електроенергії стала важливою проблемою за останнє десятиріччя завдяки відчутному збільшенню використання силової електроніки в системах електропостачання споживачів. Впровадження розподіленого генерування може відчутно впливати на цю проблему і, як правило, ускладнює її [3]. Розподілене генерування може покращити рівень напруги у мережі [4, 8]. Під’єднані через інвертори генератори вносять спотворення синусоїдності напруги в мережі. Коливання потужності, яка генерується в мережу деякими електростанціями, наприклад, вітровими і фотоелектричними, може спричинити коливання напруги [8, 10]. З іншого боку, розподілена генерація може покращити надійність електропостачання [10].

У цій статті викладено деякі результати аналізу якості електроенергії в електричних мережах з розподіленою генерацією.

2. Якість електроенергії

2.1. Відхилення напруги. Активна потужність, яку виробляють розподільні генератори, приводить до зменшення притоку активної потужності від електроенергетичної системи і, деякою мірою, стабілізує напругу вузла. Своєю чергою, реактивна потужність, яка генерується або споживається розподіленими генераторами, може викликати збільшення або зниження напруги залежно від