The Latvian Experience and Problems of the Grid Integration of Renewable Energy Sources in the Power System

A. Sauhats, V. Chuvychin, N.Gurov, V. Strelkovs, I.Svalova, A. Svalovs, *Riga Technical University*
O. Linkevics, J. Rivkins, *VAS Latvenergo*

***Abstract*--Paper considers development trends and perspectives for widespread implementation of distributed generation, based on renewable energy sources (RES) in the Baltic States. The main issue of the research is integration of RES into the power grid and electricity markets. Paper provides an overview of legislative statements and main rules, which regulates formal relationships between power producers using RES and network operators. Major problems and barriers that limit intensive development of RES are identified and possible solutions to overcome them are proposed.**

***Index Terms*--renewable energy sources (RES), distributed generation (DG), distributed energy sources (DER), grid and market integration.**

I. INTRODUCTION

The development of distributed generation and renewable electricity generation technologies in 25 years perspective are essential for achieving energy supply effectiveness, security, and commitments to reduce greenhouse gas emission [1],[2]. Tendency of widespread deployment of RES technology is common for the most European and worlds' countries. At the same time philosophy and policy for effective use of the new technology and arrangements depends very much on particular conditions of individual country and geographical area [2], [3]. Determining conditions are: climatic conditions, (water resources, wind velocity, solar activity), availability of generating units and their characteristics, availability of local and imported energy sources, transmission and distribution networks' configuration, parameters of end-users. To justify effectiveness of the DER implementation it is not enough to analyse only economical aspects of profit from selling of energy and cost of generation. The other aspects that have to be considered are: necessity to decrease environmental pollution, to increase power supply reliability, to raise quality of power.

This paper considers specific conditions of DER and RES implementation in the Baltic States region.

II. IMPACT OF CONVENTIONAL CENTRALISED POWER SUPPLY ON DER & RES DEVELOPMENT

Probably nobody seriously think, that DER and RES in the future could totally replace conventional centralised power supply chain. The question is "what is the right balance (proportion) between DER / RES and centralised sources mostly based on fossil fuels? Let's consider this question on example of Baltic power system.

After the restoration of independence in 1991, when most sectors of economy, particularly industry and agriculture had readapted the activities to new market conditions, the power demand and power flows in the system had significantly decreased.

On the other hand, one can notice reallocation of the consumption centers, and necessity for network reinforcement in large cities, where load demand is growing most dynamically.

West regions of all three Baltic States, which include such a big industrial centers as Tallinn, Ventspils, Liepaja and Klaipieda, might face congestion problems in the future in case there would not be improvements of power network and installation of new generating capacities. At the same time, these regions potentially have favourable weather conditions for wind farms operation. Construction of considerable number of such power plants would lead to necessity of network reinforcement.

As another peculiarity of Baltic States, the low density of population, particularly in rural areas should be mentioned. The energy-consuming objects are usually located in nearby area. All these aspects result in long length of the lines, particularly at distribution level, between energy infeed points (generation or HV substations) and the end-user. Consequently, despites the low load, power quality problems becomes usual in rural areas.

Furthermore, in Latvia 500 remote households still remain unconnected to electricity supply, due to high costs of installations (total estimated costs ~4.5 MEUR). Similar problem exist in Lithuania and Estonia. In the cases, when conventional installations or reinforcements are not economically reasonable, possibly RES could provide technically suitable and economically attractive solution. In fact in some areas connection costs are so huge, that isolated system based on wind generator and battery could be a better alternative.

Another significant issue is development of ancillary services (balancing and reserve) market in the Baltic States. It will encourage more predictable power supply and demand, and responsibility of each market participants for scheduled transactions. It's not clear to what extent RES should participate in this market.

Nowadays the level of wholesale power prices in the Baltic

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States does not encourage the development of neither central power plants, nor distributed generation sources. However the structure of power supply in the Baltic electricity market will change significantly in the next 5-10 years as the result of market liberalization and developments in the generation and transmission asset.

The negative impact of various economics sectors, including energy sector on environment has substantially reduced since 1990. About 47% of total electricity demand in Latvia is covered by renewable energy resources, which is much higher than EU target for 2010 – 22.1%. Cogeneration power plants share in Latvia's energy balance is around 24%, which is also higher than EU target for 2010 – 18%. Thus, Latvia has a potential of selling CO_2 emission quotas. Deployment of RES will have minor effect on emissions reduction.

III. Potential Clients of RES

Economically feasible implementations of RES depend on many factors. Each individual case should be studied separately to identify its business attractiveness, taken into account local climatic and wind conditions, availability of engineering infrastructure (for example gas networks), environmental requirements. The main requirement for RES efficient implementation is necessity of potential user:

- Potential consumers (especially households), who are willing connection to electrical network, but who are located in a long distance from the network (high interconnection costs, potential place for installation of autonomous RES, for example wind generator and battery).
- Consumers who would like to increase its security of power supply (who need emergency power source).
- Small dispersed consumers, who are supplied through power network of high capacity rating with high power losses (decentralization / disconnection option).
- Consumers, who plan to increase its power demand, but who could not be satisfied (without substantial distribution investments) due to bottlenecks in the network.
- Consumers, who simultaneously consume electricity, heat and / or cooling (cogeneration / trigeneration).
- Consumers (usually industrial or commercial), who would like to be independent from the centralized power supply and prefer to have their own base-load generator. Such consumers remain connected to central power supply to exchange a surplus (top-up) and deficit (back-up, usually to cover its peak load demand) of power.
- Distribution system operators, who may be interested in enhancement of power quality (especially voltage problems).
- Isolated consumers / energy systems (such as oil derricks, islands, etc.).
- Complicated energy systems, which aims to increase total efficiency of energy supply:
    - Heat supply system with cogeneration (for example, biomass CHP), heat accumulator, electric heating boiler, heat pumps.
    - Power supply system with wind generators and hydro or battery storage technologies.

IV. Comparison of RES Development in The Baltic States

Development of renewable energy sources in each country of the Baltic's was determined by its legislation and promotion schemes. Comparison of figures in Table I show that Latvian legislation was the most favorable for wide deployment of RES.

This superiority of Latvia in development of DER and RES seems to be quite understandable, because Latvia is the only country from the Baltic States that have insufficient capacity (capacity deficit) to cover the demand.

Table I:
Existing Renewable Energy Sources in the Baltic States

	Number of Plants			*Capacity MW*		
	Estonia	Latvia	Lithuania	Estonia	Latvia	Lithuania
Small hydro	18	149	47	3.5	26.2	16.9
Big hydro	-	3	1*	-	1535	100
Wind	2	16	-	2.0	26.9	-
Biogas	-	1	-	-	2	-
Landfill gas	1	1	3	0.8	5.3	0.8
Total	**21**	**170**	**51**	**6.3**	**1595.4**	**117.7**

** Kruonis hydro pump storage plant (800 MW) is not taken into account.*

According to Directive 2001/77/EC [5], Member States shall take appropriate steps to encourage greater consumption of electricity produced from renewable energy sources (RES). Global indicative target for RES (electricity production) is 12% of gross domestic energy consumption in the year 2010, for the European Community the target is 22,1%. National targets (Table II) for power production from renewable energy sources for the Baltic States are fixed in the Treaty of Accession to the European Union of 2003. Each country made obligation to increase its share of electricity production from RES by approximately 5% by the year 2010, however relative to gross electricity consumption of the year 2000 [4].

If we assume the average capacity utilization factor for small hydro and wind plants about 28%, then by the year 2010 each country should build additionally 200-400 MW of RES. Taking into account the size of the systems this goal seems to be very ambitious, but realistic.

Table II:
National targets for power production from renewable sources for the year 2010

Country	*Existing share of RES-E (average in 1999)*	*Target for RES-E 2010 (% of total gross power demand in 2000)*
Estonia	0.2%	5.1%
Latvia	42.4% (including large hydro)	49.3%
Lithuania	3.3%	7%

The role of renewable energy sources has been constantly increasing in the power sector of Latvia. During the last ten years the output of small dispersed RES has grown almost 6 times (Fig. 1).

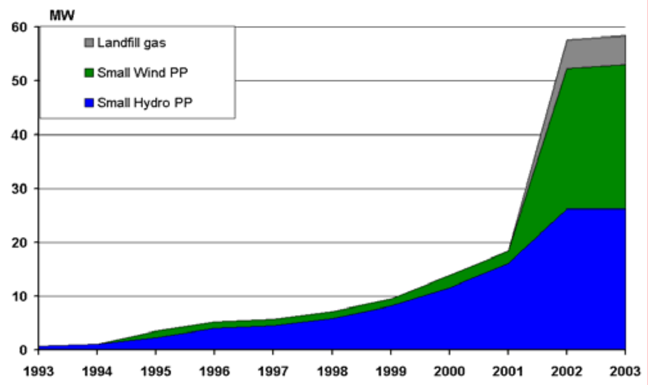

Fig. 1. Development of RES's capacity in Latvia

Practically all RES in Latvia are connected to the power system at medium and low voltage levels, and do not operate as isolated systems. This is the result of influence of promotion schemes, which by incentive tariff encourage RES power producers to sell all power to system operators.

Many wind power projects were proposed, but only several of them were implemented in reality. The biggest wind project in Latvia is the windmill Vēju parks (in the Western part of Latvia) with total installed capacity of 19.8 MW, which consists of 33 generators (were registered as 11 companies Vēju parks 10-20).

Production pattern of Vēju parks is practically unpredictable. In some periods it's operating with nominal capacity, but in some with capacity less than 1 MW.

Also on monthly basis the output of Vēju parks is fluctuating (Fig. 2).

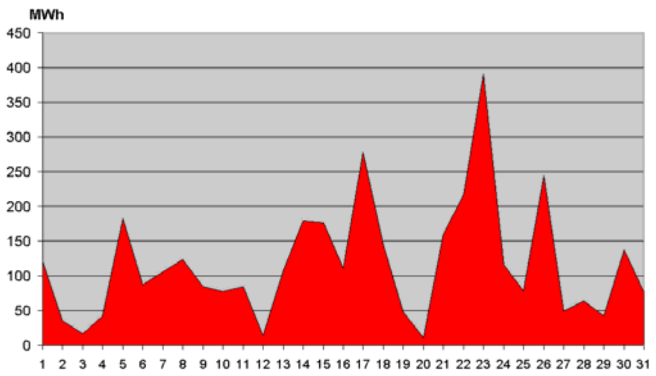

Fig. 2. Output of Vēju parks on monthly basis

Cogeneration and majority of RES are not flexible in terms of capacity availability (Fig. 3). They are energy limited energy sources, which depend from heat demand, water inflow, wind conditions, solar activity, availability of wastes, etc. For the year 2003 capacity utilization factor for RES in Latvia were as following: wind generators – 20%, small hydro – 22%, Landfill gas plant – 38%.

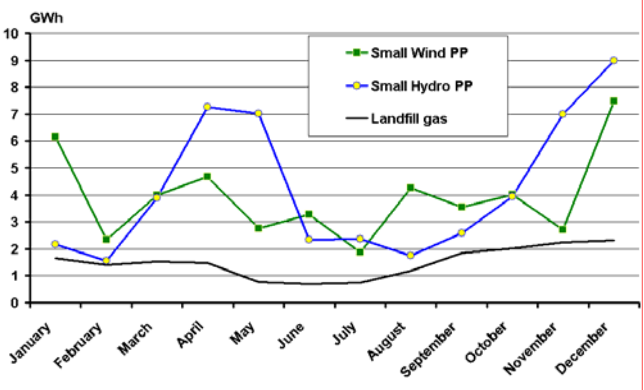

Fig. 3. Monthly output of RES and DERs in Latvia

V. Legislation on RES

Energy Law of Latvia [6] (Article 40) obliged system operators to purchase mandatory a surplus of power (that has been left after consumption for own needs and respects the electricity quality parameters) from renewable energy sources:

- Small Hydro PP with capacity not exceeding 2 MW for the price, that corresponds a double average electricity sales tariff (for the period of 8 years) if its operation was launched before 2003 and at average electricity sales tariff after.
- Power generators, which utilize household wastes or their processing product (biogas) with the capacity not exceeding 7 MW at the price, which corresponds the average electricity sales tariff, if its operation was started before 2008.
- Power generators, which use other renewable energy resources (wind, biomass, solar, etc.) at tariff set by the Regulator.

Currently average electricity sales tariff (without VAT) at distribution level is equal approximately to 48.9 EUR/MWh, while double electricity sales electricity sales tariff is 97.8 EUR/MWh. VAT rate in Latvia, applied to power sector, is 18%.

Nowadays provisions of Energy Law are going to be substituted by the Electricity Market Law [7]. According to the Law, the Public Wholesaler should purchase mandatory all the power from RES and CHP at incentive tariffs, but less than double electricity sales tariff. Both captive (non-eligible) and eligible consumers are obliged to participate in support scheme for RES and CHP, by choosing one of three possible options [7]:

1. Mandatory purchase of power (from the Public Wholesaler) produced by priority generators, in proportion to consumer's power demand.
2. Compensation of Public Wholesaler expenses associated with purchase of power from priority generators.
3. Green certificates.

Electricity Market Law is going to be adopted in the next few months. However, according to the opinion of some experts, the Law is still incomplete. Some of the problems that correspond to the implementation of the mentioned support schemes:

- It could be very problematic or even impossible to implement all three schemes simultaneously.
- Mandatory purchase scheme substantially limits purchasing portfolio of eligible consumers. In addition, there are problems with planning of this portfolio.
- Compensation scheme assumes obligation for the Public Wholesaler to purchase power without any guaranties for sale of this energy, especially at the time, when the market is fully opened. Procedure of calculation of compensation amount was not yet developed.
- Introduction of "green certificate" scheme requires some more efforts and legislative acts to be adopted.

Priority generators, which have received support before the Electricity Market Law comes into force, are regulated by the Energy Law.

Table III shows the list of power plants, which will receive governmental support.

TABLE III:
TOTAL VOLUME FOR INSTALLATION OF CAPACITIES IN 2002-2004 AND SPECIFIC VOLUME FOR EACH TYPE OF ELECTRIC POWER GENERATION IF RENEWABLE ENERGY RESOURCES ARE UTILISED FOR ELECTRIC POWER GENERATION

Type of RES	*Volume for Installation of Capacities, MW*		
	2002	2003	2004
Hydro-power	10	0	0
Wind power	0	1	0
Energy acquired from bio-mass, forestry or peat	10	1	1
Energy from municipal waste or their processed products (biogas)	10	1	1
Energy of sun, sea waves and geothermal energy	0	0	0
Total	**30**	**3**	**2**

In Estonia according to the chapter 59 (Purchase obligation) of Estonian Electricity Market: a network operator shall purchase (mandatory) electricity generated from renewable energy sources from a producer connected to the network of the network operator at a price equal to the weighted average price of electricity sold by the producer specified in subsection 75 (5) of this Act (Narva Power plant regulated price) multiplied by a coefficient of 1.8 (this is about 54.4 EUR/MWh) [3]. Besides in Estonia exists Green Certificate market, which may compensate partly expenses of green power producers. Cogeneration power plants have no this privilege on the price now. Its price should not be higher than the market price basically set by Narva PP. However there are discussions now to change this situation and apply the same coefficient 1.8 as for renewable sources.

In Lithuania power from renewable energy resources is purchased (mandatory) by the market operator at incentive price:

- small hydro power plants (with capacity less than 10 MW) - approximately 57.8 EUR/MWh.
- small wind power plants - approximately 63.6 EUR/MWh.
- biofuel power plants - around 57.8 EUR/MWh.

VI. EXAMPLES OF THE PROBLEMS CAUSED BY RENEWABLE SOURCES IMPLEMENTATION

Implementation of renewable resources cause many new technical and control problems for the power system [8], [9]. This chapter illustrates some problems caused by massive penetration of renewable energy sources.

In the presence of RES in the power system there is a need in analysis of some peculiarities at the stage of planning and control of normal conditions of the power system:

- Taking into account possible problem of reactive power control. Appearance of DC/AC converters can cause excess of reactive power in a network.
- Estimation of impact of RES on frequency control in the power system. Usually RES are not participating in frequency control that put on other generators additional burden.
- Estimation of RES impact on operation stability of the power system.
- Analysis of RES parameters' influence on quality and security of power system operation during normal operational condition. To estimate possibility and application limits for the use of RES for secure control and management of interconnected grids.
- Taking into consideration possible increase of error for the weekly and monthly forecasting of generation with a growth of RES percentage.
- Impact estimation of RES implementation to a structure, operational principles and coordination of protective relaying, automation and control systems for transmission grid.
- Analysis of operation of out-of-step protection in the power system in the presence of RES. Specific parameters and operational conditions of RES can cause specific dynamic characteristics of transients.

A. Example of frequency control in the power system containing wind power

One of the main power quality parameters is power system frequency. Power system frequency control becomes more complicated with penetration of the wind power. The reason of that is instability of wind velocity (Fig. 2). For small percentage of wind power penetration in Latvian power system problem of frequency and power control were not very important. The only problem raised was voltage and reactive power control near the wind park location site. With the growth of wind power penetration frequency control problem becomes more complicated.

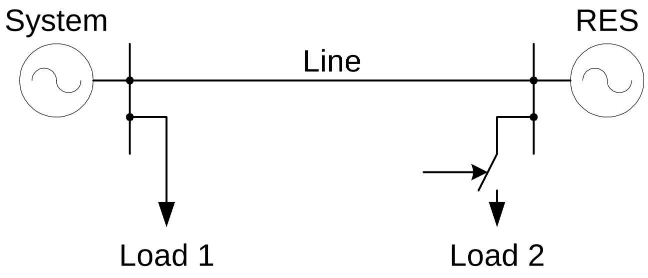

Fig. 4. The structure of analyzed power system

Few modes were suggested to solve the problem. All suggested solutions provide requested frequency control quality to the certain level of wind power penetration. Paper illustrates simulation results for frequency control of joint power system containing considering amount of wind-generated capacity (Fig. 4). Wind Park has asynchronous non-controlled generators that are connected to the main grid via transmission line. Penetration of renewable sources without governors and voltage control devices put on the remaining controlled part of the system additional burden. Generators with governors should cover reserves for the primary and secondary frequency control for all power system. The larger the RES penetration the larger is needed reserves of conventional part of the power system. The second problem associated with the frequency control is possibility of non-uniform distribution of frequency control equipment along the power system. For example, wind parks mostly are concentrated in specific areas. That means that these areas will not be provided with frequency control equipment. It causes possibility of overloading transmission lines connected wind park areas with the rest power system.

Additional features, which should be taken into account during the RES implementation, are necessity to disconnect generators on the underfrequency. Fig. 5 presents results of frequency behavior simulation of emergency situation in the power system caused by connection of additional load (Load 2) to the power system. Created 10% of active power deficiency cause decline of the system frequency. When frequency reaches 48.5 Hz level protection devices disconnect the wind park. The loss of additional 5% of generation causes frequency avalanche in considered system leading to the system blackout.

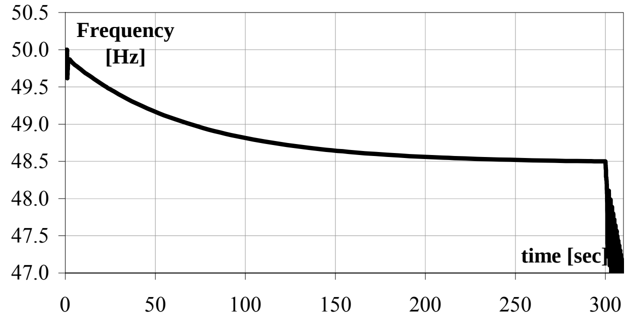

Fig. 5. Results of simulation

B. Features of out-of-step conditions in the presence of RES

Another problem raised due to a massive implementation of RES units is problem of power system synchronism. With many distributed RES units being installed, the impact to the power system stability may be significant. Now RES generators are located close to the distribution network. Loss of the synchronism problems for the generators in the transmission network are well studied [10], [11]. Analysis of out-of-step conditions at the distribution level is the new problem. Many RES units are not designed to stand asynchronous condition. For a full assessment of the overall performance of the distribution network and of the proposed RES the following steady state and transient stability investigations may be undertaken:

- prediction the ability of the generator to recover and remain connected to the network following a fault within the network;
- assessing the interaction of the generators and other rotating plant connected to the network immediately following a fault;
- to ensure that there is little possibility of voltage disturbances due to the failure of the generator to remain in synchronism.

The devices for detection and elimination of asynchronous operation (AO) (out-of-step and first swing protection) are widely accepted in the networks, having the increased risk of the loss of synchronism [15].

Within the framework of this paper the possibility of application of the considered device type is examined further with the purposes of providing a stable operation of networks with distributed energy resources including RES units. The issues include the dynamic stability consideration within the RES, the loss of synchronism example for RES and inspection of the application of an AO detection algorithm.

C. Special features of the distribution networks from the loss of stability point of view

The loss of stability processes in RES are influenced by a number of the new conditions:

- a number of new generation technologies is available and profitable for RES that operate in the same AC distribution network with synchronous generator (SG);
- specific SGs, connected to the distribution network, have small inertia constant. Difference of the generators inertia can play significant role (generation unit sizes, parks of generators);
- operational parameters of relay protection and automation devices of RES units are different from transmission networks and must be taken into account.

The electrical characteristics of synchronous generators, induction generators and electronic inverters are quite different particularly with respect to continued operation under fault condition that may lead to the loss of synchronism.

The specific transient processes are illustrated in the following section taking into account all mentioned above conditions.

D. An example of the loss of synchronism processes' dynamics

The possibility of the appearance of such processes is indicated by simulation results and presented in this paper.

A part of urban distribution system in Latvia with planned increase in RES penetration has been modelled using PSS/E software (Fig. 6). Model includes 10 kV grid, synchronous generators of different sizes (buses 57, 58, 78 and 79) and generating source connected via electronic inverter (bus 54), and connect point to the 110 kV grid.

According to the results of the simulation the fault led to the loss of the synchronism of the generators, which remained in operation.

Fig. 7 shows a change of the angles of rotor for different generators.

We can show further that the loss-of-stability process can be detected with the use of a protection device (PD in Fig. 6), which measures, for example, the current and voltage of a 110/10 kV transformer.

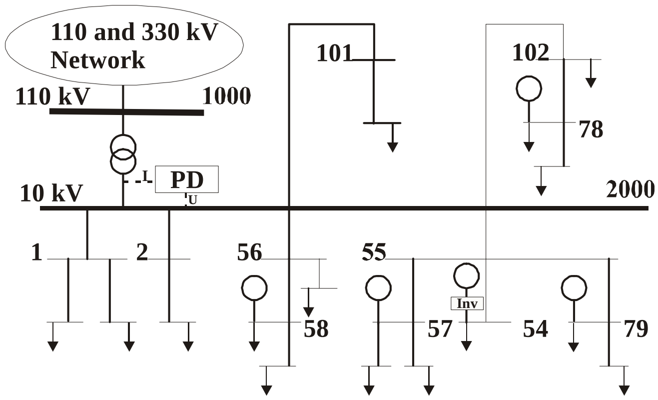

Fig. 6. Diagram of the distribution network model

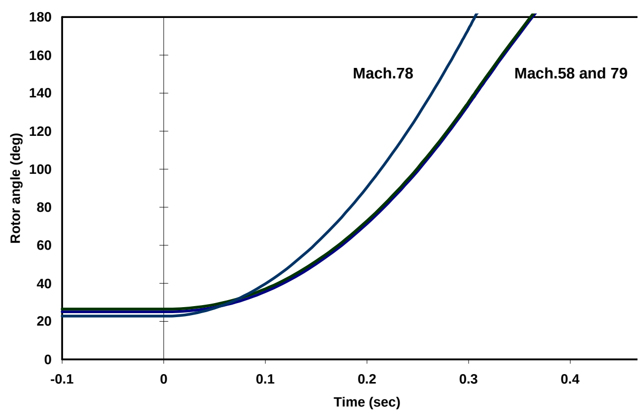

Fig. 7. Rotor angle instability

E. New algorithm for detection of out-of-step condition in the network with RES

The algorithms of devices for elimination and liquidation of unstable processes in the transmission networks are well developed and checked in practice [12], [13], [14]. For example, in the Baltic States (Lithuania, Latvia and Estonia) the local devices of automation, which prevent angular instability in the transmission grid, obtained wide application [15].

The possibility of applying the algorithms, developed by authors for detection of asynchronous conditions in the presence of RES, is the object of the further consideration in this paper.

The operation of the local devices under consideration is based on control of the angle φ between two simulated voltages $\underline{U}_1$ and $\underline{U}_2$ in a two-machine circuit, which corresponds to an angle δ between two non-synchronous equivalent EMF $\underline{E}_1$ and $\underline{E}_2$.

Calculation of the phasors of equivalent EMF $\underline{E}_1$ and $\underline{E}_2$ based on the following two hypotheses:

1. There are known modules of EMF, $\underline{E}_1$ and $\underline{E}_2$ (in power systems the voltages at the network nodes under normal conditions vary within relatively narrow limits) [15].
2. There are known angles of impedances $Z_{1\Sigma}$ and $Z_{2\Sigma}$ (in a network these angles vary within relatively narrow limits).

The proposed Algorithm was tested using an appropriate software package for simulation of dynamic transient processes in the power system. The calculated value of the angle between asynchronous EMF fully corresponds to a real transient process for all the adopted values of modules $\underline{E}_{1\Sigma}$, $\underline{E}_{2\Sigma}$ (simulated angle difference). The results obtained allow for a positive estimation of Algorithm's characteristics in the process of control over the difference of angles between the phasors of asynchronous equivalent EMF in the distribution network.

VII. Conclusions

1. Latvian utility has already positive experience with high share of RES.
2. Problems and limits for massive RES penetration are clear enough.
3. Presented examples show possible solution of the RES implementation problems.

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