The Impact of the Placement of a Renewable Energy Resources on Power Losses in the Electricity Distribution System

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Abstract — **This article discusses the possibility of reducing power losses using renewable energy resources that arise in the operation of distribution systems. Renewable energy resources have become increasingly widespread in recent years. Small photovoltaic panels or wind turbines are being used to generate electricity in households, large power plants such as water, geothermal or solar power plants can replace currently used fossil power plants and can therefore produce electricity without harmful emissions. In the past, centralized production was typical, where the electricity produced in power stations was transmitted via transmission and distribution lines to the point of consumption. Today, electricity is still dominated by centralized power plants, but with renewable energy resources, it is starting to change to decentralized, when electricity is produced in several smaller power stations close to consumption. Households can also produce electricity with small wind turbines or with photovoltaic cells, which can become self-sufficient, respectively, may reduce the take-off from the distribution system, thereby reducing the amount of transmitted electricity through transmission lines. The paper will analyse the impact of the placement of new energy sources in the distribution system on the resulting power losses.**

Keywords: power losses, renewable energy resources

I. Introduction

Renewable energy sources (RES) are in recent years used more and more often. Traditional power plants such as fossil fuel power plants are known environmental burden, they are polluting environment and causes greenhouse effect. On the contrary RES represents so called "green" energy sources. These green sources do not produce any harmful emission during their operation. According to the Paris agreement it is necessary that the global temperature does not increase by more than 2 °C [1]. This goal can be only achieved with more increased usage of RES in near future.

European Union have set a target for year 2020 that 20 % of final energy consumption will be covered by energy produced from RES. The target for year 2030 was increased to 27 % [2].

RES can be divided into categories shown at Fig. 1:

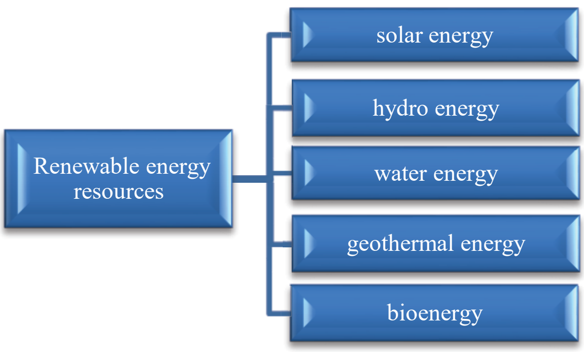

Figure 1 Renewable energy resources [3]

One of the oldest used RES is kinetic energy of water. As an example it is possible to mention watermills, which were used to convert kinetic energy of water in to the mechanical. Hydro power started to be used for electricity generation purpose at the end of the 19th century [4]. However, on the other hand, there are newer sources with higher annual global growth rates such as photovoltaics or wind. The Fig. 2 shows the average annual global growth rates of various energy sources.

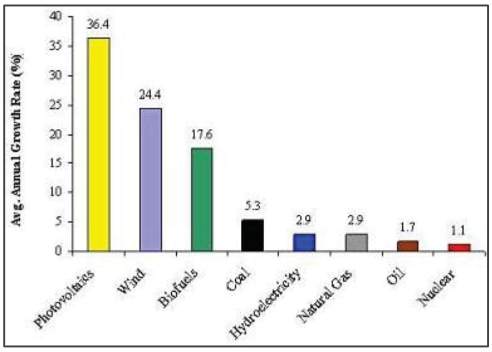

Figure 2 Average annual global growth rates of various energy sources [5]

II. STEADY-STATE MODEL

In order to investigate the impact of the placement of a renewable energy resources on power losses in the electricity distribution system it is necessary to solve steady-state. Steady-state is a condition where the line parameters does not change. At the beginning there are defined parameters, which are applied until the end of calculation.

The Fig. 3 shows the single-line network diagram that was used in the calculations.

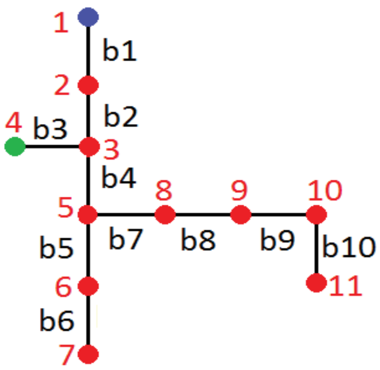

Figure 3 Single-line network diagram

The parameters of the line and the node are shown in the Table 1 and Table 2. It can be seen that examined network has 1 node where electricity is injected. Other nodes represents solely consumption. At node 1, the voltage is 22.8 kV, which characterizes the outgoing voltage of the transformer.

Table 1 Branch parameters

Branch	R (Ω)	X (Ω)
1	0.8100	0.8910
2	1.2600	1.3860
3	2.4150	1.2390
4	0.8100	0.8910
5	1.8036	1.2420
6	2.1042	1.4490
7	1.5000	1.7250
8	0.4830	0.2478
9	2.0010	1.0266
10	4.2780	2.1948

Table 2 Active and reactive power at nodes

	Production		Consumption	
Node	**P (MW)**	**Q (MVAr)**	**P (MW)**	**Q (MVAr)**
1	0	0	0	0
2	1	0	0	0
3	0	0	0	0
4	0	0	0.362	0.119
5	0	0	0	0
6	0	0	0.762	0.238
7	0	0	0.762	0.238
8	0	0	0.762	0.238
9	0	0	0	0
10	0	0	1.086	0.357
11	0	0	0.724	0.238

Newton's iteration method was used to solve steady-state. It is an iteration method which starts with initial value V_0. Calculation runs until the difference between two iteration steps is smaller than a predefined limit ε. The stopping conditions for the iteration is when: $|V_i - V_{i-1}| < \varepsilon$. Absolute value is necessary because final value can be negative.

The Newton method tends to converge very quickly, however, the speed of convergence depends strongly on the chosen initial value V_0 .

The following equations were used in the calculations:

$$\overset{*}{S_i} = \overset{*}{U_i} * \sum_{j=1}^{n} \dot{V}_j * \dot{Y}_{i,j} \tag{1}$$

Where:

S_i – apparent power (VAr)

$$\overset{*}{S_i} = P_i - j * Q_i \quad \text{(VAr)} \tag{2}$$

V_i – voltage in the i-node (V)

V_j – voltage in the j-node (V)

$$\dot{V}_i = V_{ai} - j * V_{ri} \quad \text{(V)} \tag{3}$$

$$\dot{V}_j = V_{aj} - j * V_{rj} \quad \text{(V)} \tag{4}$$

$Y_{i,j}$ – admittance matrix (Ω)

$$\dot{Y}_{i,j} = g_{ij} - j * b_{ij} \quad (\Omega) \tag{5}$$

From (1), (2), (3), (4) and (5) it is possible to state following formula:

$$P_i - j * Q_i = (V_{ai} - j * V_{ri}) * \sum_{j=1}^{n} (V_{aj} - j * V_{rj}) * (g_{ij} - j * b_{ij}) \tag{6}$$

ΔP, ΔQ is possible to calculate with equation 7:

$$\begin{bmatrix}\Delta P \\ \Delta Q\end{bmatrix} = \begin{bmatrix}\frac{\partial P}{\partial V_a} & \frac{\partial P}{\partial V_r} \\ \frac{\partial Q}{\partial V_a} & \frac{\partial Q}{\partial V_a}\end{bmatrix} * \begin{bmatrix}\Delta V_a \\ \Delta V_r\end{bmatrix} \quad (7)$$

Algorithm for solving steady-state with the Newton iteration method [6]:

1. Input data – parameter lines, active and reactive power at nodes, …
2. Initial approach – V_a^0, V_r^0
3. Calculation ΔP, ΔQ
4. ΔP, ΔQ is calculated until the difference is smaller than predefined limit ε.
   a. When the difference is smaller than a predefined limit ε – next step.
   b. When the difference is bigger than a predefined limit ε - it is necessary to calculate the partial derivative of active and reactive power. Using the equation 7 calculate ΔV_a, ΔV_r and correct the initial approaches of voltage. Then continue from the steps 3.
5. Results.

Total active and reactive power losses were calculated with following equations:

$$\Delta P_\Sigma = [V_{a\Sigma}]^T * [G] * [V_{a\Sigma}] + [V_{r\Sigma}]^T * [G] * [V_{r\Sigma}] \text{ (MW)} \quad (8)$$

$$\Delta Q_\Sigma = [V_{a\Sigma}]^T * [B] * [V_{a\Sigma}] + [V_{r\Sigma}]^T * [B] * [V_{r\Sigma}] \text{ (MVAr)} \quad (9)$$

With application of equation 8 and equation 9 were calculated voltages, total active and reactive power losses in steady-state. These values are included in the Table 3.

Table 3 Steady-state

	Voltage (kV)		
node	**Va**	**Vr**	**|(Va + j*Vr)|**
1	22.8	0	22.8
2	22.6082	-0.0851	22.608
3	22.2539	-0.2785	22.256
4	22.2078	-0.2852	22.210
5	22.0443	-0.3929	22.048
6	21.8905	-0.4371	21.895
7	21.8006	-0.4629	21.806
8	21.7952	-0.5341	21.802
9	21.7474	-0.5404	21.754
10	21.5497	-0.5662	21.557
11	21.3798	-0.5882	21.388
Total active power losses (MW)	0.1766		
Total reactive power losses (MVAr)	0.1753		

III. PLACEMENT OF A RENEWABLE RESOURCE INTO THE SYSTEM

With correct placement of new RES in to the power grid it is possible to reduce power losses and improve its parameters. One of these parameters is a voltage in the nodes.

The distribution generation (DG) technologies and their typical module size with RES are the following:

- Small hydro power plant: 25 kW – 1 MW,
- Large hydro power plant: 1 MW – 100 MW,
- Wind power plant: 200 W – 3 MW,
- Solar power plant: 20 W – 100 kW,
- Biomass: 100 kW – 20 MW,
- Geothermal power plant: 5 MW – 100 MW,
- Ocean power plant: 100 kW – 5 MW [7].

The new RES has a same power as existing source, which generate electricity in the grid, so the active power is 1 MW. Table 4. show changes in the voltages at the nodes depending on where is new RES placed. Fig. 4 and Fig. 5 shows the power losses and the voltages changes with new RES.

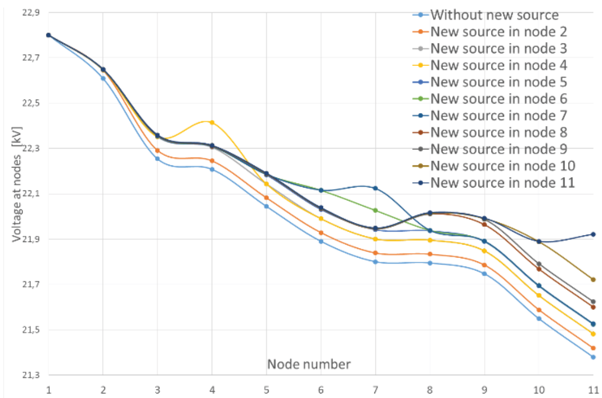

Figure 4 Voltage profile at nodes, when a new source is connected

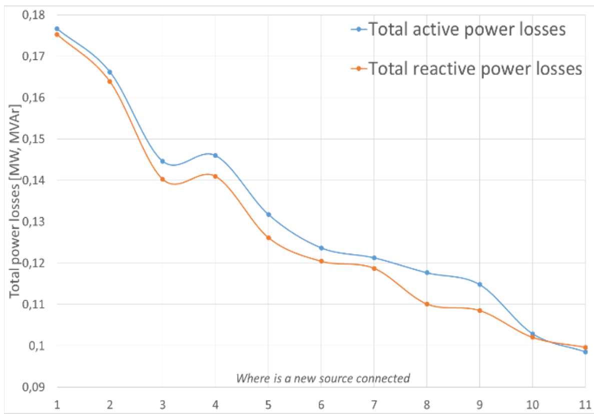

Figure 5 Depending of total power losses to which node is the new renewable source connected

Table 4 Node voltage with new RES

	RES at node:									
	2		3		4		5		6	
node	Ua (kV)	Ur (kV)	Ua (kV)	Ur (kV)	Ua (kV)	Ur (kV)	Ua (kV)	Ur (kV)	Ua (kV)	Ur (kV)
1	22.8	0	22.8	0	22.8	0	22.8	0	22.8	0
2	22.6446	-0.0460	22.6463	-0.0460	22.6462	-0.0460	22.6473	-0.0460	22.6478	-0.0459
3	22.2912	-0.2397	22.3513	-0.1786	22.3511	-0.1787	22.3539	-0.1786	22.3552	-0.1783
4	22.2452	-0.2465	22.3055	-0.1855	22.4136	-0.1310	22.3081	-0.1855	22.3094	-0.1852
5	22.0822	-0.3543	22.1432	-0.2935	22.1430	-0.2936	22.1833	-0.2539	22.1851	-0.2535
6	21.9287	-0.3987	21.9903	-0.3382	21.9901	-0.3382	22.0308	-0.2988	22.1154	-0.2433
7	21.8390	-0.4246	21.9009	-0.3642	21.9007	-0.3643	21.9416	-0.3250	22.0267	-0.2696
8	21.8337	-0.4957	21.8958	-0.4352	21.8956	-0.4353	21.9367	-0.3958	21.9385	-0.3954
9	21.7861	-0.5020	21.8484	-0.4416	21.8482	-0.4417	21.8893	-0.4023	21.8912	-0.4019
10	21.5888	-0.5281	21.6517	-0.4682	21.6515	-0.4683	21.6931	-0.4292	21.6949	-0.4288
11	21.4192	-0.5504	21.4827	-0.4909	21.4825	-0.4910	21.5244	-0.4522	21.5263	-0.4518

	(Continued) RES at node:									
	7		8		9		10		11	
node	Ua (kV)	Ur (kV)	Ua (kV)	Ur (kV)	Ua (kV)	Ur (kV)	Ua (kV)	Ur (kV)	Ua (kV)	Ur (kV)
1	22.8	0	22.8	0	22.8	0	22.8	0	22.8	0
2	22.6479	-0.0459	22.6484	-0.0460	22.6485	-0.0460	22.6492	-0.0457	22.6495	-0.0456
3	22.3556	-0.1783	22.3568	-0.1787	22.3572	-0.1785	22.3589	-0.1779	22.3596	-0.1777
4	22.3098	-0.1851	22.3109	-0.1855	22.3114	-0.1854	22.3131	-0.1848	22.3137	-0.1845
5	22.1857	-0.2534	22.1873	-0.2540	22.1879	-0.2538	22.1903	-0.2529	22.1912	-0.2526
6	22.1163	-0.2432	22.0348	-0.2988	22.0354	-0.2986	22.0378	-0.2978	22.0387	-0.2975
7	22.1237	-0.2051	21.9456	-0.3250	21.9462	-0.3248	21.9487	-0.3240	21.9496	-0.3237
8	21.9391	-0.3953	22.0113	-0.3190	22.0122	-0.3186	22.0159	-0.3173	22.0172	-0.3168
9	21.8917	-0.4018	21.9641	-0.3256	21.9872	-0.3143	21.9912	-0.3130	21.9926	-0.3125
10	21.6955	-0.4287	21.7686	-0.3531	21.7919	-0.3419	21.8888	-0.2952	21.8908	-0.2947
11	21.5268	-0.4516	21.6006	-0.3766	21.6241	-0.3654	21.7219	-0.3190	21.9216	-0.2210

Fig. 5 shown that, loss can be reduced depending on where we place the new RES. The best result is achieved when new RES is placed in to the farthest node. In this case it is node 11. Another explanation of the new RES placement is because in the node 10 and 11 is highest consumption. This means that is not necessary to transport produced electricity far away from new RES, thus power loss caused by transport is lower.

The other parameter is voltage in the nodes. It can be seen, that voltage in the nodes has increased in this case.

IV. CONCLUSION

This article was dealing with total active and reactive loss depending on placement of RES in power grid. In the nearest future, it is expected massive installation of new RES in order to reduce the greenhouse effect. Another reason is that fossil fuel reserves are limited, so it is necessary to replace them with sustainable one.

Other aspect such as quality of electricity, flicker effect, harmonics was not addressed in this article.

It is possible to expand this topic more in more details in future articles. For example, it is possible to take in the account ambient conditions such as sunlight a wind speed. As photovoltaic panels do not produce electricity through whole day and wind speed is not constant as well.

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