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MODELING AND ANALYSIS OF THE EFFECTS OF SYMMETRIC AND ASYMMETRIC LOADS ON 0.38 KV VOLTAGE ELECTRICAL NETWORKS

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Abstract. *The uneven distribution of loads across phases in low-voltage power supply networks significantly affects the quality of electricity, voltage regimes, and power losses. This article presents a comparative analysis of the influence of symmetrical and asymmetrical loads on the network operating mode in a 0.38 kV electrical network, modeled using the DigSILENT PowerFactory software environment. The obtained results showed that under symmetrical loading conditions, voltage deviations remained within permissible limits, and power losses were recorded at minimal levels (0.3-1.5%). In the asymmetric load mode, however, the phase voltage imbalance exceeded the allowable level, resulting in large currents in the neutral wire and active power losses reaching up to 6.29%. The research findings confirm that balancing loads across phases in low-voltage networks is a crucial factor in improving electricity quality and reducing losses.*

Keywords: *0.38 kV power distribution network, symmetric and asymmetric loads, voltage unbalance, power losses, power quality, DigSILENT PowerFactory, synchronous compensator.*

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МОДЕЛИРОВАНИЕ И АНАЛИЗ ВЛИЯНИЯ СИММЕТРИЧНОЙ И НЕСИММЕТРИЧНОЙ НАГРУЗКИ НА ЭЛЕКТРИЧЕСКИЕ СЕТИ НАПРЯЖЕНИЕМ 0,38 КВ

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Аннотация. *Неравномерное распределение нагрузок по фазам в низковольтных сетях электроснабжения существенно влияет на качество электроэнергии, режимы напряжения и потери мощности. В данной статье представлен сравнительный анализ влияния симметричной и несимметричной нагрузки на режим работы электрической сети напряжением 0,38 кВ, смоделированной в программной среде DigSILENT PowerFactory. Полученные результаты показали, что при симметричной нагрузке отклонения напряжения оставались в допустимых пределах, а потери мощности фиксировались на минимальных уровнях (0,3-1,5%). Однако в режиме несимметричной нагрузки несимметрия фазных напряжений превысила допустимый уровень, что привело к возникновению больших токов в нейтральном проводе и потерям активной мощности, достигавшим 6,29%. Результаты исследования подтверждают, что выравнивание нагрузок по фазам в низковольтных сетях является важнейшим фактором повышения качества электроэнергии и снижения потерь.*

Ключевые слова: *распределительная электрическая сеть 0,38 кВ, симметричная и несимметричная нагрузки, несимметрия напряжений, потери мощности, качество электроэнергии, DigSILENT PowerFactory, синхронный компенсатор.*

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0,38 KV KUCHLANISHLI ELEKTR TARMOQLARIGA SIMMETRIK VA NOSIMMETRIK YUKLAMALAR TA'SIRINI MODELLASHTIRISH HAMDA TAHLIL QILISH

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Annotatsiya. *Past kuchlanishli elektr tarmoqlarida yuklamalarning fazalar bo'yicha notekis taqsimlanishi elektr energiyasi sifati, kuchlanish rejimlari va quvvat yo'qotilishiga sezilarli ta'sir ko'rsatadi. Ushbu maqolada DigSILENT PowerFactory dasturiy muhitida modellashtirilgan 0,38 kV kuchlanishli elektr tarmog'ida simmetrik va nosimmetrik yuklamalarning tarmoq ish rejimiga ta'siri qiyosiy tahlil qilingan. Olingan natijalar shuni ko'rsatdiki, simmetrik yuklanish sharoitida kuchlanishning og'ishi ruxsat etilgan me'yorlar doirasida bo'lib, quvvat yo'qotilishi minimal darajada (0,3–1,5%) qayd etildi. Nosimmetrik yuklanish rejimida esa fazalardagi kuchlanish nomutanosibligi ruxsat etilgan me'yordan oshib ketgan, bu esa neytral o'tkazgichda yuqori toklar paydo bo'lishiga va aktiv quvvat yo'qotilishining 6,29 foizgacha yetishiga olib kelgan. Tadqiqot natijalari past kuchlanishli tarmoqlarda fazalar bo'yicha yuklamalarni muvozanatlash elektr energiyasi sifatini yaxshilash va yo'qotilishlarni kamaytirishda muhim omil ekanini tasdiqlaydi.*

Kalit so'zlar: *0,38 kV kuchlanishli elektr tarmog'i, simmetrik va nosimmetrik yuklamalar, kuchlanishning nosimmetrikligi, quvvat isroflari, elektr energiyasi sifati, DigSILENT PowerFactory, sinxron kompensator.*

Introduction

In the current era, the increasing demand for electricity, the growing complexity of consumer composition, and the rising number of modern devices connected to power networks are further elevating the requirements for the reliability of power supply systems and electricity quality. The uneven distribution of loads across phases results in asymmetric modes in the networks, which in turn leads to disruptions in power flows, voltage imbalances, and increased electricity losses [1-5]. These processes are significant as they reduce the system's efficiency and negatively impact the service life and technical condition of equipment. Asymmetric loads pose a serious threat to power supply systems. Therefore, in-depth analysis of network elements in symmetric and asymmetric modes, modeling of power flows and voltage changes in each phase is one of the urgent tasks today [6-8]. Modern computer programs, in particular DigSILENT PowerFactory, allow modeling electrical networks in close proximity to real operating conditions, accurately assessing the influence of loads in each phase, and deeply studying the processes of electricity quality degradation [9,10]. This program has extensive functionality for analyzing networks in symmetrical and asymmetrical states, quantitative assessment of power losses, voltage deviations, and the influence of load in each phase on network stability. In this study, power flows under symmetrical and asymmetrical load conditions of the network were calculated using the DigSILENT PowerFactory software environment, the phase variation of bus voltages was determined, and the difference in active and reactive power losses in the lines was analyzed. The obtained results allow for a deep study of the influence of asymmetrical load on network efficiency, electricity quality, and losses, and serve as a scientific basis for the development of practical recommendations for optimizing power supply systems.

Experimental Research

The study was conducted using the DigSILENT PowerFactory software environment to assess the influence of symmetrical and asymmetrical loads on electrical networks in power supply networks. The methodology includes the stages of creating a mathematical model of the network, distribution of loads by phases, and comparison of power flows in symmetrical and asymmetrical modes[13]. Using the DigSILENT PowerFactory software environment, the scheme was assembled, and the network parameters were introduced step by step, forming the model. For each line, technical parameters such as active resistance, reactive resistance, length, nominal voltage, and nominal current were introduced. Tire connection groups, as well as active power and power coefficients of consumers for each phase, were determined. When modeling the symmetrical mode, the phase loads of all consumers were set equal. In the asymmetrical mode, taking into account the uneven distribution of loads by phases, different load values were assigned to each consumer. Thus, an asymmetric situation that can occur in real operation was analyzed. Calculations were performed using the Balanced Load Flow [11,12] and Unbalanced Load Flow [13-15] functions of the DigSILENT PowerFactory program. In both modes, the active and reactive power at the input and output of the lines was determined, ΔP and ΔQ losses were calculated and compared. The voltage differences between each phase (A, B, C) in symmetrical and asymmetrical modes were determined, and voltage deviations were analyzed. This process allows us to identify the main factors causing the stress imbalance of the asymmetric load. The obtained results make it possible to quantitatively compare symmetrical and asymmetrical modes, assess the degree of increase in power losses, and scientifically substantiate the influence of asymmetrical loads on network stability [16-20]. This methodology provides a practical basis for further research on the optimization of real networks, load balancing, and reduction of electricity losses in the network.

Research results

During the study, in the DigSILENT PowerFactory program for the power supply network, power flows under symmetrical and asymmetrical load conditions, voltages of each phase of each tire, and power losses in lines were analyzed in detail. The calculation results allow for a deeper determination of the network performance characteristic. With the help of the DigSILENT PowerFactory program, the symmetrical network mode was analyzed (Fig. 1).

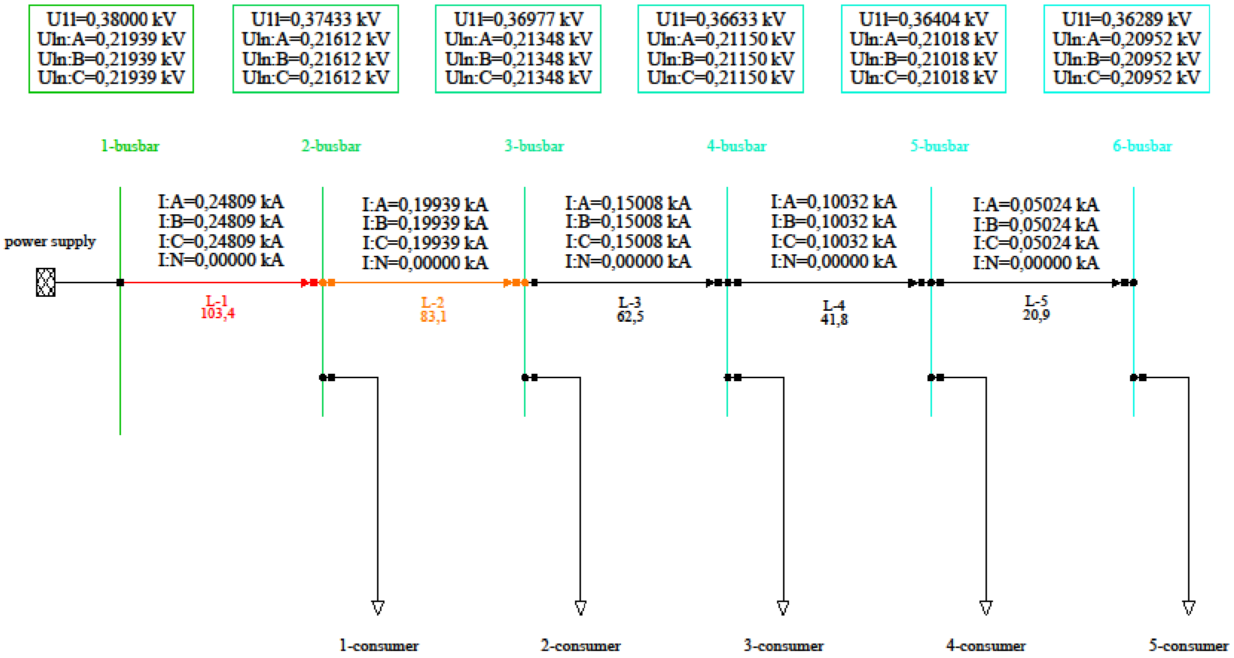

Figure 1. Symmetrical diagram of a 0.38 kV network.

Parameters were entered into each line in the assembled circuit using the DigSILENT PowerFactory program (Table 1).

Table 1

№	Line name	Phase/zero number	Active resistance, Ω	Reactive resistance, Ω	Length, m	Nominal voltage, kV	Nominal current, kA
1	L-1	3/1	0,2542	0,072256	50	1	0,24
2	L-2	3/1	0,2542	0,072256	50	1	0,24
3	L-3	3/1	0,2542	0,072256	50	1	0,24
4	L-4	3/1	0,2542	0,072256	50	1	0,24
5	L-5	3/1	0,2542	0,072256	50	1	0,24

Now each consumer is connected to a consumer consuming the same power (Table 2).

Table 2

№	Consumer name	Active power, kW			Reactive power, kVar			Power factor
		A	B	C	A	B	C	
1	1- consumer	10	10	10	3	3	3	0,95
2	2- consumer	10	10	10	3	3	3	0,95
3	3- consumer	10	10	10	3	3	3	0,95
4	4- consumer	10	10	10	3	3	3	0,95
5	5- consumer	10	10	10	3	3	3	0,95

After each consumer consumed the same active power, the difference in active and reactive power entering and exiting each line was calculated (Table 3).

Table 3

№	Line name	Active input power, kW	Reactive input power, kVar	Active output power, kW	Reactive output power, kVar
1	L-1	155,19	50,78	152,85	50,11
2	L-2	122,85	40,25	121,33	39,82
3	L-3	91,33	29,96	90,47	29,72
4	L-4	60,48	19,86	60,09	19,75
5	L-5	30,09	9,89	30	9,86

The results of power losses in the electrical network are presented in Table 4.

Table 4

№	Element name	ΔP, kW	ΔQ, kVar
1	L-1	2,34	0,67
2	L-2	1,52	0,43
3	L-3	0,86	0,24
4	L-4	0,39	0,11
5	L-5	0,09	0,03
For electrical grid		5,2	1,48

Active power losses on the lines were recorded in the range of 0.3-1.5%, and reactive power losses in the range of 0.3-1.3%. At symmetrical loads, the voltage values in all phases were practically equal, and due to the absence of current flow from the neutral wire, stable network operation was ensured. The voltage drop from bus 1 to bus 6 decreased from 219.39 V to 209.52 V, and the voltage in the network decreased from 380 V to 362.89 V. We can see that these values are within the permissible limits according to GOST, that is, in the range of -5% and 5%. (Table 5).

Table 5

№	Busbar name	Connection group	Voltage, V		
			A	B	C
1	1- busbar	ABC-N	219,39	219,39	219,39
2	2- busbar	ABC-N	216,12	216,12	216,12
3	3- busbar	ABC-N	213,48	213,48	213,48
4	4- busbar	ABC-N	211,5	211,5	211,5
5	5- busbar	ABC-N	210,18	210,18	210,18
6	6- busbar	ABC-N	209,52	209,52	209,52

These results confirm that the network's energy efficiency is high under symmetrical loads, and the voltage quality is optimal in all phases.

Now, using the DigSILENT PowerFactory program, the asymmetric network mode is analyzed (Fig. 2).

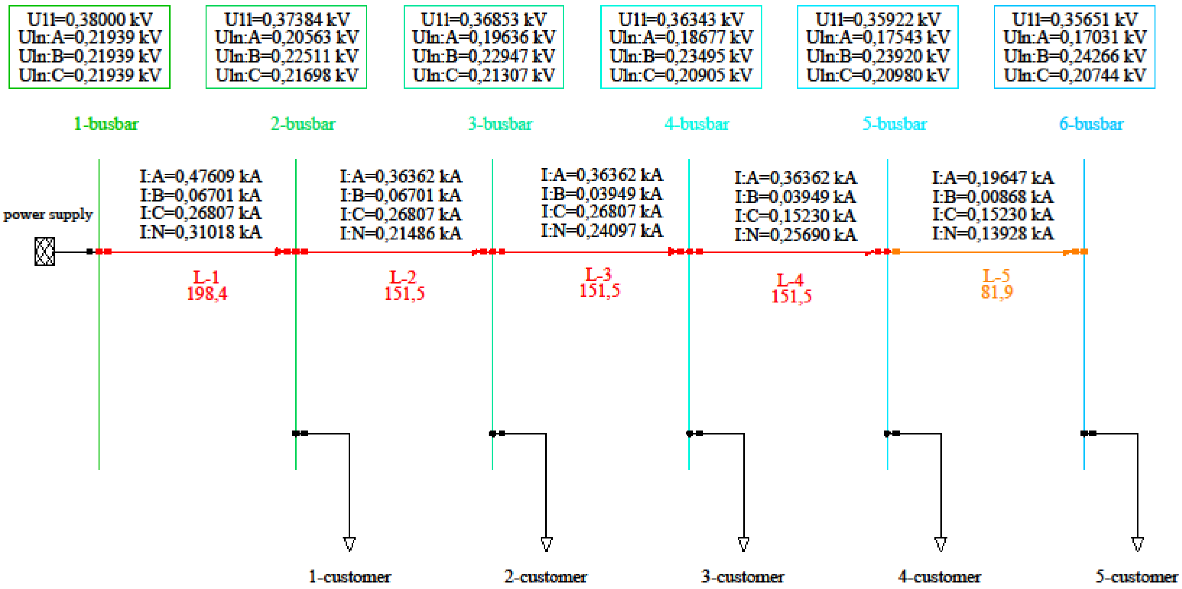

Figure 2. Asymmetrical diagram of a 0.38 kV network.

Parameters were entered into each line in the assembled circuit using the DigSILENT PowerFactory program (Table 6).

Table 6

№	Line name	Phase/zero number	Active resistance, Ω	Reactive resistance, Ω	Length, m	Nominal voltage, kV	Nominal current, kA
1	L-1	3/1	0,2542	0,072256	50	1	0,24
2	L-2	3/1	0,2542	0,072256	50	1	0,24
3	L-3	3/1	0,2542	0,072256	50	1	0,24
4	L-4	3/1	0,2542	0,072256	50	1	0,24
5	L-5	3/1	0,2542	0,072256	50	1	0,24

Now each consumer is connected to a consumer consuming different power (Table 7).

Table 7

№	Consumer name	Active power, kW			Reactive power, kVar			Power factor
		A	B	C	A	B	C	
1	1- consumer	22	0	0	8	0	0	0,95
2	2- consumer	0	6	0	0	2	0	0,95
3	3- consumer	0	0	23	0	0	6	0,95
4	4- consumer	28	7	0	11	2	0	0,95
5	5- consumer	32	2	30	13	1	8	0,95

After each consumer consumed different active power, the difference in active and reactive power entering and exiting each line was calculated (Table 8).

Table 8

№	Line name	Active input power, kW	Reactive input power, kVar	Active output power, kW	Reactive output power, kVar
1	L-1	168,76	54,65	162,47	52,86
2	L-2	140,48	45,63	136,66	44,54
3	L-3	130,66	42,57	126,58	41,41
4	L-4	103,58	33,85	99,91	32,81
5	L-5	65,07	21,34	63,79	20,97

The results of power losses in the electrical network are presented in Table 9.

Table 9

№	Element name	ΔP, kW	ΔQ, kVar
1	L-1	6,29	1,79
2	L-2	3,82	1,09
3	L-3	4,08	1,16
4	L-4	3,67	1,04
5	L-5	1,28	0,37
For electrical grid		19,14	5,45

Active power losses on the lines were recorded in the range of 1.28-6.29%, and reactive power losses in the range of 0.37-1.79%. Active power losses in symmetrical and asymmetrical modes are shown in Fig. 3.

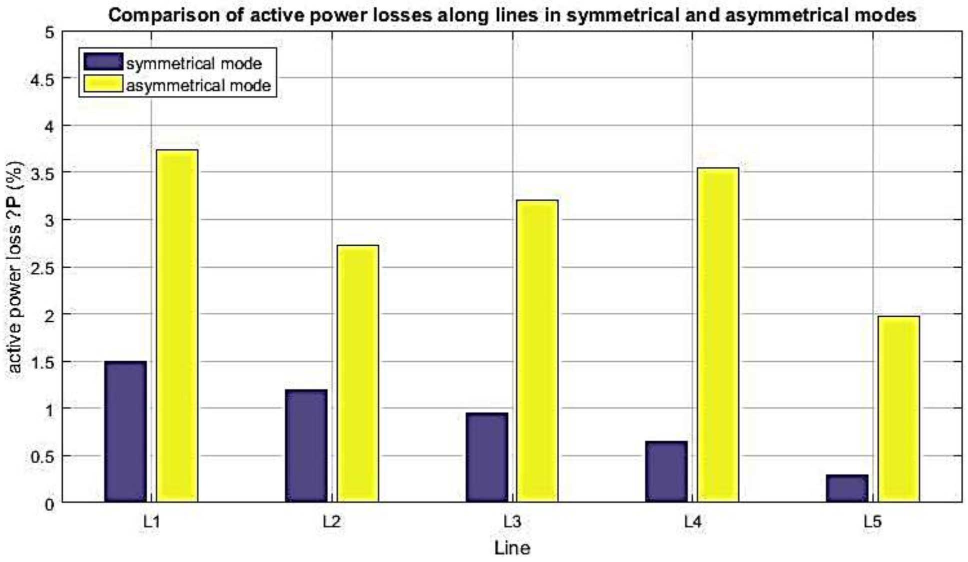

Figure 3.

Reactive power losses in symmetrical and asymmetrical modes are shown in Fig. 4.

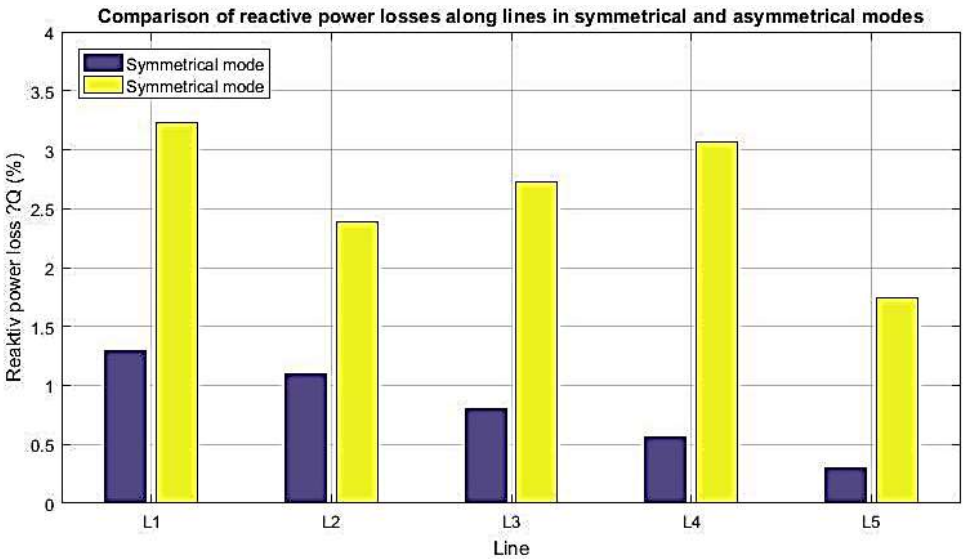

Figure 4.

At asymmetric loads, the voltage values in all phases were different, and due to current flowing through the neutral wire, stable network operation was not ensured. The voltage drop from bus 1 to bus 6 decreased from 219.39 V to 170.31 V, and the voltage in the network decreased from 380 V to 356.51 V. We can see that these values are within the permissible limits according to GOST, that is, in the range of -5% and 5%. Asymmetric loads lead to uneven power distribution across phases. Calculations showed that under asymmetric loads, the stresses in the tires differ significantly (Table 10).

Table 10

№	Busbar name	Connection group	Voltage, V		
			A	B	C
1	1-busbar	ABC-N	219,39	219,39	219,39
2	2- busbar	ABC-N	205,63	225,11	216,98
3	3- busbar	ABC-N	196,36	229,47	213,07
4	4- busbar	ABC-N	186,77	234,95	209,05
5	5- busbar	ABC-N	175,43	239,20	209,80
6	6- busbar	ABC-N	170,31	242,66	207,44

Asymmetric loads, along with an increase in voltage imbalance in busbars and electricity losses in lines, negatively affect the stable operation of the network. Calculations show that:

- With the asymmetry of the power consumed by consumers by phases, excessive heat losses occur in the network elements;
- Increased voltage imbalance, which reduces the quality of operation of electrical equipment;

Active and reactive power losses on the lines increase, and overall power efficiency decreases.

The research results showed that the phase distribution of loads in power supply systems significantly affects the overall network efficiency and voltage regimes. In the case of a symmetrical load, power flows are stable, and losses of active and reactive power on the lines are recorded at a minimum level. This situation corresponds to the normal operating mode of the network, and the equality of voltage in all phases confirms the high quality of electricity. In the symmetrical mode, active power losses are in the range of 0.3-1.5%, and reactive power losses are in the range of 0.3-1.3%, which is the result of the natural influence of line resistance and indicates the absence of excessive losses. The maximum value of the voltage drop across the tires is 9.87 V, which indicates a high level of energy efficiency of the network. In the asymmetric load mode, the results differed significantly.

Next, under asymmetric operating conditions, since the voltage at each phase of each bus exceeds or falls below the permissible ±5% limit, the possibility of bringing the voltages closer to the allowable range by connecting a synchronous compensator to each phase of each bus is considered. Figure 5 presents the schematic of the network with the synchronous compensator connected to Bus 1.

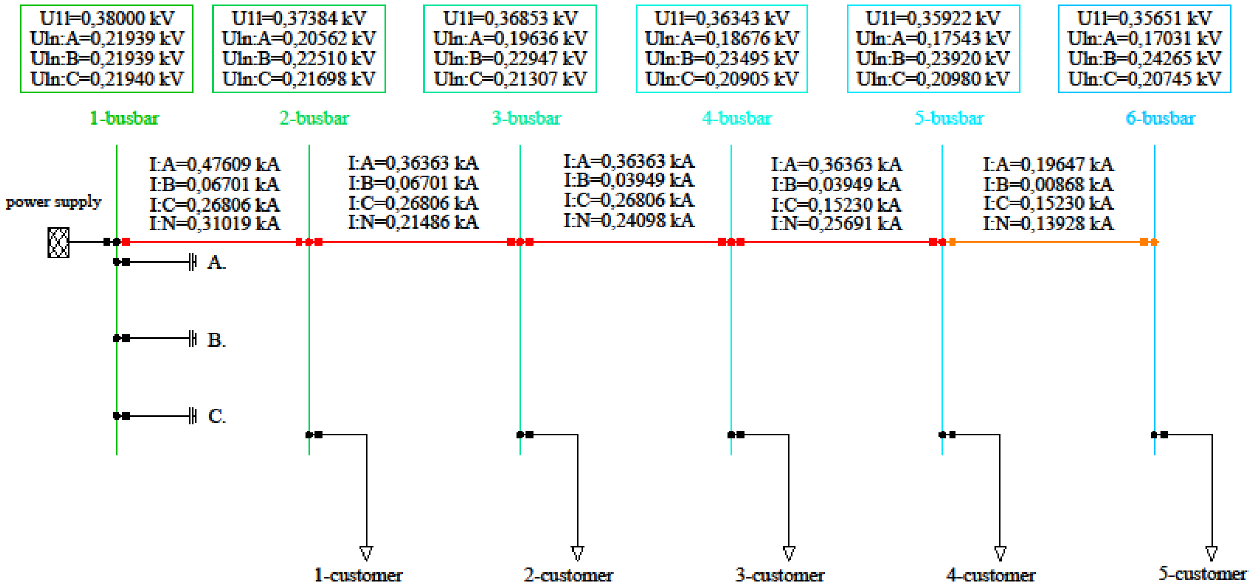

Figure 5. Synchronous compensator connected to Bus 1.

When the synchronous compensator is connected to Bus 1, the voltage values of each phase at each bus are presented in Table 11.

Table 11

№	Busbar name	Connection group	Voltage, V		
			A	B	C
1	1-busbar	ABC-N	219,39	219,39	219,40
2	2- busbar	ABC-N	205,62	225,10	216,98
3	3- busbar	ABC-N	196,36	229,47	213,07
4	4- busbar	ABC-N	186,76	234,95	209,05
5	5- busbar	ABC-N	175,43	239,20	209,80
6	6- busbar	ABC-N	170,31	242,65	207,45

By connecting the synchronous compensator to Bus 2 the voltages of each phase can be seen in Table 12.

Table 12

№	Busbar name	Connection group	Voltage, V		
			A	B	C
1	1-busbar	ABC-N	219,39	219,39	219,40
2	2- busbar	ABC-N	212,69	216,94	220,05
3	3- busbar	ABC-N	203,56	221,58	215,46
4	4- busbar	ABC-N	194,09	227,37	210,71
5	5- busbar	ABC-N	183,11	231,74	210,70
6	6- busbar	ABC-N	178,06	235,39	207,92

Shows the schematic of the network with the synchronous compensator connected to the next bus. The voltage values are presented in Table 13.

Table 13

№	Busbar name	Connection group	Voltage, V		
			A	B	C
1	1-busbar	ABC-N	219,39	219,39	219,40
2	2- busbar	ABC-N	213,07	217,36	219,21
3	3- busbar	ABC-N	211,07	213,96	217,77
4	4- busbar	ABC-N	201,69	220	212,35
5	5- busbar	ABC-N	191,03	224,45	211,65
6	6- busbar	ABC-N	186,02	228,27	208,47

Next, by connecting the synchronous compensator to Bus 4, the voltage values of each phase at each bus can be seen in Table 14.

Table 14

№	Busbar name	Connection group	Voltage, V		
			A	B	C
1	1-busbar	ABC-N	219,39	219,39	219,40
2	2- busbar	ABC-N	213,23	217,84	218,58
3	3- busbar	ABC-N	211,38	214,92	216,47
4	4- busbar	ABC-N	209,10	213,18	214,20
5	5- busbar	ABC-N	198,70	217,66	212,89
6	6- busbar	ABC-N	193,71	221,63	209,38

Shows the schematic of the network with the synchronous compensator connected to Bus 5. The voltage values are presented in Table 15.

Table 15

№	Busbar name	Connection group	Voltage, V		
			A	B	C
1	1-busbar	ABC-N	219,39	219,39	219,40
2	2- busbar	ABC-N	213,80	218,04	217,80
3	3- busbar	ABC-N	212,50	215,34	214,92
4	4- busbar	ABC-N	210,78	213,80	211,88
5	5- busbar	ABC-N	207,91	210,44	213,58
6	6- busbar	ABC-N	202,95	214,54	209,70

By connecting the synchronous compensator to the terminal bus, the changes in voltage values can be observed (Table 16).

Table 16

№	Busbar name	Connection group	Voltage, V		
			A	B	C
1	1-busbar	ABC-N	219,39	219,39	219,40
2	2- busbar	ABC-N	213,94	218,54	217,02
3	3- busbar	ABC-N	212,78	216,35	213,31
4	4- busbar	ABC-N	211,21	215,33	209,43
5	5- busbar	ABC-N	208,44	212,45	210,33
6	6- busbar	ABC-N	210,79	209,24	209,41

Conclusions

In the DigSILENT PowerFactory software environment, power flows, phase voltages, and active and reactive power losses were calculated for a 0.38 kV power distribution network under symmetric and asymmetric load operating conditions. The obtained results allowed for a quantitative assessment of the network's performance characteristics. Under symmetric loading conditions, the active and reactive powers of all consumers were set equally across all phases. Based on the calculations, active and reactive power losses were determined from the difference between line input and output powers. The total active power losses of the network amounted to 5.2 kW, while reactive power losses were 1.48 kVar. For individual lines, active power losses ranged from 0.09 to 2.34 kW, and reactive power losses ranged from 0.03 to 0.67 kVar. In the symmetric mode, the voltages of phases A, B, and C at all buses were identical. Voltage drop across the network decreased from 219.39 V at the first bus to 209.52 V at the terminal bus, resulting in a total voltage drop of 9.87 V, which remained within the ±5% limits specified by GOST standards. Almost no current was observed in the neutral conductor, confirming the stable and balanced operation of the network. Under asymmetric loading conditions, the phase powers of consumers were unevenly distributed. The calculations revealed a significant increase in active power losses along the lines. Total active power losses reached 19.14 kW, and reactive power losses reached 5.45 kVar. For individual lines, active power losses ranged from 1.28 to 6.29 kW, and reactive power losses ranged from 0.37 to 1.79 kVar, which is several times higher than in the symmetric case. Significant differences between phase voltages were observed under asymmetric conditions. While voltages were equal at the first bus, phase voltage differences increased at subsequent buses. At the terminal bus, phase A voltage dropped to 170.31 V, while phase B voltage rose to 242.66 V. These results indicate the intensification of voltage unbalance and the occurrence of current in the neutral conductor under asymmetric loading. To reduce voltage unbalance under asymmetric conditions, a synchronous compensator was modeled connected to various buses of the network. The calculations showed that in all compensator connection scenarios, the phase voltages approached the permissible limits significantly. When the compensator was connected to the initial buses of the network, its effect on voltage unbalance was limited, and voltage differences persisted at distant buses. However, when the compensator was connected to the terminal bus, the differences between phase voltages decreased, and voltages at all buses approached the ±5% permissible range. The obtained results demonstrate that the use of synchronous compensators under asymmetric loading conditions can improve network voltage conditions and enhance power quality.

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