Reduction of Power Losses Using Phase Load Balancing Method in Power Networks

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Abstract **- Power losses in power networks are one of the most important indicators of the economic operations of a power network company and also portray the condition of electric meter reading systems as well as effectiveness of the network. This indicator is the witness of the many problems which are being faced in many countries and requires urgent attention. In many countries it has been observed that there is a very big increase in the actual and relative power losses and at the same time, there is also a reduction of power output in networks. With the world economic crisis at hand, the problem of power loss reduction in power networks has become even more imperative and requires urgent attention of power network companies.**

Reduction of power losses is a complex problem which needs enough expenditure and qualified personnel. My research therefore aimed at picking the most economical method of reduction of power losses with a short cost recovery period. After the analysis of planned methods in power loss reduction in Privolshki regional power distributor, it was found that phase load balancing method was given less attention. My main priority therefore was given to phase load balancing of distributive networks of 0.38 kV. In order to reduce technical power losses by load balancing, some calculations to find the unbalances of loads were executed. Beside that, our method proved that balancing of loads in phases is still necessary especially to distributive power networks.

Index Terms **— method, phase-load balancing, power losses, reduction.**

I. Analysis of Balanced and Unbalanced Loads

The analysis of power loss reduction plan executed by Privolshki regional network company of 0.4 kV in Kazan, Russia showed that there was very little attention given to phase load balancing of 0.4 kV networks, besides the fact that the length of 0.4 kV is significant.

At present time, asymmetrical or unbalanced loads are experienced almost in all 0.4 kV distributive networks. The causes of load imbalances in city networks is usually domestic consumers; in industrial networks – welding units of different capacity; in power lines – large arc furnaces, electric locomotives of alternating current, etc.

A balanced three phase system is characterized by the same module and voltage in all the three phases. During unbalanced operation mode, voltage is not equally distributed in the phases. Unbalanced operation modes in electrical networks are caused by the following reasons:

1. Unequal loads in various phases,
2. Partial operation of lines and other elements in the network,
3. Different line parameters in different phases.

The most common voltage unbalances occur due to imbalance distribution of loads in the phases. In urban and rural networks of 0.38 kV, voltage imbalances are mainly caused by connections of domestic single phase lighting systems and single phase domestic electrical appliances of low power rating. The number of such single phase appliances is too big and it needs equal distribution in phases in order to reduce imbalances in loads [1].

In high voltage networks, load imbalances are caused by powerful single phase electrical equipments and in some cases even three phase electrical equipments with unequal load demands in phases. The main sources of load imbalances in industrial power networks of 0.38 kV are single phase thermal installations, ore – thermal furnaces, induction melting furnaces, resistance furnaces and various heating installations. Welding devices of various capacities are also a merger contributor to imbalances in loads. Traction substations of railway transport electrified on an alternating current are a powerful source of load imbalances as the electric locomotives are single – phase electrical equipments. The load demand of an independent single – phase electrical equipment may now reach several megawatts.

The inequality of parameters of overhead power lines in different phases occurs, for example, due to the absence of transposition supports on power lines or linear cycles. Transposition supports are unreliable and are sources of breakdowns and accidents. The reduction of the number of transposition support on power lines reduces damageability and increases the reliability of power lines.

The occurrence of zero – sequence voltage V_0 and current I_0 as well as negative – sequence voltage V_2 and current I_2 brings about additional losses in power networks which worsens the operation mode and the performance characteristics of a network. Negative and zero – sequence currents (I_2, I_0) increases power losses along the power network branches, while voltage of the same sequences – increases power losses in cross–section area of network branches.

Superposition of V_2 and V_0 leads to angle deviation of voltage in various phases. As a result, the voltage angle may go out of its limits. Superposition of I_2 and I_0 leads to an increase in total currents in different phases of network elements, disturbing heating conditions and reducing the current carrying capacity of wires, cables and other elements.

The balancing of voltage in networks leads to the compensation of zero – sequence and negative – sequence voltage and current. At stable load graph, reduction of systematic imbalances of voltage in networks can be achieved by the balancing of loads in phases by means of switching part of the load from overloaded phases to under loaded phases. Rational redistribution of power load does not always reduce the imbalances factor of voltage to a required level. In such cases, it is necessary to apply special balancing facilities. Common to us are many balancing circuits which largely depend on the load graph.

In order to balance single – phase power loads, circuits containing inductors and capacitors are adopted. To balance two and three – phases with imbalances in power loads, circuits with capacitive batteries of different power ratings and connected in star are applied. Some times special transformers and auto – transformers designed for load balancing are used. It is very important to apply circuits which do not only balance the loads, but also generate reactive power in order to compensate for its loss.

In order to reduce imbalances in four-line urban networks of 0.4 kV, zero-sequence current I_0 and zero-sequence resistance Z_0 in network elements must be reduced. The reduction of I_0 is achieved by redistribution of load. Balancing of loads is achieved by using networks in which all or a number of transformers working in parallel are connected on the lower voltage side of the windings. Reduction of Z_0 is easily attained in overhead lines of 0.38 kV, which are usually installed in areas with little load density. As for cables, Z_0 is reduced by increasing the cross section area of the zero line and should be based on standard technical-economic calculations [2].

II. Load balancing calculation executed for transformer substation of Privolshki Power Network company in Kazan, Russia

The analysis of power losses in distributive power networks of 10 – 0.4 kV together with the technical conditions of power equipments and network loads shows that there is need of the dependence of technical and reported power losses on load balancing of consumers.

Due to the high levels of technical power losses in distributive power networks of Privolshki Power Network Company in Kazan, Russia, the question of implementing load balancing methods becomes a priority and required urgent attention. This statement is proven by the existing levels of power losses in distributive networks of 10 – 0.4 kV. In 2007, reported losses in regional distributive Network Companies like Privolshki alone were 170 million kWh or 18.50% of the output power from the network. The highest relative levels of reported power losses on Privolshki regional distributive network in 2007 for the year 2007 was recorded in Ribno – Slobodski regional substation. The recorded losses were 12.3 million kWh or 23.37% (**Table 2**)

During my research with the aim of defining the influences of non – linear and imbalances of loads on power networks, we picked five transformer substations in which we carried out measurements on energy parameters on the 0.4 kV side (power consumption read by measuring instruments of voltage and current in each overhead phase line of 0.4 kV). Ribno – Slobodski substation of 110/35/10 kV served as our feeder centre.

To define the power losses from unbalanced load distribution on phases, the method used is described below:

Method: The calculation was based on “The instruction on the reduction of technological consumption of power during transmission in power networks of energy systems of Russia [3].”

The power losses in power Transformers (ΔW_T) consists of load losses (ΔW_L) and no-load run losses of Transformers (ΔW_{NL})

$$\Delta W_T = \Delta W_{NL} + \Delta W_L, \quad "kWh" \quad (1)$$

No-load run losses of power Transformers are calculated by:

$$\Delta W_{NL} = \Delta P_{NL} \times T \times 10^{-3}, \quad "kWh" \quad (2)$$

Where ΔP_{NL} – idle run losses of power transformer obtained from the transformer passport “kW”.

T – Transformer’s continuous running time, “h”.

Load power losses are calculated by the formula

$$\Delta W_L = \frac{(W_P^2 + W_Q^2)k_f^2}{V_{EQ}^2 \times T} \times R_{EQ}, \quad "kWh" \quad (3)$$

Where W_P - active energy passing through the transformer windings, “kWh”

W_Q – Reactive energy passing through the transformer windings, “10^3 kWh”

V_{EQ} - Equivalent voltage taken as equal to the nominal voltage V_{nom}

R_{EQ} – Equivalent resistance of winding, “Ohms”

k_f – graph form factor

In many cases, consumers do not information on reactive energy and the graph form factor of load. With the absence of such information, follows the use of a simplified formula;

$$\Delta W_L = 1.63 \times \frac{W_P^2}{V_{nom}^2 T} \times R_{EQ}, \quad "kWh" \quad (4)$$

The equivalent resistance of a power line is calculated by

$$R_{EQ} = \frac{r_O l}{1000}, \quad "\Omega" \quad (5)$$

Where r_0 – the specific line resistance in Ω/km

l - line length, m

Planned and actual power loss reduction by means of elimination of systematic imbalances (unequal distribution of current loads on phases) is calculated by the formula;

$$\delta W = \Delta W(K_{i1} - K_{i2}), \quad "kWh" \quad (6)$$

Where ΔW – power loss in 0.4 kV network with balanced phase loads, calculated using the equation (4)

K_{i1} and K_{i2} – imbalance factors before and after balancing which is found by;

$$K_i = 3 \times \frac{I_A^2 + I_B^2 + I_C^2}{I_A + I_B + I_C} \times (1 + 1.5 \times \frac{R_O}{R_{PH}}) - 1.5 \times \frac{R_O}{R_{PH}}, \quad (7)$$

Where R_O/R_{PH} – is the relation between zero – sequence and phase wire resistances.

I_A, I_B ,I_C – medium phase current values between 17 hours up to 23 hours (not less than three measurements).

When data about load currents is lacking, we consider:

For lines with $R_O/R_{PH} = 1$ $K_i = 1.13$

For lines with $R_O/R_{PH} = 2$ $K_i = 1.2$

Calculated results are shown in the table (**Table 3**)

III. ECONOMIC EFFECTS

The economic effects from the realization of this method was USD 205.6 / month

E = (Technical losses before implementation – Technical losses after implementation) × T

E = (10406 kWh – 6597 kWh) ×0.0543 USD/kWh = 205.6 USD/ month

The economical effect of implementing this method in a year equals 2468.23 USD

T = 0.0543 USD/ kWh – tariffs on electric power for consumers.

The duration of cost recovery equals 8 years.

The calculation of cost recovery and economic effects from this method is composed in the table (**Table 1**)

IV. CONCLUSIONS

Based on the calculations executed, we can conclude that:

1. The value of technical power losses in transformer substations on the chosen 0.4 kV lines with imbalanced load distribution on phases was 2009 kWh. This value confirms that there are high levels of technical power losses in 0.4 kV power networks

2. Realization of this power loss reduction method on the chosen overhead power lines of 0.4 kV allows to reduce technical losses from 2009 kWh to 910 kWh. Implementation of load balancing permits to reduce technical power losses in a short period of time and with minimal costs. It is necessary to note that network companies do not per much attention to load balancing methods especially in 0.4 kV networks.

3. In the analyzed 0.4 kV network, the technical losses in the overhead lines exceeded 30%. The highest technical losses were observed in transformer substation number 9155 as 58%. The reason of high levels of losses was due to the use of A – 16 wire size of the main overhead line. On this portion of the overhead line, we recommended that it be reconstructed and replaced with an A – 25 wire size. The replacement allows reducing the technical losses from 58% to 37%.

TABLE 1: ECONOMIC EFFECT RESULTS
The table shows the cost recovery period for each substation

№	Transformers sub №	Number of consumers	Number of organizations	Medium consumption on 1 client, kWh.	Reduction of technical power losses after implementing load balancing method, kWh.	Technical losses after the implementation of load balancing method * tariff.USD in a year	Expenditure. USD.	Cost recovery period
1	9155	69	2	117.29	2945	1920.14	1070	7 months
2	9337	27	0	150.2	98	63.896		10 years
3	9350	70	1	179.43	1248	813.669		2,5 years
4	9019	160	11	48.97	5646	3681.192	2140	7 months
5	9360	87	1	142.83	3125	2037.5	2044	1 year

TABLE 2: DATA ON REPORTED POWER LOSSES IN PRIVOLSHKI POWER NETWORK COMPANY FOR 2007

Network of Regional Power network of 10-0,4 kV	**Incoming power through transformers**	**Useful out put**	**Actual losses**	
	10^3kWh.	**10^3 kWh.**	**10^3 kWh.**	**%**
1	2	3	4	5
PRIVOLSHKI, overall on networks:	**919823**	**749614**	**170209**	**18,50**
Arski	93699	73425	20274	21,64
Atninski	23846	20742	3104	13,02
Baltatinski	60147	46670	13477	22,41
Vwisokogorski	135129	111339	23790	17,61
Pestrechinski	78003	60304	17699	22,69
Laishenski	44047	34779	9268	21,04
Zelenodolski	342686	289105	53581	15,64
Ribno – Slobodski	52578	40291	12287	23,37
Prigorodski	89688	72959	16729	18,65

TABLE 3: PHASE LOAD BALANCING OF 0.4 kV NETWORK OF PRIVOLSHKI POWER NETWORK

№	1	2			3			4			5	
TS №	9155	9337			9350			9019			9360	
№ Feeder	F-1	F-1	F-2	F-3	F-1	F-2	F-3	F-1	F-2	F-3	F-1	F-3
Consumption recorded by meters, kWh	17836	7140			33664			44565			36538	
Consumption by each feeder, kWh	17836	2380	2231.25	2528.77	8416	5429.68	10587.87	16742.65	12064.56	15757.79	15957.41	8053.27
Wire mark	A-16	AC-35	AC-35	AC-35	AC-35	AC-35	AC-35	A-50	A-50	A-50	A-50	A-50
Line length h(L), km	1,3	1,16	1,28	0,56	0,88	1,32	1,04	1,31	0,7	1,71	1,32	1,7
Currents, A **Ia, A**	62	5	3	8	18	1	19	21	10	30	44	16
Ib, A	20	8	7	1	6	9	11	24	13	11	33	10
Ic, A	24	3	5	8	7	10	9	23	26	23	30	28
Active resistance r_0 Ω/km	1,83763	0,7897	0,7897	0,7897	0,7897	0,7897	0,7897	0,588	0,588	0,588	0,588	0,588
T, h	744	744	744	744	744	744	744	744	744	744	744	744
R_{EQ}, Ω	2,389	0,853	1,011	0,411	1,042	0,695	0,821	0,770	0,412	1,005	0,776	1,211
K_{i1}	1,717	1,371	1,267	1,848	1,692	1,913	1,276	1,008	1,452	1,338	1,071	1,432
K_{i2}	1	1	1	1	1	1	1	1	1	1	1	1
Technical power losses, ΔW, kWh	10406	66	69	36	1011	281	1261	2957	820	3419	2706	1076
Technical power losses after load balancing, W, kWh	7461	25	18	30	700	256	348	24	371	1156	192	465
The effect after phase load balancing, kWh	2945	42	51	5	311	24	913	2933	450	2263	2514	611
ΔW/ consumption	58%	3%	3%	1%	12%	5%	12%	18%	7%	22%	17%	13%
Reduction of tech.losses after phase load balancing/ consumption	17%	2%	2%	0%	4%	0%	9%	18%	4%	14%	16%	8%

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