Evaluation of Unbalanced Load Impacts on Distribution Transformer Performances

Nurul Agung Pratama[1], Yuni Rahmawati[2]

Authors

[1]Electrical Engineering, Engineering Faculty, Universitas Negeri Malang, Indonesia, reiopanter@gmail.com

[2]Smart Power and Advanced Energy System, Batu, Indonesia

Corresponding:
an.afandi@ieee.com

Abstract

Distribution transformers are useful as converters of electrical energy from higher to lower voltage levels. These parts also contribute to feeding energy to consumers. Technically, these transformers are required by many operational constraints. In general, the voltage drop should not exceed 5 % while the current imbalance should not exceed 10 %. These conditions are depended on the system performances. These works are addressed to explore these requirements based on operational power loading. Moreover, these studies are also focused on voltage and current profiles which are assessed to evaluate and maintain the quality of power transformers on the distribution system. Moreover, the evaluation is also concerned with unbalanced load impacts on transformer performances. Results show that voltage and current qualities are not meet the standards of the electricity system. The highest voltage condition is 237 volt while the unbalanced factor is over 2 % for each phase and the highest imbalance factor is covered in 7.73 %. The highest current imbalance factor reaches 41.9 % with various individual unbalance impacts.

Keywords
Current, Evaluation, Load, Unbalance, Voltage, Transformer

1. Introduction

Presently, electricity demand is a major part of the whole society for supporting many activities, such as public, business, industry, and social [1]–[3]. The rapid growth of the population steers up directly the proportional usages to the energy needs. This condition leads to make the energy supply and demand in a sufficient condition every year for the energy stock [4]–[7]. Besides, the development of science encourages discovery technologies that can spur the electrical system developments. Therefore, the electric energy producers are required to provide sustainable energy with good quality [8]–[10]. Also, a reliable electric power system is required by many technical limitations. Moreover, the power system is a collection of power centers interconnected with one another, through transmission or distribution systems to supply to the load centers [9], [11]–[13]. The load centers are concentrated on the distribution substation which typically operates at various voltage levels, and delivers electric energy directly to many consumers. Distribution feeders transport power from the distribution substations to the end consumers. These feeders serve a large number of premises and usually contain many branches.

In particular, the power system is structured by sharing interrelated technical equipment and sections. The system is also equipped with transformers that are used to change the voltage from the intermediate or high levels into low voltage levels [14]–[17]. In another word, a transformer is an electrical device that can move and convert electrical energy from one or more electrical circuits to other electrical circuits through magnetic coupling and based on the principle of electromagnetic induction [18]–[21]. The principle covers voltage change with power relations between primary and secondary parts. Operationally, the transformation conditions of voltage and current values do not always match the specified standard. This measured value is very dependent on the loading conditions of the transformer [16], [22], [23]. Moreover, the transformer is the most crucial part of the electrical distribution system. This part is also the most expensive equipment in an electrical distribution system. A transformer fails unexpectedly, so it should be controlled and monitored daily. The transformer fail is not only affecting the electrical supply but also it will high cost.

In general, transformer performances can be recognized from many technical parameters that illustrate the operational status of the transformer. To cover this status, voltage and current loadings are very important things [24], [25]. The voltage drop should not exceed commonly 5% while the current unbalance should not exceed 10%. Several studies of current and voltage profiles have been worked in many different cases. These studies present and conduct to evaluate and maintain the quality of power distribution through transformer reviews based on operational conditions. These works are also focused on existing load conditions.

2. Transformer Performance

As mentioned before that the transformer is an electrical device which can move and convert electrical energy from one or more electrical circuits to other electrical circuits, through a magnetic coupling, so the performance evaluation is very important issues to know operating characteristics while load demands are fluctuated [15], [20], [21], [24]. This evaluation is also very urgent caused by this equipment is widely used in power system networks covered in all sections of power plants, transmission and distribution systems [14],

[26], [27]. On the distribution system, it is intended to convert electrical energy from the medium voltage into low voltage before channeling to the consumer. In these works, transformers are widely used to change down the 20 kV system to a low voltage system of 380 volts and 220 volts.

In principle, the transformer consists of two coils namely primary and secondary which is explained based on ampere law and faraday law for the energy conversion using a magnetic relation. When the primary coil is connected to an alternating voltage source, the alternating flux will occur on the primary side coil, then the natural flux flows on the transformer core [28], [29]. Furthermore, this flux will impact the coil on the secondary side resulting in the emergence of magnetic flux on the secondary side, so that on the secondary side will arise voltage. The current flows into a transformer depend on the load consumption which is fluctuated every time. Besides, the load demand is also possible in an unbalance condition associated with three-phase systems for R, S, and T phases. Voltage changes and unbalance currents also affect the transformer performance [30]–[33].

Regular measurement is conducted to monitor and maintain every time based on the load changes. This recognition is used to know the higher unbalance current flowing in the neutral carrier because this current leads to the power loss in the system [34]–[38]. By considering this measurement, the intended voltage change is the incompatibility of the transformer output voltage. In these works, it is approached using the following equations.

$$\Delta V = V1 - V2 \tag{1}$$

$$\%\Delta V = (V1 - V2) \times 100\% \tag{2}$$

$$Vrs = \frac{Vr - Vs}{Vs} \tag{3}$$

$$Vst = \frac{Vs - Vt}{Vt} \tag{4}$$

$$Vtr = \frac{Vt - Vr}{Vr} \tag{5}$$

$$Irs = \frac{Ir - Is}{Is} \tag{6}$$

$$Ist = \frac{Is - It}{It} \tag{7}$$

$$Itr = \frac{It - Ir}{Ir} \tag{8}$$

$$Iavg = \frac{Ir + Is + It}{3} \tag{9}$$

$$a = \frac{Ir}{Iavg} \tag{10}$$

$$b = \frac{Is}{Iavg} \tag{11}$$

$$c = \frac{It}{Iavg} \tag{12}$$

$$Ix = \frac{\{|a-1| + |b-1| + |c-1|\}}{3} \tag{13}$$

Where V1 is a measured voltage, V2 is a nominal voltage, ΔV is the voltage change, vt; vr; and vs are phase voltages, It; Ir; and Is are phase currents, Vtr is an unbalance voltage between phase T and phase R, Irs is an unbalance current between phase R and phase S, Iavg is a current average, a; b; and c are unbalanced factors, and Ix is an unbalance current.

3. Method

In these studies, the evaluation is subjected to the field data which is collected directly from Rayon Sumber Pucung Area. The data presents the operational transformers on the distribution system captive in several ports. In detail, these transformers are located at a center load of the South Selorejo Area as illustrated in Figure 1. Moreover, technical data for these transformers are listed in Table 1 covered for 15 ports.

Figure 1 shows that the system structures using a radial topology that is distributed to the load centers. In detail, this system has 27 transformers for supplying load centers. By considering this connection, these studies are concentrated in 15 transformers caused by the possibility of unbalance loads. As given in Table 1, the data cover for 15 transformers covered in codes, powers, and voltages. In these works, the problem is focused on the impacts of unbalanced loads for evaluating transformer performances.

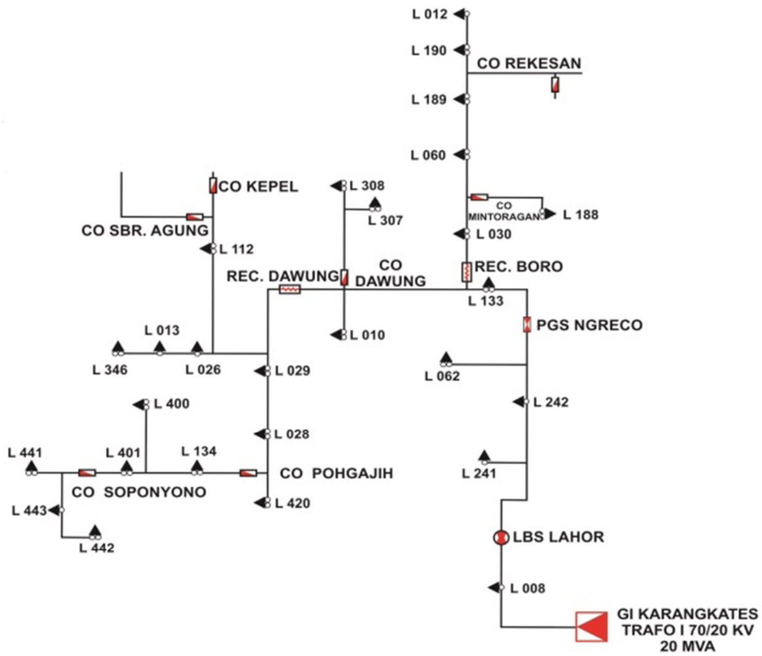

Figure 1. Single line South Selorejo Area

TABLE I
Transformer Information

Transformer		Power	Voltage	
No	Code	(kVA)	High (kV)	Low (V)
1	L0008	100	20	220
2	L0010	200	20	220
3	L0013	100	20	220
4	L0026	100	20	220
5	L0028	160	20	220
6	L0029	200	20	220
7	L0030	100	20	220
8	L0034	100	20	220
9	L0060	100	20	220
10	L0062	160	20	220
11	L0112	160	20	220
12	L0133	160	20	220
13	L0134	160	20	220
14	L0188	160	20	220
15	L0189	100	20	220

In particular, the evaluation conducts several steps for determining technical parameters that are used to perform transformers. The first step is to process the data of the measurement of voltage followed by current measurement results. Thus, to determine the profile value of each transformer, the evaluation is focused on the unbalance calculation. Finally, data is processed for determining numerical and graphical results.

4. Result

As mentioned before that the quality of voltage and current can be used to evaluating the status of transformer performances. From the measurement and analysis, several distribution transformer units are performed in technical parameters to show the balance problem. By considering Figure 1 and Table I, the measuring results are listed in Table II. This table shows the power demand, current, and voltage conditions of the transformer. From Table II, it is known that each phase has different values for voltages and currents of R, S, and T phases.

TABLE III
Measuring Data of Transformer

No	Load		Voltage (kV)			Current (A)		
	(kVA)	(%)	R	S	T	R	S	T
1	40.12	41	227	228	225	49	67	61
2	57.41	29	221	225	222	118	84	56
3	2.85	3	239	236	236	5	5	2
4	56.95	57	227	230	226	61	98	91
5	74.39	47	225	224	228	118	125	87
6	118.87	60	224	226	223	177	166	187
7	56.49	57	230	229	230	83	87	76
8	68.63	69	227	226	229	97	110	95
9	49.09	50	221	223	219	65	85	72
10	87.18	55	220	220	222	106	149	140
11	41.81	27	230	227	228	71	58	54
12	56.01	36	231	228	229	97	60	87
13	119.66	75	237	236	234	166	146	196
14	78.53	50	231	234	233	157	90	91
15	62.21	63	229	232	230	94	100	76

TABLE IIII
Transformer Voltage Evaluations

No	Phase Fluctuation (%)			Phase to phase Unbalance (%)			Unbalance Factor (%)
	R	S	T	R-S	S-T	T-R	
1	3.00	4.00	2.00	0.00	1.00	-1.00	3.03
2	0.00	2.00	1.00	-2.00	1.00	0.00	1.21
3	9.00	7.00	7.00	1.00	0.00	-1.00	7.73
4	3.00	5.00	3.00	-1.00	2.00	0.00	3.48
5	2.00	2.00	4.00	0.00	-2.00	1.00	2.58
6	2.00	3.00	1.00	-1.00	1.00	0.00	1.97
7	5.00	4.00	5.00	0.00	0.00	0.00	4.39
8	3.00	3.00	4.00	0.00	-1.00	1.00	3.33
9	0.00	1.00	0.00	-1.00	2.00	-1.00	0.45
10	0.00	0.00	1.00	0.00	-1.00	1.00	0.30
11	5.00	3.00	4.00	1.00	0.00	-1.00	3.79
12	5.00	4.00	4.00	1.00	0.00	-1.00	4.24
13	8.00	7.00	6.00	0.00	1.00	-1.00	7.12
14	5.00	6.00	6.00	-1.00	0.00	1.00	5.76
15	4.00	5.00	5.00	-1.00	1.00	0.00	4.70

TABLE IVV
Unbalance Current Evaluation

No	Phase to phase unbalance (%)			Average (A)	Unbalance Factor (%)
	R-S	S-T	T-R		
1	-27.00	10.00	24.00	59.0	14.9
2	40.00	50.00	-53.00	86.0	14.3
3	0.00	150.00	-60.00	4.0	41.9
4	-38.00	8.00	49.00	83.3	20.9
5	-6.00	44.00	-26.00	110.0	20.7
6	7.00	-11.00	6.00	176.7	8.0
7	-5.00	14.00	-8.00	82.0	8.5
8	-12.00	16.00	-2.00	100.7	11.2
9	-24.00	18.00	11.00	74.0	15.9
10	-29.00	6.00	32.00	131.7	15.5
11	22.00	7.00	-24.00	61.0	8.9
12	62.00	-31.00	-10.00	81.3	28.7
13	14.00	-26.00	18.00	169.3	19.0
14	74.00	-1.00	-42.00	112.7	26.9
15	-6.00	32.00	-19.00	90.0	16.3

Refer to Table II, the result of the analysis in these studies are given in the following tables for the unbalance impacts. Table III shows the results of the voltage evaluation on the fluctuation values and unbalance voltage conditions. From this table, it is also known that all transformer has overvoltage conditions compared to the nominal voltages. Besides, this table also indicates that the voltage of R; S; and T phases are stayed on unbalancing situations with higher factors. Other results are detailed in Table IV for the unbalance current evaluations of the transformers. The highest voltage change value occurs in a transformer number 3 for all phases. the R phase has a change value of 9%, and fluctuation in 7% belongs S and T phases. Besides, transformer number 13 also has the highest voltage change for the R phase in 7%.

TABLE V
Power Loss Evaluation

No	Demand (kVA)		Power Loss		
	Average	Load	Loss factor	Loss load factor	Total loss (kW)
1	24.94	40.12	0.6	0.5	0.25
2	45.99	57.41	0.8	0.7	0.39
3	2.60	2.85	0.9	0.9	0.21
4	39.09	56.95	0.7	0.5	0.35
5	48.51	74.39	0.7	0.5	0.40
6	80.99	118.87	0.7	0.5	0.62
7	39.01	56.49	0.7	0.5	0.35
8	38.77	68.63	0.6	0.4	0.39
9	30.91	49.09	0.6	0.5	0.29
10	58.23	87.18	0.7	0.5	0.47
11	33.98	41.81	0.8	0.7	0.33
12	39.99	56.01	0.7	0.6	0.35
13	98.78	119.66	0.8	0.7	0.91
14	50.00	78.53	0.6	0.5	0.29
15	42.78	62.21	0.7	0.5	0.40

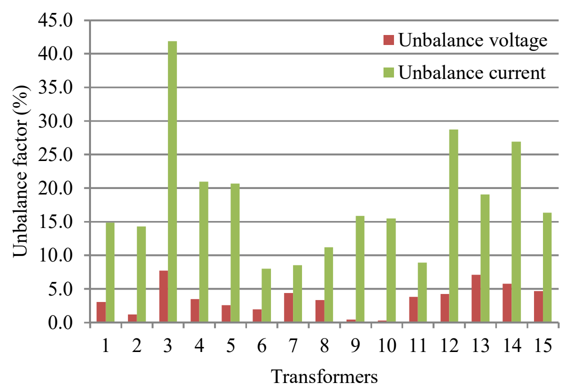

Figure 2. Unbalance factor status

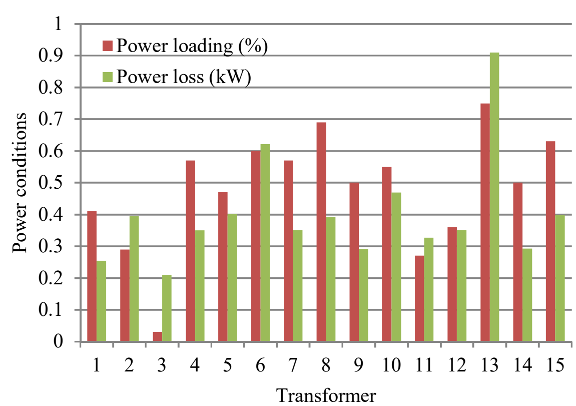

Figure 3. Power usage status

By considering the three-phase of the distribution system, the transformers are connected in the three types. Technically, these transformers also take three-phase loads for each phase in R; S; and T. The intended unbalance results are performed indifference for each phase pair as detailed Table IV. This table shows the calculation results of currents on all phases of R; S; and T. Based on these results, many transformers have not matched the standard of 10%. On the hands, all transformers are operated in unbalance conditions which are penetrated by high unbalance factors for the current flows. As provided in Table IV, there are only transformers 6 and 7 lower. By considering unbalance current evaluations, the higher percentage of these unbalances transformers are 3,4,5,12, 14. In particular, 41.9 % of the unbalance factor belongs to Transformer 3. Moreover, the unbalance impacts are performed in Figure 2 and Figure 3 for the voltage, current, and power status.

5. Conclusion

These studies are subjected to evaluate the unbalance load impacts on transformer performances. From the calculation and analysis of the quality of voltage and current values, the 15 transformers have unbalanced performances as affected by unbalanced loads. It means that the transformers are not meet the unbalance standard for the voltage and current values. In detail, individual performances of the transformer also indicate similar results of the unbalance values with various factors. By considering these works, the quality of transformers on the distribution system needs to maintain regularly. Form these studies, reconfiguration of the load connected to the transformer is recommended for the future works. Besides, distributed load portions of each phase are also interested in the next topic.

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