Comparison of Effect Efficiency and Voltage Regulation Between Three-Phase Transformer Winding Connections

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ABSTRACT

A transformer is an important device in electrical processes, as we know static electricity that involves magnetically coupled coils to increase or decrease the voltage. In three-phase transformer, there are various winding connections such as delta-delta (Δ, Δ), wye-wye (Y, Y), wye-delta (Y, Δ), delta-wye (Δ, Y), zig-zag (Z, Z), etc. And of the many often used connection are Yy0, Yd11, Dd0, and Dy5. From these various connections, each connection has different efficiency, losses, and voltage regulation. If they are connected with resistive, inductive, or capacitive loads. This paper method has discussed a transformer connection used are Yy0, Dd0, Yd11, and Dy5 in Laboratory Konversi Energi USU to see how the influence of load changes, on voltage regulation Where a state of balance load using are resistive, inductive, capacitive, and RLC combination. The result analysis of the experiment show, the best efficiency is at Dd0 connection, when loaded condition using capacitive is average 97.87%, and the best voltage regulation is obtained at Dy5, when loaded condition using resistive is average 28.35%

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1. INTRODUCTION

Common the electric power system consists of generators, substations, transmission lines, and loads. In the distribution of electrical energy, the distance traveled from the generator to the consumer is usually quite far. So that, losses of the transmission line will be large. To overcome this, a transformer is used to be installed on the transmission line with a certain distance. Therefore, the transformer is very important in transmission, distribution, and utilization of alternating current (AC) power.

Three-phase transformer is designed to have all six windings on a common magnetic core. For economic reasons, a common magnetic core can also be either a core type or a shell type [1]. Due to the distribution of AC electrical energy to other equipment, through a magnetic coupling that can be increased and decrease the voltage. Therefore, a transformer must be reduced to minimum losses. So, that electrical processes to consumer energy can be as much as possible. Transformer can be divided into one-phase transformer and three-phase transformer. Various entanglement connections such as delta (Δ), wye (Y), interconnected star or zigzag (Z), etc. A three-phase transformer three primary winding and three secondary windings mounted on a core and the windings are connected internally[2][3], cause behaviour of transformers can be considered by assuming it to have an equivalent ideal transformer[4].

From the research discussed next, it can be concluded: Z. Tang [5] has simple that similarity calculation method is the core Transformers to verify many influence factors, such as voltage regulation. If the secondary voltage changes under the load, then the regulation is performed with an alternating magnetic flux will will affect the voltage curves [6]. After that, usually the electricity on the transformer is supplied by the generator in unbalanced load condition is Y_d connected load[7].

One disorder from transformer is that often occurs interference overcurrent, caused by an overload condition. whereas overload is a condition when the load is carried exceed the capacity of the transformer alone. Overheating condition or overload can cause damage to the transformer. Peak oil temperature, ambient temperature, load (current), etc. can be combined to find out the temperature and set the conditions temperature of the transformer [8]–[12]. Our experiment has limited by using the Fourier transform for accurate approximation of the hysteresis characteristics, and magnetization model that the magnetic field strength produced to the variation of the magnetic flux density[13][14]. This research analyzed the effect of efficiency and voltage regulation between three-phase transformer to know a best performance on various windings.

2. RESEARCH METHOD

The research experiment was conducted at the Laboratory Konversi Energi, Faculty of Engineering, Departement of Electrical Engineering, Universitas Sumatera Utara, with use a three-phase transformer with a capacity of 2 kVA. The steps are conducted:

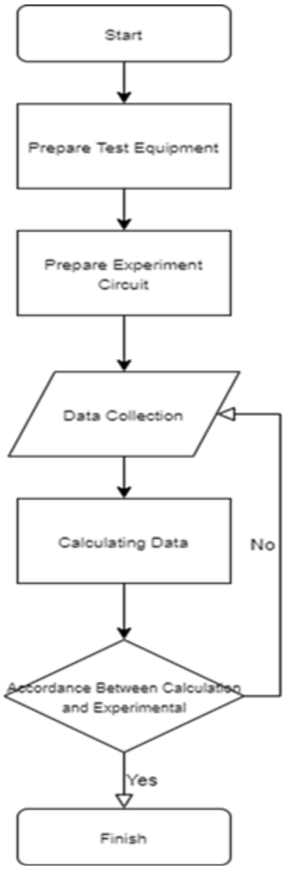


Figure 1. Flowchart of the experiment

This method discusses a transformer connection used are Y_{y0}, D_{d0}, Y_{d11}, and D_{y5}. To be able to see how the influence of load changes, on voltage regulation and efficiency of the three-phase transformer, the first step, we will get the output voltage V2 with the input voltage V1 on the 220 Volt transformer with the no-load experiment.

While the load experiment, the second step, connections tested is same, in each connection in a balanced state. The load used in the experiment is resistive load, inductive load and capacitive load which will be connected with variations of the experiment, namely the experiment is loaded with 3 resistive loads, the experiment is loaded with 3 inductive loads, the experiment is loaded with 3 capacitive loads and the experiment is loaded with a combination of the negative load, inductive and capacitive will then be tested with the input voltage on the 220 Volt transformer. Then from the no-load and load data, we can find the voltage regulation and the efficiency of the transformer in each winding connection[15]. Therefore, these are applied for other groups. in the case of the V1-connected transformer, three-phase unloaded deteriorates, when a phase which has a large power sources output of the V1-connected transformer is connected to the phase[16].

Data obtained is then analyzed with the experiment, to perform calculations. The power output of the transformer can be calculated by few equations.

$$I_L = I_{ph} = I_R = I_S = I_T \quad (1)$$

$$V_{L-L} = V_{FL} = V_2 \quad (2)$$

$$P_{Out} = \sqrt{3}\, V_{L-L}\ I_{L-L}\ Cos\ \emptyset \quad (3)$$

$$\eta = \frac{P_{Out}}{P_{In}}\ x\ 100\% \quad (4)$$

$$\%VR = \frac{V_{NL}-V_{FL}}{V_{NL}}\ x\ 100\% \quad (5)$$

Where I_L, I_{ph}, I_R, I_S, I_T, - current in line, phase, R,S,T, and V_{L-L}, V_{FL}, V_2, V_{NL} – voltages line in line and full load, no-load. The equation (1) - (5) is used to find the load resistive, inductive, capacitive. RLC combination was obtained by ratio power per phase and calculated P_{total} [2].

$$P_R = \frac{V_{ph}}{\sqrt{3}}\ I_R\ Cos\ \emptyset = \frac{V_{L-L}}{\sqrt{3}}\ I_R\ Cos\ \emptyset \quad (6)$$

$$P_S = \frac{V_{ph}}{\sqrt{3}}\ I_S\ Cos\ \emptyset = \frac{V_{L-L}}{\sqrt{3}}\ I_S\ Cos\ \emptyset \quad (7)$$

$$P_T = \frac{V_{ph}}{\sqrt{3}}\ I_T\ Cos\ \emptyset = \frac{V_{L-L}}{\sqrt{3}}\ I_T\ Cos\ \emptyset \quad (8)$$

$$P_{Total} = P_R + P_S + P_T \quad (9)$$

Table 1. Experimental equipment

List Equipment	Description	Quantity
Three-phase transformer	Primer: 36,7 – 63,5 Volt ; 5,3 Ampere Secondary: 127 – 220 Volt ; 3,2 Ampere Connecting Yy_0,Yd_{11},Dd_0,Dy_5	1 Unit
LCR multimeter Test	2712	6 Set
Wattmeter three-phase	Yokogawa	1 Set
Cos ∅ meter	Yokogawa	1 Set
PTAC		1 Unit
Resistive load	Variable resistance 66,67 Ω	3 Unit
Inductive load	208 VA	3 Unit
Capacitive Load	16 µF, 20 µF, 25 µF	3 Unit
Cables		sufficiently

According to IEEE standards, in the experimental equipment, as the show from table 1[17], we will circuit there is a connection as we know. That are strung together to resistive, inductive, capacitive, and RLC combination load.

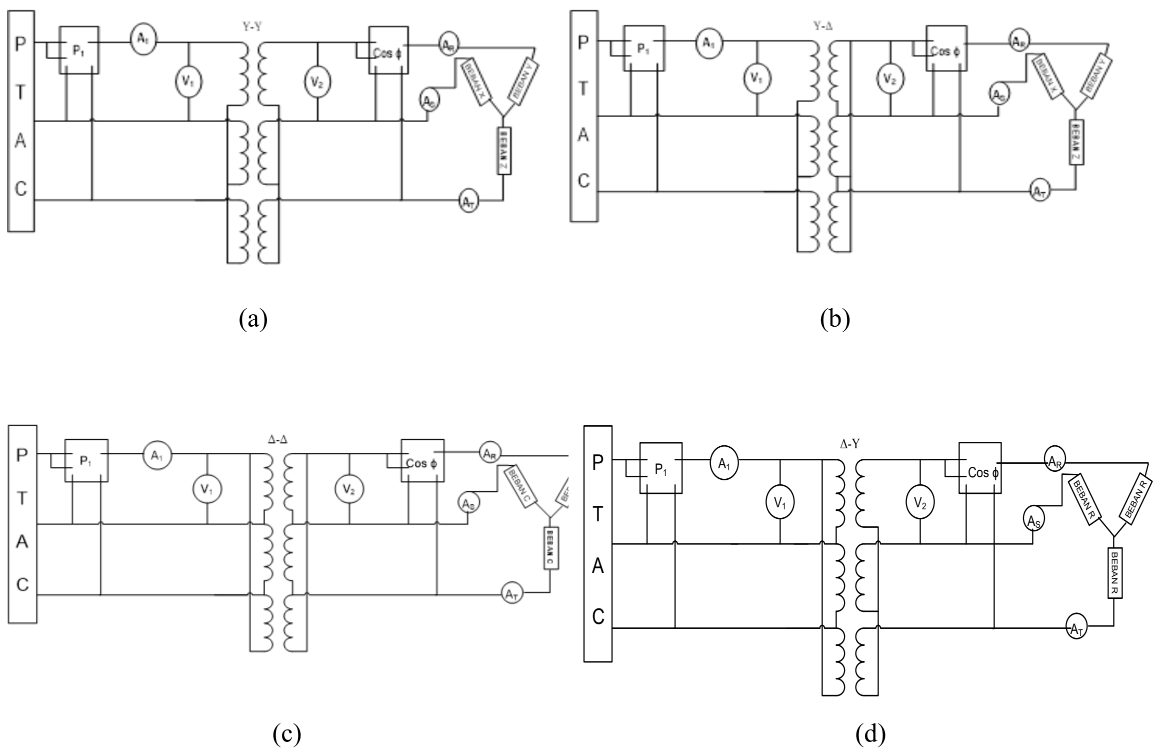


Figure 2. Circuit connection,
(a) Yy0 connection (b) Yd11 connection, (c) Dd0 connection, (d) Dy5 connection

2.1. Experimental data

In this section, needed data supporting the goals of the research as to when no-load condition and load condition. Data and circuit connection from figure 2 has merged to last step reached a result to be get an efficiency and knowed the voltage regulation, it can be presented in figures, graphs, tables in chapter 3.

2.1.1. No-Load condition

Table 2. Y_{y0} no-load connection

P1 (Watt)	A1 (Ampere)	V1 (Volt)	V2 (Volt)
25	0.7	220	158

Table 3. Y_{d11} no-load connection

P1 (Watt)	A1 (Ampere)	V1 (Volt)	V2 (Volt)
20	0.7	220	94

Table 4. Y_{d0} no-load connection

P1 (Watt)	A1 (Ampere)	V1 (Volt)	V2 (Volt)
55	4.8	220	147

Table 5. Y_{y5} no-load connection

P1 (Watt)	A1 (Ampere)	V1 (Volt)	V2 (Volt)
60	4.8	220	321

When no-load condition from the table 2-5 above, described an experiment carried out by testing 4 connections are Y_{y0}, D_{d0}, Y_{d11}, and D_{y5}. Which obtained an output voltage V2 with an input voltage V1 by the transformer is 220 Volt.

2.1.2. Load condition

2.1.2.1. Resistive load

For load condition will be explained in table 6-9 below, where in known V1 is 220 Volt. After that, we will be set value of R,S,T appropriate resistive load adjustable the parameter equipment for testing 4 connection in circuit above. This method for load condition is same for inductive, capacitive, and RLC combination load.

Table 6. Resistive load

R (Ω)	S (Ω)	T (Ω)
66.67	66.67	66.67
53.34	53.34	53.34
40	40	40

P_1 (W)	A_1 (A)	V_2 (V)	A_R (A)	A_S (A)	A_T (A)	Cos ϕ
Y_{y0} Connection						
850	2.50	230	1.58	1.58	1.58	1
970	2.80	230	1.87	1.87	1.87	1
1120	3.39	230	2.12	2.12	2.12	1
Y_{d11} Connection						
110	0.31	75	0.54	0.54	0.54	1
122	0.35	75	0.63	0.63	0.63	1
148	0.41	75	0.72	0.72	0.72	1
D_{d0} Connection						
270	1.08	132	0.84	0.84	0.84	1
310	1.17	131	0.97	0.97	0.97	1
400	1.36	130	1.05	1.05	1.05	1
D_{y5} Connection						
36	0.70	133	0.14	0.14	0.14	0.55 Lagging
48	0.93	132	0.22	0.22	0.22	0.50 Lagging
60	1.14	131	0.28	0.28	0.28	0.40 Lagging

2.1.2.2. Inductive load

Table 7. Inductive load

R (VA)	S (VA)	T (VA)
208	208	208
416	416	416
624	624	624

P_1 (W)	A_1 (A)	V_2 (V)	A_R (A)	A_S (A)	A_T (A)	Cos ϕ
Y_{y0} Connection						
36	0.70	133	0.14	0.14	0.14	0.55 Lagging
48	0.93	132	0.22	0.22	0.22	0.50 Lagging
60	1.14	131	0.28	0.28	0.28	0.40 Lagging
Y_{d11} Connection						
14	0.27	75	0.12	0.12	0.12	0.50 Lagging
20	0.34	75	0.18	0.18	0.18	0.45 Lagging
24	0.42	75	0.22	0.22	0.22	0.40 Lagging
D_{d0} Connection						
72	1.11	132	0.30	0.30	0.30	0.55 Lagging
82	1.33	132	0.42	0.42	0.42	0.50 Lagging
92	1.54	132	0.55	0.55	0.55	0.40 Lagging
D_{y5} Connection						
50	2.53	233	0.14	0.14	0.14	0.5 Lagging
70	3.19	233	0.24	0.24	0.24	0.4 Lagging
120	3.90	233	0.31	0.31	0.31	0.3 Lagging

2.1.2.3. Capacitive load

Table 8. Capacitive load

R (μF)	S (μF)	T (μF)
16	16	16
20	20	20
25	25	25

P_1 (W)	A_1 (A)	V_2 (V)	A_R (A)	A_S (A)	A_T (A)	Cos ϕ
Y_{y0} Connection						
24	0.18	132	0.16	0.16	0.16	0.6 Leading
28	0.23	133	0.28	0.28	0.28	0.4 Leading
32	0.30	134	0.44	0.44	0.44	0.3 Leading
Y_{d11} Connection						
P_1 (W)	A_1 (A)	V_2 (V)	A_R (A)	A_S (A)	A_T (A)	Cos ϕ

16	0.06	76	0.17	0.17	0.17	0.6 Leading
24	0.07	76	0.40	0.40	0.40	0.4 Leading
32	0.09	76	0.77	0.77	0.77	0.3 Leading
			D_{d0} Connection			
P_1 (W)	A_1 (A)	V_2 (V)	A_R (A)	A_S (A)	A_T (A)	Cos ϕ
46	0.30	133	0.32	0.32	0.32	0.6 Leading
48	0.28	133	0.51	0.51	0.51	0.4 Leading
50	0.27	133	0.72	0.72	0.72	0.3 Leading
			D_{y5} Connection			
P_1 (W)	A_1 (A)	V_2 (V)	A_R (A)	A_S (A)	A_T (A)	Cos ϕ
56	0.34	235	0.18	0.18	0.18	0.7 Leading
68	0.50	235	0.40	0.40	0.40	0.4 Leading
80	0.71	235	0.64	0.64	0.64	0.3 Leading

2.1.2.4. RLC combination load

Table 9. RLC Combination load

R (Ω)	S (VA)	T (μF)				
40	208	16				
53.34	416	20				
66.67	624	25				
			Y_{y0} Connection			
P_1 (W)	A_1 (A)	V_2 (V)	A_R (A)	A_S (A)	A_T (A)	Cos ϕ
110	1.01	131	0.73	0.35	0.51	0.7 Lagging
140	1.41	131	0.77	0.38	0.55	1
160	1.23	131	0.84	0.42	0.61	0.65 Leading
			Y_{d11} Connection			
P_1 (W)	A_1 (A)	V_2 (V)	A_R (A)	A_S (A)	A_T (A)	Cos ϕ
78	0.40	75	0.85	0.18	0.73	0.7 Lagging
88	0.44	75	1.00	0.23	0.75	1
90	0.45	75	1.08	0.37	0.69	0.7 Leading
			D_{d0} Connection			
P_1 (W)	A_1 (A)	V_2 (V)	A_R (A)	A_S (A)	A_T (A)	Cos ϕ
200	1.49	131	1.53	0.34	1.16	0.7 Lagging
250	1.41	132	1.57	0.38	1.20	1
280	1.44	132	1.60	0.40	1.24	0.6 Leading
			D_{y5} Connection			
P_1 (W)	A_1 (A)	V_2 (V)	A_R (A)	A_S (A)	A_T (A)	Cos ϕ
720	3.66	232	2.82	0.65	2.40	0.55 Leading
760	3.76	233	2.92	0.69	2.01	1
750	3.72	233	3.34	1.19	1.98	0.5 Leading

3. RESULTS AND DISCUSSION

After the circuit has finished and running, the experimental data from the experiments in this paper will be analyzed to find the voltage and efficiency from three-phase transformer. V_{L-L} values are indicated by V_2 in the experimental circuit, I_R, I_S and I_T values are indicated by A_R, A_S and A_T in the experimental circuit. In this connection, $V_{ph} = V_{L-L}$ is the same with equation (1) and (2).

So, the total power of all three phases for this connection in a state of balanced load, the results of the data shown in the table 10 below, where in that table are examples and explained of any calculations so as to get result on inductive, capacitive, and RLC combination load.

Table 10. Resistive load result

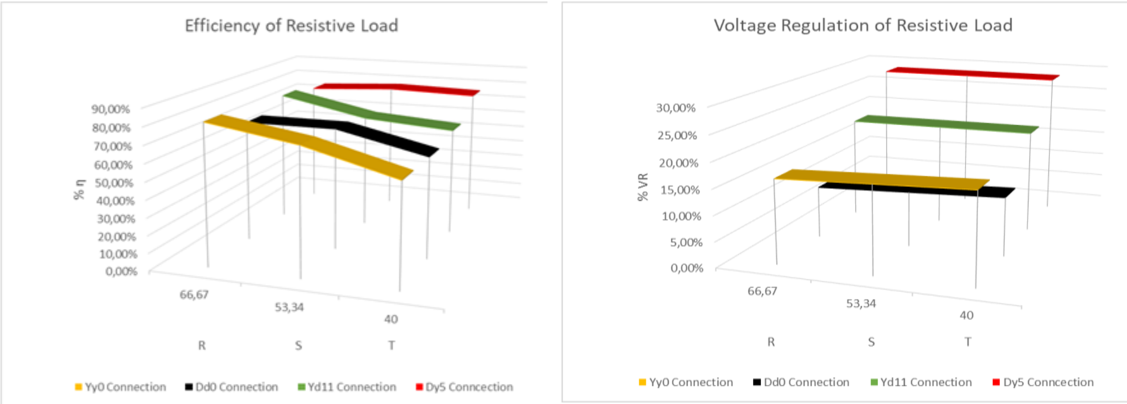
Resistive Load			I_{PH}			V_{L-L}		P_{INPUT} (Watt)	P_{OUT} (Watt)	% η	%VR
						Y_{y0} Connection					
R (Ω)	S (Ω)	T (Ω)	I_R (Amp)	I_S (Amp)	I_T (Amp)	V_{FL} (Volt)	V_{NL} (Volt)				
66,67	66.67	66.67	0,82	0,82	0,82	132	158	230	187.47	81,51%	16,45%
53,34	53.34	53.34	0.87	0.87	0.87	131	158	270	197.40	73,12%	17,10%
40	40	40	0.92	0.92	0.92	130	158	350	207.20	59,19%	17,72%
						Y_{d11} Connection					
R (Ω)	S (Ω)	T (Ω)	I_R (Amp)	I_S (Amp)	I_T (Amp)	V_{FL} (Volt)	V_{NL} (Volt)	P_{INPUT} (Watt)	P_{OUT} (Watt)	% η	%VR
66.67	66.67	66.67	0.54	0.54	0.54	75	94	110	70.15	77,95%	20,21%
53.34	53.34	53.34	0.63	0.63	0.63	75	94	122	81.84	67,09%	20,21%
40	40	40	0.72	0.72	0.72	75	94	148	93.53	63,20%	20,21%
						D_{d0} Connection					

Resistive Load			I_{PH}			V_{L-L}		P_{INPUT} (Watt)	P_{OUT} (Watt)	% η	%VR
R (Ω)	S (Ω)	T (Ω)	I_R (Amp)	I_S (Amp)	I_T (Amp)	V_{FL} (Volt)	V_{NL} (Volt)				
66.67	66.67	66.67	0.84	0.84	0.84	132	147	270	192.04	71,13%	10,20%
53.34	53.34	53.34	0.97	0.97	0.97	131	147	310	220.08	71,00%	10,88%
40	40	40	1.05	1.05	1.05	130	147	400	236.42	59,11%	11,56%

D_{y5} Connection

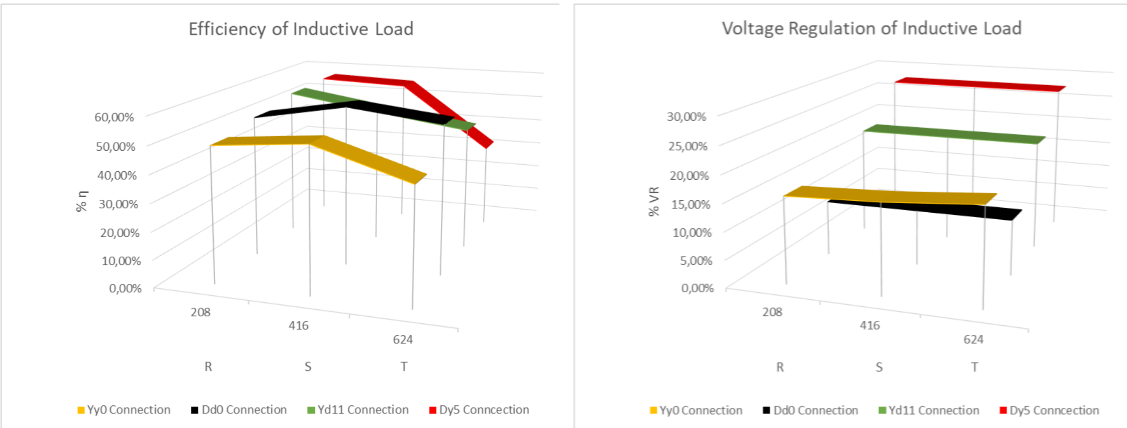
Resistive Load			I_{PH}			V_{L-L}		P_{INPUT} (Watt)	P_{OUT} (Watt)	% η	%VR
R (Ω)	S (Ω)	T (Ω)	I_R (Amp)	I_S (Amp)	I_T (Amp)	V_{FL} (Volt)	V_{NL} (Volt)				
66.67	66.67	66.67	1.58	1.58	1.58	230	321	850	629.41	74,05%	28,35%
53.34	53.34	53.34	1.87	1.87	1.87	230	321	970	744.93	76,80%	28,35%
40	40	40	2.12	2.12	2.12	230	321	1120	844.53	75,41%	28,35%

From the results of calculations on the data obtained from above for each connection, efficiency and voltage regulation versus a state of balanced load shown by the graphs in Figure 3 as follows:



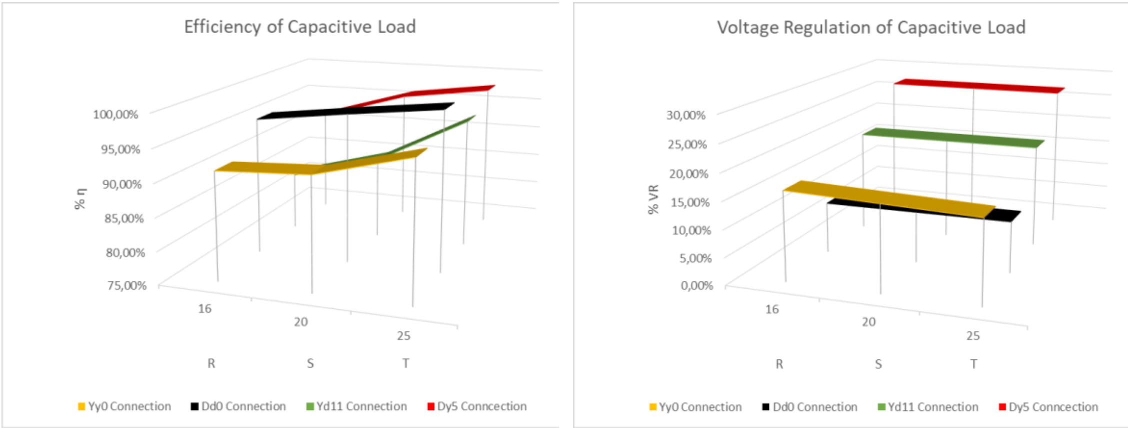
(a) (b)

Figure 3. Resistive load result,
(a) Efficiency (b) Voltage regulation



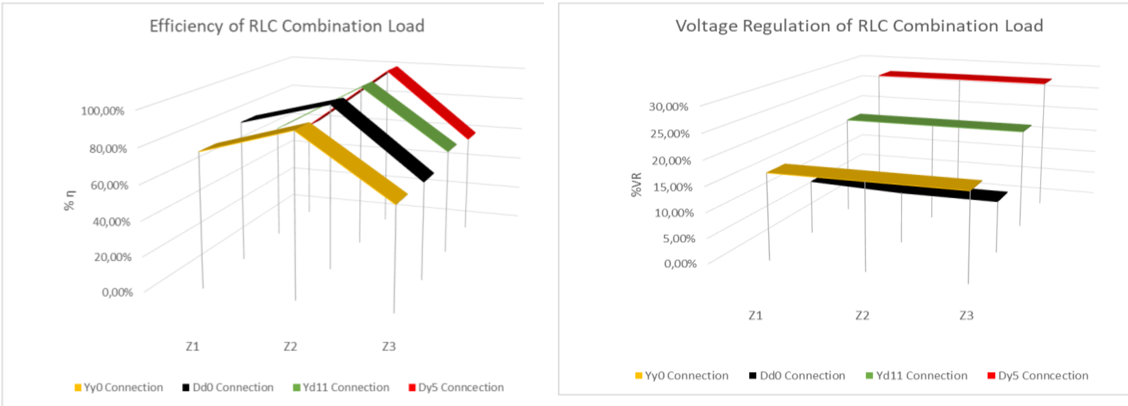
(a) (b)

Figure 4. Inductive load result,
(a) Efficiency (b) Voltage regulation



(a) (b)

Figure 5. Capacitive load result,
(a) Efficiency (b) Voltage regulation



(a) (b)

Figure 6. RLC Combination load result,
(a) Efficiency (b) Voltage regulation

4. CONCLUSION

The result of the experiment can be concluded, the best efficiency is in the Dd0 winding connection, when a state of balanced load given of capacitive load with an average percentage is 97,87%. This is because the output power of the transformer approaches the value of the input power of the transformer. Whereas, the best voltage regulation is in the Dy5 winding connection, when a state of balanced load given of resistive load with an average percentage is 28,35%. This is because the secondary winding moves closer to the primary, if the load increased due to a decrease in voltage compared by the secondary winding. The voltage regulation is used for find out the three-phase transformer prevent overheating. IEC Standard exceeds the maximum voltage regulation can improve efficiently. It means that a comparison between efficiency and voltage regulation three-phase transformer is defined by power input, power output, load, voltage in line, current, as well as in the input values can be set of these experiments.

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