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ENEE5102-Power Lab

"Power Transmission Line"

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Abstract

The purpose of this experiment is to get hands on the operation of power transmission lines in single, series, and parallel connections and under different values of line capacitance at no load. And to observe the different load situations which were tested such as resistive, inductive, and capacitive loads. The obtained results have shown that each of long and medium transmission lines have the received voltage higher than the sending end voltage especially at light loaded lines because of the higher charging current flowing through the capacitance of the line. Moreover, the inductive load added at the receiving end has consumed the reactive power produced by the line capacitance.

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Acronyms and Abbreviations

T.L	Transmission Line

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Chapter 1

Introduction

Electrical power is generated at different generating stations. These generating stations are not necessarily situated at the load centre. During construction of generating station number of factors to be considered from economical point of view. These all factors may not be easily available at load centre, hence generating stations are not normally situated very nearer to load centre. Load centre is the place where maximum power is consumed. Hence there must be some means by which the generated power must be transmitted to the load center. Electrical transmission system is the means of transmitting power from generating station to different load centers. Factor to be Considered for Constructing a Generating Station During planning of construction of generating station the following factors to be considered for economical generation of electrical power. 1)Easy availability of water for thermal power generating station. 2) Easy availability of land for construction of power station including it's staff township. 3) For hydro power station there must be a dam on river. So proper place on the river must be chosen in such a way that the construction of the dam can be done in most optimum way. 4) For thermal power station easy availability of fuel is one of the most important factors to be considered. 5) Better communication for goods as well as employees of the power station also to be kept into consideration. 6) For transporting very big spare parts of turbines, alternators etc, there must be wide road ways, rain communication, and deep and wide river must pass away nearby the power station. 7) For nuclear power plant, it must be situated in such a distance from common location so that there may be any effect from nuclear reaction the heath of common people. Many other factors also to be considered, but there are beyond the scope of our discussion. All the factors listed above are very difficult to be available at load center. The power station or generating station must be situated where all the facilities are easily available. This place may not be necessarily at the load center. The power generated at generating station then transmitted to the load center by means of electrical power transmission system as we said earlier.

The power generated at generating station is in low voltage level as low voltage power generation has some economical values. Low voltage power generation is more economical than high voltage power generation. At low voltage level, bot weight and wide of insulation is less in the alternator, this directly reduces the cost and size of alternator. But this low voltage level power can not be transmitted directly to the consumer end as because this low voltage power transmission is not at all economical. Hence although low voltage power generation is economical but low voltage electrical power transmission is not economical. Electrical power is directly proportional to the product of electrical current and voltage of system. So for transmitting certain electrical power from one place to another, if the voltage of the power is increased then associated current of this power is reduced. Reduced current means less I 2R loss in the system, less cross sectional area of the conductor means less capital involvement and decreased current causes improvement in voltage regulation of power transmission system and improved voltage regulation indicates quality power. Because of these three reasons electrical power mainly transmitted at high voltage level. Again at distribution end for efficient distribution of the transmitted power, it is stepped down to its desired low voltage level. So it can be concluded that first the electrical power is generated at low voltage level then it stepped up to high voltage for efficient transmission of electrical energy. Lastly for distribution of electrical energy or power to different consumers it is stepped down to desired low voltage level. This brief discussion of electrical transmission system and network, but now we will discussed little bit more details about transmission of electrical energy.

The transmission lines are categorized as three types1) Short transmission line– the line length is up to 80 km. 2) Medium transmission line– the line length is between 80km to 160 km. 3) Long transmission line – the line length is more than 160 km. Whatever may be the category of transmission line, the main aim is to transmit power from one end to another. Like other electrical system, the transmission network also will have some power loss and voltage drop during transmitting power from sending end to receiving end. Hence, performance of transmission line can be determined by its efficiency and voltage regulation.

Ferranti Effect in Power System

In general practice we know, that for all electrical systems current flows from the region of higher potential to the region of lower potential, to compensate for the electrical potential difference that exists in the system. In all practical cases the sending end voltage is higher than the receiving end, so current flows from the source or the supply end to the load. But during nights when load is lean, due to the fact the most of the offices , school and industries close down at night, Load goes down.

Major loads on grid are Inductive in nature. So this is directly Proportional to MVAR. This leads to lagging VAR due inductive nature of the Load.

During night, most of the inductive load are turned off which give rise to capacitive current in the line. We know that capacitor charging current leads to voltage drop across the line inductor of the transmission system which is in phase with the sending end voltages. Thus generating Leading Var and giving rise to situation where receiving current is greater that sending end current. This is generally called Ferranti effect after Sir S.Z. Ferranti. In terms of Sir Ferranti,"A long transmission line can be considered to compose a considerably high amount of capacitance and inductor distributed across the entire length of the line. Ferranti Effect occurs when current drawn by the distributed capacitance of the line itself is greater than the current associated with the load at the receiving end of the line(during light or no load). This capacitorcharging current leads to voltage drop across the line inductor of the transmission system which is in phase with the sending end voltages. This voltage drop keeps on increasing additively as we move towards the load end of the line and subsequently the receiving end voltage tends to get larger than applied voltage leading to the phenomena called Ferranti effect in power system".

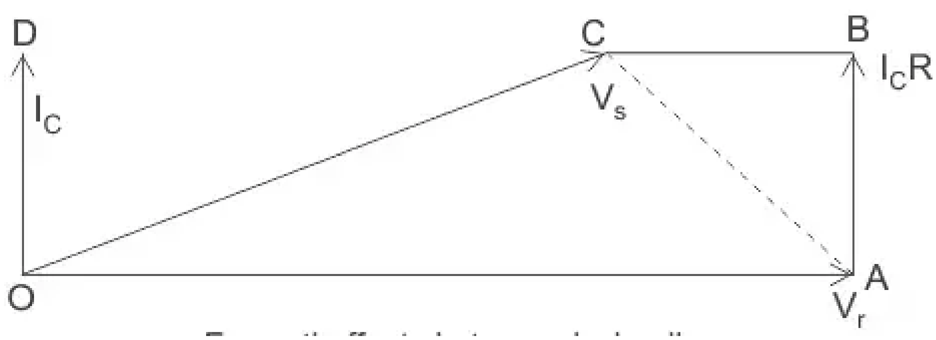

Fig. 1.1: Ferranti Effect in Transmission Line

Chapter 2

Results and Discussion

2.1 Single Transmission Line

The Single Transmission Line was connected as shown in Fig2.1. Then the sending voltage was set to 380V.

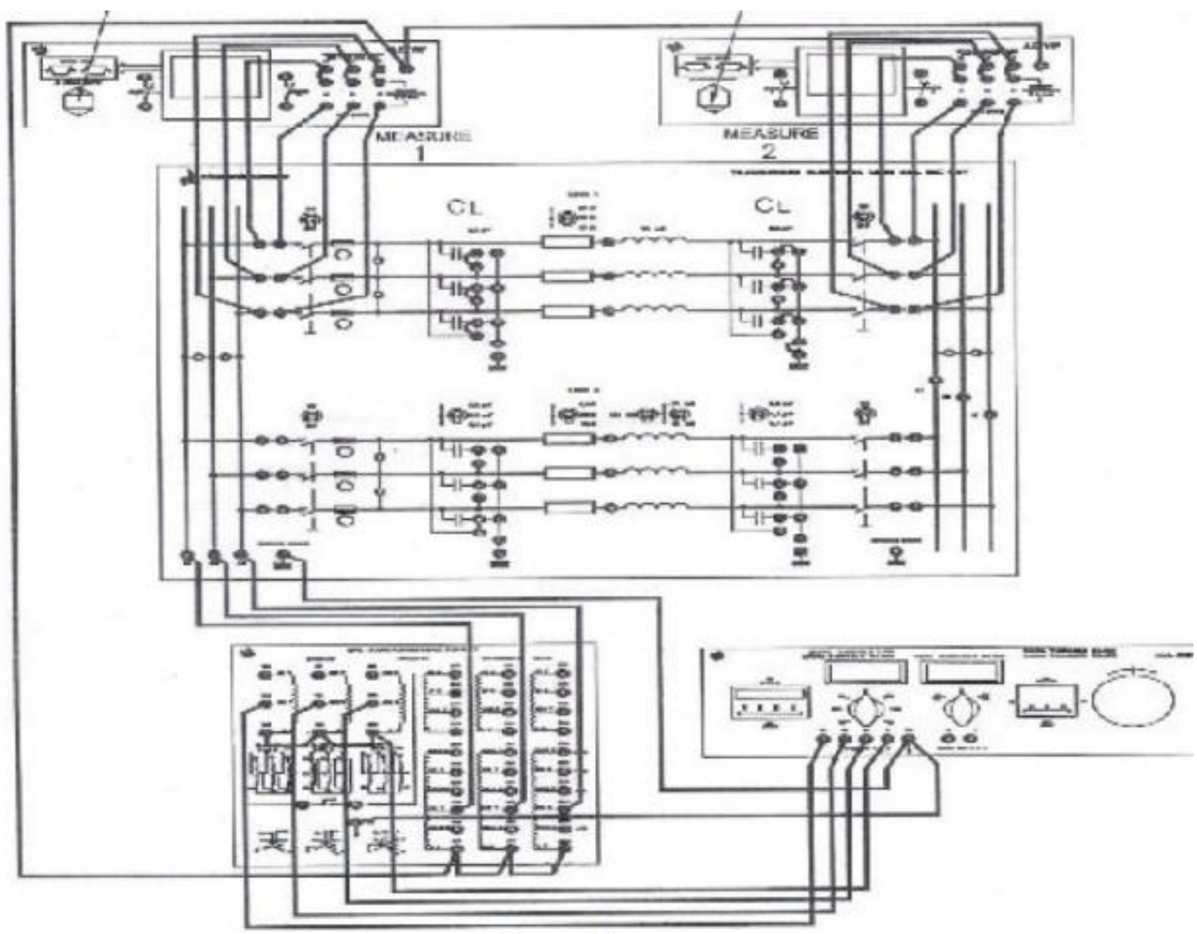

Fig. 2.1: Single Transmission Line Connection

2.1.1 Single Line Capacitors Connected on Δ-Y .

Capacitors at the sending and the receiving end of the transmission line were connected on Δ-Y connection, respectively, then the measured quantities are summarized table 1:

Table. 1: Electric quantities of Δ-Y capacitor connection

L-L voltage at sending part (V)	Line current (A)	Total active power at sending part (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)
380	0.056	1.4	382	-37.5

$$\text{Total Capacitor Reactive Power Produced by } \Delta \text{ Capacitors}$$

$$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^2{}_{\Phi} * \omega * C$$

$$Q_{\Delta} = 3 * (380)^2 * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{\Delta} = 27.24\,Var$$

$$\text{Total Capacitor Reactive Power Produced by } Y \text{ Capacitors}$$

$$Q_{Y} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^2{}_{\Phi} * \omega * C$$

$$Q_{Y} = 3 * (\frac{380}{\sqrt{3}})^2 * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{Y} = 9\,Var$$

$$Q_{total} = 36.32$$

It is clear that the calculated value is close enough to the measured value.

2.1.2 Single Line Capacitors Connected on Δ- Δ .

Capacitors at the sending and the receiving end of the transmission line were connected on Δ-Δ connection, respectively. Then the sending voltage was set to 380V, The measured quantities are summarized in table 2:

Table. 2: Electric quantities of Δ-Δ capacitor single line connection

L-L voltage at sending part (V)	Line current (A)	Total active power at sending part (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)
381	0.085	1.8	383	-56.7

Total Capacitor Reactive Power Produced by Δ Capacitors

$$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^2_{\Phi} * \omega * C$$

$$Q_{\Delta} = 3 * (379.7)^2 * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{\Delta} = 27.24 \text{ Var}$$

Total Capacitor Reactive Power Produced by Δ Capacitors

$$Q_{Y} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^2_{\Phi} * \omega * C$$

$$Q_{Y} = 3 * (381.9)^2 * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{Y} = 27.49 \text{ Var}$$

$$Q_{total} = 54.73 \text{ Var}$$

It is clear that the calculated value is close enough to the measured value.

2.2 Series Operation of Two Transmission Lines at No-Load

Two series transmission Lines were connected as shown in Fig2.2. Then the sending voltage was set to 380V.

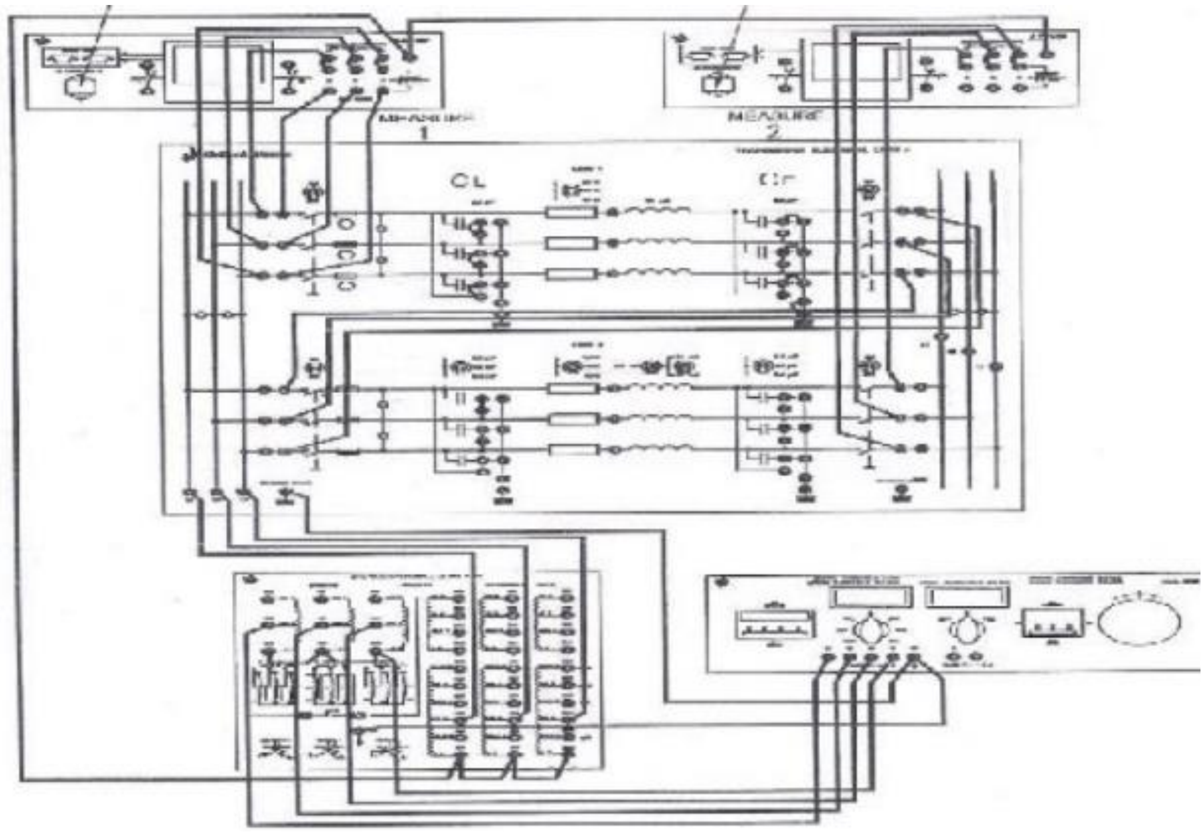

Fig. 2.2: Two Series Transmission Lines Connection

2.2.1 Two Series Transmission Lines Capacitors Connected on Δ-y- Δ - Δ.

In this part, the sending and the receiving end of the first transmission line were connected on Δ,Y connection, respectively, and the sending and the receiving end of the first transmission line were connected on Δ, Δ connection, respectively. The measured quantities are summarized in table 3 :

Table. 3: Electric quantities Δ-Y-Δ-Δ capacitor connection of two series T.Ls

L-L voltage at sending part (V)	Line current (A)	Total active power at sending part (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)
380	0.146	3.6	386.5	-88

$$\text{Total Capacitor Reactive Power Produced by } \Delta \text{ Capacitors}$$

$$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^2{}_{\Phi} * \omega * C$$

$$Q_{\Delta} = 3 * (381.3)^2 * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{\Delta} = 27.40\,Var$$

$$\text{Total Capacitor Reactive Power Produced by } Y \text{ Capacitors}$$

$$Q_{Y} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^2{}_{\Phi} * \omega * C$$

$$Q_{Y} = 3 * (\frac{382}{\sqrt{3}})^2 * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{Y} = 9.16\,Var$$

$$Q_{total} = 36.56\,Var$$

$$\text{Total Capacitor Reactive Power Produced by } \Delta \text{ Capacitors}$$

$$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^2{}_{\Phi} * \omega * C$$

$$Q_{\Delta} = 3 * (383)^2 * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{\Delta} = 27.65 \text{ Var}$$

$$\text{Total Capacitor Reactive Power Produced by } \Delta \text{ Capacitors}$$

$$Q_{Y} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^2{}_{\Phi} * \omega * C$$

$$Q_{Y} = 3 * (385.5)^2 * (2 * \pi * 50) * (0.1 * 10^{-6})$$

$$Q_{Y} = 14 \text{ Var}$$

$$Q_{total} = 41.65 \text{ Var}$$

$$Q_{total} = Q_{\text{first}} + Q_{\text{second}}$$

$$Q_{total} = 36.56 + 41.65 = 78.2 \text{ Var}$$

<u>It is clear that the calculated value is close enough to the measured value.</u>

2.2.2 Two Series Transmission Lines Capacitors Connected on Δ- Δ - Δ - Δ.

In this part, the sending and the receiving end of the first transmission line were connected on Δ, Δ connection, respectively, and the sending and the receiving end of the first transmission line were connected on Δ, Δ connection, respectively. The measured quantities are summarized in table 4 :

Table. 4: Electric quantities Δ-Δ-Δ-Δ capacitor connection of series T.Ls

L-L voltage at sending part (V)	Line current (A)	Total active power at sending part (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)
381	0.173	4.4	388	-113

- ✓ Calculation for the first T.L :

Total Capacitor Reactive Power Produced by Δ Capacitors

$$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^{2}_{\Phi} * \omega * C$$

$$Q_{\Delta} = 3 * (381.3)^{2} * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{\Delta} = 27.40\, Var$$

Total Capacitor Reactive Power Produced by Δ Capacitors

$$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^{2}_{\Phi} * \omega * C$$

$$Q_{\Delta} = 3 * (382)^{2} * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{\Delta} = 27.5\, Var$$

$$Q_{total} = 54.9\, Var$$

- ✓ Calculation for the second T.L :

Total Capacitor Reactive Power Produced by Δ Capacitors

$$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^{2}{}_{\Phi} * \omega * C$$

$$Q_{\Delta} = 3 * (383)^{2} * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{\Delta} = 27.65 \text{ Var}$$

Total Capacitor Reactive Power Produced by Δ Capacitors

$$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^{2}{}_{\Phi} * \omega * C$$

$$Q_{\Delta} = 3 * (386.7)^{2} * (2 * \pi * 50) * (0.1 * 10^{-6})$$

$$Q_{\Delta} = 14.1 \text{ Var}$$

$$Q_{total} = 41.75 \text{ Var}$$

Hence ,

$$Q_{total} = Q_{\text{first}} + Q_{\text{second}}$$

$$Q_{total} = 54.9 + 41.75 = 96.65 \text{ Var}$$

<u>It is clear that the calculated value is close enough to the measured value.</u>

2.3 Parallel Operation of Two Transmission Lines at No-Load

Two Parallel transmission Lines were connected as shown in Fig2.3. Then the sending voltage was set to 380V.

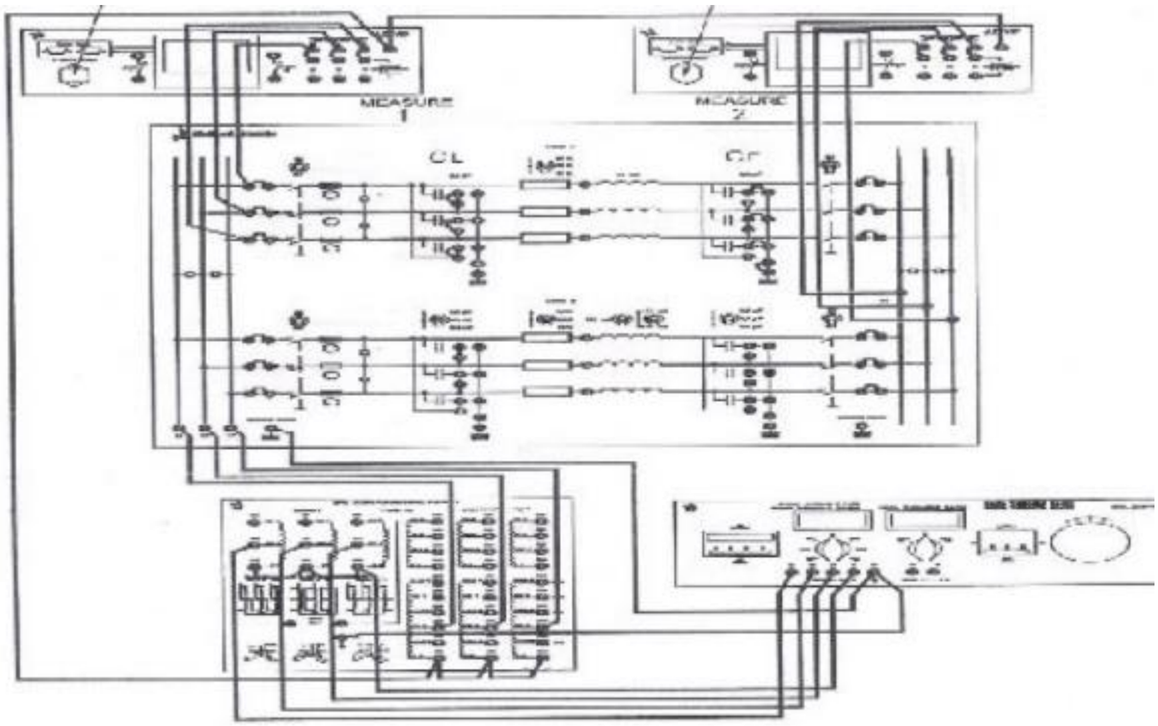

Fig. 2.3: Two Parallel Transmission Lines Connection

2.3.1 Two Parallel Transmission Lines Capacitors Connected on Δ-y- Δ - Δ.

In this section, the two lines were connected to each other in parallel, the sending and the receiving end of the first transmission line were connected on Δ,Y connection, respectively, and the sending and the receiving end of the first transmission line were connected on Δ, Δ connection, respectively. The measured quantities are summarized in table 5 :

Table. 5: Electric quantities Δ-Y-Δ-Δ capacitor connections of two parallel T.Ls

L-L voltage at sending part (V)	Line current of First transmission line(A)	Total active power at sending part of (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)
379	0.042	2	380	-28

- ✓ Calculation for the first T.L :

$\text{Total Capacitor Reactive Power Produced by } \Delta \text{ Capacitors}$

$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^{2}{}_{\Phi} * \omega * C$

$Q_{\Delta} = 3 * (382)^{2} * (2 * \pi * 50) * (0.2 * 10^{-6})$

$Q_{\Delta} = 27.50\, Var$

$\text{Total Capacitor Reactive Power Produced by } Y \text{ Capacitors}$

$Q_{Y} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^{2}{}_{\Phi} * \omega * C$

$Q_{Y} = 3 * (\frac{382.4}{\sqrt{3}})^{2} * (2 * \pi * 50) * (0.2 * 10^{-6})$

$Q_{Y} = 9.18\, Var$

$Q_{total} = 36.68\, Var$

- ✓ Calculation for the second T.L :

$\text{Total Capacitor Reactive Power Produced by } \Delta \text{ Capacitors}$

$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^{2}{}_{\Phi} * \omega * C$

$Q_{\Delta} = 3 * (382)^{2} * (2 * \pi * 50) * (0.2 * 10^{-6})$

$Q_{\Delta} = 27.50 \text{ Var}$

$\text{Total Capacitor Reactive Power Produced by } \Delta \text{ Capacitors}$

$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^{2}{}_{\Phi} * \omega * C$

$Q_{\Delta} = 3 * (382.4)^{2} * (2 * \pi * 50) * (0.1 * 10^{-6})$

$Q_{\Delta} = 13.78 \text{ Var}$

$Q_{total} = 41.28 \text{ Var}$

2.3.2 Two Parallel Transmission Lines Capacitors Connected on Δ- Δ - Δ - Δ.

In this section, the two lines were connected to each other in parallel, the sending and the receiving end of the first transmission line were connected on Δ, Δ connection, respectively, and the sending and the receiving end of the first transmission line were connected on Δ, Δ connection, respectively. The measured quantities are summarized in table 6 :

Table. 6: Electric quantities Δ-Δ-Δ-Δ capacitor connections of two parallel T.Ls

L-L voltage at sending part (V)	Line current of First transmission line(A)	Total active power at sending part of (W)	L-L voltage at receiving part (V)	Total reactive power at sending part (VAR)
380	0.08	2.4	383	-52

- ✓ Calculation for the first T.L :

Total Capacitor Reactive Power Produced by Δ Capacitors

$$Q_{\Delta} = 3 * \mathrm{V}_{\Phi} * \mathrm{I}_{\Phi} = 3 * \mathrm{V}^{2}{}_{\Phi} * \omega * C$$

$$Q_{\Delta} = 3 * (382)^{2} * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{\Delta} = 27.50\,Var$$

Total Capacitor Reactive Power Produced by Δ Capacitors

$$Q_{\Delta} = 3 * \mathrm{V}_{\Phi} * \mathrm{I}_{\Phi} = 3 * \mathrm{V}^{2}{}_{\Phi} * \omega * C$$

$$Q_{\Delta} = 3 * (382.7)^{2} * (2 * \pi * 50) * (0.2 * 10^{-6})$$

$$Q_{\Delta} = 27.60\,Var$$

$$Q_{total} = 55.1\,Var$$

- ✓ Calculation for the Second T.L :

Total Capacitor Reactive Power Produced by Δ Capacitors

$Q_{\Delta} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^2_{\Phi} * \omega * C$

$Q_{\Delta} = 3 * (382)^2 * (2 * \pi * 50) * (0.2 * 10^{-6})$

$Q_{\Delta} = 27.50$ Var

Total Capacitor Reactive Power Produced by Δ Capacitors

$Q_{Y} = 3 * V_{\Phi} * I_{\Phi} = 3 * V^2_{\Phi} * \omega * C$

$Q_{Y} = 3 * (382.7)^2 * (2 * \pi * 50) * (0.1 * 10^{-6})$

$Q_{Y} = 13.78$ Var

$Q_{total} = 41.28$ Var

- ✓ The sign of the reactive power is negative because it's being consumed by the three-phase source and produced by the line capacitances.
- ✓ We noticed that the voltage at receiving end has become noticeably higher than the voltage at the sending end.

- ✓ To Sum up, we can conclude that when the line is classified as a short T.L, the charging current is small and thus the voltage at receiving end is slightly higher than the voltage at the sending end. In Contrast, for long T.L, the charging current through the capacitance of the line is higher than the current in the line itself since the operation is at no load; this current produces a voltage drop through the line inductance which adds with the sending end voltage resulting in a higher voltage at the receiving side which is known as Ferranti Effect.

2.4 Operation of a Transmission Lines with Different Load Conditions.

2.4.1 Detecting the Performance with Resistive Load.

The power supply voltage was set to 380V, then the breakers were turned on at the origin and at the end of line 2, then different values of resistive load were connected, then the measured quantities are summarized in table 7:

Table. 7: Electric quantities Δ-Y capacitor connections T.L with resistive load

	Us (V)	Is (A)	Ps (W)	Qs (VAR)	PFs	U_R (V)	I_R (V)	P_R (W)	Q_R (VAR)	PF_R	Voltage Drop(**U_S-U_R)**	Power Loss(**P_S-P_R)**	η
No load	382	0.029	1.2	-18.8	0.064	381	0	0	0	1	1	1.2	100%
735 Ω	378.5	0.3	197.4	-17	0.996	373	0.3	193.7	0	1	4.5	3.7	98.12%
365 Ω	377.8	0.6	382.4	-20.5	0.998	365.3	0.6	366.6	0	1	11.2	15.8	95.86%
240 Ω	374	0.86	555	-1.8	1	357.6	0.8	529.1	0	1	16.4	25.9	93.33%

2.4.2 Detecting the Performance with Inductive Load.

This time, different values of inductive load were connected, then the measured quantities are summarized in table 9:

Table. 9: Electric quantities Δ-Y capacitor connections T.L with inductive load

	Us (V)	Is (A)	Ps (W)	Qs (VAR)	PFs	U_R (V)	I_R (V)	P_R (W)	Q_R (VAR)	PF_R	Voltage Drop(**U_S-U_R)**	Power Loss(**P_S-P_R)**	η
No load	382	0.029	1.2	-18.8	0.064	381	0	0	0	1	1	1.2	100%
2.3 H	380	0.28	30	182	0.16	375.3	0.31	25.8	198	0.13	4.7	4.2	86%
1.15 H	381	0.55	55.3	354	0.15	368	0.57	42.6	362	0.117	13	12.7	77%
0.77 H	379.5	0.84	92	538	0.17	362.1	0.871	64.8	535.6	0.12	17.4	27.2	70.43%

2.4.3 Detecting the Performance with Capacitive Load.

This time, different values of capacitive load were connected, then the measured quantities are summarized in table 10:

Table. 10: Electric quantities Δ-Y capacitor connections T.L with Capacitive load

	Us (V)	Is (A)	Ps (W)	Qs (VAR)	PFs	U_R (V)	I_R (V)	P_R (W)	Q_R (VAR)	PF_R	Voltage Drop(**U_S-U_R)**	Power Loss(**P_S-P_R)**	ƞ
No load	382	0.029	1.2	-18.8	0.064	381	0	0	0	1	1	1.2	100%
4.5 μF	382	0.37	15	-244	0.061	389.3	0.33	9.5	-288.8	0.04	-7.3	5.5	63.33%
9 μF	384	0.71	32	-468	0.067	394.8	0.68	13.5	-465	0.029	-10.8	45.5	42.18%
13 μF	383	1.06	64	-702	0.09	400	1.03	24	-713.6	0.033	-17	40	37.5%

2.4.4 Detecting the Performance with R-L Load and R-C Load.

This time, different values of R-L and R-C loads were connected, Then the measured quantities are summarized in table 11:

Table. 11: Electric quantities Δ-Y capacitor connections T.L with Capacitive load

	Us (V)	Is (A)	Ps (W)	Qs (VAR)	PFs	U_R (V)	I_R (V)	P_R (W)	Q_R (VAR)	PF_R	Voltage Drop(**U_S-U_R)**	Power Loss(**P_S-P_R)**	ƞ
No load	382	0.029	1.2	-18.8	0.064	381	0	0	0	1	1	1.2	100%
360Ω+L1	377	0.665	394	174	0.91	359	0.67	378	177	0.904	18	16	95.94%
360Ω+L2	376	0.894	409	334	0.775	355	0.83	385	330	0.759	21	24	94.13%
360Ω+L3	375	1.238	431	673	0.54	343	1.23	375	644	0.5	32	56	87%
360Ω+C1	377	0.69	405	-209	0.89	371	0.68	384.6	-205	0.884	6	20.4	94.96%
360Ω+C2	377	0.91	431	-410	0.73	376	0.9	403	-714	0.7	1	28	93.5%
360Ω+C3	375	1.4	500	-808	0.526	384	1.4	424	-845	0.045	-9	76	84.8%

Conclusion

This experiment tested the operation of power transmission lines and identified some important characteristics related to them. It was observed that the reactive power was consumed by the three phase supply and the calculations verified that the source of this reactive power is the line capacitance. The calculations were close to the measured values of reactive power. It was confirmed that the series connection made the voltage at the receiving end to exceed the voltage at the sending end; this is due to the charging currents that produce a voltage drop across the series line inductance which add to the sending end voltage resulting in this phenomenon. Under load operation, as the load increases, the voltage drop and the power loss have increased due to drawing larger currents.

References

[1]Bennett S., A History of Power Systems. 1800-1930. IET. 142−148, June 1986.