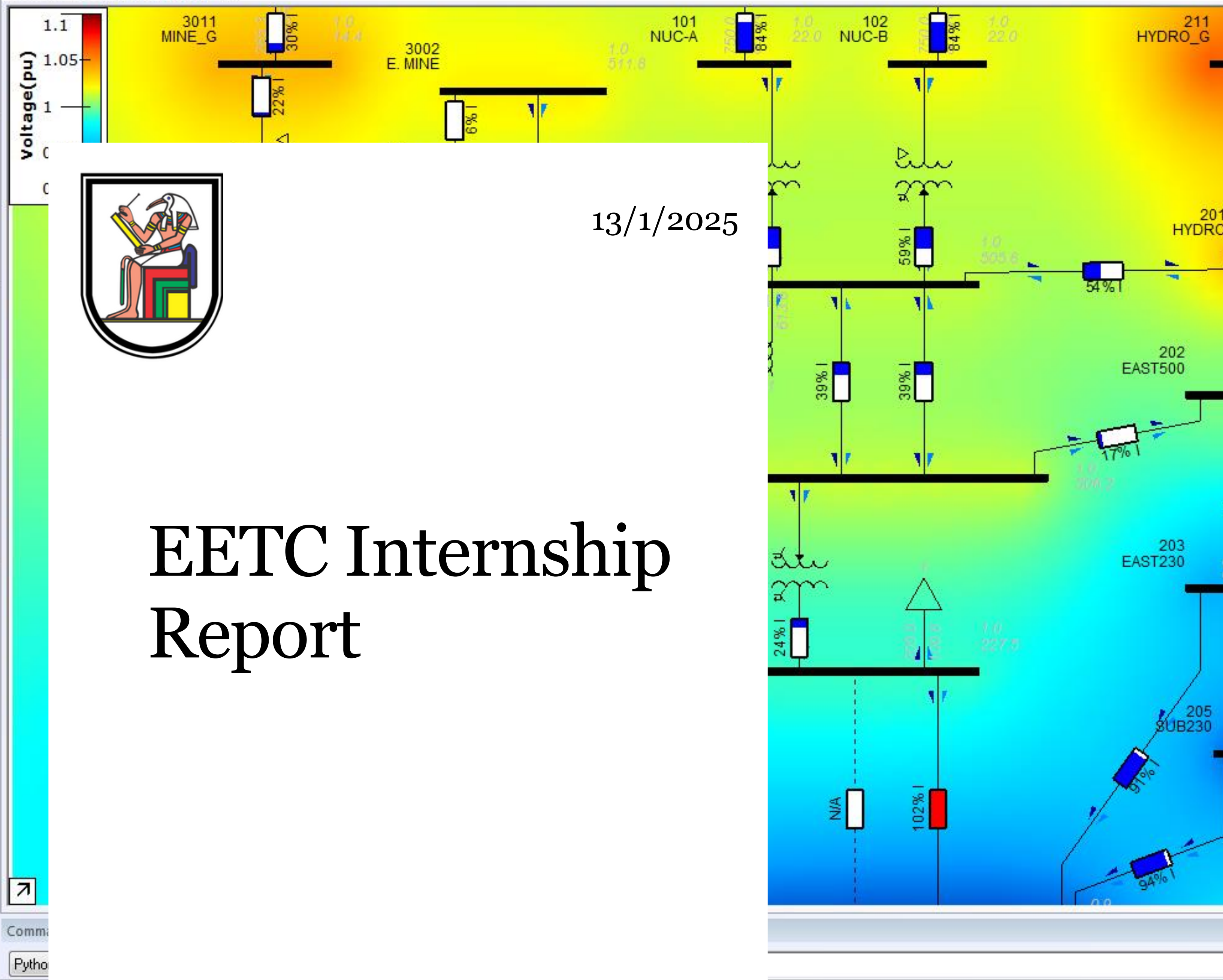

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EETC Internship Report

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1.Introduction

This report highlights my Industrial Training 1 period at The Egypt Electrical Transmission company. I am Ali Mohamed Aly Mahmoud, and my 4 weeks of training provided a comprehensive framework on the program PSS/E. The program PSS/E is an industry standard program used for modelling and solving transmission systems. Consequentially, understanding its fundamentals, and practical applications in the work place, is integral to developing an effective electrical engineer. The report will outline the Theoretical knowledge gained Then, the practical assignments worked on and developed during the training.

1.1.Scope

The theory covered by this internship had a scope of single line diagram load flow analysis. Load flow analysis is steady state and its objective is verifying loading conditions and nominal voltages. This is contrary to short circuit analysis, Dynamic / transient analysis and among other comprehensive analysis that focus on the transient of the transmission system.

To achieve successful load flow model, a few steps were followed throughout the internship. First the transmission system is modelled, including its generators, loads, transmission lines, and busses. Then, a modelled system is diagnosed to achieve intended loading conditions or nominal voltage. Finally, this model is extended to include areas and zones, which is how its applied in real-work environments, accounting for the full system.

2.Transmission system modelling

2.1.Per unit system

The first aspect of modelling on pss/e and of any large transmission system, is applying the per unit system for convenience. This internship was my first introduction the per unit system, and its fundamental need in large systems, where real values of voltage and current would be overwhelming. Instead, a base is defined for voltage and apparent power, and from them a base for current and impedance is chosen, and every value displayed, is in reference to these bases, hence representing the system in percentages to nominal values.

2.2.Modelling a bus-bar

In real life systems, a busbar is paramount for acting as a node for transmission lines. They're made of large copper bars which maximizes their current rating. They're found everywhere, at generator side, at load side, and in between at substations, wherever they're needed to connect lines together. A bus is parametrized by its nominal voltage, and the minimum and maximum limits to its value. In pss/e, buses fall into 4 categories, 1. Load bus, 2. Bus with generator, 3. Slack bus, and 4. Disconnected bus.

Slack buses have a particularly important role in role in load flow analysis. By definition, a sack bus is what's varied to equalize the load flow, such that input power is equal to the output. They have power angle 0, and act as a reference for the transmission system. As such, in the program, only 1 bus within an area can be a slack bus. In real life, whilst 1 station can be delegated as slack, multiple stations adjust their power output depending on requirements and situations as relayed by the control unit.

2.3.Modelling a generator

The basic model of a generator utilizes its intended power output, its rated apparent from which the program calculates its reactive power, and its limits on reactive power and active power. The reactive power is constrained by the operating voltage of the bus the generator is connected to. Additional data required is the transformer impedance, generator impedance, and the generators transformer tab ratio.

Importantly, the basic model misses the true capability of a generator. In the basic model, the Reactive power Q of a generator at any give power is limited by the rated S, following the circular curve $S = \sqrt{P^2 + Q^2}$. In reality, generators follow a D curve which is less than the ideal curve. If at a given power a generator fails to supply Q needed, Voltage must change, and voltage mitigation strategies are applied, either by the programming automatically adjusting tabs, or by later adding shunts

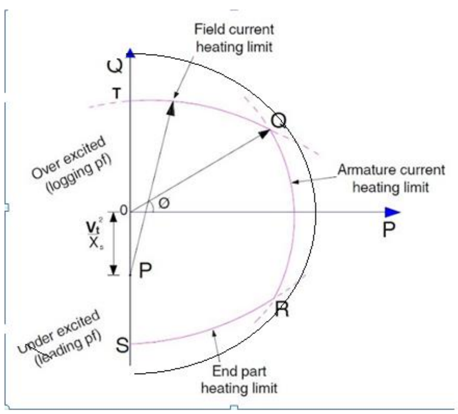


Figure 1: Ideal curve (circular) vs practical d curve

2.4.Modelling loads

Its important to correctly understand load behaviour with voltage change. A single load in reality might be powering thousands of individual devices. Hence, in transmission systems, the ZIP model is used as it models the 3 components of a given load, constant power, constant current, and constant impedance or admittance load. A constant power load automatically adjusts the equivalent impedance, lowering its drawn current with the inverse of the voltage to maintain constant power. A constant current load, has constant input current, and therefor its power varies linearly with voltage. A constant admittance load is the simplest, as it represents a classical load where power varies with the square of voltage. Majority of the grid is constant power and constant impedance, as modern power electronics maintain constant power draw, and motors are modelled as constant impedance during steady state draw. In real life load modelling, surveyors vary substation voltage slightly and see how current reacts to make a ZIP model of a given load. This allows proper prediction for load flow analysis

2.5.Modelling Transmission lines

A transmission line is simply modelled by its rated current, operating voltage, resistance, inductive reactance, and shunt admittance per kilometer. The program calculates these total values through its given length, and then applies either a T or PI model for modelling the line. The T model, while available, is not used because the Pi model is more accurate for real transmission line behaviour. For long lines, the user has the capability to choose a distributed model, which calculates the matrix parameters using sinh and cosh. the best way to model multi-sectioned lines in PSS/E, is by creating pseudo buses, and linking lines of different specifications.

2.6.Modelling transformers

The basic modelling of a transformer is identifying the turns ratio, and rating. PSS/E offers a few options, either by identifying the turns ration directly, primary and secondary nominal voltage, or by identifying primary and secondary impedance. In addition, is the importance of identifying vector group of the transformer to verify parallel operation. In basic parallel operation, its assumed that vector group is either 0 or 6 if its Yy or Dd, and 1 or 11 if its Dy or Yd. however, In this internship, We went in depth on how to identify vector group given primary and secondary polarity. This method is important for applied work, because of transformer rewinding maintenance where vector group can be changed. Hence, its important to be able to conduct a polarity test, and identify vector group.

3.Solving Transmission system

Given 2 nodes, the power flow between them is dependant on the power angle. The power angle is a deeply fundamental quantity in load flow analysis as it's the single quantity that describes how power flows between busses. Its simply defined, as the angle difference between the voltage at 2 busses.

In load flow analysis, we work on a steady state constant frequency system. But it must be stated, that the frequency of a given rotor fluctuates slightly, and that change, is what creates power imbalance. A generator near a load will naturally experience more MMF force from the load drawing electric power, so the rotors frequency will slightly decrease. If unloaded at all, generators frequency will increase as they experience no load torque. The relationship between the generator's actual frequency, the grid frequency, and the power angle is as such:

$$\frac{d\delta}{dt} = \omega_r - \omega_r.$$

This relationship is lost in the details of power flow, but it explains why frequency regulation is so important to the grid, as rotor frequency and tiny changes in it what determines power flow entirely.

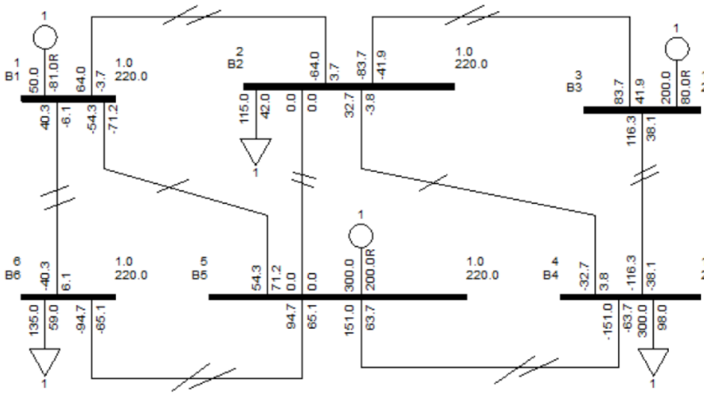
We've established, that if we know the voltage and its angle at every bus, wed know the exact power flow in all lines. Recall, in basic circuit theory, one would be given the source voltages, and an admittance matrix can be constructed using KCL to find the currents and power. This was an entirely linear solution. However, to find the inverse of KCL and determine the voltage, is nonlinear. The newton Raphson method is about linearizing the same admittance matrix using the Jacobian matrix. This essentially makes the complex system solvable.

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_2 \\ \vdots \\ \Delta P_{n-1} \\ \cdots\cdots \\ \Delta Q_1 \\ \Delta Q_2 \\ \vdots \\ \Delta Q_{n-1} \end{bmatrix} = \left[\begin{array}{cccc:cccc} H_{11} & H_{12} & \cdots & H_{1,n-1} & & & & \\ H_{21} & H_{22} & \cdots & H_{2,n-1} & & & & \\ & & \cdots & & & & & \\ H_{n-1,1} & H_{n-1,2} & \cdots & H_{n-1,n-1} & & & & \\ \cdots\cdots & \cdots\cdots & \cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots & \cdots\cdots \\ & & & & L_{11} & L_{12} & \cdots & L_{1,n-1} \\ & & & & L_{21} & L_{22} & \cdots & L_{2,n-1} \\ & & & & & & \cdots & \\ . & & & & J_{n-1,1} & J_{n-1,2} & \cdots & J_{n-1,n-1} \end{array}\right] \times \begin{bmatrix} \Delta\theta_1 \\ \Delta\theta_2 \\ \vdots \\ \Delta\theta_{n-1} \\ \cdots\cdots \\ \Delta V_1/V_1 \\ \Delta V_2/V_2 \\ \vdots \\ \Delta V_{n-1}/V_{n-1} \end{bmatrix}$$

Figure 2: Jacobian matrix, which linearizes admittance matrix

4.Assignment: modelling system and diagnosing loading

The aforementioned knowledge was gained practically, through this first assignment. Given the following data, I was expected to model a transmission system and diagnose current loading



Data

						ohm/KM			ohm/KM		
FROM	To	NO of Ct	KV	km	Rate(amp)	R	X	B*10-6	R0	X0	B0*10-6
B1	b2	2	220	11	550	0.052395	0.3213	3.25	0.13	0.83	2.23
B2	b3	2	220	6.2	400	0.016485	0.20958	62	0.202	0.07	52
B3	b4	2	220	3	500	0.052395	0.3213	3.25	0.13	0.83	2.23
B4	b5	2	220	30	400	0.119875	0.46414	2.59534	0.33897	1.2826	1.741287
B5	b6	2	220	Multi Sections							
B6	B1	2	220	7.8	400	0.016485	0.20958	62	0.202	0.07	52
B1	B5	2	220	7.4	600	0.119875	0.46414	2.59534	0.33897	1.2826	1.741287
B2	B5	1	220	25	500	0.04326	0.3171	3.72	0.11	0.95	2.5
B2	B4	1	220	11.6	500	0.04326	0.3171	3.72	0.11	0.95	2.5
b4	b444	b5									

القضبان	نوعه	ID_unit	P	Q	P_{max}	P_{min}	Q_{max}	Q_{min}	MVA
b1	توليد	1	Slack		450	150	400	-200	500
b3	توليد	1	100		150	30	80	-50	175
b3	توليد	2	50		50	30	40	-10	70
b3	توليد	3	50		50	30	40	-10	70
b6	توليد	1	150		250	60	200	-40	350
b6	توليد	2	200		300	80	180	-50	400

عدد الدوائر
14

		const P	const Cur.	const Y
القضبان	نوعه	P/Q		
b2	احمال	80/45	25/15	15/7
b4	احمال	250/100	50/30	20/12
b5	احمال	150/60	80/60	30/16
b6	احمال	80/45	30/12	20/10

bus	area	a_name	zone	z_name
1	1	aaa	1	aaa_z1
2	1	aaa	2	aaa_z2
3	2	bbb	1	bbb_z2
4	2	bbb	2	bbb_z3
5	3	ccc	1	ccc_z1
6	3	ccc	2	ccc_z2

Figure 3: Given data I modelled, and corresponding Sld diagram produced

In this internship, I learned the practical method to modelling a grid. The data is inserted using PSS/E's sav files which specify all the important data for all components. Its useful to input data in a grid format, as in larger systems its inefficient to input the information of each component individually. Then, using PSS/Es auto draw, the components are automatically placed, and its up to the user to organize them. This drawn, functional SLD, allows the user to read loading properly.

5.Solving Line over-loading

In a real work environment, its paramount to always run at acceptable loading in our transmission system. Special events, new facilities / industrial buildings, and normal growth, all cause increase in transmission line loading that must be studied and accounted for. Particularly, in the case of normal growth, bi annual studies are conducted to verify acceptable loading. In our particular case, a load was artificially increased over the given data to simulate solving an overloading issue, and we explored potential solutions to address the issue.

5.1. Operational solutions

These solutions are the first option for addressing overloading, as they are simple to implement without development costs

1. Changing generator loading

By increasing the power output of one generator and decreasing that of another, current gets rerouted depending on load position. Increasing the power output of a generator on the same bus as a load, for example, mitigates current moving through transmission lines at all. The advantages of this solution is it's the simplest, generator loading is normal procedure. However, changing generator loading is problematic, as it may no longer operate at its maximum efficiency point. Additionally, sometimes there isn't enough available local generated power to change loading as such

2. Disconnecting lines.

Disconnecting lines may appear counter intuitive, as the net conductor paths in the system decrease, so how could transmission line loading improve? The subtle detail however, is there exist longer path lines that are underutilized. By disconnecting a line, current is forced to move in those higher rating lines. When disconnecting a line, the line isn't entirely disconnected, but left floating (connected) at one end. This offer 2 major advantages, the lines Shunt admittance acts as a capacitor and improves voltage regulation of the transmission system, even if the line isn't transmitting power. Secondly, this guarantees the disconnected line is safe from theft, as its always at high voltage when floating from one end. The disadvantage of this solution, is longer current path leads to higher losses

3. Splitting bus bars

The third solution discussed, was rerouting current by splitting busses. by moving specific lines and specific loads on different sides of a bus, we are able to effectively isolate a load from specific lines, forcing the current to take the longer path. This is similar to disconnecting a line; however, we don't need to disconnect the line and therefore don't lower the net available current paths. This overall makes for a more efficient solution, because all current paths remain available, and the over loaded lines return to acceptable loading. Efficiency is largely case dependant however.

Determining which solution to apply, requires the reporting feature PSS/E. The report feature identifies the efficiency of the entire transmission system. by iteratively attempting solutions that lower loading to acceptable and checking efficiency, the best solution is identified.

5.2.Developmental solutions

With sustained growth over time, inevitably new developments must be made to account for increase in loading. Operational solutions are effective for efficiently utilizing existing infrastructure, but its necessary to identify and apply developmental solutions when necessary.

1.Building new transmission lines

This is the obvious option, as it increases the net conduction paths. However, it meets the practical issues of new towers, legal approvals, Tedious environmental studies and long development lead time. Building a new line is done, when necessary, but is preceded by the other solutions of rewiring conductors.

2.Rewiring conductors.

Rewiring conductors can be a more cost effective, quick solution. Because the existing infrastructure exists, its only matter of replacing the low-capacity conductors with higher capacity lines. This solution has a hard limit of weight. The existing towers, have a rated weight capacity, limiting the maximum current rating possible for a given line. If the increase in capacity isn't enough to fix overloading, building new lines is considered.

6.Voltage control

The second important goal of load flow analysis is maintaining correct nominal voltages at bus bars and loads. In practice, voltage usually decreases from the nominal due to overloading of the grid. Thus, strategies exist to mitigate voltage drop and maintain stable voltage within $\pm 5\%$ of the nominal value.

The main mechanism by which voltage is controlled is tab changers in transformers. On most give grid transmission transformers, are tabs which allow change of the turns ratio. Tabs come in 2 types: Off circuit de energized tabs, and on load tap changers (OLTCS). Off circuit tabs are more planning tools, and are changed during maintained periods to meet anticipated demand based on load forecasting. OLTCS on the other hand, respond to local changes in voltage depending on loading condition. Tabs are always place near high side voltage. The reason being, transformers are passive elements that conserve power, so at the high voltage side, there must be less current than the low voltage side given $P = IV$. Higher current leads to hotter, short arcs during tab changing which cut the lifespan of the tabs.

Tab changing is done constantly in grid operation to respond to local load changes, however system wide Increases or decreases in reactive power require more drastic addressal: adding shunts. Shunt devices are passive capacitors or reactors, as capacitors produce reactive power, and reactors (inductors) consume it. Now, the grid is naturally consuming reactive power, often increasing with loading, as it's dominated by inductive loads, such as motors, transformers, and the transmission lines themselves. As such, there are often more capacitive shunts used on a grid and more emphasis on their types and operation. In the following section, I elaborate on their types and operation

6.1. Fixed shunt

This is the simplest type of shunt and is simply a fixed value connected to the grid, and it can be a capacitor or reactor. It's the most economical option, as it doesn't rely on complex power electronics and has no switching losses. However, it has poor voltage regulating in reacting to dynamic loads.

6.2. MCSR Switched shunt

A switched shunt is an improvement over a fixed shunt as it offers a discrete number of steps of shunt value it can activate depending on need. Instead of one single fixed value, multiple values are connected in parallel. The switched shunt then disconnects or connects to achieve the best fit value needed for a given loading. This is more economical than dynamic shunts, whilst offering some dynamic voltage regulation.

6.3.Dynamic

Dynamic shunts offer a continuous range of shunt values, and they're powerful at meeting exact grid tolerance for reactive power and voltage. There are 2 main types of dynamic shunts: SVC and STATCOM. SVC is the older type of dynamic shunts, and it relies on thyristors and passive to control shunt value. Thyristors allow for change of duty cycle by parodically turning them on and off. However, this produces a non sinusoidal waveform. SVCS include passive LC filtering which produce an output sinusoid which has a different phase angle. By changing the duty cycle of firing, SVCS effectively change the angle and therefore reactive power of the input current.
The main disadvantage of SVCS, is their incapability to preform at low voltages. Because they include passive filtering devices, the current they can provide drops depending on voltage drop

Statcoms, on the other hand are complete ac sources. The function by internally rectifying input ac, converting it to dc, then using IGBT inverters, produce any waveform of any needed angle automatically. Because Statcoms are active sources, they're not limited by input voltage and are capable of preforming in low voltage grids. Statcoms are a relatively newer technology, and require higher initial investment than the mature SVCs, however they're becoming increasingly popular due to their advantages.

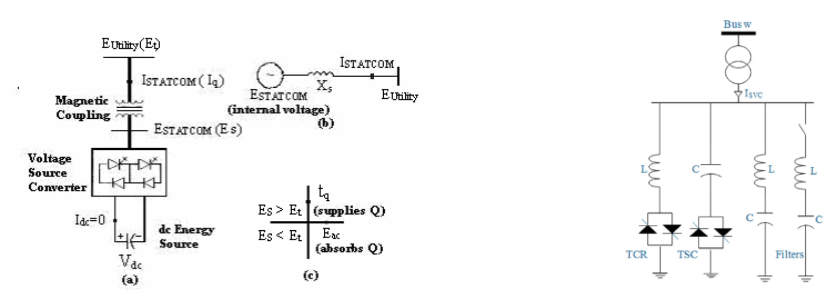


Figure 5: Left: STATCOM simplified circuit diagram, Right: SVC circuit diagram

7.Assignment: Voltage control

In this given assignment, we found the voltage at a specific bus was lower than acceptable nominal. I initially thought, that new capacitive shunts had to be installed, or that more generator capacity needs to be applied. However, the instructor reviled a much simpler solution, to disconnect a nearby reactive shunt. This demonstrated to me the passive nature of transmission line operation, seeking the simplest, quickest solution, and being able to notice them.

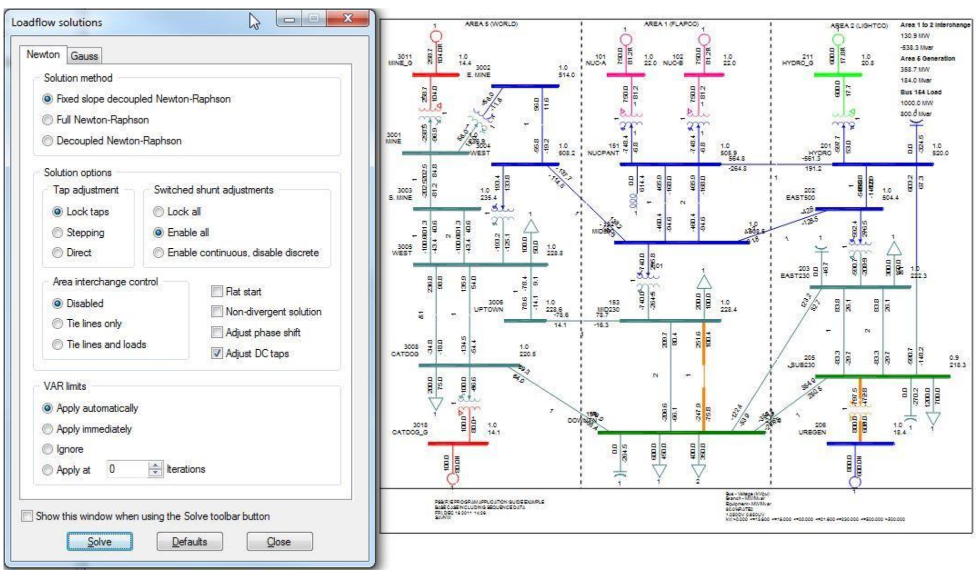


Figure 6: SLD of example system which was worked on in assignment. Bus 151 was undervoltaged, and to fix the issue the reactor shunt was disconnected

8.Areas, Zones, and large system modelling

In real work application, transmission systems must encapsulate a large system as a whole. As such, PSS/E includes the owner, areas and zones system to clarify where transmission systems are. Because grid interconnection is useful, modern transmission systems span the entire world, not just the local region. However, its impractical, for local calculations, to model every transmission system in the world every time a load flow is conducted. At the same time, its necessary to correctly account for power draw of all inputs and outputs to your local system.

To solve this, we construct an electrical equivalent at the connecting nodes. The externally connected system is modelled as an nxn, (where n is the number of nodes) admittance matrix. This electrical equivalent multiport allows simplification of solutions. If given the entire transmission system, one can simplify neighbouring areas into the equivalent multiport. In real work environment however, network data of this form is shared between countries and areas, and if data is unavailable, tests can be conducted at the connecting nodes to determine an electrical equivalent.

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_1 & Y_2 \\ Y_3 & Y_4 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

Figure 7: Multiport admittance matrix of a 2-node system

9.Conclusion

This IT1 training was effective at building foundational knowledge of the transmission system, and utilizing PSS/E to model it and solve it. For me, it was foundational and largely helpful with university work as it gave a me a lens into the real-world use of the concepts, I relearned in fall 2025. TO summarize the knowledge gained, This IT1 training explained how to model a transmission system, how its solved, how to diagnose over loading and under voltage, and finally extended it large scale system.