Electric Substations in the growing Power Grid

Christopher Le, Electrical Engineering

Mentor: Dr. Saeed Monemi

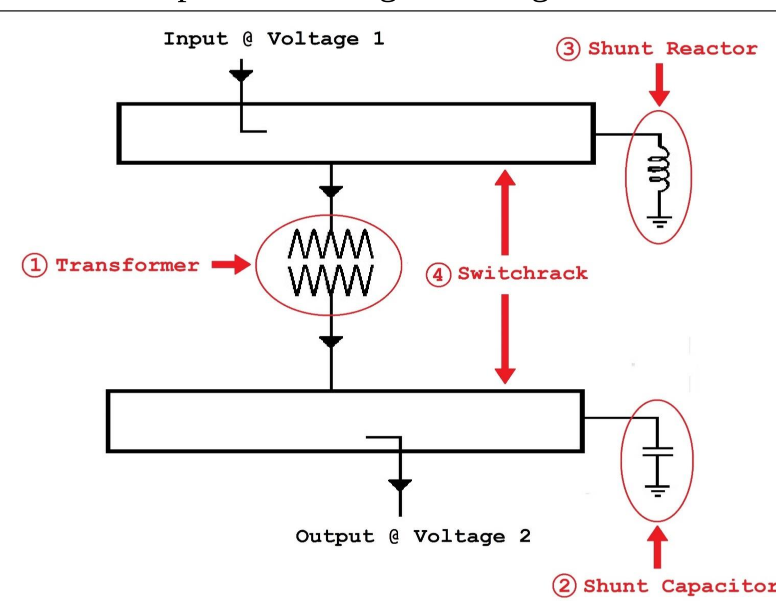
Kellogg Honors College Capstone Project

CAL POLY POMONA

Abstract: As renewable energy sources are being implemented into our power system, delivering reliable power to the consumer has become much more difficult. In the state of California, state officials have mandated utilities to have 33% of the electrical grid supplied by renewable energy by 2020. There are concerns with these new types of energy sources. These renewable sources are neither highly reliable nor consistent as compared to the generation sources of the pre-renewable integration grid. To deliver power to the consumer, the utility companies have 3 distinct parts to the power grid: transmission, substation, and distribution. Transmission and distribution are parts of power delivery we see in our daily lives from the giant wires that are strung high above our heads. Electric substations are the part we do not see clearly. Even though we do not see the electric substation in our daily lives, they play a huge role in how electricity is delivered to us by transforming the voltages to either minimize losses or to a usable level. Because of the new renewable energy sources and the exponentially growing electricity usage, more electric substations are being built at a rapid rate. To deliver reliable power, a substation must have schemes to allow it to be cost effective, flexible, and reliable. The goal of this project is determine how an electric substation achieves these three characteristics. In order to do so, the main components of a substation will be analyzed to see how they affect the substation in those three characteristics. Also different bus configurations will be analyzed using PowerWorld (a simulation program) to research the power flow of system.

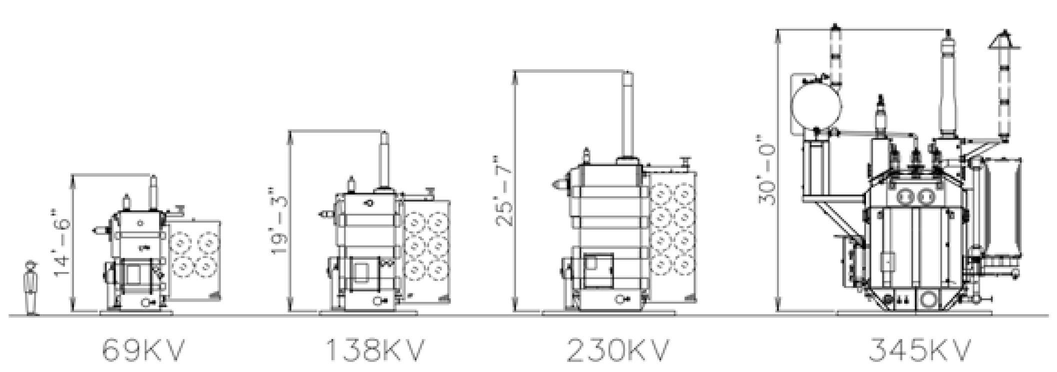
What is an Electric Substation?

Substations take the electricity from generation sources (e.g. Fossil fuels or renewables) and from the transmission lines and "step-up" or "step-down" the voltage. They also distribute electricity to the consumers and supervise and protect the power grid to keep it working safely and efficiently. For example if there is a problem, for example downed power line, high voltage circuit breakers will cut the power to mitigate damages.



1) Transformer

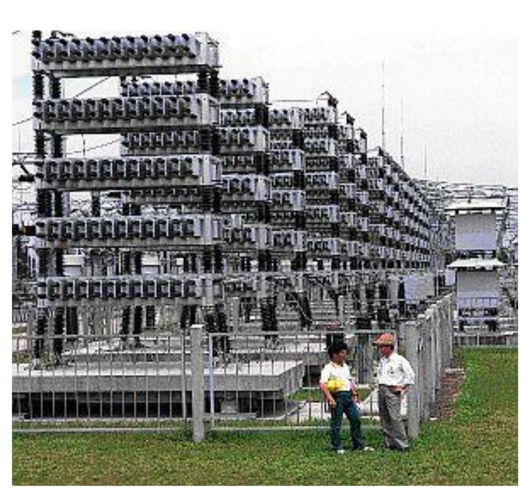
A transformer is a device that allows us to "step-up" or "step-down" AC voltages. When we transmit bulk power from long distances away, we "step-up" up the voltage to mitigate losses. Then the voltages are "stepped-down" to a usable level for consumers. Transformers are the reason why we do not mainly use DC to transmit power. AC is more efficient and cost effective up to lengths of about 250 miles, which nearly all of our power lines fit this range.



2) Shunt Capacitor

The load of the system, the electric devices that we turn on, are all of inductive nature (e.g. washing machines, dishwashers, electric furnaces, fluorescent lighting, etc.). As the load increases during peak hours, the load becomes more and more inductive. This causes the current to lag behind the voltage more and more which causes a power factor decrease. With a decreased power factor and the same active power demand, the current from the source increases and consequently, with more current means more line losses. Also with a lower power factor the voltage regulation becomes poor, which means that you may not be getting the guaranteed 120 Volts from your wall plug.

To compensate for the increase in inductive load, a shunt capacitor is put into place. Since capacitive load and inductive load are opposite, the shunt capacitor will compensate for some of the load. This will reduce the current flowing the in lines which mitigates losses and will increase the power factor which will help the voltage regulation to stay relatively nominal. Usually shunt capacitors are placed in substations that are at the distribution voltage level such as 12 kV.



3) Shunt Reactor

Transmission lines are naturally capacitive and inductive. In a shorter transmission line, the capacitance of a line is very low; however, lately as we have been incorporating renewable energy sources into the grid, lines have been getting longer. Renewable energy sources tend to be in remote areas such as deserts and large rivers, but large loads tend to be far from these places. This causes us to build extremely long transmission lines. Since the load of the system is inductive in nature the capacitance of the line is usually compensated by the load. However, in a no-load or light load situation, the capacitance of the line comes into play. The capacitance of the line continues to supply reactive current which is in phase with the sending side's voltage due to a lack of inductive load. This in turn causes a voltage drop over the transmission lines inductance that increases additively as we approach the load side. This will then cause the load side to have a higher voltage than the sending side. This effect is called the Ferranti Effect. This is not optimal due to the fact that this voltage can exceed ratings of equipment and damage them.

To compensate for this effect, we can install a shunt reactor, shunt inductor, at the sending side. This will do the same job as the shunt capacitor except in the opposite way. It will compensate for the capacitance of the long transmission line. These are usually found in bulk power transmission voltage levels such as 500 kV.

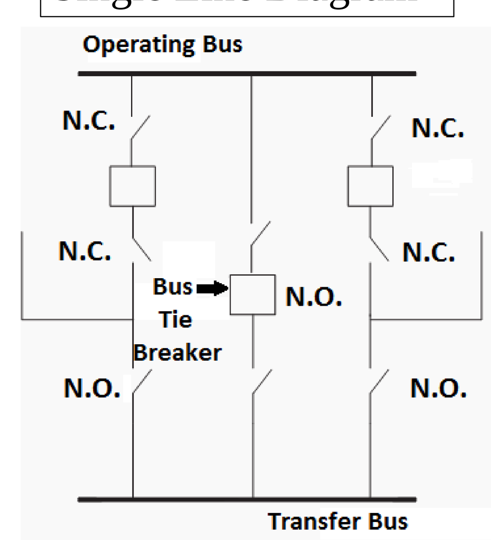
4) Switchrack

Switchracks are the nodes that connect the entire power grid together. The job of a switchrack is to protect the equipment. The switchrack consists of conducting buses and circuit breakers arranged in a way to always have the electricity flows through a circuit breaker for protective reasons. Switchrack configurations can vary depending on the amount of reliability and cost. Below are a few common configurations with their pros and cons.

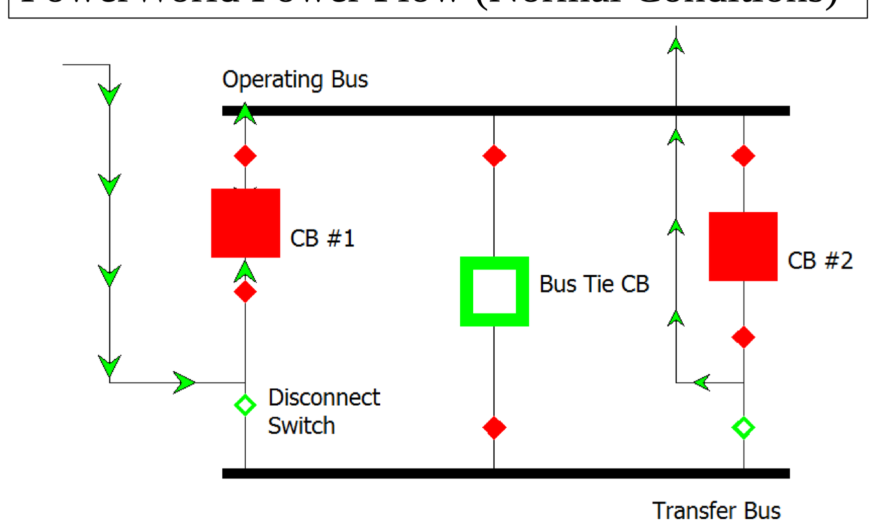
Operating/Transfer Bus Configuration

Pros	Cons
• Circuit Breaker maintenance without interrupting circuits	• Relaying and switching schemes are complicated
• More reliable than Single Breaker Single Bus Configuration	• Normal Operation is Single Breaker Single Bus Configuration
• Relatively Cheap	• No protection in Bus Tie configuration

Single Line Diagram



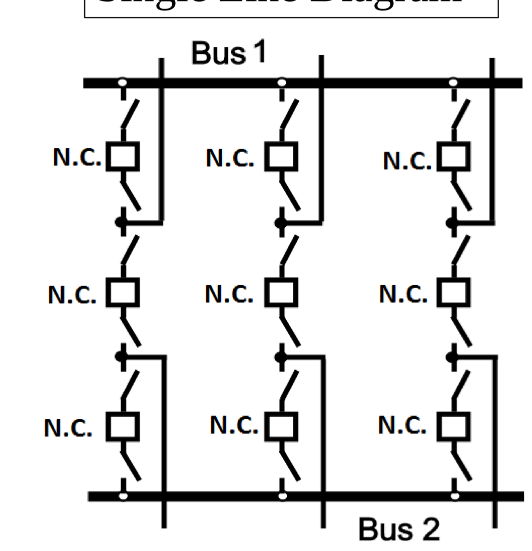
PowerWorld Power Flow (Normal Conditions)



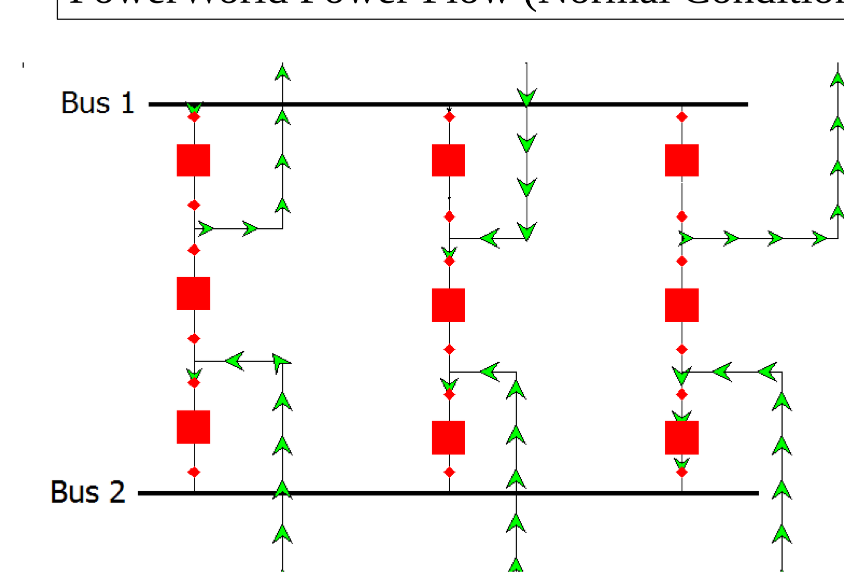
Breaker and a Half Configuration

Pros	Cons
• Any Circuit Breaker can be removed without interrupting a circuit	• 2 circuits share center breaker
• Very reliable and expandable	• Failed center breaker = 2 lost circuits
• Cheaper than Double Breaker Double Bus Configuration with minimum less of reliability	• Protection scheme is complicated
	• Requires lots of space

Single Line Diagram



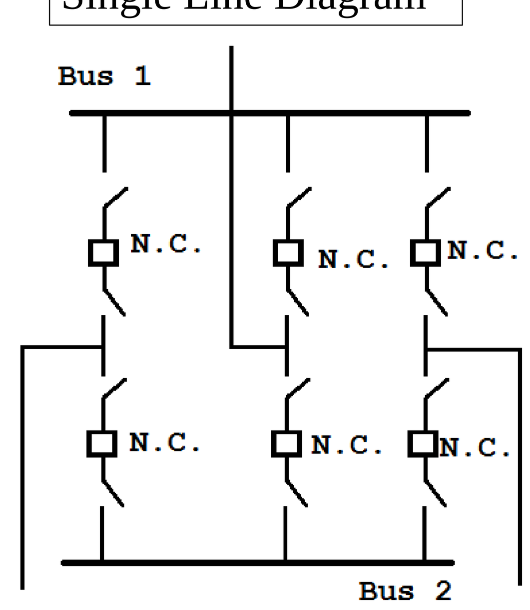
PowerWorld Power Flow (Normal Conditions)



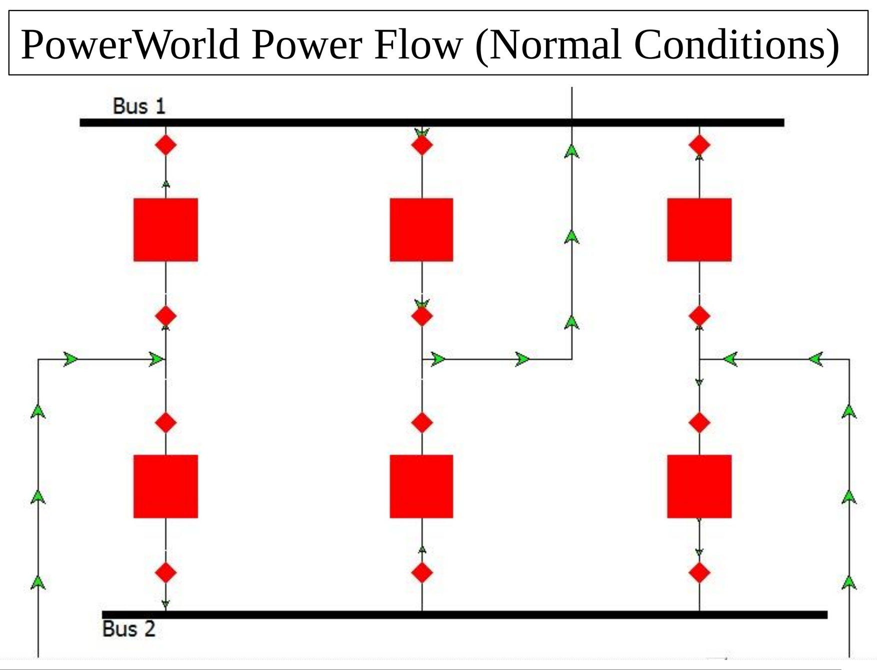
Double Breaker Double Bus Configuration

Pros	Cons
• Bus faults do not interrupt circuits	• Expensive- 2 Breakers and 4 switches per circuit
• Circuit faults do not affect any other circuits	• Physically large
• Breaker failure = only 1 lost circuit	
• Very reliable and expandable	
• Any Circuit Breaker can be removed without interrupting a circuit	

Single Line Diagram



PowerWorld Power Flow (Normal Conditions)



Conclusion

As the power grid continues to grow, more and more electric substations are being built to accommodate the consumer. Due to renewable energy integration, more of these compensation devices will be needed. Switchrack configurations will be determined by weighing the pros and cons for each individual situation.