INTERCONNECTION AND TRANSMISSION CONSIDERATIONS IN RENEWABLE ENERGY DEVELOPMENT IN UKRAINE

This appendix provides additional background information on interconnection and transmission issues for Ukraine. The interconnection constraints section provides background on potential interconnection considerations at different voltage levels and project sizes. The transmission constraints section discusses the overall constraints of the national power system for renewable energy development. It also examines the transfer capability of the existing transmission system between regions and existing load to absorb the renewable energy generation. All of these are factors in developing estimates of maximum renewable energy development scenarios for various regions.

In the mid-1990s, the Ukraine government re-structured the power sector to allow for competition between electricity producers. The ownership and management of the sector was split into generation assets, the transmission network, distribution assets, and the power market (Energorynok). The state transmission company, Ukrenergo, owns and operates the transmission grid, and is independent of the generation and distribution companies. Ukrenergo collaborates closely with the market operator, Energorynok, but the two entities are separate.

The bulk electrical energy on the Ukrainian system is transported primarily on 750 kV and 330 kV transmission lines for long distances and on 110 kV lines for shorter distances. Twenty-seven distribution companies deliver energy to the end use customers over 0.5 kV to 35 kV distribution lines.[1]

1. INTERCONNECTION CONSTRAINTS

There are three main voltage classes to a power system: distribution, subtransmission, and transmission.

- Distribution voltages would likely include voltages up to 35 kV in Ukraine. Distribution is the voltage class that typically serves local loads, such as residential and commercial.) The distribution system is characterized as being outdated and have not been renovated in the past 30-40 years. The variability of wind and solar resources cannot be controlled properly by existing substation automation.

- Subtransmission voltages in the Ukraine would likely consist of the 110 kV network, but typically encompasses the range from approximately 69 kV to 200 kV. Subtransmission is the voltage class in between the load serving and the bulk delivery of power across the power grid. Sometimes this voltage class is associated with transmission, but is pertinent to differentiate when discussing renewable resource interconnections.

- Transmission can be categorized as voltages over 200 kV, primarily 330 kV and 750 kV in the Ukraine. Transmission is the voltage level that transfers power across longer distances with lower system losses, and is the link between the large generation facilities and load centers. Transmission is mostly alternating current (AC) in the Ukraine, but high voltage direct current (HVDC) transmission is seen between neighboring countries, most likely to be able to control “islanding” of power systems between bulk electric transmission providers.

The majority of Ukraine’s thermal generation capacity, such as coal and nuclear, is connected to the grid at subtransmission and transmission voltages. However, the remote

[1] Jennex, Murray E. (2003) "IT Use in the Utilities of Ukraine, Armenia and Georgia," Communications of the Association for Information Systems: Vol. 11, Article 24.
Available at: http://aisel.aisnet.org/cais/vol11/iss1/24)

location or smaller size of many renewable energy projects may require them to connect to distribution-level voltages.

Projects interconnecting at the distribution system to serve local load should not be sized larger than the minimum load. This prevents power from backfeeding onto the subtransmission and transmission systems. The minimum load can be either the load at the end of a radial line (if tapping a distribution line), or the total load served from a substation (if interconnected directly at the substation). Figure 1 illustrates the relationships between transmission, subtransmission, distribution, and load, whether radial or networked.

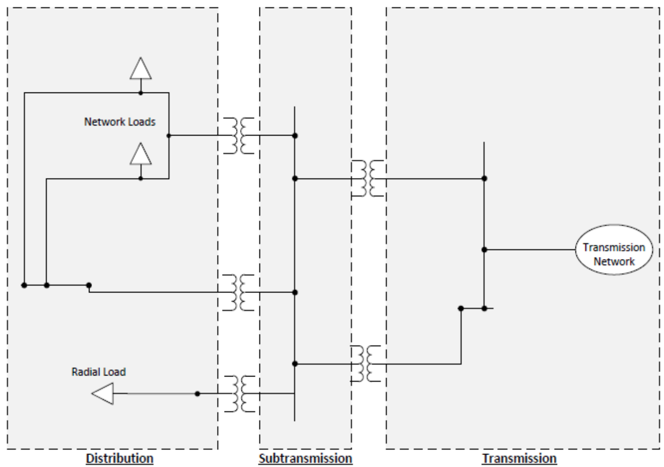

Figure 1. Typical Electrical System

It is generally better to interconnect at a distribution substation rather than tapping a line, due to the limited amount of load on radial circuits as well as stability concerns due to voltage flicker[2] and harmonic[3] content. It is also very important for interconnections to the distribution system to be able to provide reactive power[4] support to the distribution system, to eliminate many of the stability concerns due to voltage rise and drop. Long, radial distribution lines have a high amount of power losses to the end of the circuit, which can cause a large voltage drop at the receiving end. It is important, in these instances, for the generating facility to be able to provide voltage support to offset the losses due to the increased amount of power flowing on the system at the point of interconnection. Distribution interconnections should be able to provide voltage support from a range of 0.90 leading power factor to 0.90 lagging power factor.

Projects interconnecting at the subtransmission level can be larger due to the amount of load that is served from these substations, as they typically are networked to many distribution and transmission substations. It is not as important to size these to be less than the minimum load, unless they are radial in nature between a transmission and distribution center. Higher voltages decrease the amount of fault current seen on the system by a generating facility, and equipment is generally sized with higher fault current allowances due to the amount of power carried on a subtransmission system.

Interconnections into the subtransmission system should also loop-in subtransmission lines if not going directly into a subtransmission substation, but are not necessarily required. Each transmission owner has different guidelines for tapping a line. Interconnecting at the substation directly is better than looping-in a subtransmission line due to multiple outlets for power export. Generating facilities should be able to provide reactive power support to

[2] See Appendix B for the definition of voltage flicker
[3] See Appendix B for the definition of harmonics
[4] See Appendix B for the definition of reactive power

the subtransmission system as well. These systems are often more networked, so large losses are not as common; however, voltage regulation for power factors ranging from 0.95 leading to 0.95 lagging should be designed into the plant.

Generation projects interconnecting at the transmission system level should be relatively large in size due to the complexities of interconnecting onto higher voltages. Interconnections at higher voltages must offer more reliability by either looping-in a transmission line by ring bus or breaker-and-a-half (BAAH) schemes, or interconnecting directly into the transmission substation. Tapping a transmission line is not a reliable means to access a system, as transmission lines have to carry large quantities of power across large areas. If the generator trips, it should in no way inhibit the operation of the transmission line. Transmission systems operate at high voltages with multiple interconnections, so voltage swings due to losses are not as common. Interconnected generators should be capable of providing voltage regulation for power factors ranging from 0.95 leading to 0.95 lagging for reliability purposes.

When integrating large amounts of renewables in a specific area, it is important to study these together for loading and stability issues, and also to gather them in some sort of reasonable, open and transparent queue. It is important to study projects together so that system equipment upgrades can be phased in to facilitate the delivery of each project as each is completed. This process is extremely important when studying the distribution system, due to aging equipment, loading issues, and fault current considerations of the lower voltage systems.

2. TRANSMISSION CONSTRAINTS

Ukrenergo operates the central dispatch centre in Kyiv and the high-voltage transmission lines across Ukraine, and is also responsible for maintaining and upgrading those lines as necessary.[5] The national system is divided into eight regional electric power systems as shown in Table 1.

Table 1. Regional Electric Power Systems and Oblasts

Regional Electric Power Systems	Oblast
Central	Cherkasy
	Chernihiv
	Kyiv
	Zhytomyr
Crimea	Crimea
Dnipro	Dnipropetrovsk
	Kirovohrad
	Zaporizhia
Donbass	Donetsk
	Luhansk
Northern	Kharkiv
	Poltava
	Sumy
Southern	Kherson
	Mykolaiv
	Odessa
Southwestern	Chernivtsi
	Khmelnytskyi
	Ternopil
	Vinnytsia
Western	Ivano-Frankivsk
	L'viv
	Rivne
	Volyn
	Zakarpattia

Overall, the majority of the generation capacity in Ukraine is thermal power plants (64%). Nuclear power plants account for 26% of the capacity and hydro for another 9%. Ukraine currently has significant excess power production capacity, as power generation has

[5] "Ukraine Energy Policy Review 2006," International Energy Agency. 2006.

dropped considerably following the dissolution of the Soviet Union. A significant amount of power generation capacity is centralized in the Dnipro and Donbass Electric Power Systems. Ukraine also exports electricity to neighboring countries, though export volumes have been dropping over the past few years as the regional economy has declined. Its thermal plants have been operating well below historical load factors, though many of the units are in disrepair and may need to be retired.

At present, any increased renewable generation in the country would displace the production at these thermal and nuclear facilities, unless the economy improves and demand in and around Ukraine increases. Furthermore, these large baseload facilities cannot react quickly to the variable nature of renewable resources, such as wind and solar. Any significant amount of variable renewable energy development would require more quick-response generation capacity, such as dispatchable hydropower, pumped storage, and gas-fired combustion turbines, as well as improvements in grid management technologies.

In addition to the limitations associated with the existing generation and outdated grid management technology, the transfer capabilities of the existing transmission lines and existing load will also constrain the amount of renewable energy that can be developed in different parts of the country. Black & Veatch estimated the maximum potential build-out of wind and solar by examining these constraints. Due to limited information regarding the transfer capabilities of the system, Black & Veatch estimated the transfer capabilities from oblasts using representative capacity estimates for each transmission voltage for lines greater than 220 kV as shown in Table 2. Lower voltage transmission and distribution data were not available.

Table 2. Transmission Capacity Estimates

Transmission Type	MW Capacity
750 kV AC Single	3000
500 kV AC Single	1500
330 kV AC Single	750
220 kV AC Single	400
500 kV DC Bi-Pole	3000
800 kV DC Bi-Pole	5000

Table 3 presents the estimated transfer capability between oblasts, as well as the 2010 annual energy demand, peak load, and generation capacity by oblast. As shown in Table 3, most oblasts in Ukraine have excess generation capacity to export and tremendous transfer capability with neighboring oblasts; however, the neighboring oblasts with its own excess generation and limited load would not be able to absorb all of the exported renewable energy from its neighbors. Thus, the transfer capability is a theoretical maximum for estimating the export capacity of renewable energy from an oblast, but it is not realistic except in a few cases. A more conservative approach is to assume that the renewable resource is either limited by the availability of the resource in the region or by the load in the immediate region that can consume the energy, whichever is lower. These limitations were used to create the Regional Development Scenarios for Wind Only, Solar Only and Combined Wind and Solar Scenarios. Items in green represent resource limitations; grey reflects transfer capability limitations; and blue represents regional load limitations.

For example, in Crimea, there is considerable wind potential but limited transfer capability with its neighbors, so the maximum wind and/or solar development is based on the oblast's transfer capability and net import requirements. Additional transfer capability may be possible with the new or upgraded lines out of Crimea, but this analysis did not assume any transmission line upgrades. For the Western region, where there is considerable wind potential in Lviv, Rivne, and Ivano-Frankivsk and extensive transfer capabilities, the limitation in this region is the regional load. It is assumed development is capped at the local load. It is possible that more could be developed if any excess production can be stored in hydro pump storage facilities or exported to neighboring countries, but for purposes of the SER, development is assumed to be limited based on in-country load.

This approach also does not take into account operational considerations due to local distribution limitations, operating reserve, planning contingencies and generation/load balancing requirements for the system operator. For more precise estimates, appropriate load flow and other transmission modeling analysis would be needed on a case by case basis. There may also be cumulative effects with projects in neighboring oblasts that would connect at different points along the same transmission line that were not entirely accounted for.

Table 3. Ukraine Load, Generation, and Renewable Energy Scenarios

		Load Cap		acity			Wind Only Scenario			Solar Only Scenario	Combined Wind and Solar Scenario	
Regional Electric Power Systems	Oblast 2010	Annual Demand (GWh)*	2010 Peak Load (MW)*	Total Generation Capacity (MW)**	Net Export/ (Import) (MW)	Transfer Capability (MW)***	Technical Potential for Wind (MW)	Development Potential in Oblast (MW)	Regional Development Scenario (MW)	Regional Development Scenario (MW)	Regional Wind Development (MW)	Regional Solar Development (MW)
Central	Cherkasy	3,593	351	1,373	1,022	1,900	813	813	1,229	1,800	1,229	571
	Chernihiv	2,141	216	200	-16	3,000	0	0				
	Kyiv	9,465	963	3,944	2,981	21,000	333	333				
	Zhytomyr	2,721	270	-	-270	2,250	83	83				
Crimea	Crimea	5,335	525	336	-189	2,650	7,021	2,839	2,839	2,839	2,129	710
Dnipro	Dnipropetrovsk	30,090	2,670	5,334	2,663	11,250	229	229	2,979	3,980	2,979	1,001
	Kirovohrad	3,238	327	7	-320	4,150	646	646				
	Zaporizhia	10,514	983	10,973	9,990	21,000	2,104	2,104				
Donbass	Donetsk	25,674	2,389	10,685	8,296	19,900	1,521	1,521	3,526	0	3,526	0
	Luhansk	12,019	1,137	1,928	791	12,650	2,292	2,292				
Northern	Kharkiv	8,115	804	2,985	2,181	12,000	0	0	229	0	229	0
	Poltava	5,845	543	274	-269	2,250	229	229				
	Sumy	2,523	238	125	-113	13,500	0	0				
Southern	Kherson	2,629	252	455	203	10,900	1,979	1,979	1,281	1,281	961	320
	Mykolaiv	3,372	329	3,495	3,166	15,800	63	63				
	Odessa	7,018	700	-	-700	18,400	833	833				
Southwestern	Chernivtsi	1,562	168	1,053	885	3,750	396	396	894	0	894	0
	Khmelnytskyi	2,578	252	2,000	1,748	14,250	250	250				
	Ternopil	1,457	149	-	-149	3,000	3,438	3,149				
	Vinnytsia	3,443	325	1,818	1,493	16,500	0	0				
Western	Ivano-Frankivsk	2,675	229	2,401	2,172	6,050	6,042	3,878	1,408	0	1,408	0
	L'viv	5,047	508	729	221	18,200	12,083	12,083				
	Rivne	2,765	261	2,880	2,619	9,800	2,438	2,438				
	Volyn	1,692	168	9	-159	3,450	0	0				
	Zakarpattia	2,226	242	32	-210	7,600	0	0				

Source:
*Ukrenergo data
**UDI data
***Black & Veatch estimates

Resource Limited

Transfer Capacity Limited

Regional Load Limited

For purposes of the SER, the scenarios developed are an acceptable indication of the development potential in good resource areas, but should not be used for system planning purposes.

Regional Electric Power Systems and Renewable Energy

(a) Crimea

Crimea is a net importer of power. There are four major transmission lines available to export power from Crimea to the rest of Ukraine. The approximate amount of power that can be imported or exported from Crimea from or to the north is estimated to be 2650 MW based on representative capacity on the transmission lines. In 2010, the peak load in Crimea exceeded the generation capacity in Crimea by approximately 190 MW. Renewable energy development could serve this load directly instead of relying on imports from the north. This allows for a total maximum development in Crimea of approximately 2800 MW to serve local load and export north.

Moderate wind resources are located in the eastern, western, and central part of Crimea. These areas are relatively flat areas that are good for development. The southern portion of Crimea has moderate wind resources, but is occupied by the Crimean Mountains, which are generally too steep for utility-scale wind development.

In the eastern portion of Crimea near the CHP (Kerch) power plant, the development is limited by a radial 220 kV transmission line that connects to the main 330 kV transmission system at the Simferopol substation in the center of Crimea. The Simferopol substation then connects north into the Southern and Dnipro electrical transmission systems. The radial 220 kV transmission line limits the development capacity to approximately 400 MW. Similarly, there is some wind development potential in western Crimea where a single 220 kV line connects the region to the northern border of Crimea. This area may be limited to 400 MW as well. The eastern and western regions would need transmission upgrades or additional transmission lines to reach overall wind development of 2800 MW.

The total maximum development potential for wind in Crimea is about 2100 to 2800 MW, based on transfer capability and net load.

The entire oblast of Crimea, with the exception of the area south of the Crimean Mountains, has some of the best solar resources in the country available for development. The limitation in developing the solar resource is the transmission system. The only way to transfer t power from Crimea to the Ukrainian backbone transmission system is to the north via three 330 kV and one 220 kV transmission lines. The total transfer capability of these lines is approximately 2650 MW. Accounting for the net load in the oblast, this equals a total maximum development potential for solar in the oblast is about 2800 MW.

In general, it is anticipated that both solar and wind projects will be developed in Crimea, for purposes of the SER, a combined scenario would contain about 2,130 MW of wind and 700 MW of solar.

This development potential may be reduced further by resource developments in Kherson and Zaporizhia, reducing the export capabilities on the tie lines connecting to these oblasts from Crimea. Since Crimea is isolated from the major transmission backbone, it would rely solely on these tie lines to export excess capacity out of the oblast.

(b) Southern Coastal Ukraine (Odessa, Mykolaiv, Kherson)

There is a 330 kV transmission system that connects Ukraine to Moldova that runs through Odessa. Along the southern coast of Odessa, near Mykolaiv, the Usatove and Adzhalyk 330 kV substations appear to have adequate transmission into the neighboring country of Moldova and to the north and northeastern Ukrainian transmission systems.

Odessa is a net importer of power. About 700 MW of peak load could be served by local generation resources instead of being imported from outside of Odessa. There is adequate export capacity on the 330 kV substations along the southern coast where good wind resources are located. The maximum available export capacity in Odessa at the Usatove and Adzhalyk 330 kV substations totals approximately 4000 MW.

Since Odessa currently imports generation, it has the capability to serve local load and export excess power over the 750 kV, 330 kV, and 220 kV transmission systems with renewable energy development.

Mykolaiv is currently a net exporter of power and has limited good wind resources. Its solar resources are also not as good as Odessa.

Kherson currently generates more than its load by approximately 200 MW. There is a robust 330 kV transmission system within Kherson and two 750 kV transmission lines, which allows for development potential in the oblast.

The wind resource in the region is along the coast and can be greater than 2500 MW. The wind resource in the center of Kherson can accommodate more capacity if interconnected at Kakhovska 330/220 kV substation. The capacity into that substation is approximately 4150 MW. However, since there is limited load in the region, it is assumed that the development is limited to 1280 MW in a wind only scenario, with projects located mainly along the coast in Kherson and Odessa.

In Odessa, the solar resource is moderate to high throughout the oblast and the solar resource is moderate across the oblast of Kherson. The solar development potential is not transmission constrained assuming the resource can connect into the transmission system. The limitation is the ability of the regional system to use all of the excess energy. In the solar only scenario, the maximum development potential for solar in the Southern Region is about 1280 MW, with most of the projects located in Odessa.

Overall, the Southern Coastal region can accommodate a large amount of resource development based on transfer capacity on its transmission, but the limitation would be based on the load in the region. For a combined scenario, it is assumed that wind development would be 960 MW and solar development would be 320 MW.

(c) Dnipro Region (Zaporizhia, Kirovohrad, Dnipropetrovsk)

There is plenty of export capacity from Zaporizhia to neighboring oblasts, though there is already significant generation capacity in the region. The development potential would be limited due to the excess capacity, even though the transmission system is robust with multiple 750 kV transmission lines. The development in the oblast could be exported to other oblasts via the 750 kV transmission network, though all the neighboring oblasts appear to be net exporters as well and would not be able to absorb the excess energy.

There is good wind power density in the southern half of Zaporizhia. However, there are limited transmission substations along the coast, so the first main point of interconnection may be at Molochansk and Melitopol. Between these two 330 kV substations, an approximate substation capacity is 1500 MW. The other benefit to this is that there is a looped transmission system between these two substations, so there is more redundancy under a 330 kV transmission outage. The wind development in the region is only limited by the resource itself. It is estimated that wind development could be up to 2100 MW in Zaporizhia, 650 MW in Kirovohrad, and 230 MW in Dnipropetrovsk.

The region has moderate to high solar development potential and the land is relatively flat for solar development. Zaporizhia has a robust transmission system in the central portion of the oblast, away from the coast. This transmission system could allow for substantial solar development as well. In a solar-only scenario, the total development could be up to 4000 MW of solar in the region with most of the solar development in Zaphorizhia. Less development of solar and wind is expected in the other two oblasts in this region due to lower quality resources.

In a combined scenario, it is estimated that the regional wind development would equal 3000 MW and solar development would be about 1000 MW.

(d) Donbass (Donetsk/Luhansk)

While there is capacity likely reserved for exports and imports to and from Russia, there is adequate transmission capacity for wind resource interconnection in the region of Luhansk. There is approximately 1900 MW of transmission capacity at Permona 500/220 kV substation alone, injecting into the Donbass electrical transmission system. There is a robust 220 kV transmission system that ties into the 800 kV HVDC transmission line into Russia, as well as the 750 kV transmission backbone running west through the country.

Luhansk currently generates more than their load by approximately 800 MW.

In Donetsk, there are two substations: Zorya 220 kV substation and Myrna 330 kV substation. Both of these substations inject into the main transmission system in Donetsk, including a 750 kV transmission line from east to west. These substations could potentially accommodate 1500 MW of wind. There is more wind potential further north where there is plenty of access to transmission. Overall, there is adequate transmission access for wind development.

The wind resources in the both of these oblasts are moderate towards the southern portion of the oblasts. The wind resources are near high voltage substations, which allows for easy delivery of wind power to the robust transmission system. The development limitation for wind in this region would be load, which totals 3,500 MW.

The solar resources in the region are low to moderate across the entire oblast and there the area is rather hilly for solar development. It is assumed there is no large-scale solar development in this region.

(e) Western Ukraine (Carpathians/Lviv)

In the Western electrical transmission system cutting perpendicular through the mountains is a 750 kV transmission line and two 220 kV transmission lines. The 750 kV transmission line connects to the Western Ukraine 750/330 kV substation, and the 220 kV transmission lines connect to the Western Ukraine 220 kV substation. These overhead transmission lines may be difficult to interconnect to from the Carpathian Mountains due to heavy sloping. This heavy sloping would make it difficult to build an interconnection substation to tap the transmission lines, especially the 750 kV transmission line, which would be the most desirable for delivery of power.

The transmission system includes multiple 750 kV transmission lines and connects to the Ukrainian transmission backbone. Zakarpathia and Lviv are balanced from a generation to load comparison, with Zakarpattia having excess load totaling 200 MW and Lviv having excess capacity totaling 200 MW. Ivano-Frankivsk has excess generation of about 2100 MW, which could be exported to serve Zakarpathia load. All incremental resources would be exported to Poland and other surrounding countries as well as other oblasts via tie lines, since there is so much excess generation in Ivano-Frankivsk.

The best wind resources in Ukraine are located in the foothills of the Carpathian Mountains in Lviv and Ivano-Frankivsk. Steep slopes of the Carpathian Mountains would prevent construction in much of Zakarpathia. Where the wind development potential is located, there is adequate transmission capacity, assuming the resource could be connected the high voltage transmission substations in the region and be able to export to neighboring countries or oblasts. The overall limitation to wind development, assuming no exports of excess renewable energy, is the local load in the region, which is capped at about 1400 MW. More wind could potentially be developed if pump-storage and hydro is coordinated in the region for export purposes, but 1400 MW is assumed as a conservative scenario for purposes of the SER.

The solar resource potential is not optimal in the region and mountainous terrain would make utility-scale solar development challenging. Therefore, it is assumed that there is no utility-scale solar development in this area.

(f) Southwestern Ukraine (Ternopil)

The best wind resources in Southwestern Ukraine are in Ternopil, but the overall development of wind in the region is capped at the regional load of around 900 MW. Solar development is assumed minimal due to its hilly terrain and poor solar quality.

(g) Central Ukraine (Dnieper River)

Development near Tripol Thermal Power Plant results in the highest amount of power injection onto the Central electrical transmission grid with an approximate transmission capability of 4500 MW (five 330 kV transmission lines). The entire region is not transmission constrained, but there is a major load center with Kiev City. Despite the large load of the city, Kyiv has excess generation capacity of approximately 2500 MW for export and far more transfer capability.

Central Ukraine has low to moderate wind resources along the Dneiper River with 330 kV transmission lines running along the river. Much of this transmission likely is allocated to the load center of Kiev City and the numerous existing hydro and thermal facilities along the river. Tripol TES has the most transmission export capability with six 330 kV transmission lines exiting the substation. Thought the approximate transmission capacity is about 4500 MW in the region, the overall wind development potential in the region is limited to about 1200 MW based on the availability of good wind resources in Kiev and Cherkasy.

There is moderate to high solar resources in the region and very few transmission constraints. The solar development potential in the region is assumed to be capped at the regional load of 1800 MW. Under a combined scenario, the wind development would be about 1200 MW and the solar development would be close to 600 MW.

(h) Northern Ukraine

Northern Ukraine does not have good wind or solar resources and is limited to the small amount of wind in Poltava of about 200 MW.

FIGURES

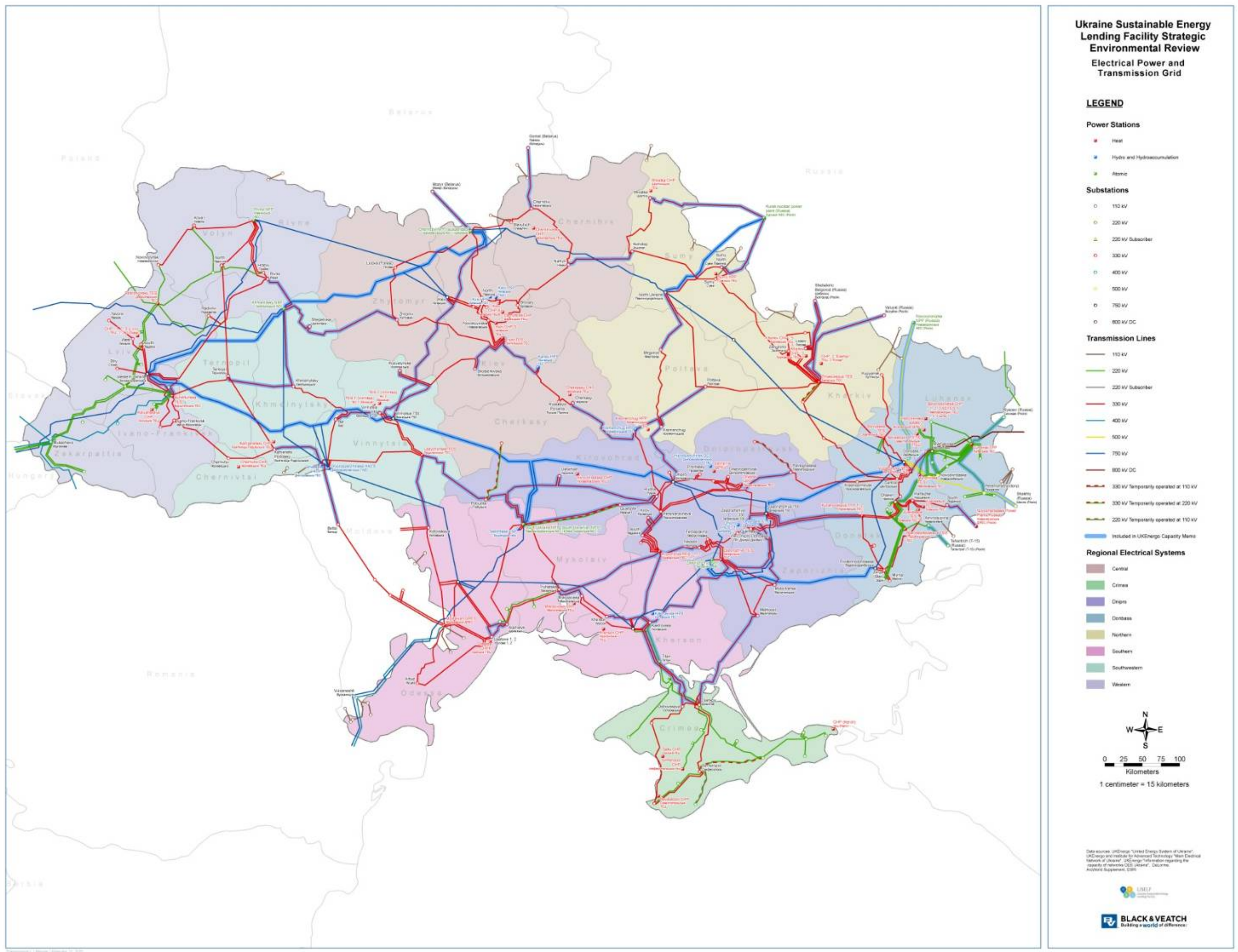

Figure 2. Ukraine Transmission Network and Regional Electrical Systems

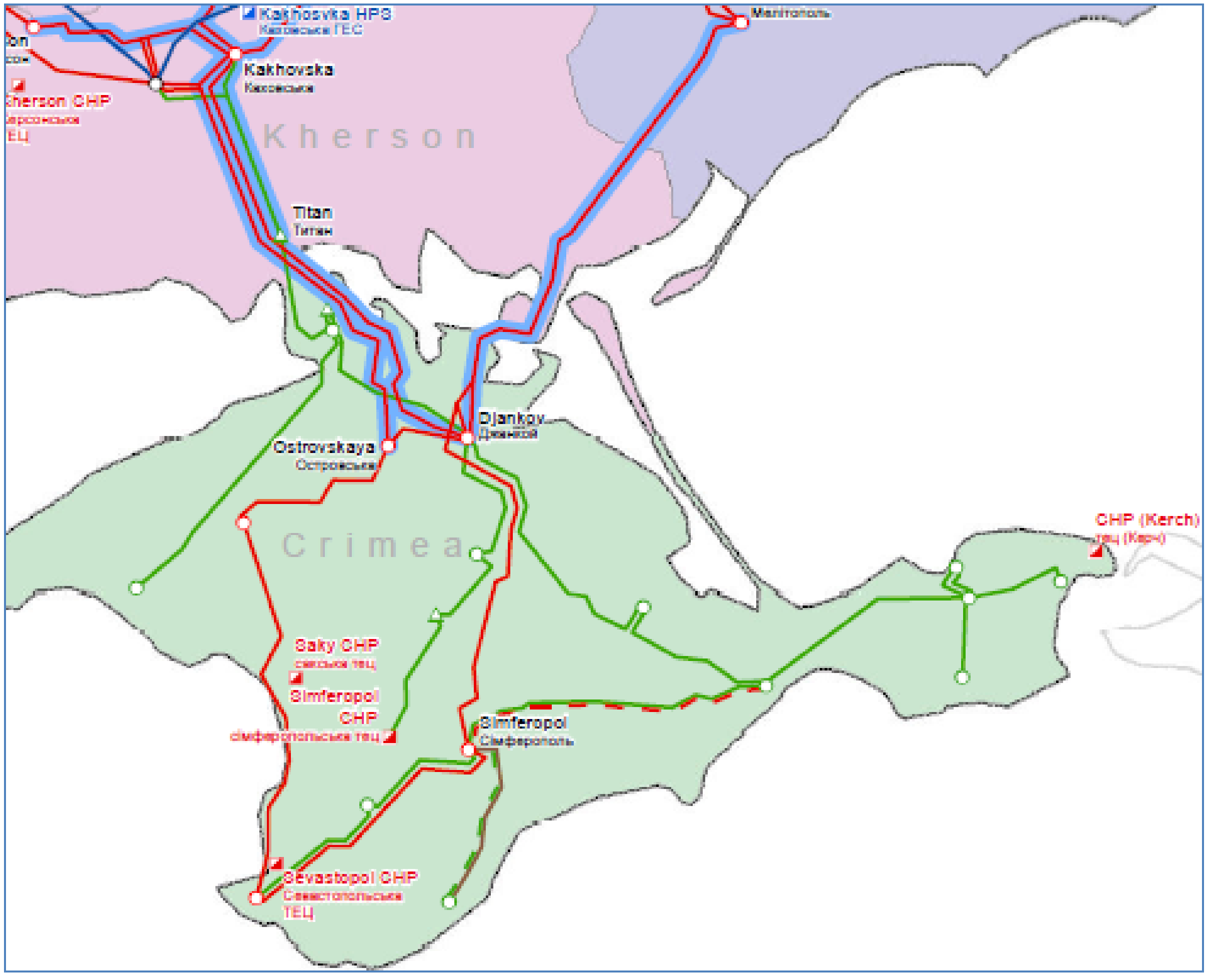

Figure 3. Crimea Transmission

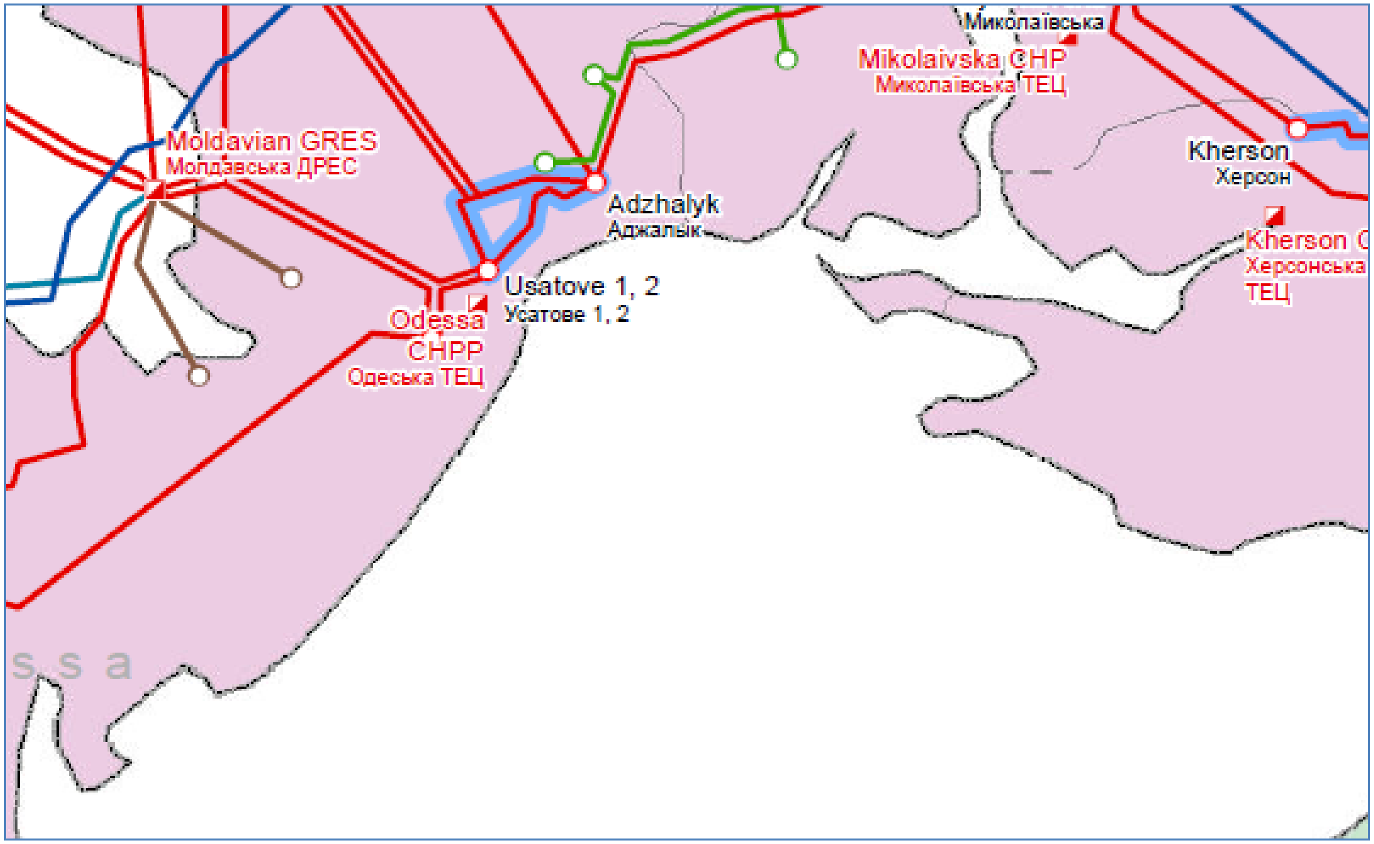

Figure 4. Southern Ukraine Coastal Transmission

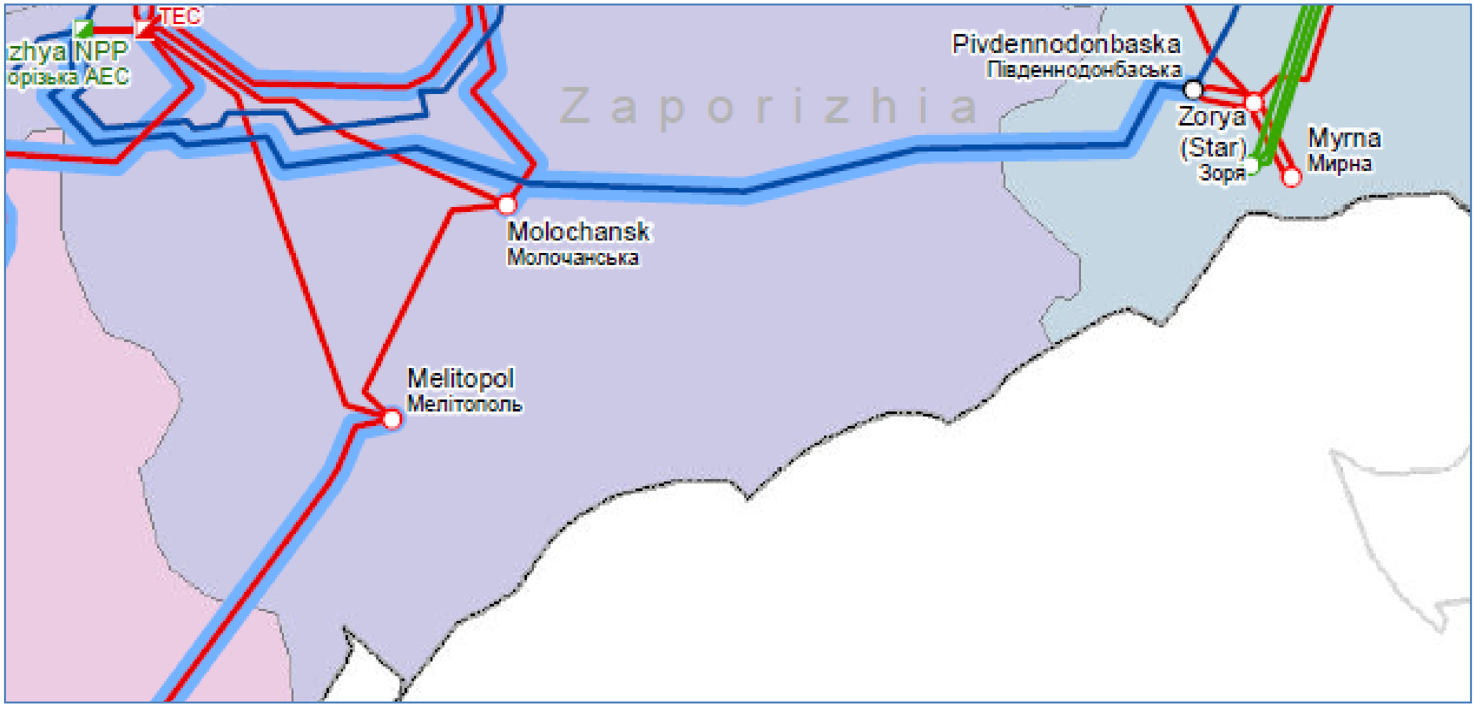

Figure 5. Donets'ka and Zaporiz'ka Coastal Transmission

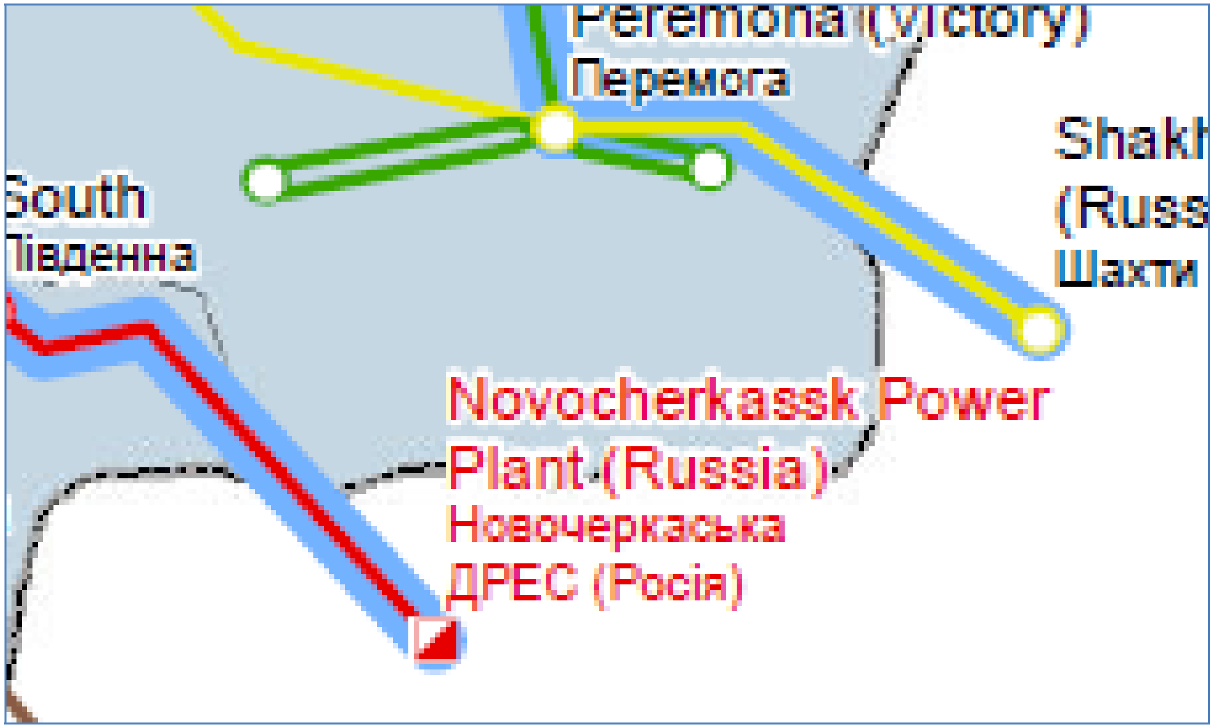

Figure 6. Southern Luhans'ka Transmission System

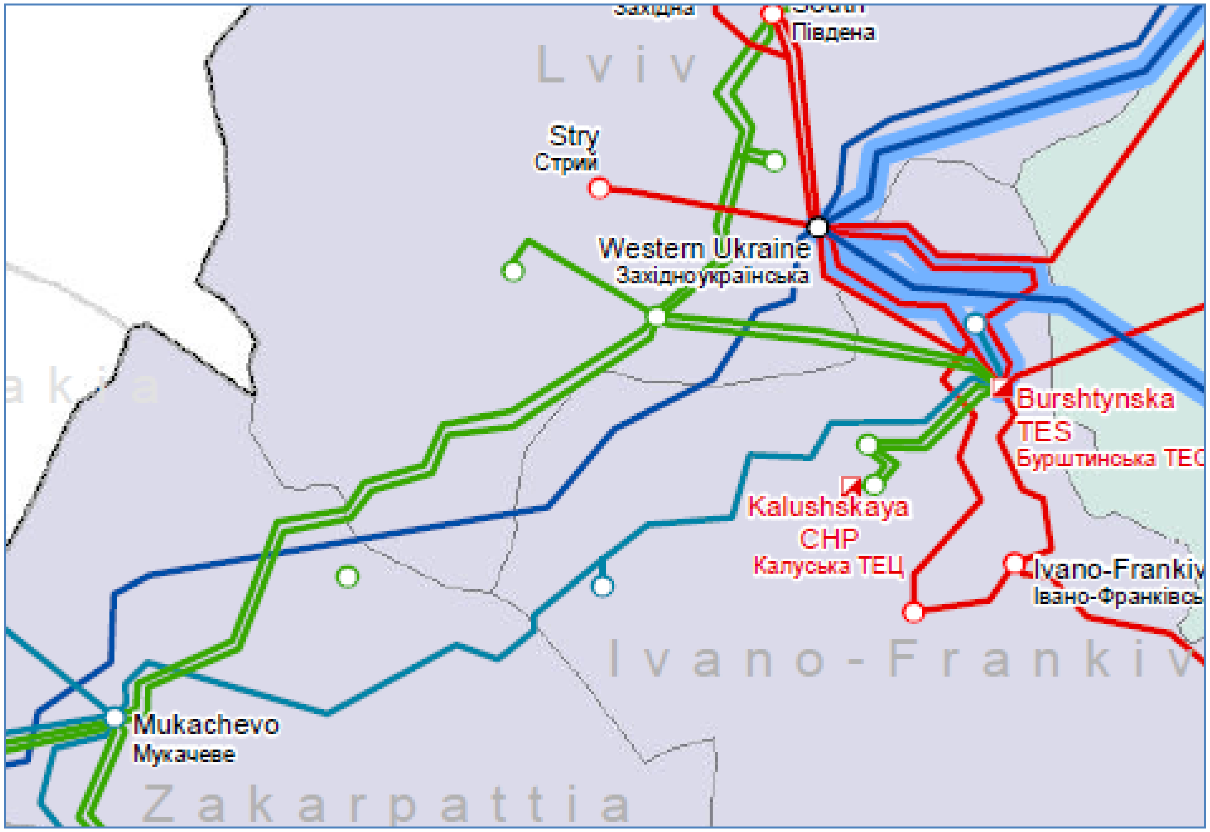

Figure 7. Western Ukraine Transmission System

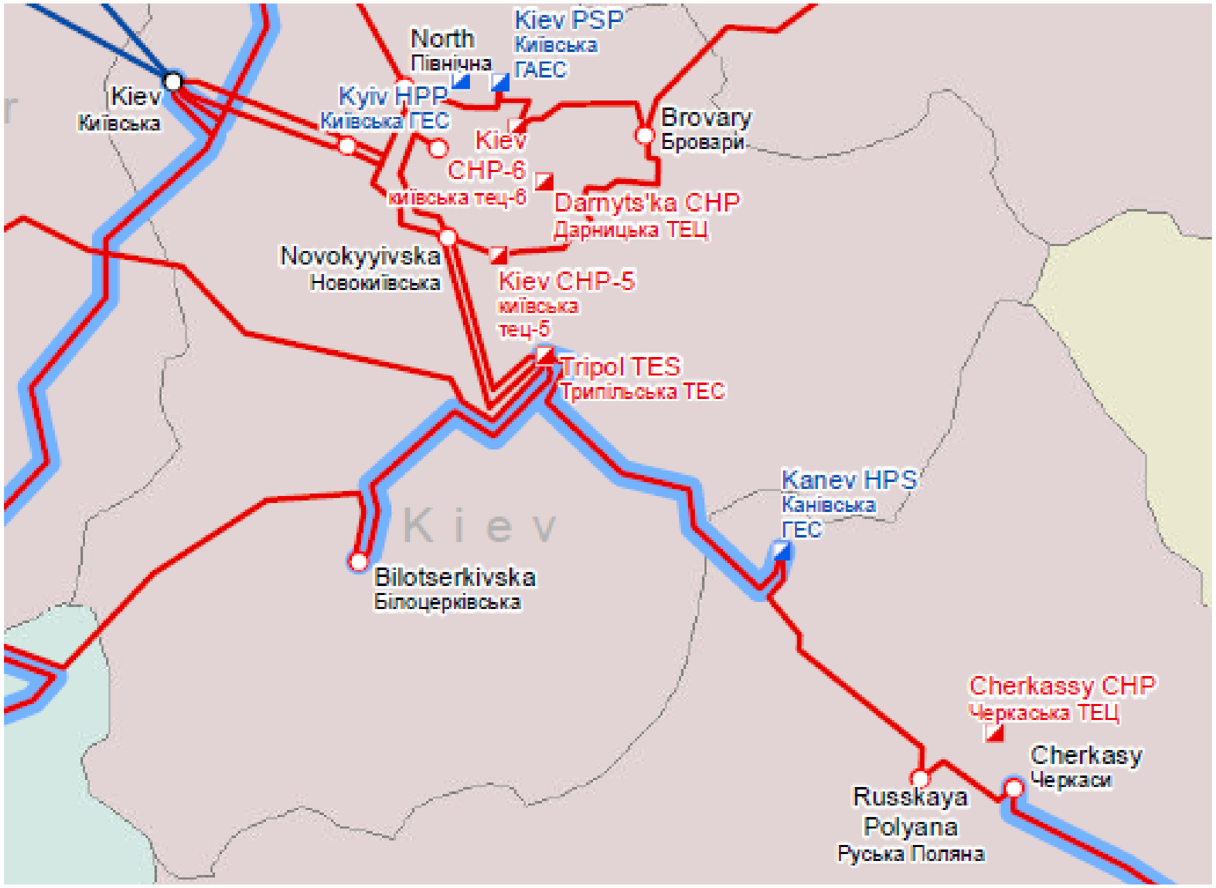

Figure 8. Central Electrical Transmission System