

The TVA Transmission System: Facts, Figures and Trends

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Abstract—The Tennessee Valley Authority (TVA) is a wholly-owned corporation of the United States of America formed in 1933 by an Act of Congress. This paper presents an historical overview of the TVA system, a present day and future outlook, and a discussion of future trends in the power industry and their impact on the bulk transmission system.

I. INTRODUCTION

The Tennessee Valley Authority (TVA) is a wholly-owned corporation of the United States of America. The TVA was created in the first 100 days of President Franklin Roosevelt's first Presidential term as part of the New Deal legislations. Roosevelt searched for innovative solutions to help lift the nation out of the depths of the Great Depression. But even by Depression standards, the Tennessee Valley was in sad shape in 1933. TVA became one of Roosevelt's most innovative ideas [1].

President Roosevelt envisioned TVA as a totally different kind of agency. He asked Congress to create "a corporation clothed with the power of government but possessed of the flexibility and initiative of a private enterprise." On May 18, 1933, Congress passed and President Roosevelt signed the TVA Act [2] (See Figure 1). Its mission was integrated resource management of the Tennessee River drainage basin and adjoining territory affected by the development. This included responsibilities for flood control and navigation improvement of the Tennessee River; reforestation and proper use of marginal lands; furthering the proper use, conservation, and development of the natural resources; generation and transmission of electric energy and application of electric power for the fuller and better balanced development of the regions resources; agricultural and industrial development; and the production of chemicals necessary to national defense and useful in agriculture.

TVA built dams to harness the region's rivers, control floods, improve navigation and generate electricity. TVA developed fertilizers, taught farmers how to improve crop yields, helped replant forests, helped control forest fires, and improved habitat for wildlife and fish. But by far, the most



Figure 1. President Franklin D. Roosevelt signs the TVA Act on May 18, 1933 surrounded by various members of Congress from the TVA region.

dramatic change in Tennessee Valley life came from the electricity generated by TVA. Electric lights and modern appliances made life easier and farms more productive. Electricity also drew industries into the region, providing desperately needed jobs [1]. But this was not only true for the Tennessee Valley region, but for the nation as a whole. Electrification was named the greatest achievement of the 20th century in a collaborative project, led by the National Academy of Engineering, with the purpose of highlighting the effects of engineering on the quality of life. The Academy stated, "At the beginning of the 20th century, ...electric power was poised to become the muscle of the modern world. Today it keeps our factories running—as well as the telecommunications industry, the appliances in our homes, and the lifesaving equipment in our hospitals. In myriad other ways the ready access to electricity helps maintain the well-being of billions of people around the globe." In fact, an examination of the top twenty greatest engineering achievements of the 20th century [3] reveals that more than half of the other nineteen achievements are reliant upon electricity and would not have been possible without electric power.

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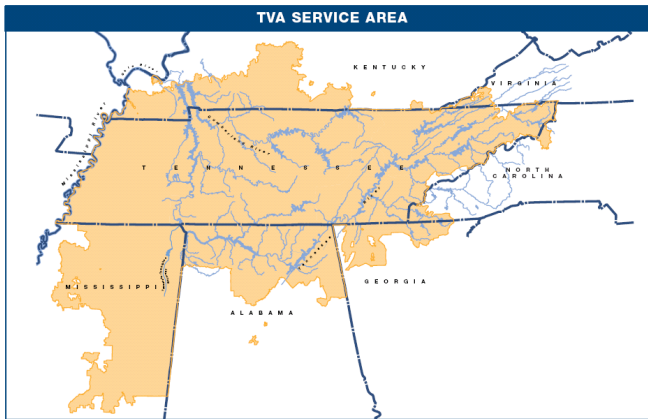


Figure 2. The Tennessee Valley Authority service area.

In 2009, TVA provided electricity to 52 large industrial customers, six federal customers, and 158 distributor customers that serve nearly nine million people in seven southeastern states over an area approximately 80,000 square miles (See Figure 2). It operates 29 hydroelectric dams, 11 coal-fired power plants, 3 nuclear power plants, 7 natural gas-fired power plants, 1 pumped-storage facility, and almost 16,000 miles of transmission lines [9].

Initially, all TVA operations were funded by federal appropriations. Appropriations for the TVA power program ended in 1959, and appropriations for TVA's environmental stewardship and economic development activities were phased out in 1999. TVA now generates almost all of its revenue from the sale of electricity and in 2009 revenue from the sale of electricity totaled \$11.1 billion [9].

II. TRANSMISSION SYSTEM

A. Historical Overview

The majority of this historical overview of the TVA transmission system has been taken from [4].

Prior to TVA, the electric transmission system consisted of small pockets of sub-transmission voltage lines around whatever generating sources were available. There was often steam generating plants in the centers of the major towns in the valley, like Chattanooga, where the first central generating plant in the South began operation in May of 1882. There were also several generating plants outside of major towns. Wilson Dam, on the Tennessee River, was built by the U. S. Army Corps of Engineers. It was the largest dam of its time and the first federal hydroelectric project and was placed in service in 1925. The Tennessee Electric Power Company (TEPCO) completed the Ocoee No. 1 and No. 2 dams in 1911 and 1913, Hales Bar Dam in 1913 (first dam to be constructed on the Tennessee River), and Great Falls Dam in 1916. In addition, TEPCO built the Nashville Steam Plant in 1903, Parksville Steam Plant in 1916 and Hales Bar Steam Plant in 1924. The Alcoa Aluminum Company completed the Cheoah Dam in 1916, the Santeelah Dam in 1928 and the Calderwood Dam in 1930. Short 69-kV and 46-kV lines (actually operated at 66 and 44 kV, respectively) were built from the generating plants to the surrounding towns.

A number of transmission lines were constructed in the TVA service area during the 1920s and early 1930s. Most were constructed by the three largest power companies that existed in the area at the time - TEPCO, Mississippi Power Company and Alabama Power Company. The development of the transmission system in the Northern Alabama area is of specific interest. Hales Bar Dam was a major source of power at the time and eventually a 66-kV line was extended from there to Huntsville, Alabama. A 44-kV system was constructed beginning in 1924 around the Wilson Dam area.

The Mississippi Power Company became very active around 1923 constructing a 44-kV system throughout the Mississippi service area. A few different power companies were active in Tennessee in the 1920's, TEPCO being the largest. TEPCO constructed almost all of the lines in Tennessee, including a significant 44-kV system and the first long 154-kV transmission line in Middle Tennessee, the Nashville-Centerville-Waynesboro line, which was placed in-service in 1929. There was a noticeable lack of line construction in Kentucky at the time, as only three 66-kV lines were recorded as being built. The total generating capacity in the 1920s in the area now served by TVA was estimated to be about 800 MW.

At the beginning of TVA, the formulation of a transmission system was only in its infancy. One of the first events was to take ownership from the War Department of all the government-owned properties at Muscle Shoals, AL. This included a 110-kV double circuit from Wilson Dam to the steam generating plant at the nitrate plant, three miles of 154-kV line from Wilson to Alabama Power's Gorgas Steam Plant, and another 2.8 mile 110-kV line from the nitrate plant over to the line that Alabama Power constructed to Huntsville. These lines to Alabama Power in 1933 became the first interconnections between TVA and another utility. Less than three months after the TVA Act was signed, construction began on the agency's first hydroelectric dams. The city of Tupelo, Mississippi became the first distributor of TVA power on 7 February 1934, under the first TVA wholesale contract. By 1939, five dams were in operation and three other dams were under construction. Most of the transmission system construction during the decade was related to these eight large generation projects. Also in 1939, TVA acquired several generating plants, many substations and over 2000 miles of lines from TEPCO, West Tennessee Light and Power Company, Memphis Power and Light Company, and the Mississippi Power Company. Power sales climbed from 16 million to 1,618 million kWh.

By 1940, substantial progress had been made in agriculture, power production, and flood control. Although real prosperity still did not exist in the Tennessee Valley, world developments were to bring TVA a new mission. TVA accomplished major tasks in short periods of time as it supported the nation's war effort. It completed Cherokee Dam in 16 months and Douglas Dam in only 13 months. This power was used by Alcoa to manufacture aluminum for war planes and by the secret "Manhattan Project" in Oak Ridge where the atomic bomb was being developed.

By 1940 TVA's transmission system had expanded into all the areas that it presently serves except for Kentucky and upper east Tennessee. During 1940 TVA constructed 481 miles of new transmission line and acquired another 256 miles of line, mostly from Alabama Power. For the first time, the majority of new construction was at the 154-kV level. TVA expanded its transmission system into Kentucky in 1942 by acquiring facilities from the Kentucky-Tennessee Light and Power Company.

During the post-war period 1945 to 1950, the number of TVA electricity customers nearly doubled, as power distributors pushed forward in electrifying the Tennessee Valley. By the end of 1949, power production had increased to 15,700 million kWh. Total number of transmission lines was 6,975 miles including 2,490 miles of 154-kV line.

The 1950s held periods of significant growth for the TVA system, which had now expanded into all the areas that it presently covers. Load growth during the 1950s was 267%. The rapid growth in the region's use of electric power resulted in TVA building seven large coal-fired generating plants and three hydroelectric plants during the decade. In 1956, a second unit added at Hiwassee Dam became the first reversible pump-turbine installed in the U.S. solely for the purpose of storing electrical energy in a pumped-storage plant. TVA became the largest producer of electric power in the United States. Major expansion of the transmission system was required, primarily related to connection of the coal-fired generating plants to the system and local expansions to supply the rapidly growing power demands. Total energy sales increased to 57,163 million kWh by 1959.

Around the end of the 1950s, TVA changed the official designation of the operating levels of its transmission system. Voltages had been operated at a high level for several years and higher voltage rated equipment had been purchased. From this point on, 220-kV lines are designated 230-kV, 154 as 161-kV, 110 as 115-kV, 66 as 69-kV, and 44 as 46-kV.

While load growth in the 1960s was not as much as the 1950s, it was still a significant increase of almost 56%. Economic growth in the Tennessee Valley was even greater than the load growth. As a result, the long era of outward migration of Valley people ended. Job opportunities and living standards were quickly catching up with those in other areas of the country. Two major decisions related to the growth were the start of construction of the first nuclear power plants and the construction of TVA's 500-kV transmission system.

During the 1960s, TVA constructed five coal-fired generating plants, four hydroelectric generating plants, and began construction on two nuclear power plants: Browns Ferry in 1966 and Sequoyah in 1969, both of which are in operation today.

The most important change ever to TVA's transmission system took place during the 1960s. This was the construction of the first 500-kV transmission system in the free world. TVA found it economical for almost three decades to operate a 161-kV transmission system instead of the 230-kV systems that have been commonly developed by many other utilities.

Studies performed during the late 1950s showed that as total system loads reached 12,000 to 15,000 MW, a higher transmission voltage would be required. Studies also showed that the most economical voltage would be 460-kV which was the standard voltage at the time. In fact, a 7-mile section of 460-kV line was constructed in 1959 in order to gain experience with construction methods and costs. As the studies were refined with new load forecast information, it was determined that a 500-kV system should be placed in service by 1966.

The first sections were energized during 1964 and the entire first line was actually placed in service a year early on 15 May 1965. It was 155 miles long and extended from the Johnsonville Coal-Fired Plant to the Mississippi River crossing where the interconnection was made to Arkansas Power & Light. In the spring of 1966, a new 500-161-kV substation was energized at Cordova, Tennessee, just east of Memphis, and the 500-kV line was looped into Cordova. Also during the spring of 1966, a 204-mile 500-kV line was completed from the Widows Creek Coal-Fired Plant to the Madison 500-kV Substation near Huntsville, Alabama, and then on to the West Point 500-kV Substation near Columbus, Mississippi. By the spring of 1967, the line was extended to a new interconnection with Mississippi Power & Light (See Figure 3). By 1969, a massive construction effort had created a very significant 500-kV network. The details of the design decisions made for the TVA 500-kV system are described in four IEEE papers published in 1966 [5] [6] [7] [8].

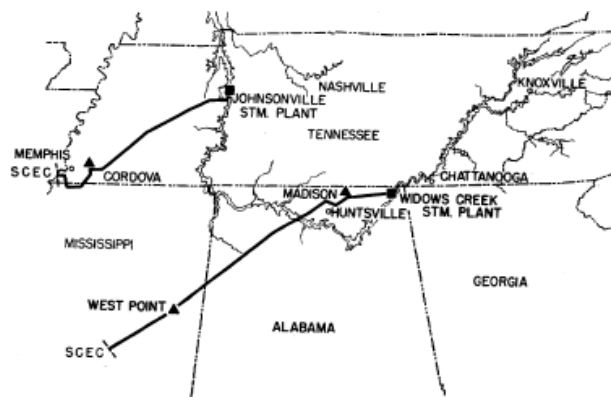


Figure 3. TVA's initial 500-kV circuits [5].

TVA began a lease-purchase program with its distributors in 1968 to encourage them to take over all responsibilities for lower voltage facilities. Total energy sales increased to 86,374 million kWh by 1969. In January 1970, TVA joined 21 other power systems in the southeastern U. S. in the formation of the Southeastern Electric Reliability Council (SERC). SERC was formed as a regional organization of the National Electric Reliability Council (NERC) to address national grid reliability following the northeast blackout in 1965.

At the start of the 1970s TVA had initiated a significant program to build several nuclear power plants. With a

continuing 7% annual load growth rate, TVA predicted it must double its power system every ten years. But significant changes occurred in the economy of the Tennessee Valley and the nation, prompted by an international oil embargo in 1973 and resulting in accelerating fuel costs for the rest of the decade. Industrial power use fell severely as the national economy slowed; interest rates began a steady climb skyward; unanticipated regulatory requirements, construction delays, runaway inflation, and high interest rates caused nuclear plant construction costs nationwide to skyrocket; and power rates increased rapidly and were accompanied by a major slowdown in the growth trend for electric power. With energy demand dropping and construction costs rising, TVA began to consider cancelling several nuclear plants, as did other utilities around the nation. Energy conservation became an economic necessity and TVA became a leader in promoting it.

TVA completed only two coal-fired generating plants in the 1970s, along with four hydroelectric plants and several gas turbine peaking plants. The Raccoon Mountain Pumped-Storage Plant began production in 1978. Despite the slowing growth trend for electric power, total energy sales increased to 117,688 million kWh by 1979. TVA significantly increased its 500-kV system through the 1970s and into the mid 1980s.

The U. S. economy continued to suffer into the 1980s and energy sales fell in 1981 to 114,000 million kWh. TVA began to defer construction on some nuclear units and eventually cancelled them. For the first decade since the 1930s, no construction work was in progress on any major new coal-fired generating plants. Work was stopped on the nearly complete Columbia Dam in September 1983 due to environmental concerns. Only two new nuclear generating units were placed in service during the 1980s. Peak system load decreased and total energy sales decreased to 109,300 million kWh by 1988. The highest sales for the decade were in 1980. As a result, growth in TVA transmission also slowed.

Through the 1990s and the early years of the 21st century, economic growth returned to the Tennessee Valley and the nation. TVA restarted Browns Ferry Nuclear Units 2 and 3 in the 1990s. Watts Bar Nuclear Unit 1, the last commercial nuclear unit in the United States to come online in the 20th century, began commercial operation in May 1996. After an extensive recovery effort, Browns Ferry Unit 1 became the nation's first nuclear unit to come online in the 21st century when it was restarted in May 2007.

During the last decade new generation facilities have been dominated by gas-fired combustion turbine plants. In the early years of the 21st century, independent power producers (IPPs) rushed to find the areas where gas lines and high voltage transmission lines crossed each other in order to minimize transmission costs and speed in-service of generating plants. An economic downturn starting in 2003 had a negative impact on IPPs and many of these companies eventually sold their gas turbine facilities at reduced cost. TVA has purchased or leased several of these facilities within the Tennessee Valley.

In the last 20 years transmission work has been in large part a response to TVA's distributors building 161-kV

substations, the majority of which are tapped off the TVA 161-kV system. Several 500-kV substations were built in the last 20 years, but most were built adjacent to existing 500-kV transmission lines only requiring breaking the line and looping into the substation. In 2008, TVA constructed the first significant 500-kV transmission line in 20 years, a 39.5-mile line from Cumberland Coal-Fired Plant to the existing Montgomery 500-kV Substation. A new 29.4-mile 500-kV transmission line was recently finished from the existing Maury 500-kV Substation to the new Rutherford 500-kV Substation. Total energy sales reached 176,304 million kWh by 2008 [9], an average load growth per year over 20 years of 2.5%.

B. Present Day Outlook

In 2009, TVA provided electricity to 52 large industrial customers, six federal customers, and 158 distributor customers that serve nearly nine million people in a service area that covers parts of seven states - Alabama, Georgia, Kentucky, Mississippi, Tennessee, North Carolina and Virginia (See Figure 2). The TVA transmission system has maintained customer reliability at 99.999% for over 10 consecutive years.

TVA has 16,000 miles of transmission lines; over 500 substations, switchyards and switching stations; and over 1,000 individual interconnection and customer connection points, including 63 interconnections with neighboring utilities. The current 500-kV system consists of over 2400 miles of 500-kV transmission lines and over forty 500-kV substations and switching stations (See Figure 4). The goal for the bulk transmission system is to plan, design, build and operate a robust transmission system to meet regulatory requirements; ensure compliance with NERC reliability standards; maintain long-term area reliability while ensuring real-time system operability; deliver customer-driven service; support TVA's changing generation portfolio; and support regional growth.

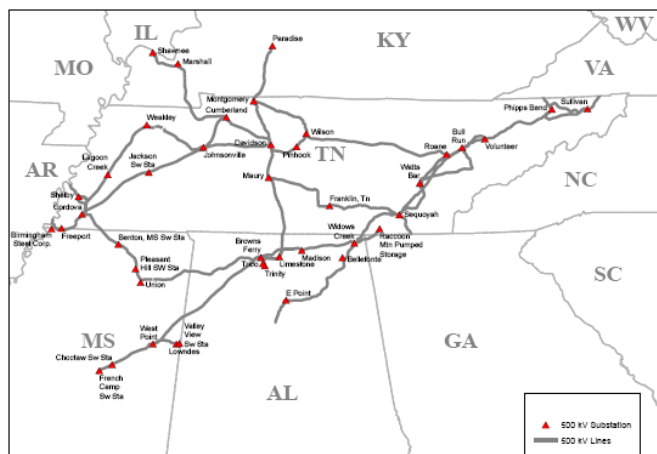


Figure 4. The 2009 TVA 500-kV system [25].

On 20 July 2006, NERC was certified as the Electric Reliability Organization (ERO) in the United States. SERC is the regional entity responsible for enforcing NERC reliability standards in all or portions of 16 central and southeastern

states. The TVA system makes up the majority of the Central sub-region of SERC (See Figure 5).

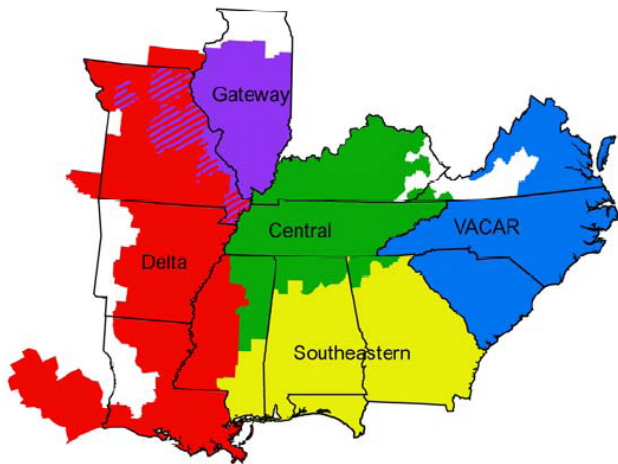


Figure 5. SERC sub-regions [10].

Beginning in 2008, the United States went into an economic recession. Like all of the U.S., the Tennessee Valley suffered from the recession. Overall, unemployment in the TVA region reached 10%, which is about the national average. However, of the 170 counties TVA serves, 136 had higher unemployment rates than the national average with some reaching over 18% (See Figure 6).

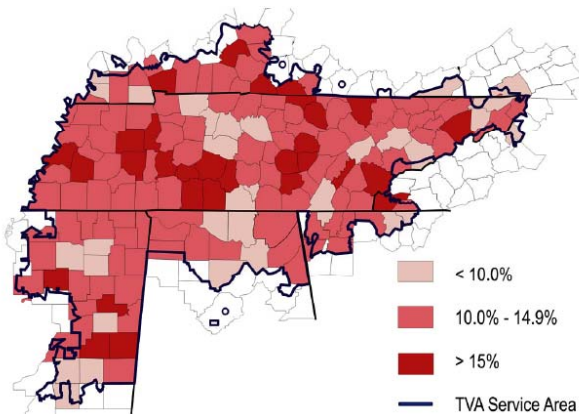


Figure 6. Tennessee Valley county unemployment rates [26].

Manufacturing employment was down more than 11% for most of 2009. Electricity demand dropped by more than 7% from 2008 levels, with total energy sales in 2009 dropping to 163,804 million kWh. Most of this was directly related to lower business activity in the region. On the positive side, on 16 January 2009, TVA hit an all-time winter peak demand of 32,572 MW (the all-time summer peak demand was 33,482 MW on 8 August 2008); rainfall returned to better than normal levels in 2009 for the first time in several years, which served to push hydro generation well above projections for the year; after months of escalating fuel prices, coal dropped steeply back to near its January 2008 levels; and prices of natural gas moved even lower [11].

A similar outlook is forecast throughout the U.S. In [12], NERC states that “Depressed electricity demand due to a slow economic recovery continues to be the major driver affecting bulk power system reliability during the upcoming summer months” of 2010. The recession also continues to drive broad decline in forecast demand. Projected forecast of the 2010 summer total internal demand for utilities in the SERC Central sub-region is 42,364 MW. This is 0.8% lower than the forecast 2009 summer peak demand of 42,733 MW; though the actual 2009 summer peak was only 38,966 MW (8.7% lower than forecasted). The lower than projected summer peak in 2009 was attributed to lower temperatures and the prolonged effects of the economic slowdown on industrial demand. The change in demand from prior forecasts for 2010 also reflects the effects of the economic slowdown in lowering growth in customers, manufacturing plant closings, and energy use [12].

III. FUTURE TRENDS AND IMPACTS ON TRANSMISSION

In the future, TVA expects slower growth for electricity usage (See Figure 7) at around 1 to 2% per year, though there is a range of uncertainty of expected future energy requirements (See Figure 8) due to factors outside TVA control such as potential environmental regulations, various economic recovery scenarios, foreign energy source dependence, potential game-changing technologies, various renewable energy scenarios, and potential carbon legislation. TVA’s expected growth is in close agreement to the projected growth rate of 1.69% in the SERC region [10] (See Figure 9). TVA’s goal is to move toward 50% clean and zero carbon energy by 2020 and to utilize demand reduction and energy efficiency to improve TVA’s overall load factor.

TVA’s strategic direction [13] calls for:

- Increase in energy efficiency & demand response
- Additional gas peaking units
- Additional nuclear units
- Consider retirement of older coal-fired units
- Expand transmission capacity
- Use of emerging technologies

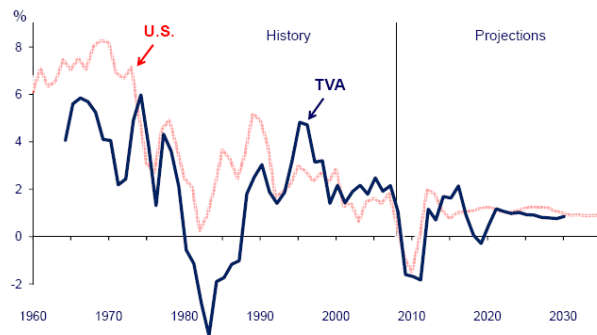


Figure 7. Actual and estimated average growth in electricity use [13].

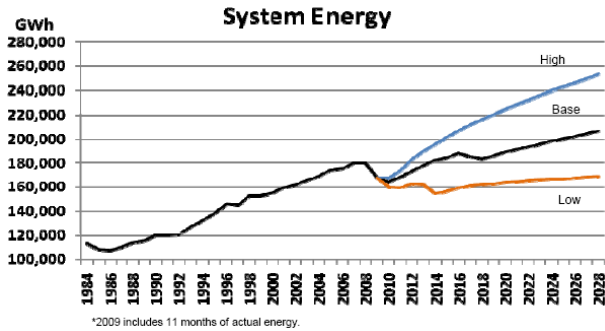


Figure 8. Range of uncertainty in estimated future energy requirements for the Tennessee Valley [14].

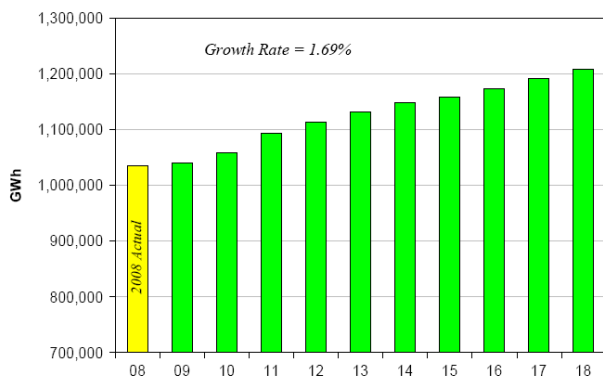


Figure 9. Actual/Projected net energy requirements in SERC region [10].

Watts Bar Nuclear Unit 2 is expected to go on-line in 2012. An additional nuclear unit is being considered at the TVA Bellefonte site which could either be a new unit or completion of an existing unit on the site. Modular nuclear reactors could be considered in the future, where 125-MW reactors would be built in groups. These could replace aging coal units and use existing sites and transmission. Demonstration of this technology is expected by 2020. New gas turbines will also be considered for replacing older coal-fired generation [13].

Transmission will be required to integrate new generation assets into the power system and to successfully meet a wide range of future scenarios related to environmental, renewable energy and climate change legislation. At the same time game-changing technologies (see IIIB), which can help companies achieve their strategic vision, must be evaluated and factored in. Future transmission expansion will require more 500-kV substations, place greater emphasis on coordinated regional planning and require stronger interties to improve grid stability and import potential renewable generation. TVA has a 30-year 500-kV plan based on a peak demand of approximately double the current peak demand (See Figure 10). This plan is reassessed each year based on changes in several factors, such as customer needs, power system forecasts and pending regulatory requirements. The challenge might best be summed up with a saying attributed to

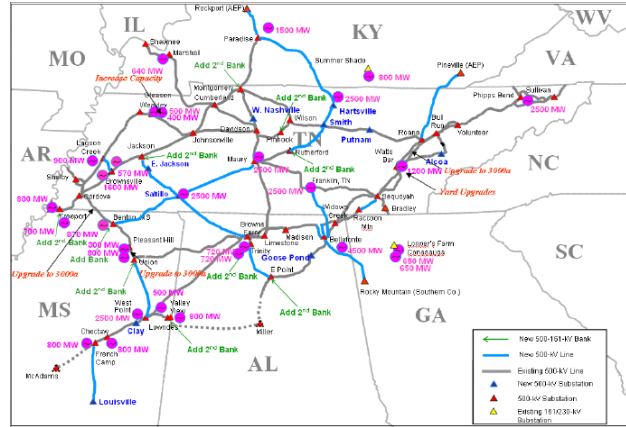


Figure 10. Potential 30 year TVA 500-kV system plan [27].

Yogi Bera, “It’s tough making predictions, especially about the future.”

Currently, pending federal legislation involving renewable energy and energy efficiency is under consideration. Depending upon which bill gets enacted TVA might have to ensure that over the 2011 to 2038 timeframe, anywhere from 3 percent to 20 percent of the electricity it sells will be produced by renewable resources as defined by Congress, or make alternative compliance payments for any deficiencies [9]. According to [18], over 145,000 MW of new variable resources are projected to be added to the North American bulk power system in the next decade. Even if only half of this capacity comes into service, it will represent a 350% increase in variable resources over what existed in 2008. Driven in large part by new policies and environmental priorities, this growth will represent one of the largest new resource integration efforts in the history of the electric industry [19].

In addition, HR 2454 “American Clean Energy and Security Act of 2009” passed by the House of Representatives would cut U.S. Greenhouse Gas emissions 17 percent by 2020 from 2005 levels and 83 percent by 2050. In addition, TVA expects additional increased environmental regulation. TVA has considered, and it intends to continue considering, fuel mix in making future decisions about additional generation and the evaluation of required transmission [9].

To successfully meet a wide range of potential future scenarios requires extensive study of transmission contingencies. TVA is a principal member of the Eastern Interconnection Planning Collaborative, set up to evaluate scenarios determined by a diverse stakeholder group that includes state and federal policymakers. The results of interconnection-wide studies will identify transmission impacts of competing policy positions. This follows TVA’s participation in large area transmission studies such as the Joint Coordinated System Plan study [17], which resulted in one option for transmission expansion to accommodate a potential 20% wind mandate for the Eastern Interconnection (See Figure 11), and the Southeastern Inter-Regional Planning Process studies, of which the first iteration is complete. TVA is also currently conducting transmission impact studies to

support business decisions regarding large, market-driven transmission infrastructure projects, and updating the TVA Integrated Resource Plan [20] with strong input from Valley Stakeholders. These activities are all consistent with current industry trends.

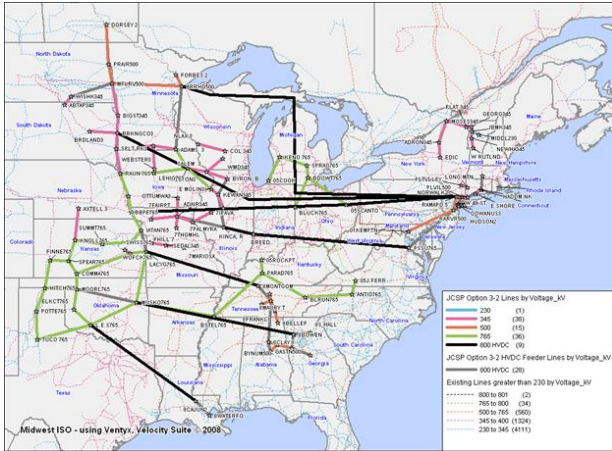


Figure 11. Conceptual transmission overlay for a 20% wind energy scenario [17].

Concurrent with these planning activities to provide greater clarity, and consistent with the need to appropriately delay major expenditures, TVA is committing to incremental transmission expansion that is necessary to keep available a range of attractive options. TVA also continues to study potential impacts to the coal-fired fleet due to environmental and pending climate change legislation to identify and optimize transmission modifications to provide maximum flexibility for future state scenarios.

A. Integration of Variable Generation

Resources for variable, or renewable, generation include wind, solar, ocean, and some forms of hydro. TVA encourages increased use of renewable energy as part of future power generation efforts.

Variable resources have fuel sources that cannot currently be controlled or stored and must be used when and where they are available. Also, fuel availability for variable resources often does not correlate with electricity demand in terms of time of use/availability [19].

High levels of variable generation will require significant transmission additions and improvements to move wind and solar power from their source to demand centers [17].

1) Wind Power

Only 7% of the U.S. population inhabits the top ten states for wind potential. Additionally, peak availability of wind power, the most abundant variable resource in terms of megawatt value today, often can occur during periods of relatively low customer demand for electricity [19].

The wind resource in the SERC Central sub-region is generally unsuitable for large-scale wind generation as is reflected in Figure 12, which shows a zero projected increase

for summer wind installed capacity for the SERC region through 2017 [19]. One of the challenges for wind power is the intermittent nature of wind resulting in a low capacity factor. For example, TVA has 29 MW of wind turbines available at Buffalo Mountain, but only 2 MW is reported capacity expected on peak for the summer season [12].

Because inconsistent and generally lower-speed winds in the Southeast make local wind power projects less reliable and less feasible than other areas, TVA has contracted for 1380 MW of electricity from wind generation projects in the Midwest and Great Plains, where winds are generally stronger and more consistent (See Figure 13). The first of these new contracts will begin providing 415 MW of wind energy from wind farms in the Midwest to the Tennessee Valley in 2010 [24].

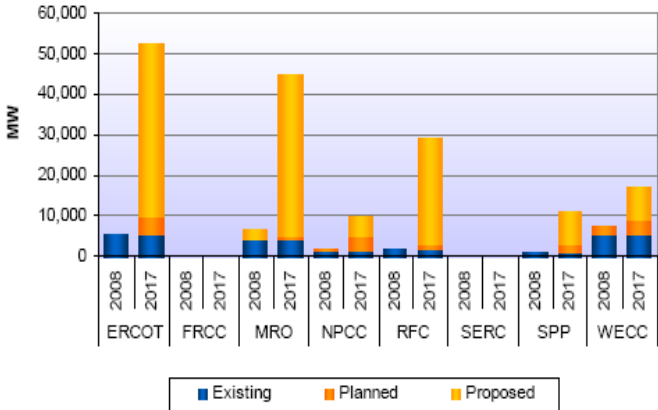


Figure 12. Projected increase in summer wind nameplate/installed capacity for 2008 and 2017 by NERC region [19].

Total Capacity Under Contract: 1,380 megawatts

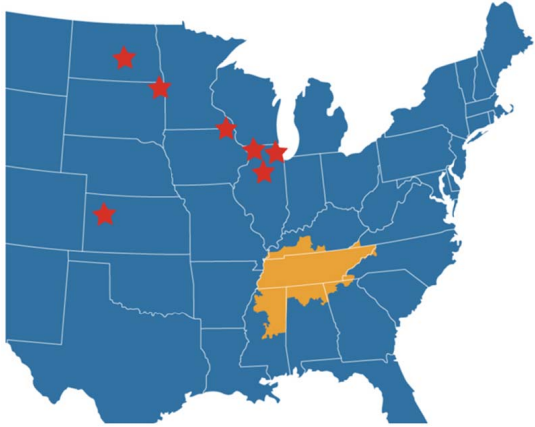


Figure 13. Locations of wind generation under contract by TVA.

2) Bulk Transmission (HVDC and/or UHV AC)

The 20% Wind Energy Scenario [17] presumes construction of a transmission overlay with 15,000 miles of new EHV transmission to deliver wind energy into the U.S. Eastern Interconnection. The majority of the conceptual overlay, approximately 75%, would be 765-kV AC or 800-kV DC (See Figure 11).

TVA's wind contracts to date have been primarily accommodated by existing transmission, but the import of significantly larger amounts of off-system variable generation would require substantial new inter-regional, transmission infrastructure. Factors such as the benefits of interfacing with existing and planned 765 kV for a robust grid overlay will compete with the advantage of reduced losses of HVDC or UHV AC for long-range transmission, and the limited capacity gains of moving from a 500-kV overlay to 765 kV in the event that these variable generation options materialize.

3) Transmission Planning and Operation Effects

Maintaining system reliability while integrating higher levels of variable generation requires changes to traditional methods of planning and operating the bulk transmission system. The required changes rely on a number of factors [19], including;

- Whether government renewable policies or mandates exist;
- Level of variable generation mandated and available variable generation in remote locations;
- Time horizon across which capital investments in variable generation are to be made; and
- Geographic footprint across which the investments occur.

An increase in variable generation will increase the amount of uncertainty system operators must factor into operating practices. New forecasting techniques must be developed and integrated into real-time operating practice and daily operational planning, including consideration of seasonal weather patterns. More frequent and shorter intervals for variable generation transactions may be required.

The ability to accurately assess the availability of variable generation to serve peak demand is needed for operational and long-term system planning. Coordinated inter-regional bulk transmission planning efforts will be necessary to maintain system reliability.

4) Generation Partners

TVA's Generation Partners program is an end-use renewable energy program that gives homeowners and businesses an opportunity to own and generate renewable energy. Under the program, TVA will buy 100 percent of the renewable generation that participants produce, paying the retail rate, plus a premium per kWh, depending on the type of renewable energy produced. The local power company

reimburses the customer for the generation received through a credit on their monthly electric bill [20].

A renewable generation system is installed by a residential, commercial, or industrial power customer served by a participating distributor of TVA power. Eligible resources include solar, wind, low-impact hydro, and biomass. The program also provides technical support and incentives for the installation of the renewable generation systems. The system must have a minimum total nameplate generation capacity of 500 W and a maximum of less than 1 MW. In addition it must be manufactured and installed in compliance with the National Electric Code and certified by a licensed electrician, and must comply with requirements of the local power distributor for interconnection to their distribution system.

TVA launched Generation Partners as a pilot project to encourage customer interest in small to medium sized renewable energy projects, such as rooftop solar panels. The response exceeded expectations, prompting an expansion and enhancement of the program to include additional projects. The program currently has 264 projects approved or completed, 260 of which are 200 kW or less, and TVA is encouraging more widespread use of renewable energy resources across the TVA service area.

B. Game Changing Technologies

Game-changing technologies, enabled by a smart grid, will drive demand response, peak demand reduction, direct load control, dispatched voltage reduction, and time-of-use pricing. Future plug-in hybrid and electric vehicles will also influence the drive to improve transmission efficiency and maximize the return on investment.

1) Smart Grid

Characteristics of a smart grid were identified in [15], of which, the following are related to transmission:

- Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid;
- Dynamic optimization of grid operations and resources, with full cyber-security;
- Deployment and integration of distributed resources and generation, including renewable resources;
- Deployment of smart technologies for communications concerning grid operations and status;
- Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal storage air conditioning; and
- Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices and services.

The Department of Energy's (DOE) Office of Electricity Delivery and Energy Reliability also identified five key technology areas that it thinks represents the opportunity to address most transmission concerns [16]:

- Sensing and measurement
- Advanced control methods
- Improved interfaces and decision support
- Advanced components
- Integrated communication

As a generation and transmission organization, the TVA approach to "smart grid" may be different than some vertically integrated utilities that also serve residential distribution loads. Therefore, TVA has established an executive steering team to set a strategic direction for expectations of a smart grid initiative in determining what we have now, what we need, and how we get there. The overarching goal of TVA's transmission smart grid initiative is to improve effective management of grid assets to meet financial and strategic objectives through 1) a unified approach to optimization of the transmission grid for multiple benefits to TVA, our customers and stakeholders; and 2) developing and implementing recommendations to establish intelligent information, communications and power system architectures for the grid. Operational benefits of implementing smart grid technologies include increased reliability, the ability to adequately integrate variable generation and variable load, wide-area grid visualization, improved asset management, and the ability to apply time-of-use pricing.

One near-term objective TVA has is to develop a Transmission Smart Grid Road Map, in collaboration with the Electric Power Research Institute (EPRI), for implementation of selected technologies. Key focus areas for this road map will be:

- Reliability
- Energy efficiency
- Asset Management

The process to establish this road map includes identifying opportunity areas and stakeholders, documenting stakeholder requirements, investigating technologies for intelligent devices and advanced applications, and conducting pilot projects to establish feasibility of an application to the TVA grid. To this end, TVA is currently establishing a test lab to evaluate various devices in areas such as interoperability, secure operation (e.g. cyber security), energy efficiency, reliability and flexibility. Also, TVA plans to initiate pilot projects in 2011 at three different substations in an effort to evaluate the interoperability of devices between stations which have different capabilities and communication protocols, as well as transmission and integration of output data into a common data system for archival and processing. Ultimately, the goal would be to develop systems able to turn the data into information useful for making business decisions. One of these pilot projects will be done jointly with one of the distributors of TVA power.

Additional objectives for smart grid development include the need to assess requirements of an information infrastructure and telecommunications architecture, including physical and cyber security; determine useful smart grid elements that meet specific business needs; and establish a timeline and budget for implementation of smart grid elements (hardware and software).

Keys to being successful in the planning and implementation of this effort include: A strategic vision of near and long term objectives and expectations; clear understanding of the Federal Energy Regulatory Commission (FERC) and NERC smart grid policy requirements for cyber security, inter-system communications, wide-area situational awareness, and coordination of the bulk power systems with new and emerging technologies; adequate internal coordination between all affected organizations within TVA; and identification of and engagement in opportunities for collaboration with external groups such as the Institute of Electrical and Electronics Engineers (IEEE), EPRI, DOE, National Institute of Standards and Technology (NIST), Tennessee Valley Public Power Association, TVA power distributors, local universities and various manufacturers of intelligent devices.

2) *Transmission Efficiency*

The largest single user of electricity is the electric utility industry itself. Transmission losses account for approximately 2% to 4% of the total electricity generated in the U. S. Based on 2007 generation data, this equates to approximately 83 million MWh to 166 million MWh of lost energy each year [21].

In 2009, TVA participated in a series of EPRI Green Transmission Initiative Workshops that brought together various stakeholders in the power industry. The objectives of these workshops were to increase awareness of transmission as a resource for energy efficiency, facilitate and share examples of best practice for reducing transmission losses, and explore and formulate regional demonstration projects to improve transmission efficiency. Various engineering, construction and operational options for improving efficiency were discussed [22]. As a result, TVA is evaluating several demonstration projects to improve transmission efficiency.

One demonstration project being considered to improve transmission system efficiency is "Voltage Control Optimization." Voltage control is an effective method for increasing transmission capacity. Managing voltage reduces resistive losses and minimizes reactive power flow on the grid, allowing maximum real power transfer across congested transmission lines. The goal is to set the TVA transmission system voltage profile so that the desired reactive power reserves are met through the following controls: generator voltage set points, bulk transformer tap settings, capacitor and reactor switching, smoothly controlled compensators, and optimal placement of new reactive power sources.

Another initiative being considered is improvements in energy efficiency of substation auxiliary systems (i.e. HVAC, motors, fans, lighting, etc.). Energy usage within the substation has not been an area that many utilities have

considered, or given a high priority, for efficiency improvement. Objectives of the initiative are to evaluate measures to reduce energy consumption of substation auxiliary system and associated equipment, develop new standards for building more energy efficient substations, and refurbish or remodel existing substations to make them more energy efficient.

Improvement in transmission efficiency to reduce losses taps a resource which allows allocation of more generation for consumer use. Reduction in transmission losses can also help utilities defer investments in new generation and transmission facilities. But, reliability must remain a primary focus for any efficiency improvement initiatives.

3) *Peak Demand Reduction*

Reducing demand growth in a cost-effective manner addresses on-peak cost of operation, maintains power system reliability and preserves reserve requirements. TVA has set a goal of achieving a 1,400 MW demand reduction by 2012 through energy efficiency and demand response programs [23]. Three areas TVA is focusing on to achieve peak demand reduction are voltage regulation, direct load control, and time-of-use rates with critical peak pricing. Voltage regulation, or Voltage Control Optimization, was discussed in the previous section.

Direct load control programs provide rate incentives to customers for TVA to have the ability to shed or cycle non-essential electrical loads to reduce peak demand during hours of peak electrical usage. A smart grid would produce an end-to-end solution creating a communications path from TVA's system operations center to each distributor and potentially within the distributor's system down to individual loads.

TVA is developing plans that would allow the future implementation of time-of-use rates with critical peak pricing. Time-of-use pricing is based on the time of day electrical energy is used and the cost of supplying electricity during that time. Time-of-use pricing would be in effect except for certain peak days when prices may reflect additional costs of generating and/or purchasing electricity, known as critical peak pricing. The structure of rates charged for electric power can have a significant impact on how effectively energy efficiency measures are pursued. Rate structures can indicate to the ratepayer the value of conservation and demand reduction and also the timing when such activities are most beneficial to the power system. Rate structures, such as time-of-use and critical peak pricing rates, do a better job of motivating such activities than simpler rate structures that neither indicate how much utility costs vary across time nor indicate the times at which electric supply costs are highest. TVA and interested power distributors have already offered pilot programs involving time-of-use rate structures

Through direct load control, voltage regulation, or critical peak price signals, a smart grid can deliver peak load reduction either by dispatch or autonomously, piloted by a schedule. Many commercial, industrial, and direct-served industry consumers also have programs targeted to focus on efficiency improvements in HVAC, lighting, motors and

controls, and other electrical intensive equipment [12] to help reduce peak demand.

4) *Plug-In Hybrid and Electric Vehicles*

The transition from petroleum to electricity as a transportation fuel challenges traditional planning processes and utility systems. Unpredictable mobile loads will create a need to have a fully integrated communications and control architecture to maximize the benefits of electric vehicles.

Short-term focus is on the demand of this new load and its immediate impact on distribution and transmission systems. As we look to the future, TVA is working to create the shift from demand focus to a focus of supply, where the energy stored in the electric vehicle can be used as a resource. As the vehicle and battery technologies continue to develop, shorter charge times will enable load shaping opportunities and, as the number of vehicles continue to grow, load control technologies will help utilities better manage critical peak events.

Developing a strategy to take full advantage of environmental benefits from transportation electrification is a cornerstone to TVA's research in this technology area. By refining traditional system control processes, carbon and other mobile emissions can be reduced.

The scale of the TVA system, regional electric vehicle manufacturing and infrastructure development, and the concept of a fully integrated smart grid system provide the ideal situation to fully understand and maximize the benefits of electricity as a transportation fuel.

IV. CONCLUSIONS

Today uncertainty in timing of future economic activity, load forecasts, and environmental legislation including the focus on renewable energy and carbon emission reduction push transmission to the forefront of policy discussions. Transmission is seen as the bridge to numerous future state energy visions for not only TVA but for the country. Often discussions revolve around movement of renewable energy from the mid-west to the eastern markets, or localized generation changes as a result of carbon legislation. In either case, relatively modest investments in transmission mitigate the risk associated with potential future states and buy companies the option of planning for an uncertain future. Generation decisions involving billions of dollars carry substantial risk, and while companies must be making decisions today that position themselves for tomorrow, legislative action is needed to provide the measure of certainty required for public power stakeholders and investor-owned shareholders to plan decisively.

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BIOGRAPHIES

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