MATCHING WIND RESOURCE IN THE SOUTHERN GREAT PLAINS WITH UTILITY ELECTRICAL LOADING

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ABSTRACT

A study was conducted to see how well wind generated electricity in the Southern Great Plains matched the utility electrical loading and whether there were ways to improve this match so that renewable energy could make up a more significant portion (10-30%) of the utility's total generation. Wind generated electricity is a maximum during April and wind generated electricity is a minimum in August when the utility loading is highest; therefore, these two months were analyzed. Adding as much as 1500 MW -- average utility load for XCEL (SPS region) was 2700 MW -- of wind generated electricity appeared feasible even without the utility grid absorbing excess wind generated electricity if the utility could lower its base load. Combining solar energy with wind energy and adding a storage facility resulted in a very good match to the utility loading and resulted in little change to the utility's current operations.

INTRODUCTION

A Danish utility Eltra has proven how wind generated electricity can be a high percentage (~ 20 % as of 2003) of a utility's total generation (Pederson, 2000). However, although Denmark has adequate transmission lines to transmit the excess wind generated electricity to other countries, Eltra has had a few close calls with their high level of wind penetration (Jensen, 2002). A small Iowa utility also has a high percentage of wind penetration, but again it has adequate transmission line capacity to absorb excess wind generated electricity (Wind, 2000).

Invariably, when we hold renewable energy workshops, farmers and ranchers interested in the lucrative wind royalty payments (averaging $3500-5000 per MW of wind turbine capacity per year) have asked why more wind farms are not going up in the SPS region (Figure 1). According to XCEL Energy, currently the cost of the wind generated electricity is less than their natural gas powered steam or combustion turbines, but still more expensive than their coal powered steam turbines. It's good to remember though that the coal generated power was more expensive after their construction in order to pay off the building of the plants while the cost of the wind generated electricity will be the same for the lifetime of the wind project (at least 20 years). XCEL's SPS region has 5 coal powered steam turbines (2200 MW), 13 natural gas powered steam turbines (2000 MW), and 4 natural gas powered combustion turbines (300 MW). The only major wind farm in the SPS region is the 80 MW wind farm near White Deer, TX (Llano Estacado Wind Ranch) while there are over 1200 MW of wind farms in the rest of Texas (mainly West Texas).

XCEL Energy Territory

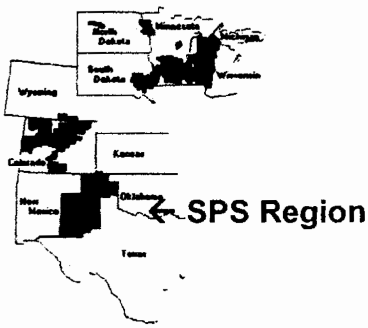

Fig. 1 SPS utility grid in XCEL Territory.

The main reason the majority of these wind farms are in Texas is due to the passing of Senate Bill #7 in the Texas legislature which basically says that all the utilities operating in Texas have to have 3% (2000 MW) of their electrical generation capacity come from renewable energy sources (wind, solar, biomass) by the year 2009 or penalties will be levied against the utilities. Also specified in the bill is that certain levels of wind generated capacity are to be achieved in 2004 and 2007 which encourages a steady growth in the wind industry. Unfortunately, the on again off again federal production tax credit (1.8 cents/kWh before expired on Dec. 31, 2003) has resulted in the wind energy industry companies hiring and then laying off workers for the past 10 years due to the PTC expiring every 1 to 3 years. The Renewable Portfolio Standard in Texas (Senate Bill #7) has been the model for other states since it provides for utilities without good renewable energy sources in their regions to buy renewable energy credits. So far most of the renewable energy added has been in the form of wind farms since it is currently the cheapest renewable energy.

The reason there have been more wind farms in West Texas is due to the electrical grid (Electrical Reliability Council of Texas or ERCOT) in that region being connected to high electrical load centers in East Central Texas. XCEL (SPS region) is not connected to ERCOT except through a small 200 MW AC-DC-AC intertie near Vernon, TX. However, this intertie is not owned by XCEL Energy (owned by AEP), and can only be used on a space available basis. XCEL Energy (SPS region) does not have any high voltage lines connected to any high electrical load centers except to Kansas City. However, it makes more sense for wind generated electricity going to Kansas City to come from wind farms in Kansas due to line loss. The cost of building a 235 kV transmission line is approximately $1 million per mile. So the only way currently for SPS to increase their amount of wind generated electricity is to increase the percentage of wind generated electricity in their total mix of power generation. We therefore decided to see if we could determine how difficult it would be for SPS/XCEL to increase its percentage of wind generated electricity from an operational viewpoint and let others evaluate the economic feasibility.

We began analyzing increasing the amount of wind generated electricity by seeing how well the wind generated electricity matched the utility electrical loading on an annual and a diurnal perspective. From this analysis we decided to analyze increasing the amount of wind generated electricity during two particular months. April was chosen since it is representative of an average utility electrical load month and it is typically the highest wind energy month. August was the other month chosen since it represents the highest utility electrical load month and it is typically the lowest wind energy month. While we increased the amount of wind generated electricity, we also looked at how lowering the base load of the utility could help increase the percentage of electricity if excess wind generated electricity from the utility could not be transmitted out of the SPS region. We also looked at ways of improving the diurnal match of wind generated electricity to the utility electrical loading through storage and combining it with a solar thermal plant. Four renewable energy options are shown in this report and they were:

1. Wind only
2. Solar thermal only
3. Wind and Solar thermal
4. Wind, Solar thermal and storage

While storing the wind generated electricity helped some to match utility loading, the only good match occurred by combining wind farms with solar thermal power plants and adding a storage facility so power could be provided when wind or solar thermal generated electricity was not available. On a large scale, this is the same way that renewable energy is used to power remote locations needing high reliability on a small scale (e.g. like powering satellite communication sites with a small wind turbine, solar-PV, and batteries).

Some assumptions were made of the renewable energy options analyzed. We assumed the wind turbines would be 1 MW or larger on towers with hub heights in range of 65 to 70 meters. With the wind resource in the SPS region and these wind turbine specs, annual capacity factors around 40% can be reached. If taller towers are used then more wind generated electricity would be generated for the same power rating (e.g. higher capacity factors). Taller towers will also mean a higher percentage of the wind generated electricity will be added during low utility electrical loading. For utility scale plants, the types of solar thermal plants available are parabolic trough and power tower (Sargent, 2003). Although there are no solar thermal plants in Texas, we modeled them using global radiation data collected at the USDA-ARS laboratory in Bushland, TX and solar thermal plant models developed at Sandia and NREL after the radiation data was converted to Direct Normal radiation. For utility scale storage capacities, the type storage facilities available for wind include pumped hydro (70 to 80% efficiency) and compressed air energy storage (CAES, 65% efficiency). However, pumped hydro is probably not likely for the arid mainly flat region of the SPS region of XCEL. CAES systems have been investigated for use with wind farms recently (Desai, 2003 and Wind, 2003). For solar thermal plants, heat is stored instead of electricity which can result in an efficiency of 99% (Pacheco, 2002). Although higher levels of storage efficiency appeared feasible for wind and solar thermal systems, we decided to be conservative and assume only 50% of the storage energy was recoverable.

Wind Resource (Nocturnal Jet of the Great Plains)

Figure 2 shows the annual diurnal distribution of wind speed at the heights of small to medium size wind turbines (e.g. 10 to 25 meters, 33 to 80 ft) through 1990 – note how the highest wind speeds occur in the afternoons. However, since the year 2000 the hub heights of wind turbine towers have been increasing to range of 65 to 80 meters (213 to 262 ft). This increase in height has exposed the wind turbines to what is referred to as the nocturnal jet -- highest wind speeds occur in early morning and late evening hours. Figure 3 shows a graphical representation of this nocturnal jet for Hobart, OK (although Hobart is not in the SPS region, it is typical of the wind shear that has been seen at several locations in the Great Plains – including the SPS region).

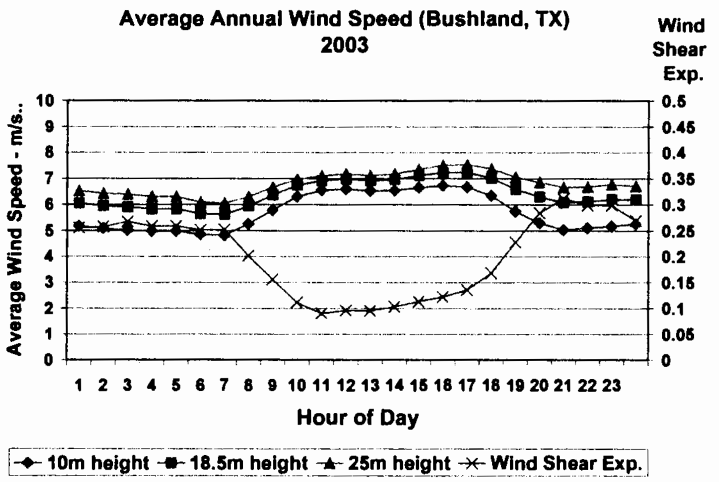

Fig. 2. Heights of Wind Turbines Prior to 1990.

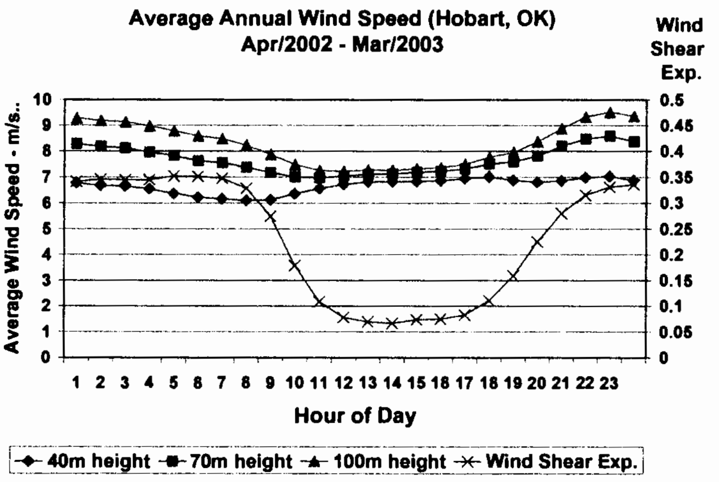

Fig. 3. Heights of Wind Turbines after 2000 (note significant change in diurnal wind speed).

In the past, the following equation (Rohatgi, 1994) has been used to determine the wind speed at higher heights from a known height:

$$V = V_o (h/ h_o)^{\alpha}$$

Where V = unknown wind speed

V_o = known wind speed

h = height of unknown wind speed

h_o = height of known wind speed

α = wind shear exponent

While this equation using a constant wind shear exponent may still be useful for predicting the daily or monthly average wind speeds at higher heights, it is evident from Figure 3 that the wind shear exponent varying from 0.35 in early morning and late evening to 0.05 during the afternoon results in large errors if a constant wind shear exponent was used to predict the wind speed during the day. Research is being conducted (Archer, 2003) to see if higher height data can be determined from lower heights, but currently data are needed for these higher wind turbine hub heights to evaluate wind farm electrical generation. Wind turbines being exposed to this nocturnal jet has resulted in an improvement in the capacity factor for wind farms, and also has helped increase the amount of wind generated electricity in the summer during utility peak loading months. However, wind turbines being exposed to the nocturnal jet has also resulted in a diurnal mismatch of wind generated electricity to utility electrical peaking loads in late morning and in the afternoon (a good thing about the nocturnal jet is that it has improved the match for wind generation for peaks in the utility loading occurring in the evening).

Selection of Months Used in Analysis

Figure 4 shows the average monthly electrical loading for XCEL Energy (SPS region) for years 2002 and 2003. Also shown for the same two years is the monthly average capacity factor of a typical wind farm for this region. The utility electrical loading is always higher for 2003 compared to 2002 except for June. This is because in June 2003 there was significant rainfall which resulted in less electricity being used for irrigation and air conditioning. For both years 2002 and 2003 the highest capacity factor occurred in April and the average utility electrical load during that month was the annual average. The highest utility electrical load occurred in August which corresponded to the lowest wind turbine capacity factor month in 2003. Therefore, we decided to choose these two months in 2003 (April and August) to evaluate the utility's ability to accommodate the higher percentages of wind generated electricity. Figures 5 and 6 show the diurnal utility electrical loading and wind turbine capacity factor for April and August, respectively. Comparing these two graphs indicates there is a substantial difference for these two months when comparing utility electrical loading to wind farm capacity factor. Referring back to Figure 3, the diurnal average wind speed curve for the 70 m height is very close to the wind farm capacity factor curve for April and August.

Affect on Utility Loading When Wind Generated Electricity Increased

As the percentage of wind generated electricity is increased (referred to as penetration), it soon became obvious that whether there was excess wind generated electricity or not depended on what the base load was. We finally decided to pick 3 different base loads for the months of April and August since the electrical loading was so different. The 3 base loads chosen for April were 2000, 1600, and 1200 MW while for August the base loads chosen were 2800, 2400, and 2000 MW. As the base load is decreased this will require more coal and natural gas power plants to be operating at less than rated capacity in order to cover the additional electrical load required – this is a result of the variability of the wind generated electricity. We were not sure what the base load was for the utility because this was proprietary information. The three total wind farm capacities selected were 500, 1000, and 1500 MW. So we had a matrix of 3 base loads and 3 wind farm capacities.

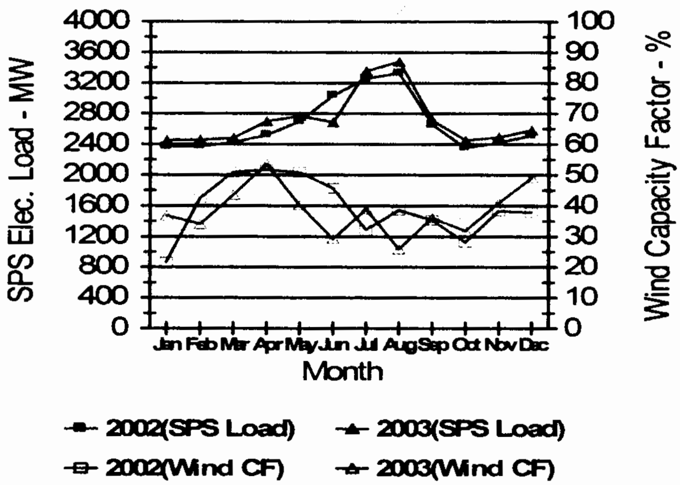

Fig. 4. Average SPS Electrical Load and Average Wind Capacity Factor.

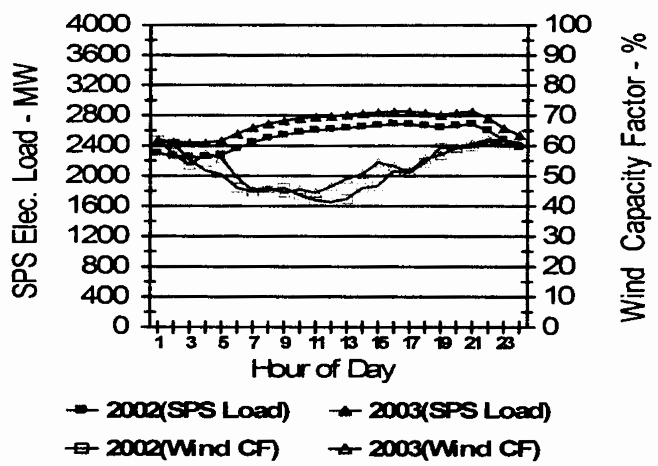

Fig. 5. Diurnal SPS Elec. Load and Diurnal Wind Capacity Factor for April.

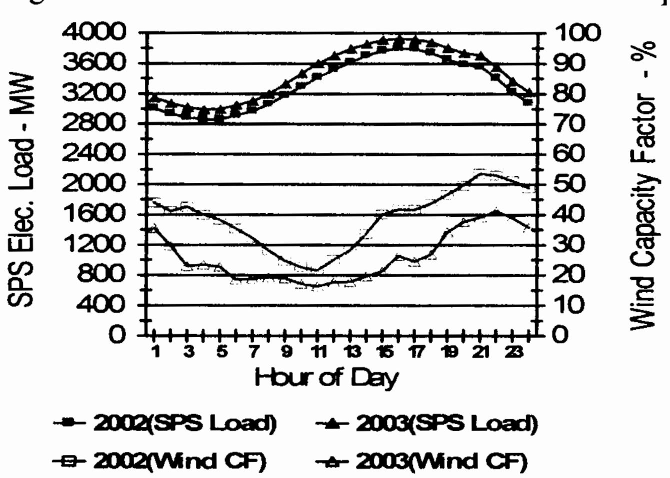

Fig. 6. Diurnal SPS Elec. Load and Diurnal Wind Capacity Factor for August.

Figure 7 shows the average additional utility loading required during April for a utility base loading of 2000 MW for three wind farms ranging in size from 500 MW to 1500 MW. For the 500 MW wind farm capacity, no excess electricity is generated by the wind farms, but for the 1000 and 1500 MW wind farm capacities, excess electricity is generated in the early morning and late at night. It should be remembered that the additional utility load shown is a monthly average, so on a very windy day, excess wind generated electricity will be generated all day long for the 1500 MW wind farm capacity. When the utility base load is decreased to 1600 MW (see Figure 8) only the 1500 MW wind capacity is still negative in early morning and late night hours. When the base load is lowered to 1200 MW (see Fig. 9) all three wind farm capacities (500, 1000, and 1500 MW) do not deliver excess wind generated electricity onto the grid. For the month of April, the wind energy percentage of the utility load for the 500, 1000, and 1500 MW wind capacities were 10, 20, and 30% respectively.

Figures 10-12 show the wind farm load penetration for August 2003 for the base loads 2800, 2400, and 2000, respectively. Again, as in April, the 1000 and 1500 MW wind farm capacities generate excess electricity in the early morning and late night hours (see Figure 10). However, when the base load is reduced 400 MW from 2800 MW to 2400 MW (see Fig. 11), no excess electricity would be generated by the wind farms – different from the result in April for a similar decrease in base load. This is due to the fact that only half as much electricity is generated by the wind farms in August 2003 compared to April 2003. Figure 12 shows the average amount of additional utility electricity required for a base load of 2000 MW for the 3 wind farm capacities. The percentage of wind generated electricity of the utility load for the 3 wind farm capacities of 500, 1000, and 1500 MW were 3.7, 7.5, and 11.2%, respectively. These lower percentages compared to April are due to more electricity needed in August than April and that more electricity was generated by the wind in April than in August.

Maximum Hourly Electrical Generation Change Due to Increasing the Percentage of Wind Generated Electricity

For electricity being delivered from wind farms to the utility grid, there occasionally will be times when the wind speed will increase or decrease rapidly which will cause the utility to counter this with one or more of their fossil-fueled power plants. We only analyzed power fluctuations from hour to hour, but it has also been analyzed on smaller increments of one minute for a similar study looking at increasing the amount of wind generated electricity penetration for a utility with transmission line constraints (Hirst, 2003). Figure 13 shows the maximum hourly change in utility supplied electricity for the 3 wind farm capacities used before in this paper – 500, 1000, and 1500 MW for April 2003. The solid black line without symbols shows the actual maximum hourly diurnal change in the utility load. The maximum hourly load that actually occurred last year during April happened at 11 p.m. and the power fluctuation was 217 MW. If 500 MW of wind had been operating the maximum hourly wind generated electricity change would have been 340 MW at 6 a.m. For the 1000 MW and 1500 MW wind farm capacities, the maximum hourly wind generated electricity change would have been 572 and 803 MW, respectively (both occurred at 6 a.m. again). Of course the average maximum hourly wind generated electricity variations for these 3 wind projects were much lower (being in the 180-200 MW range), but occasionally the utility would need to handle these fluctuations.

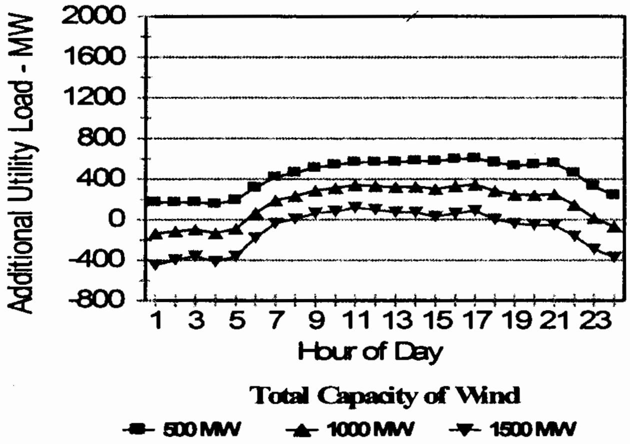

Fig. 7. Wind Farm Load Penetration for April 2003 (Base Utility Load=2000 MW).

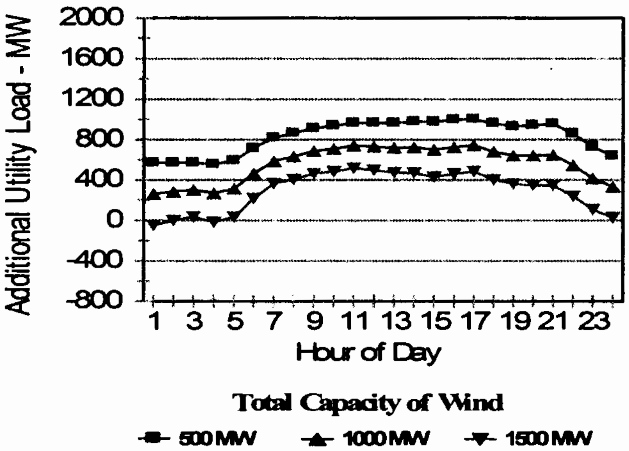

Fig. 8. Wind Farm Load Penetration for April 2003 (Base Utility Load=1600 MW).

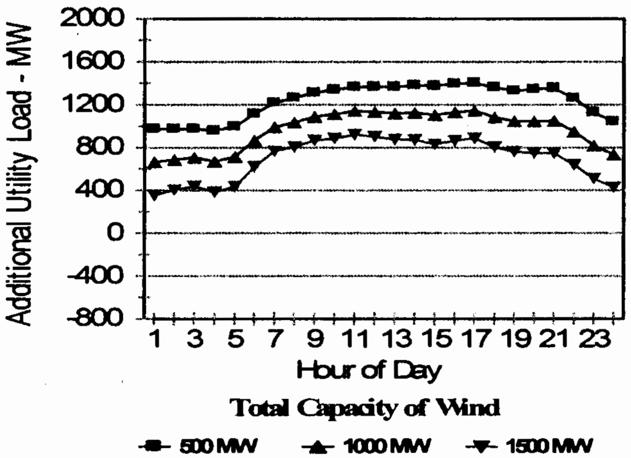

Fig. 9. Wind Farm Load Penetration for April 2003 (Base Utility Load = 1200 MW).

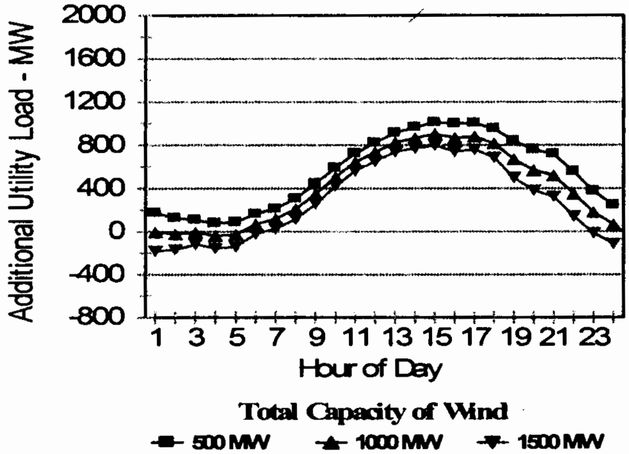

Fig. 10. Wind Farm Load Penetration for August 2003 (Base Utility Load = 2800 MW).

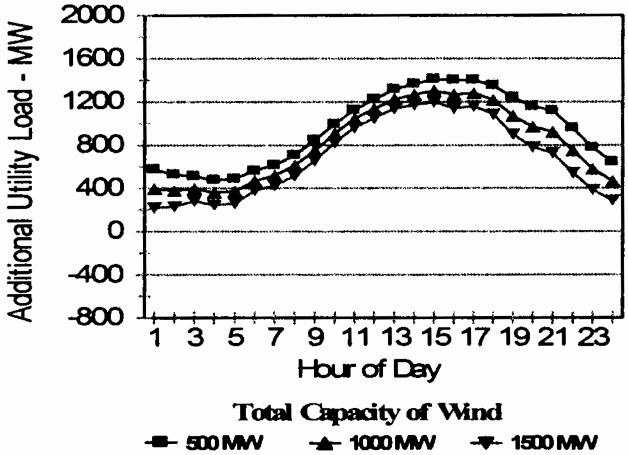

Fig. 11. Wind Farm Load Penetration for August 2003 (Base Utility Load = 2400 MW).

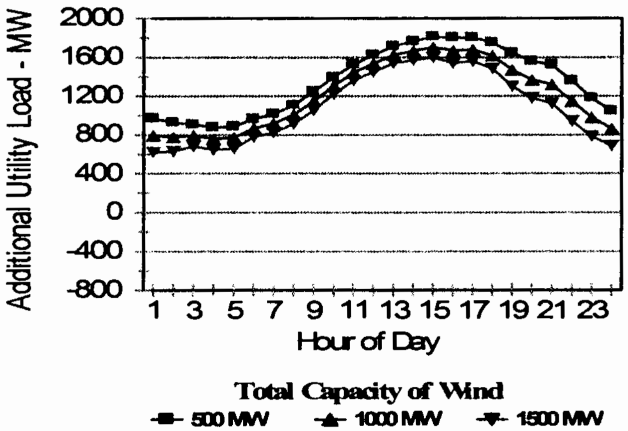

Fig. 12. Wind Farm Load Penetration for August 2003 (Base Utility Load = 2000 MW).

Figure 14 shows the maximum hourly load change experienced by the utility in August 2003 which occurred again at 11 p.m. and was 246 MW. The maximum hourly wind generated electricity change experienced in August 2003 for wind farm capacities of 500, 1000, and 1500 MW were 347 MW (at 10 p.m.), 491 MW (at 10 p.m.) and 686 MW (at 3 a.m.) respectively.

Although the change in maximum wind generated electricity seems fairly dramatic for the months of April and August discussed above, XCEL Energy's (SPS region) power pool should be able to handle the change. Even for the 1500 MW wind capacity case where the maximum hourly wind generated electricity change was 800 MW, the fact that all 21 of XCEL Energy's (SPS region) fossil-fueled power plants can ramp up or down at 3 to 4 MW per minute which would allow just a few of them to handle this wind generated electricity change (this is assuming the power plants are online and not having to start from a cold start). Of course these maximum hourly wind generated electricity changes will not be this large if the wind farms are scattered around the SPS region (e.g. not exposed to the same winds at the same time).

<u>Improving the Match of Wind Generated Electricity to the Utility Electrical Loading</u>

Two ways of improving the match between wind generated electricity and the utility electrical loading are:

1. Storage of excess renewable energy to be delivered when the utility load increases.
2. Combining wind farm with a solar thermal power plant.

Since the utility electrical load is always lowest in the early morning hours and the wind energy is usually high due to the nocturnal jet, then it is logical to store this wind generated electricity and use it later when the electrical load increases in the late morning to afternoon time. Although storing this wind generated electricity for later use did help somewhat, it did not really help a significant amount due to losing about half during storage (even assuming a better efficiency did not help significantly) and also to the continuous decrease in wind speed from midnight to about 1 p.m. while the utility load began increasing at around 7 a.m. The cost of storing the electricity in a CAES system depends on the size of the system, but as a reference, for a CAES system able to deliver 500 MW for 24 hours the cost would be around $185 million.

Combining solar thermal power plants with wind farms is another good way of improving the utility load match since the sun's radiation energy increases in the morning and peaks in the afternoon while the wind generated electricity is highest in the early morning and evening – so the two together seemed like a perfect fit. We only considered solar thermal plants instead of solar-PV because solar thermal is much more efficient. Most solar thermal power plants are in California and are augmented with natural gas when the solar radiation is low or to provide dispatchable power to the utility. Current solar thermal plant designs almost always include storage, and it is much more efficient than using CAES since heat is stored without having to do the conversion from electrical to potential to electrical required for CAES systems. While the cost of energy of these plants are in $0.125 range (cost of including storage actually cheaper in solar thermal -- $0.123) which is factor of 3 over the wind generated cost of energy $0.042, the additional improvement in the match to the utility's electrical load plus diversifying (improves reliability) the generation mix may be worth the additional cost. A National Academy of Science Review indicates that with development and deployment, the solar thermal cost of electricity is expected to drop into the range of 3.5 to 6.2 cents per kWh (Baldwin, 2002).

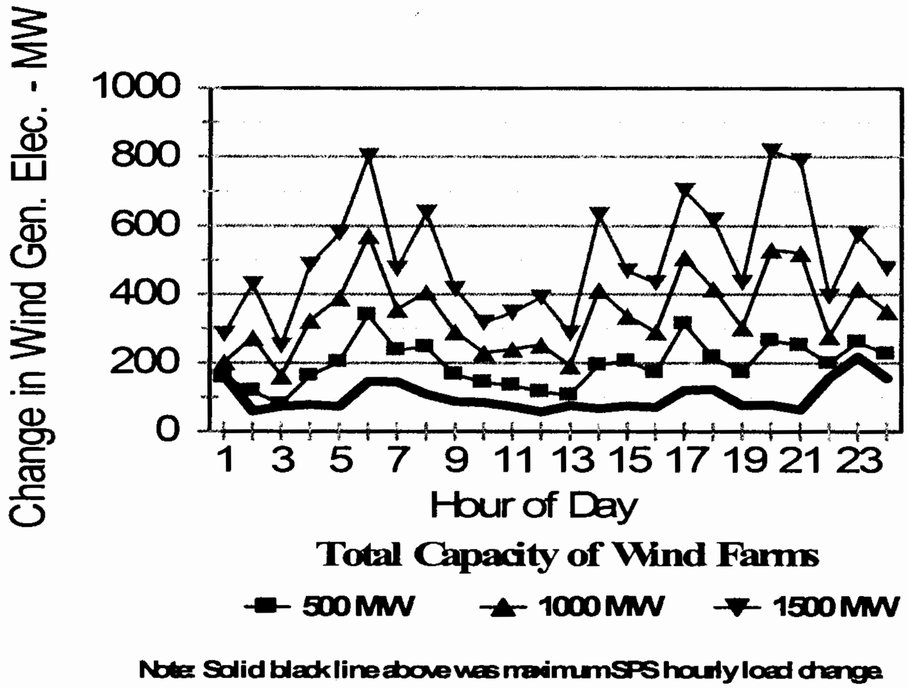

Fig. 13. Maximum Hourly Wind Generated Electricity Change for Various Wind Farm Capacities (Apr.2003).

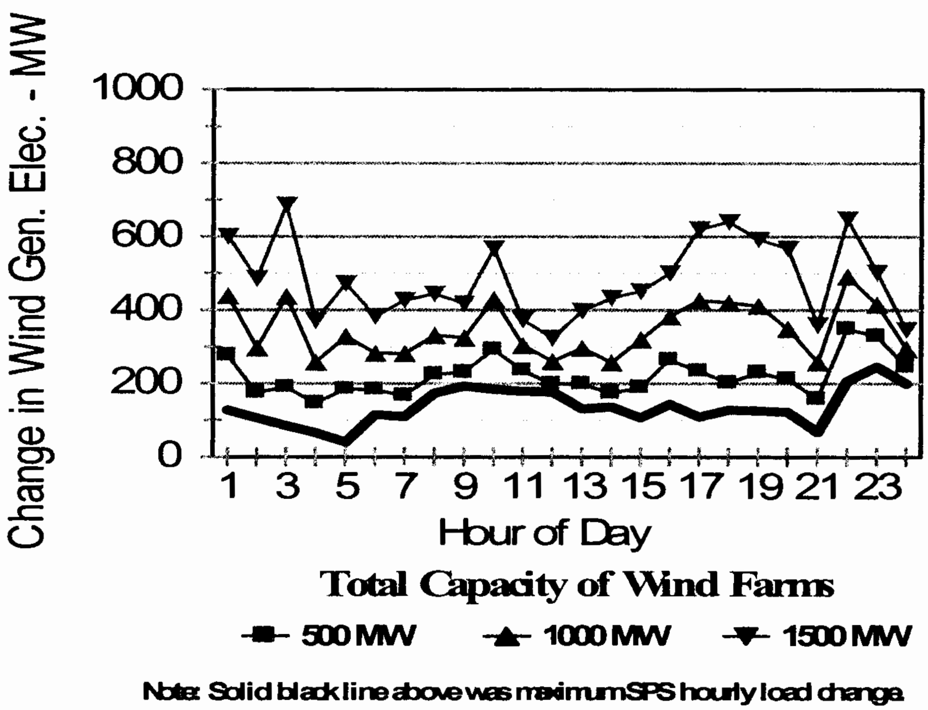

Fig. 14. Maximum Hourly Wind Generated Electricity Change for Various Wind Farm Capacities (Aug.2003).

The various type solar thermal plants focus the sun's radiation on some type of fluid (oil) in a pipe (later energy transferred to molten salt for parabolic trough) or a tower (power tower uses molten salt) and that heat is transferred via a heat exchanger to heating steam in a boiler. So just adding the solar thermal part (mirrors and pipes or tower) to an existing coal or natural gas steam turbine plant may not be as expensive as in California.

Figure 15 shows the average utility electrical load and the capacity factor for various renewable energy options for April 2003. The utility electrical load is lowest from 1a.m.-5 a.m. and begins to steadily increase from 6 a.m. to 1 p.m.; at that point it remains relatively constant until 9 p.m. when it begins to steadily decrease back to 1 a.m. again. The wind generated electricity (as shown before in Figure 5) starts out at its highest level at 1 a.m. and unsteadily decreases to 7 a.m. at which point it remains relatively steady until 11 a.m. whereupon it begins to increase somewhat steadily until 1 a.m. again. The capacity factor for solar thermal begins to ramp up from 7 a.m. until 10 a.m. and then remains relatively constant until 5 p.m. at which point it ramps down to zero at 8:00 p.m. When the wind generated electricity was combined with the solar thermal electricity we assumed a 50/50 mix of the two, therefore it is an average of wind only option and the solar thermal only option. While combining the wind with the solar thermal helps supply more electricity to the utility in the late morning and afternoon, it doesn't follow the electrical load mid morning and in the evening. Therefore, the last case is the same as previous case (combination of wind and solar thermal) except storage is added to help follow the utility loading more precisely. The wind energy is stored in the early morning and is delivered to the grid in mid morning when the utility load is increasing. Then during the late morning and afternoon some of the solar thermal power is stored to be used later in the evening. This last option (wind, solar thermal, storage) was able to meet the additional utility loading very well.

Figure 16 shows the utility electrical loading and the same renewable energy options discussed in Figure 15 except it is for August 2003. The wind generated electricity is about half of what it is in April and the solar thermal is also down significantly from April. The wind generated electricity is down due to lower wind speeds, but the solar thermal is down due to more clouds. The combination of wind with solar thermal is not a bad match to the utility electrical load except dies off somewhat abruptly in the evening. For the wind, solar thermal, storage option the wind energy is stored in the morning and used some in afternoon and some in the evening to follow the decline in the utility load more closely. No solar thermal is stored in August since the utility load is so high in the afternoon. All the rest of the months of 2003 were analyzed with these four renewable energy options (wind only, solar thermal only, wind/solar thermal, wind/solar thermal/storage), and though the storage requirements needed to be varied, the wind/solar thermal/storage option did a very nice job of tracking the utility electrical loading. These graphs show the average capacity factor, so there will be days when the wind, solar thermal, storage option will not track the utility electrical loading, but on average it will.

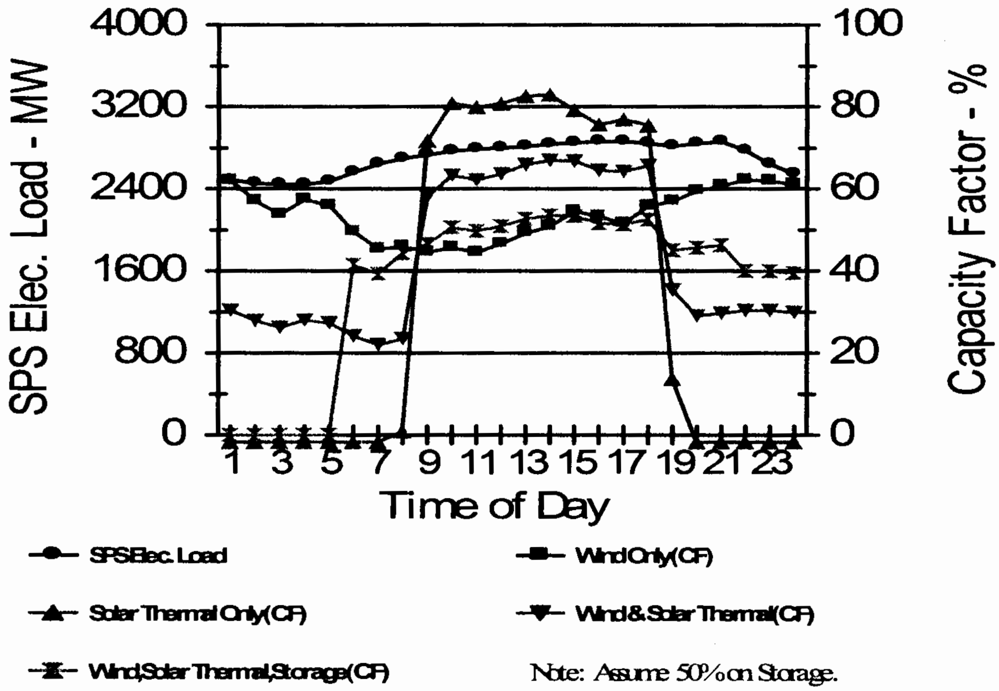

Fig. 15. Comparison of SPS Elec. Load to Renewable Energy Options for April 2003.

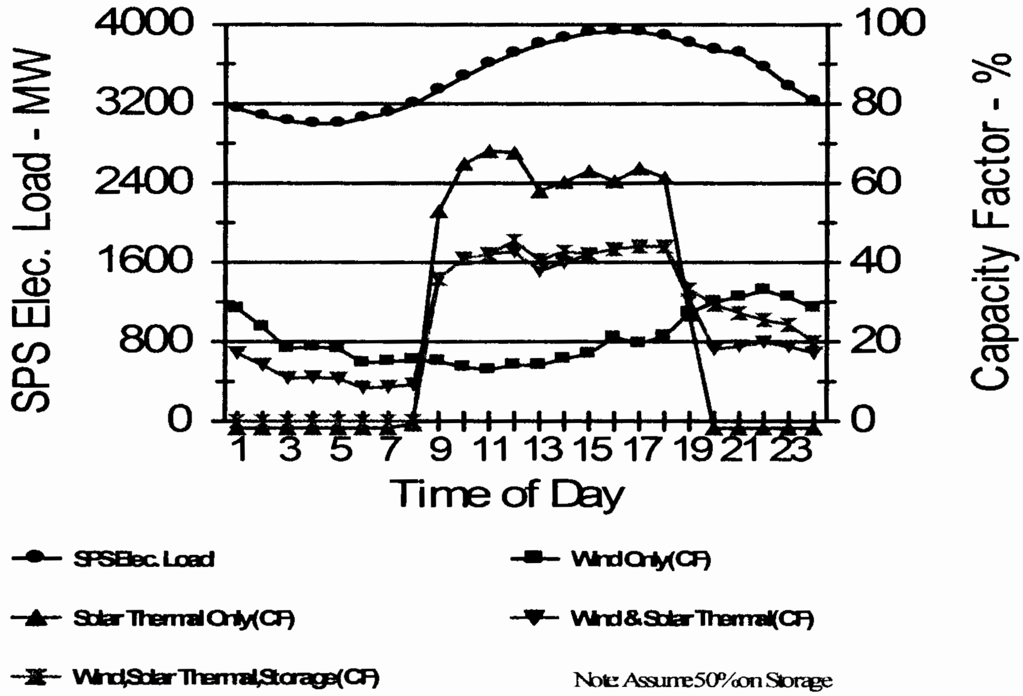

Fig. 16. Comparison of SPS Elec. Load to Renewable Energy Options for August 2003.

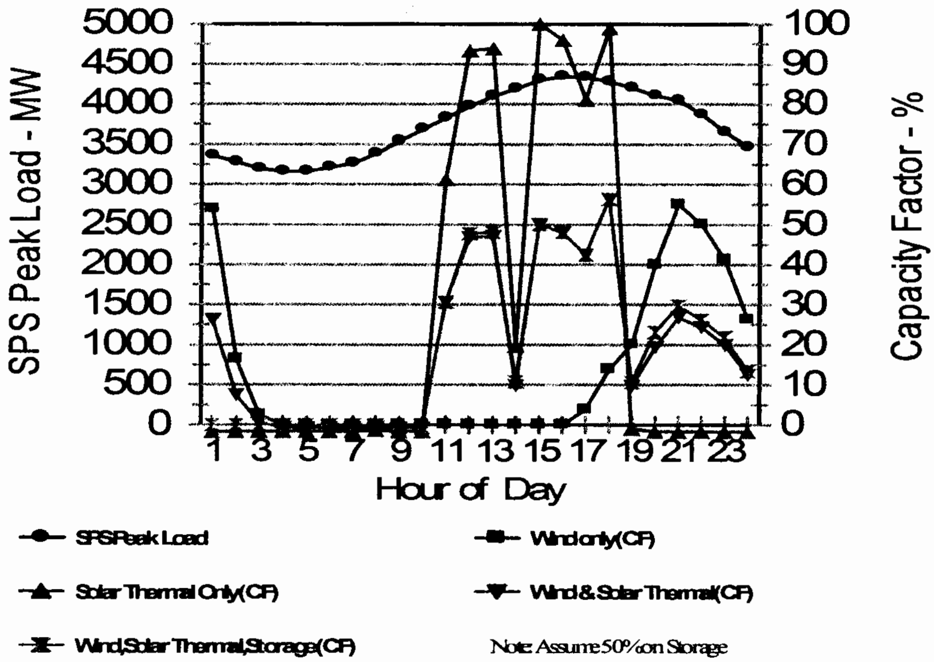

Fig. 17. Peak SPS Load (Aug. 5, 2003, 4338 MW @ 4 p.m.) and Renewable Energy Options.

Figure 17 shows the XCEL Energy (SPS region) peak electrical loading for 2003 and the capacity factors for all the renewable energy options on that day (Aug. 5, 2003). For this particular day it would have been better to have only solar thermal because there was no wind generated electricity from 4 a.m. until 4 p.m. (this is when the peak electrical load was reached). However, the second best option was the wind/solar thermal/storage option. While it is obvious that combining solar thermal with wind helps track the utility loading during the day, does it help on an annual basis?

Figure 18 shows that solar thermal does help wind out in tracking the utility load during the year. The energy produced by the utility is shown in Figure 18 along with 3 renewable energy options – Wind Only, Solar Thermal Only, and Wind/Solar Thermal (Wind/Solar Thermal/Storage not shown since it is similar to Wind/Solar Thermal). For demonstration purposes, the size of the renewable energy options was chosen as 4500 MW. A least squares second order polynomial was fit through the SPS utility loading data and the three renewable energy options. As was pointed out earlier for Figure 4, the Wind Only option doesn't track the utility loading well during the year which is evident in Figure 18 by the SPS loading parabola opening down and the Wind Only parabola opening up. Both the Solar Thermal Only and the Wind/Solar Thermal cases have parabolas opening down like the SPS loading which indicates that solar thermal generated electricity matches the utility loading better on an annual basis. In addition, solar thermal energy has a much higher correlation coefficient than wind energy. Wind energy having such a low correlation coefficient has been a major argument against increasing the percentage of wind generated electricity.

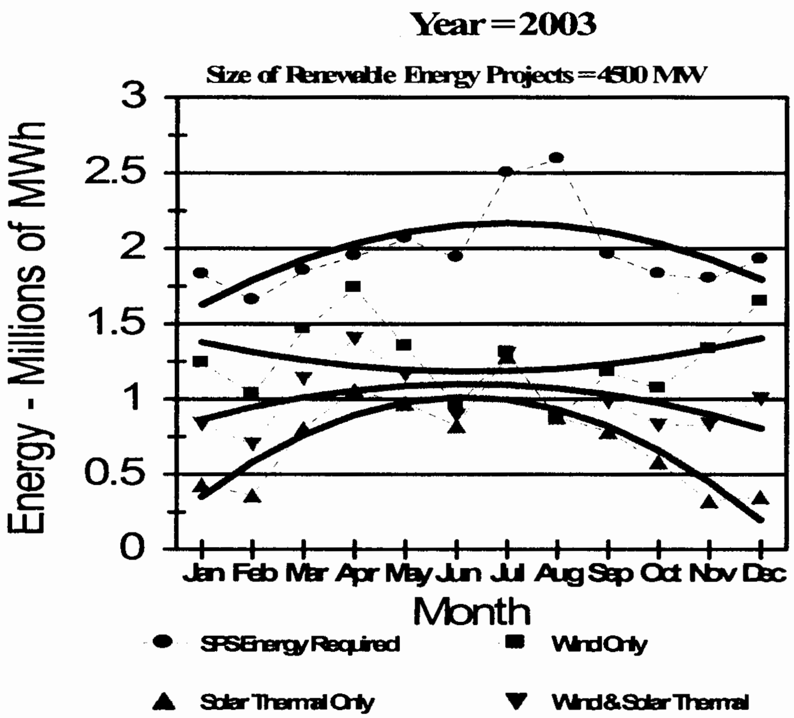

Fig. 18. Energy Required by XCEL (SPS Region) and Energy Produced by Different Renewable Energy Options Assuming a 4500 MW size.

<u>Affect on Utility Loading Using Wind/Solar Thermal/Storage Renewable Energy Option</u>

In Figures 19-24 we show the affect of using the Wind/Solar Thermal/Storage option discussed above for the same utility base loads, renewable energy power plant capacities, and months that were used for the Wind Only case in Figures 7-12. In Figures 19-21 the affect on the additional utility load for 3 base loads (same as wind only – 2000, 1600, and 1200 MW) and 3 wind/solar thermal/storage power plants (same as wind only 500, 1000, and 1500 MW) are shown for April 2003. For the 2000 MW base load case, while the 1500 MW case still provided some excess renewable energy generated electricity, the 1000 MW case did not – this finding was different from the Wind Only case. With some modification of when the wind generated and solar thermal electricity was stored and used during the day – no excess electricity would have gone on the grid. The addition of the solar thermal electricity in the morning and afternoon also kept the additional utility load from changing significantly during the day for all 3 base loads. Figures 22-24 show the affect on the utility loading for the wind/solar thermal/storage renewable energy option for August 2003. This time no excess renewable energy was generated for the utility for all 3 base loads (2800, 2400, and 2000 MW) and all 3 renewable energy plant capacities (500, 1000, and 1500 MW). It should be noted that for the Wind/Solar Thermal/Storage case we expect the maximum hourly fluctuations in renewable generated electricity would not be any different than currently being experienced by the utility since the storage facility would be able to absorb the fluctuations provided the storage facility was large enough.

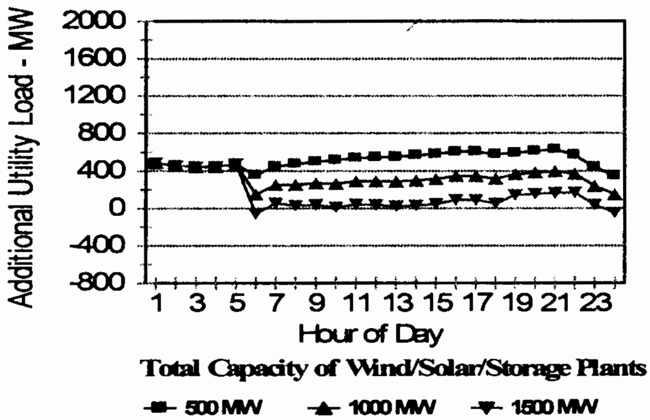

Fig. 19. Wind/Solar/Storage Penetration for April 2003 (Base Utility Load = 2000 MW).

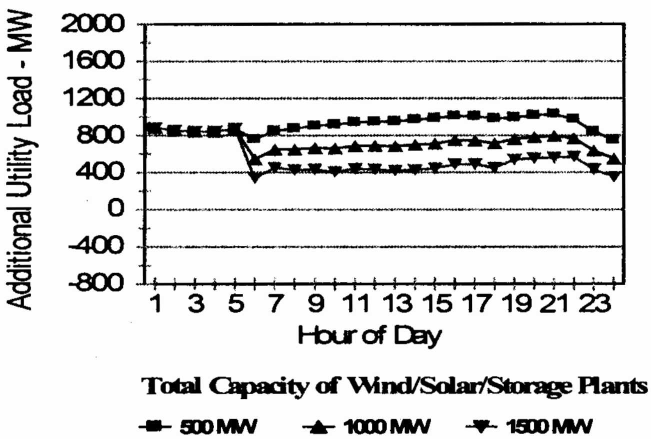

Fig. 20. Wind/Solar/Storage Penetration for April 2003 (Base Utility Load = 1600 MW).

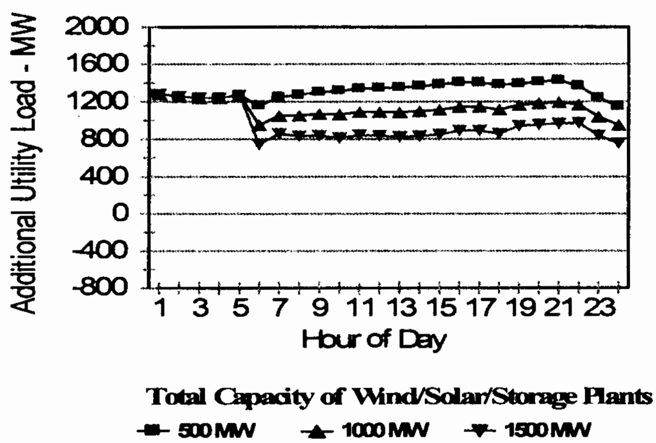

Fig. 21. Wind/Solar/Storage Penetration for April 2003 (Base Utility Load = 1200 MW).

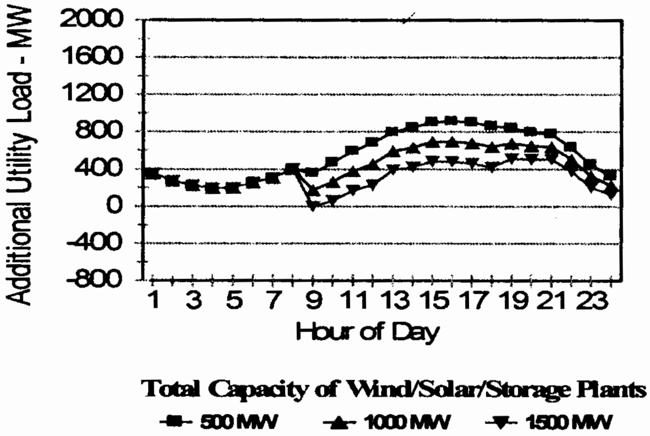

Fig. 22. Wind/Solar/Storage Penetration for Aug. 2003 (Base Utility Load = 2800 MW).

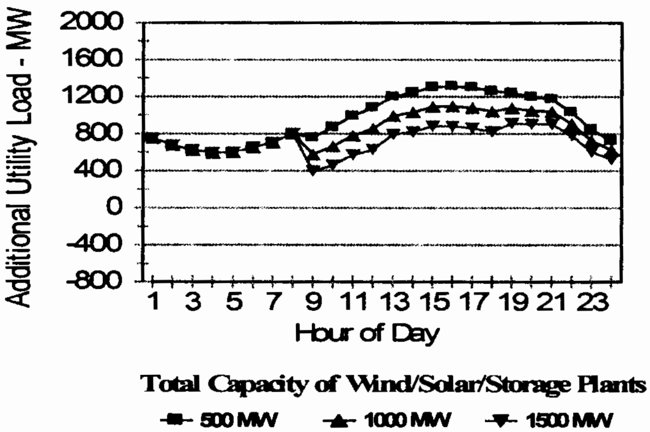

Fig. 23. Wind/Solar/Storage Penetration for Aug. 2003 (Base Utility Load = 2400 MW).

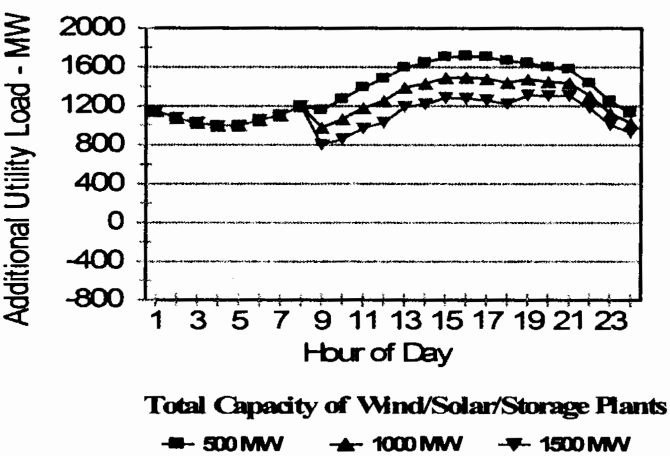

Fig. 24. Wind/Solar/Storage Penetration for Aug. 2003 (Base Utility Load = 2000 MW).

CONCLUSIONS

Modeling was performed for a utility in the Southern Great Plains (XCEL Energy, SPS region) to determine the affect on the utility loading and operations by increasing the amount of wind generated electricity. For the wind farm only option, the higher the base load, the more likely it was for generating excess renewable energy on the utility grid in the early morning and late night hours (not usually a desirable situation for the utility). However, if the base load could be decreased by increasing the number of the power plants that could operate at variable generation, then the utility would not have to handle excess wind generated electricity. Various renewable energy options were investigated for a windy month with an average utility load (April) and a low wind month with a high utility load (August). The amount of energy generated by each renewable system for a 1500 MW size is shown in Table 1 (for other sizes multiply the numbers by ratio x/1500). No specific type of storage of the excess renewable energy was specified, but it was assumed that 50% of the energy stored would be recoverable. While the solar thermal electrical generation was always less than the wind generated electricity (except for the lowest wind energy months), the solar thermal electricity improved diurnally and annually the tracking of the utility electrical load – especially during the summer. Combining wind with solar thermal and adding storage resulted in an ability to match the utility loading for all months of the year -- assuming monthly average. For the wind only option, XCEL (SPS region) will have to be able to handle larger hourly electrical load swings when larger amounts of wind generation are included on the system – for 1500 MW of wind capacity, the maximum hourly change in electricity generated can be 700 to 800 MW while currently the maximum electrical load variance is about 230 MW. Depending on the size of the storage facility, the wind/solar thermal/storage option should not have any larger swings then the utility is accustomed to at the present time since the storage facilities should be able to smooth out the renewable energy generated.

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Table 1. Energy required by XCEL (SPS Region) and Energy Predicted for each 1500 MW Renewable Option in 2003.

	XCEL (SPS Region)									
	Energy	Average Load	Wind		Solar Thermal		Wind Plus Solar Thermal		Wind Plus Solar Thermal Plus Storage	
	10^6 MWh	MW	10^6 MWh	%	10^6 MWh	%	10^6 MWh	%	10^6 MWh	%
Jan	1.83	2453	0.41	22.56	0.14	7.83	0.28	15.17	0.23	12.72
Feb	1.65	2460	0.34	20.79	0.12	7.26	0.23	14.02	0.20	11.89
Mar	1.85	2481	0.49	26.36	0.27	14.51	0.38	20.44	0.32	17.35
Apr	1.94	2701	0.58	29.77	0.35	18.10	0.47	23.94	0.40	20.71
May	2.06	2769	0.45	21.83	0.32	15.66	0.39	18.74	0.35	16.96
Jun	1.93	2686	0.32	16.36	0.27	14.13	0.29	15.25	0.27	14.02
Jul	2.49	3353	0.44	17.45	0.43	17.13	0.43	17.31	0.39	15.79
Aug	2.59	3477	0.29	11.17	0.29	11.30	0.29	11.26	0.27	10.44
Sep	1.95	2714	0.39	20.01	0.26	13.32	0.33	16.64	0.29	14.92
Oct	1.83	2455	0.36	19.49	0.19	10.57	0.27	15.03	0.24	13.14
Nov	1.80	2495	0.44	24.71	0.11	5.95	0.28	15.33	0.24	13.17
Dec	1.92	2586	0.55	28.54	0.12	6.03	0.33	17.29	0.28	14.56
Total/Avg	23.85	2722	5.05	21.18	2.87	12.06	3.96	16.62	3.48	14.61

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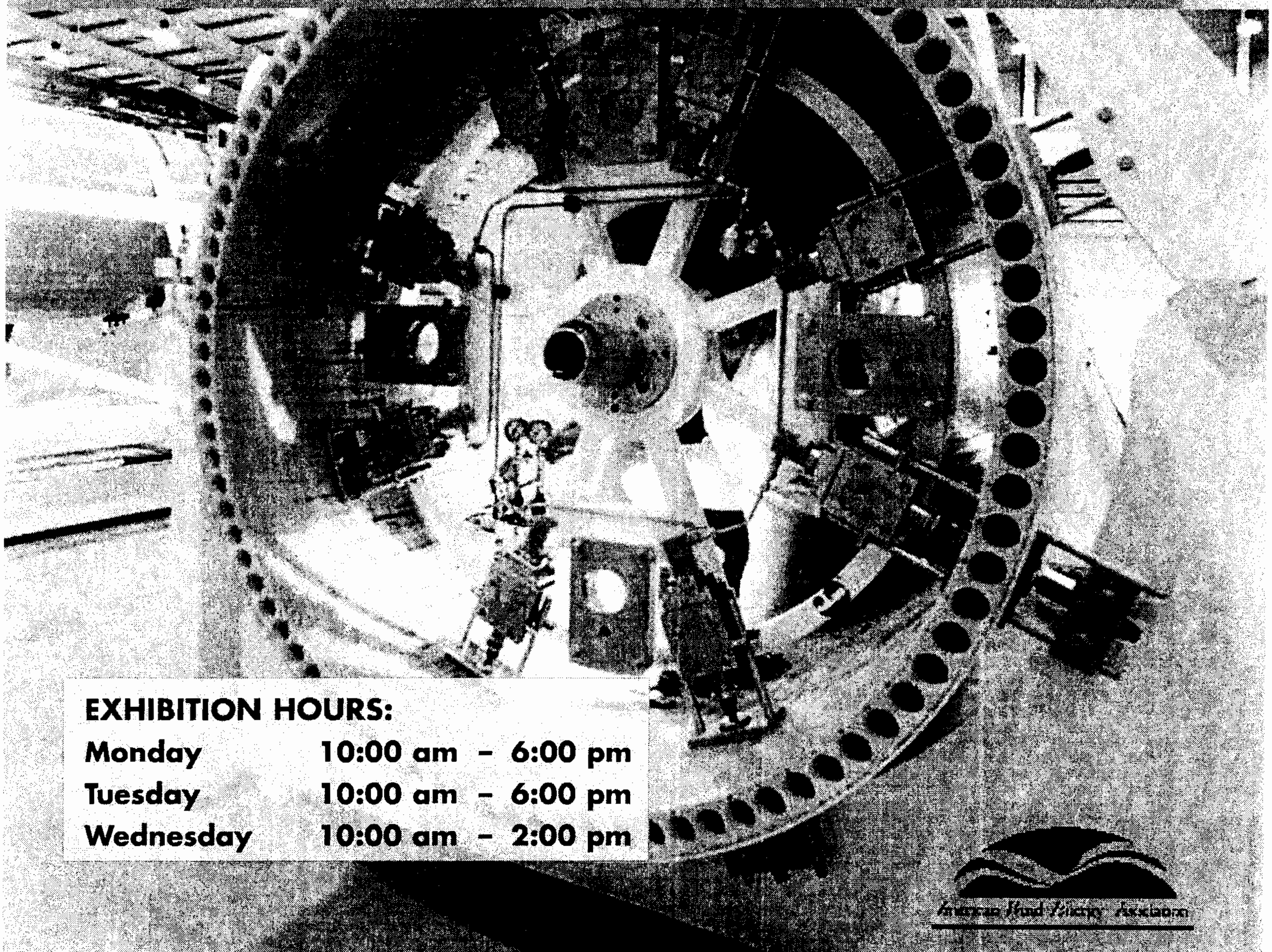

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