The Story of a Rural Public Power District – Before and After Distribution Grid Connected Wind Power Generation

Srikanth Madala*
Bluestem Energy Solutions
Omaha, NE, USA
smadala@bstem.biz

Tim Ramaekers
Loup River Public Power District
Columbus, NE, USA
tjr@loup.com

Adam Herink
Bluestem Energy Solutions
Omaha, NE, USA
aherink@bstem.biz

Mitch Hyde
Bluestem Energy Solutions
Omaha, NE, USA
mhyde@bstem.biz

Roy Palk
New Horizons Consulting
Bradenton, FL, USA
roypalk@me.com

Dan Brewer
RBC Consulting
Sarasota, FL, USA
danbrewer3@gmail.com

***Abstract*—Utility-scale distributed generation is growing at an increasingly faster pace every year in the United States. This paper discusses the growth of wind power in rural America in recent years. A case study of a rural public power district is presented. This study evaluates the before and after scenarios for the public power district. Did the localized wind power generation (13.78 MW) tied into the distribution grid benefit the public power district? If so, in what ways? is a ubiquitous question that this research paper tries to answer. The analysis is based on data collected by the distribution grid level SCADA system. How did the distribution grid connected wind generation address the Summer peak demand? is also discussed. The auxiliary benefits of voltage and frequency regulation are quantified. An increase in the daily energy sale during the summer days of load control hours is also investigated.**

Keywords—SCADA, Midwest agriculture, irrigation load control, distribution connected generation, solar, wind, CHP.

I. INTRODUCTION

Electric cooperatives and public power utilities predominantly serve the electric needs of the rural United States. Electric cooperatives have added 240 MW of solar power in the year 2017 with an overall cumulative solar power capacity reaching 1,021 MW. Public power utilities have added 1,210 MW of solar power in 2017 with an overall cumulative solar power capacity reaching 4,626 MW [1]. When it comes to wind power, 563 electric cooperatives in 36 states have wind power in their generation mix; for a cumulative total of 7,027 MW [2]. However, many of these renewable energy projects are tied into the transmission grid. Hence, the concept of distribution grid connected renewable energy projects are still alien to many in the rural electric utility industry.

In this research study, grid analytics are performed using real world data from a public power district (PPD) to investigate the pros and cons of distribution grid connected wind power generation. The distribution grid of the rural PPD (RPPD) is analyzed in two phases:

I. Pre-wind power era (Years 2013, 2014, and 2015) &
II. Post-wind power era (Years 2016, 2017, and 2018)

In the Pre-wind power era, the utility had no wind power connected to their distribution grid. However, the utility harbored two hydropower facilities of nameplate capacities 7.8 MW and 45.6 MW. These two facilities generate approximately 150,000 MWh annually.

In the Post-wind power era, the utility interconnected four 1.72 MW wind turbines in mid-December 2015 (CR-I Project), and later added three 2.3 MW wind turbines in late-June 2017 (CR-II project). Thus, the total operating name plate of wind power capacity from mid-December 2015 through late-June 2017 is 6.88 MW from four turbines, and after the additional installation in late-June 2017, the wind generation has been 13.78 MW, from all the seven turbines put together. A SCADA system is in place monitoring various performance parameters of all these wind turbines. Additionally, the utility has a SCADA system that monitors their distribution grid. The analysis that follows is carried out using interval data collected from both SCADA systems.

II. Load Portfolio of the Rural Public Power District (RPPD)

The RPPD's customers are classified into three groups namely – residential, commercial, and industrial. The RPPD has seen growth in both residential and commercial customer subscriptions as shown by the bar graphs in Figure 1 and Figure 2. However, in the recent years, the residential energy sales have remained relatively flat while the commercial energy sales have increased as indicated by the line graphs on the same figures. This is a strong indicator of the RPPD's effective residential energy efficiency programs have taken great precedence in newer construction over the years. The industrial customer subscriptions have been fluctuating between 52 and 54 over the years as shown by the bar graph on Figure 3. The industrial energy sales have declined from 2013 through 2015 and remained relatively flat thereafter as shown by the line graph on the same figure. In fact, all three customer classes have experienced energy sale reduction from 2013 through 2015 despite the increase in the number of subscriptions, possibly attributed to the energy efficiency and irrigation load control programs implemented by the utility.

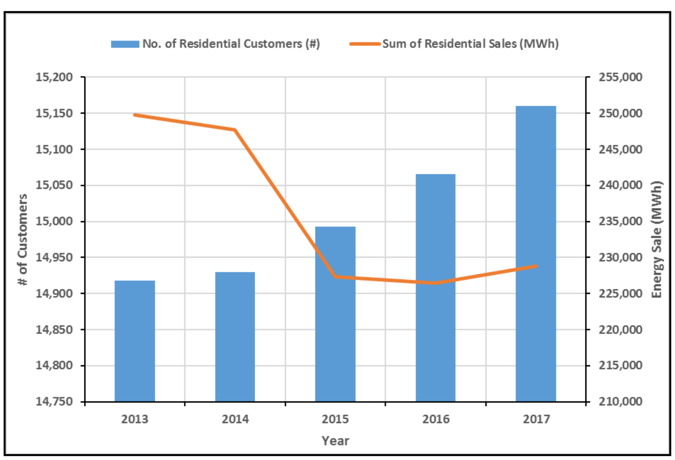

Figure 1. Growth in residential customers over five recent years

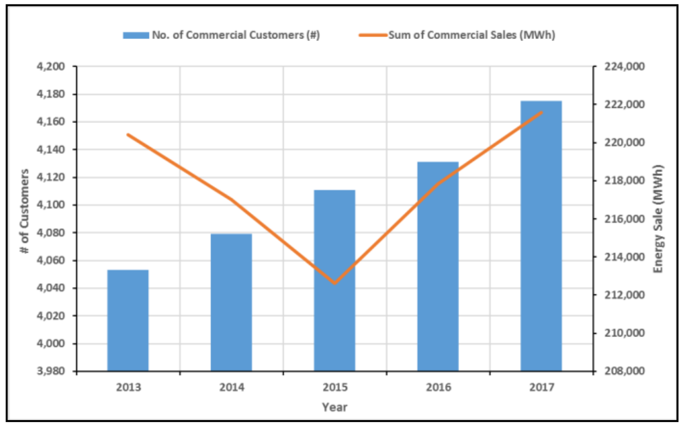

Figure 2. Growth in commercial customers over five recent years

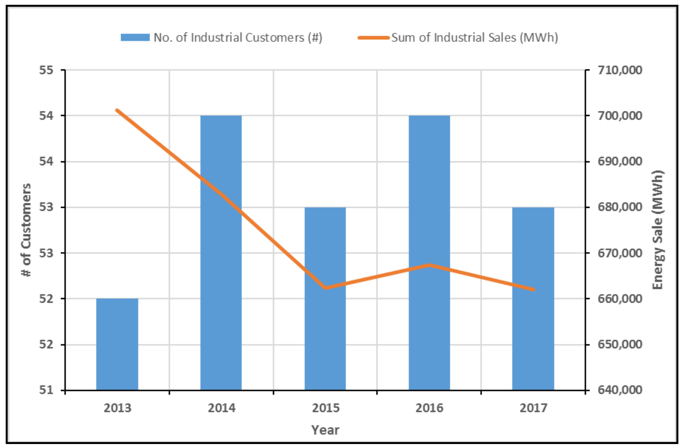

Figure 3. Growth in industrial customers over five recent years

In 2017, Industrial sales contribute to approximately 59.9% of the sales while residential and commercial sales make up 21.3% and 18.8% respectively. Irrigation loads (approx. 600 customers) are classified under commercial loads.

III. Distribution System Load Analysis

The RPPD's distribution system load during summer months is compared over the years. A strong correlation is observed between the daily average ambient temperature and the distribution system load during all the six summers in both Pre-wind era (2013-15) and Post-wind era (2016-18), indicating a strong temperature-driven customer demand. This inference can be validated by comparing Figure 4 & Figure 5, and Figure 7 & Figure 8. From these figures, it can be noticed that the distribution system load variation almost mirrors the daily average temperature variation as shown by the polynomial (poly.) trendlines. The overall load on the system during the pre-wind power era years fluctuated between 90 MW and 190 MW as shown on Figure 4. The overall load on the system during the post-wind power era years fluctuated between 60 MW and 200 MW as shown on Figure 7. In this case, the correlation between temperature and system load is very conspicuous as observed from earlier plots.

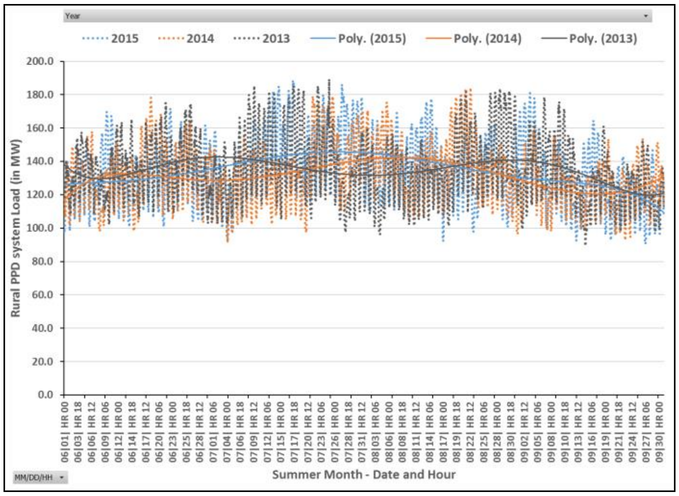

Figure 4. Load on the Rural PPD's distribution system during the Summer months of Pre-wind power Era

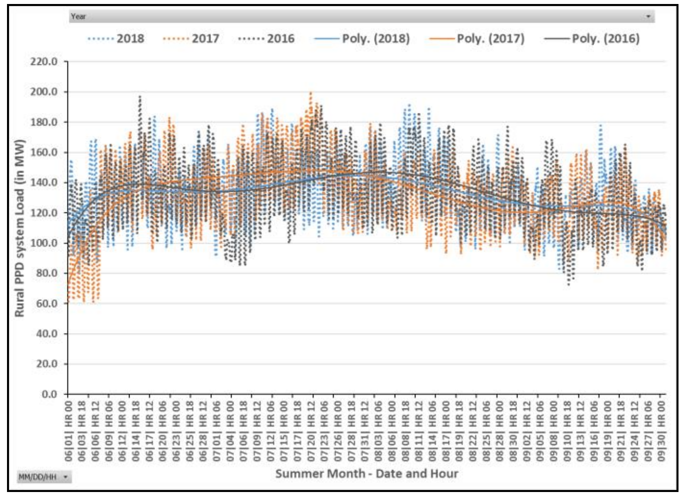

Figure 7. Load on the Rural PPD's distribution system during the Summer months of Post-wind power Era

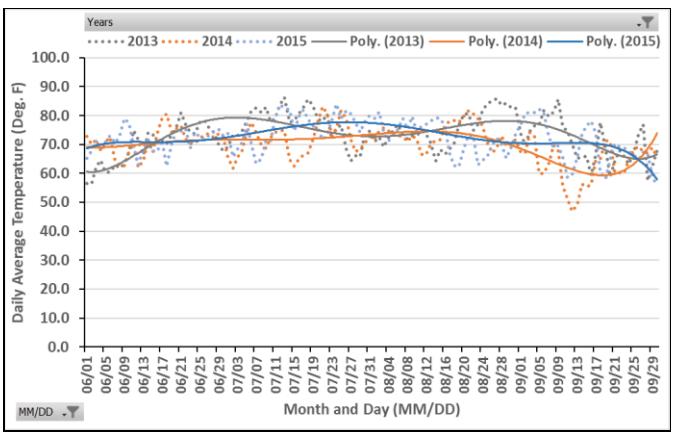

Figure 5. Temperature variation during the Summer months of Pre-wind power Era

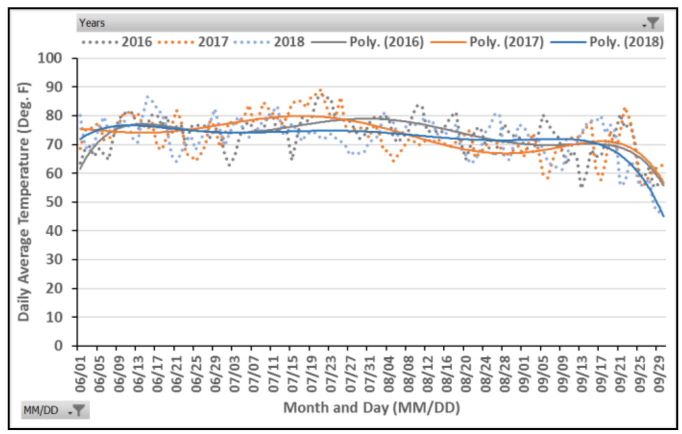

Figure 8. Temperature variation during the Summer months of Post-wind power Era

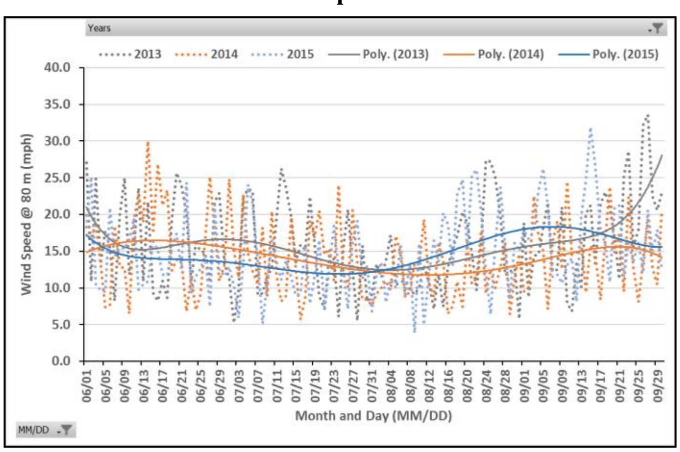

Figure 6. Wind speed variation (@ 80-meter hub height) during the Summer months of Pre-wind power Era

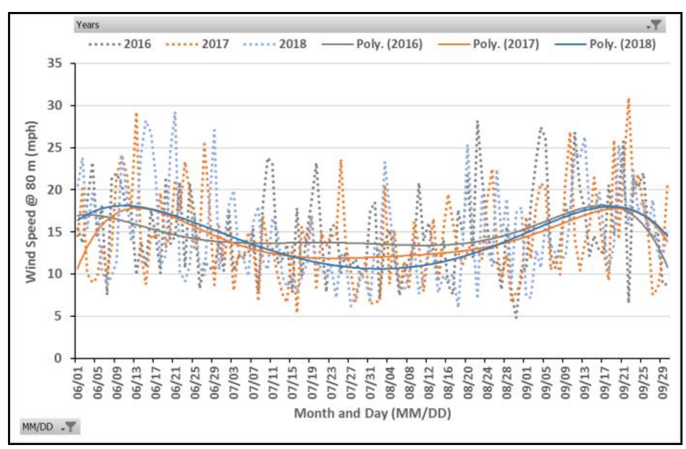

Figure 9. Wind speed variation (@ 80-meter hub height) during the Summer months of Post-wind power Era

Although, the median system loads remained around 132 MW in all the six summers, the standard deviation of the loads increased during post-wind power era. Again, this deviation can be largely attributed to the higher deviations of summer temperatures in post-wind power era. The wind speed variations for both eras are shown on Figure 6 and Figure 9 respectively. Average Summer wind speeds (in miles per hour) of 15.8, 14.1, 14.7, 14.8, 14.3, and 14.5 were observed in 2013, 2014, 2015, 2016, 2017, and 2018 respectively.

IV. Wind Turbine Operations & Power Generation

The installed wind turbine technologies operate at wind speeds between 7.5 mph and 71.5 mph, with peak generation occurring at wind speeds between 24 mph and 50 mph. The annual wind capacity factors of the project from actual years of operation in 2016, 2017, and 2018 are listed as shown on Table 1. Please note that year 2017 is split into two phases as the project size changed on June 23rd, 2017 due to the addition of capacity from new wind turbines (CR-II project). The capacity factor for year 2016 is higher compared to years 2017 and 2018 owing to greater wind speeds. The monthly average wind speeds over a period from Jan. 2013 through Dec. 2018 are shown on Figure 10 for comparison. In this geographic region, peak Summer months of July and August are associated with lower wind speeds in all years. However, June and September, the additional two summer months experience decent wind speeds. Figure 11 shows wind power generation in all the summers of post-wind era years – 2016, 2017, and 2018. It is interesting to note that the months of June and September experience substantially more generation compared to July and August. Also, the year 2016 had only 6.88 MW of installed name-plate wind capacity while since June 23rd, 2017, the installed capacity is 13.78 MW.

Table 1. Operational details of the Wind power project interconnected to the Rural PPD's distribution grid

Year	1.72 MW Turbines	2.3 MW Turbines	Name-plate Wind Power Capacity (MW)	Net Capacity Factor
2016	4 (CR-01, CR-02, CR-03, CR-04)	0	6.88	55.1%
Before June 21, 2017		0	6.88	54.0%
Rest of 2017		3 (CR2-01, CR2-02, CR3-03)	13.78	47.0%
2018			13.78	49.5%

Average of Wind speed @ 80m (mph)	Year						
Month	2013	2014	2015	2016	2017	2018	Grand Total
Jan	17.9	23.8	19.6	17.3	17.5	19.0	19.2
Feb	20.3	19.1	19.0	20.2	18.6	18.2	19.2
Mar	19.9	21.0	17.8	19.7	19.8	20.2	19.7
Apr	20.1	22.3	19.0	22.7	19.2	19.8	20.5
May	18.7	16.8	18.2	15.5	16.8	14.1	16.7
Jun	16.6	15.8	14.4	15.4	16.3	17.1	15.9
Jul	14.4	14.1	12.6	13.8	12.1	11.6	13.1
Aug	14.0	11.8	14.8	13.4	12.5	13.2	13.3
Sep	18.3	15.0	17.3	16.9	16.6	16.1	16.7
Oct	19.1	16.8	16.3	16.9	19.4	15.9	17.4
Nov	18.9	21.6	19.2	17.4	17.1	16.6	18.5
Dec	18.1	17.4	18.1	20.0	19.1	17.6	18.4
Grand Total	18.0	17.9	17.2	17.4	17.1	16.6	17.4

Figure 10. Heatmap of monthly average wind speeds at 80-meter height.

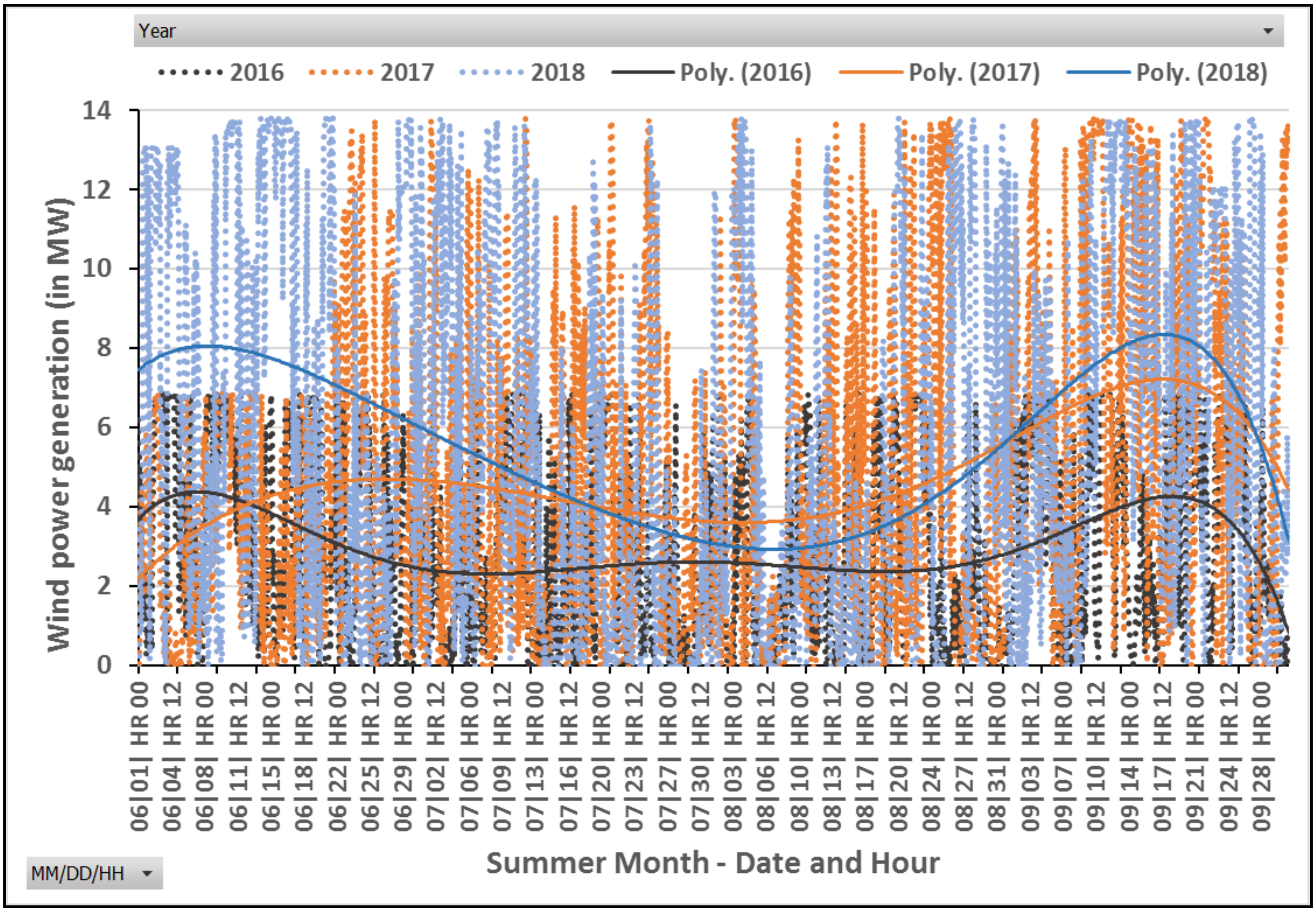

Figure 11. Wind power generation during summer months of 2016, 2017, and 2018. Installed Capacity (2016, June 2017) = 6.88 MW, Installed Capacity (July, August, September 2017, 2018) = 13.78 MW

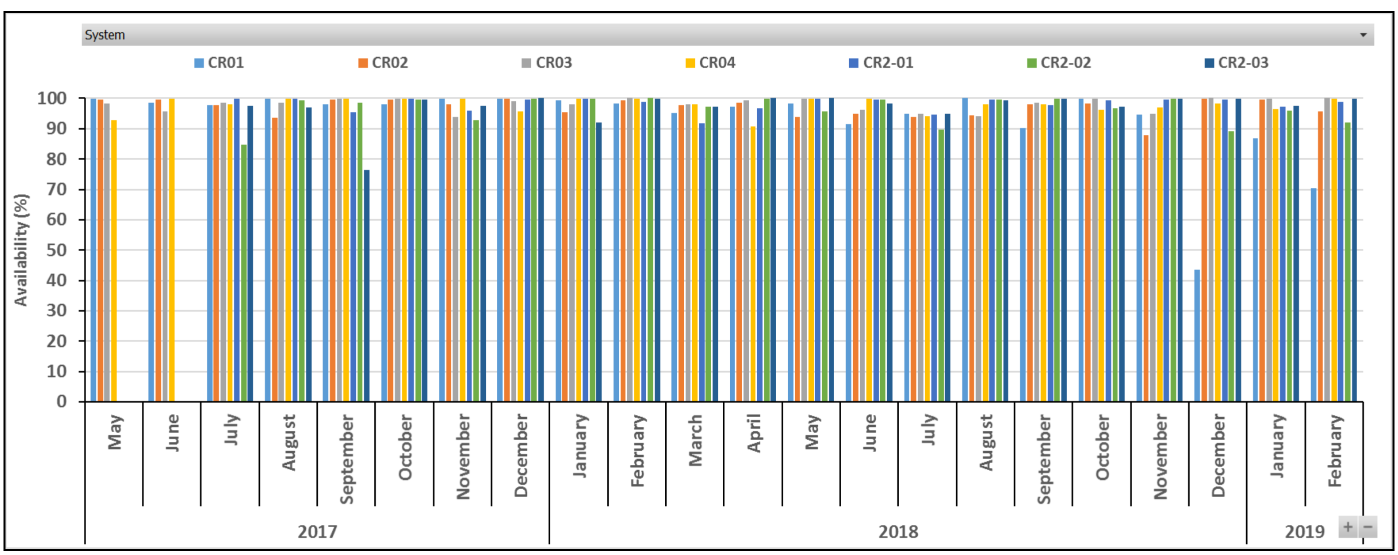

Figure 12. Availability of all the Wind turbines from May 2017 through February 2019

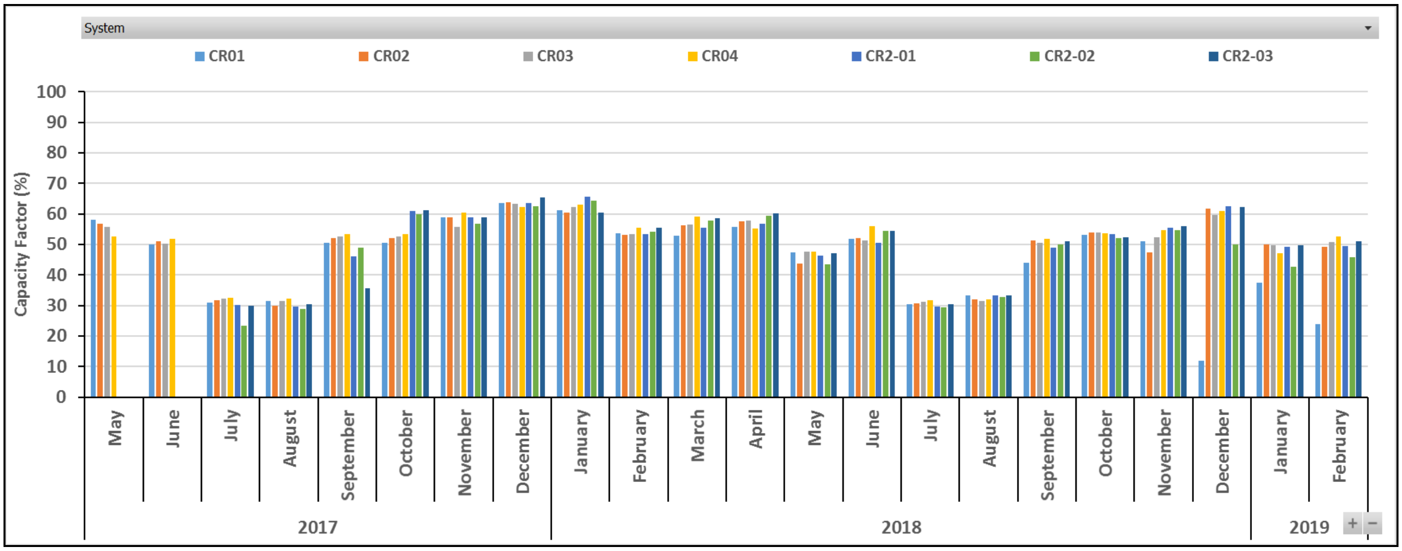

Figure 13. Capacity factors of all the Wind turbines from May 2017 through February 2019

A. *Capacity Factor and Availability*

Both availability (%) and capacity factor (%) are important parameters in determining the energy production. Typically, availability is over 95%. The average availability of all the wind turbines over the span of the previous 20-months is found to be approximately 96.7%. Occasional, mechanical gearbox part failures have hampered this number. As it can be observed from Figure 12 and Figure 13, the capacity factor and availability are interrelated. For instance, CR-01 experienced a mechanical gear box part failure in December 2018, which hampered the capacity factor for that month. Thorough service contracts with the turbine manufacturer and timely O&M attention are critical in identifying and correcting such operational anomalies.

B. *Load Control Hours*

The wholesale power provider of the distribution utility calls for irrigation load control during peak summer months. Table 2 shows the number of days/hours that the wholesale power provider requested irrigation load control, and the actual number of days/hours load control was enacted by the distribution utility. Wind generation during load control hours enables the distribution utility to selectively carryout load control. In all the post-wind era years 2016, 2017, and 2018, the actual controlled hours are a smaller percentage of the wholesale power provider requested hours compared to 2015. This is made possible partially due to adding distribution grid connected wind generation. Also, with an effective distribution grid monitoring SCADA system in place, load control is done very effectively to begin with as it can be noticed on the percentage of hours controlled in 2015. The ranges in the actual controlled hours (refer to Table 2) are arising from the fact that there are numerous customer groups on different interruptible rate schedules with varying control periods – 5 days, 3 days, or 2 days per week.

Table 2. Irrigation load control in summer months of 2015-2018

Year	Actual control days | Requested control days	Actual Controlled Hours | Requested Hours	% Hours Controlled
2015	11 | 15	25-48.4 | 111	22-44%
2016	13 | 23	28.4-57 | 192.5	15-30%
2017	13 | 19	28.5-58.8 | 149	19-39%
2018	3 | 8	3-4 | 29	10-14%

C. *Power Factor and Reactive Power*

The power factor associated with the generating wind turbines is typically unity. A measure of the power factor from SCADA data for summer months of 2018 is shown in Table 3.

Because of this close-to-unity power factor, distribution connected wind turbines act in rectifying reactive power losses on the distribution grid.

Table 3. Power factors in Summer 2018

Month, Year	Median Power Factor
June, 2018	99.8%
July, 2018	99.5%
August, 2018	99.7%
September, 2018	99.8%

D. *Local Grid Resiliency, and Transmission Congestion Avoidance*

The presence of distribution grid connected wind generation provides the utility with a power generation source immune to transmission grid failures. It also acts as a non–wires alternative in transmission grid congestion scenarios. Transmission upgrades could be deferred with distribution grid connected generation as a potential solution.

E. *Peak Demand Hours*

One of the major benefits of distribution grid connected renewable power generation is production during coincidental peak billing hours. Figure 14 and Figure 15 quantifies this value stack. Jun. 2016, Oct. 2017, Feb. 2018, and May 2018 are the only 4 months out of 36 months when wind generation didn't provide any demand savings to the distribution utility. During the rest of the months, wind power generated on co-incidental peak hours providing direct cost savings to the distribution utility, and a ripple effect value by reducing demand for the generation and transmission utility. This is a win-win situation for both the distribution utility and the generation & transmission utility. The distribution utility effectively reduces the demand component of their wholesale bill while the generation & transmission utility will save on not operating the peaker natural gas generators resulting in less wear & tear, less O&M and replacement costs.

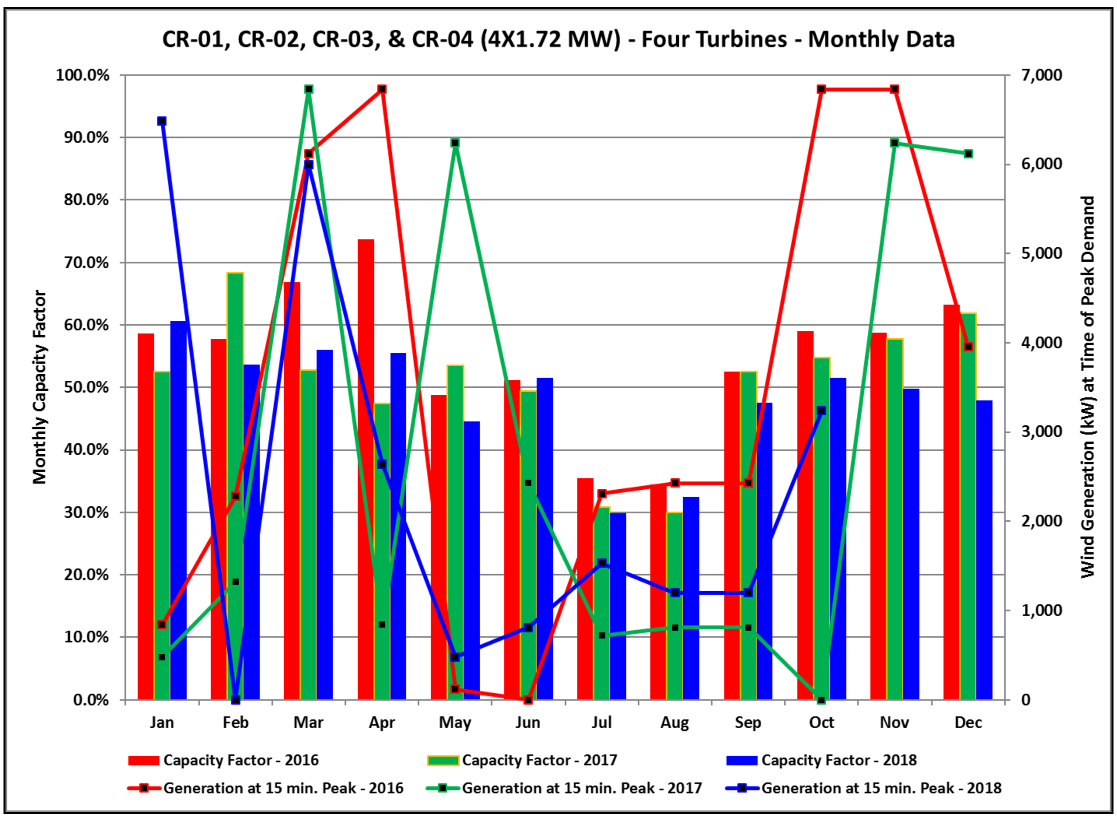

Figure 14. Monthly average capacity factors, and generation at 15-minute peak demand time periods for CRI project

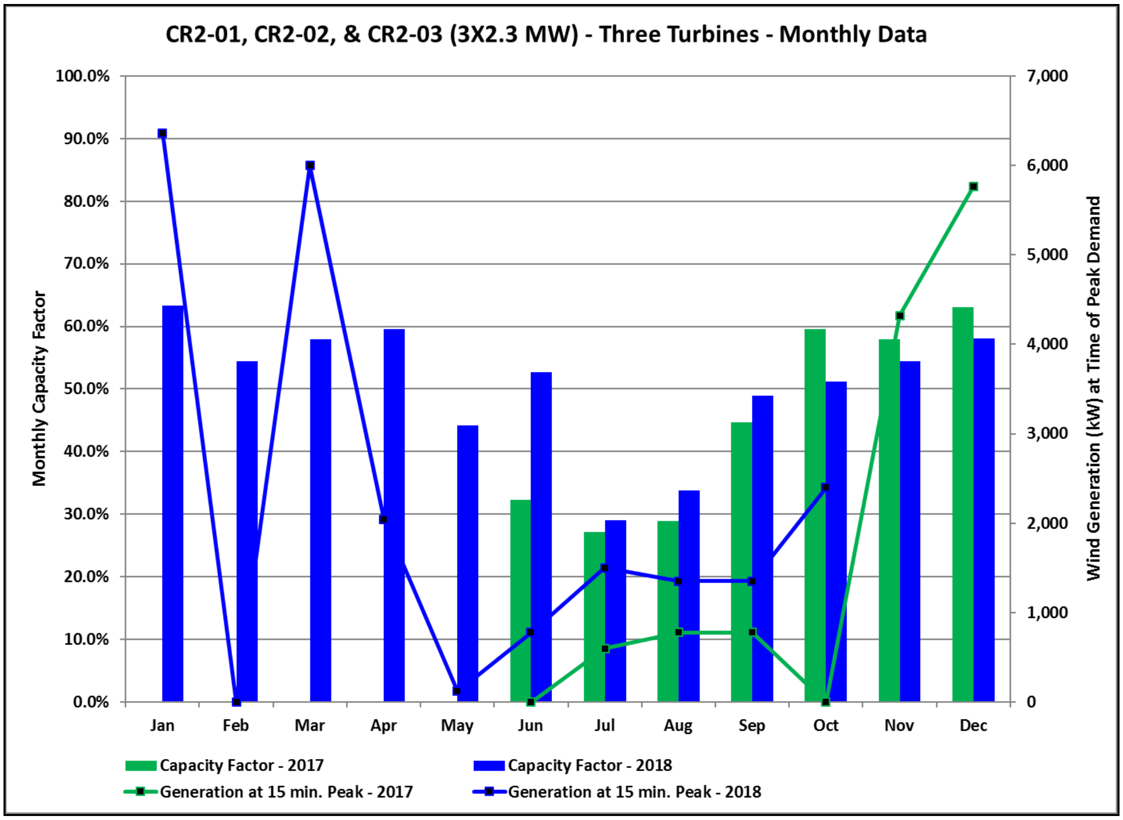

Figure 15. Monthly average capacity factors, and generation at 15-minute peak demand time periods for CRII project

V. Discussion on Losses

The operation of CRI and CRII projects have experienced various losses during these three years of observation.

A. Wake Effect

Although the turbine siting did take the distance between the turbines into consideration, there is a mutual wake effect experienced by both CRI & CRII turbines. This can be prominently noted by the small capacity factor differences in the Summer months. Artificial intelligence is fast changing the landscape by enabling mutual communication between adjacent wind turbines.

B. Weather Outages

The weather outages accounted to a total of 1,137 hours out of the 102,144 operating hours of all turbines (7 x 14,592 hours) i.e. approximately 1.11% of the total operating time period. As seen on Figure 16, the effect of the recent 2019 polar vortex can be clearly noticed from January 2019 month’s weather outage accounting to 121 hours and 19 minutes which is the highest for all the operating months so far.

C. Maintenance Time

The maintenance time accounted to a total of 562 hours out of the 102,144 operating hours of all turbines (7 x 14,592 hours) i.e. approximately 0.55% of the total operating time period. As seen on Figure 17, more maintenance is scheduled to happen in transitional months of March, April, September, & October when utility demand is less. However, there will be unplanned maintenance that might occur after an extreme weather event such as the 2019 polar vortex.

D. Down Time

The down time accounted to a total of 409 hours out of the 102,144 operating hours of all turbines (7 x 14,592 hours) i.e. approximately 0.4% of the total operating time period. In general, the older 1.72 MW model wind turbines experienced more down time than the newer 2.3 MW model wind turbines as observed from the heatmap on Figure 18.

Weather Outage (hh:mm:ss)	Column Labels							
Row Labels	CR01	CR02	CR03	CR04	CR2-01	CR2-02	CR2-03	Grand Total
2017	**55:03:05**	**64:26:20**	**64:31:16**	**59:00:16**	**48:09:25**	**45:30:41**	**64:10:35**	**400:51:38**
July	12:48:57	12:41:38	17:10:33	15:15:34	10:31:46	7:51:58	18:37:51	94:58:17
August	0:00:00	19:09:54	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	19:09:54
September	6:12:02	6:28:26	9:09:08	10:13:35	8:46:51	12:29:51	15:11:00	68:30:53
October	6:12:02	6:28:26	9:09:08	10:13:35	11:13:44	9:30:12	9:43:04	62:30:11
November	12:09:23	8:41:41	12:18:46	9:27:25	14:20:44	11:20:07	15:23:04	83:41:10
December	17:40:41	10:56:15	16:43:41	13:50:07	3:16:20	4:18:33	5:15:36	72:01:13
2018	**79:16:43**	**117:26:17**	**96:53:31**	**77:37:06**	**60:36:07**	**55:47:37**	**84:47:53**	**572:25:14**
January	0:00:00	21:18:36	0:00:00	20:34:13	6:08:53	6:36:33	6:49:27	61:27:42
February	2:48:20	2:27:36	7:16:24	3:30:22	7:21:59	6:55:34	9:01:10	39:21:25
March	0:00:00	13:57:27	22:54:57	15:50:54	2:47:16	8:28:09	9:47:46	73:46:29
April	19:00:58	7:58:13	17:23:41	7:58:14	4:02:04	5:40:43	7:46:22	69:50:15
July	0:00:00	20:37:35	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	20:37:35
August	22:05:53	21:08:33	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	43:14:26
September	4:19:08	3:54:55	5:19:50	3:15:39	8:07:16	7:35:07	9:31:23	42:03:18
October	7:32:30	5:01:07	8:02:04	4:49:31	7:28:36	6:50:27	8:58:05	48:42:20
November	15:36:17	11:13:44	14:35:55	10:53:46	13:40:14	13:41:04	17:31:20	97:12:20
December	7:53:37	9:48:31	21:20:40	10:44:27	10:59:49	0:00:00	15:22:20	76:09:24
2019	**22:44:29**	**24:04:50**	**38:28:57**	**20:51:03**	**24:47:13**	**3:13:09**	**29:37:18**	**163:46:59**
January	22:44:29	17:54:28	22:52:02	14:58:50	20:51:29	0:00:00	21:57:48	121:19:06
February	0:00:00	6:10:22	15:36:55	5:52:13	3:55:44	3:13:09	7:39:30	42:27:53
Grand Total	**157:04:17**	**205:57:27**	**199:53:44**	**157:28:25**	**133:32:45**	**104:31:27**	**178:35:46**	**1137:03:51**

Figure 16. Weather outages heatmap of both CRI and CRII turbines

Maintenance Time(hh:mm:ss)	Column Labels							
Row Labels	CR01	CR02	CR03	CR04	CR2-01	CR2-02	CR2-03	Grand Total
2017	**29:53:17**	**33:23:56**	**18:04:15**	**14:29:17**	**28:03:03**	**47:22:40**	**33:51:37**	**205:08:05**
July	14:56:34	15:34:30	2:16:07	10:29:46	0:00:00	10:06:29	0:00:02	53:23:28
August	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	3:54:39	3:54:39
September	7:19:40	2:56:28	1:23:01	0:55:00	0:19:09	0:00:00	13:01:42	25:55:00
October	7:19:40	2:56:28	1:23:01	0:55:00	0:00:00	0:00:00	0:00:00	12:34:09
November	0:00:00	11:37:34	12:34:06	0:00:10	27:43:54	37:16:11	16:55:14	106:07:09
December	0:17:23	0:18:56	0:28:00	2:09:21	0:00:00	0:00:00	0:00:00	3:13:40
2018	**39:22:15**	**45:53:25**	**31:41:04**	**44:04:46**	**32:57:54**	**43:46:24**	**27:48:01**	**265:33:49**
January	0:00:00	1:05:34	1:53:44	0:00:00	0:00:00	0:00:00	4:02:58	7:02:16
February	0:00:00	0:02:19	0:00:00	0:00:00	3:20:12	0:00:00	0:00:00	3:22:31
March	18:09:50	14:37:52	13:23:01	13:38:48	17:55:06	18:16:17	17:42:41	113:43:35
April	6:12:11	5:03:39	3:27:31	16:51:40	3:08:02	0:00:00	0:00:00	34:43:03
July	0:08:10	5:04:31	0:00:00	2:05:40	0:00:00	2:25:11	0:00:00	9:43:32
August	0:00:00	4:27:07	4:14:09	0:00:16	0:40:09	2:23:42	0:43:20	12:28:43
September	13:19:26	10:32:55	8:01:09	7:49:36	3:16:54	0:58:35	0:57:58	44:56:33
October	1:32:38	3:25:39	0:41:30	2:44:48	4:37:31	5:55:35	4:21:04	23:18:45
November	0:00:00	1:33:49	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	1:33:49
December	0:00:00	0:00:00	0:00:00	0:53:58	0:00:00	13:47:04	0:00:00	14:41:02
2019	**66:34:58**	**3:52:06**	**0:00:00**	**0:00:00**	**7:26:39**	**13:15:24**	**0:00:00**	**91:09:07**
January	2:35:42	0:00:00	0:00:00	0:00:00	5:09:14	9:30:00	0:00:00	17:14:56
February	63:59:16	3:52:06	0:00:00	0:00:00	2:17:25	3:45:24	0:00:00	73:54:11
Grand Total	**135:50:30**	**83:09:27**	**49:45:19**	**58:34:03**	**68:27:36**	**104:24:28**	**61:39:38**	**561:51:01**

Figure 17. Maintenance Time heatmap for both CRI and CRII Turbines

Down Time (hh:mm:ss)	Column Labels							
Row Labels	CR01	CR02	CR03	CR04	CR2-01	CR2-02	CR2-03	Grand Total
2017	**13:45:47**	**4:27:33**	**10:18:34**	**3:00:19**	**4:59:26**	**31:12:29**	**40:04:50**	**107:48:58**
July	0:11:34	0:01:45	0:04:08	0:00:13	0:07:51	0:00:00	18:22:43	18:48:14
August	0:31:21	0:00:00	5:16:02	1:38:00	0:43:20	3:57:49	18:02:18	30:08:50
September	6:10:51	0:12:05	0:10:33	0:20:11	0:00:00	10:08:34	0:00:00	17:02:14
October	6:10:51	0:12:05	0:10:33	0:20:11	0:49:31	3:44:13	3:31:23	14:58:47
November	0:15:12	2:30:51	0:00:00	0:41:44	0:20:05	13:19:23	0:08:26	17:15:41
December	0:25:58	1:30:47	4:37:18	0:00:00	2:58:39	0:02:30	0:00:00	9:35:12
2018	**46:32:23**	**19:29:15**	**15:29:03**	**61:00:41**	**46:28:47**	**18:28:44**	**13:33:09**	**221:02:02**
January	4:10:47	0:00:00	11:32:22	1:32:40	1:23:31	0:09:34	0:00:00	18:48:54
February	10:54:36	3:59:59	0:00:00	0:17:43	4:26:10	0:00:00	0:34:22	20:12:50
March	17:26:16	0:24:34	0:15:58	0:07:14	0:00:00	0:47:04	1:39:59	20:41:05
April	13:39:36	4:19:53	0:13:21	0:00:00	17:49:12	0:05:00	0:00:00	36:07:02
July	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00
August	0:00:00	0:00:00	0:00:00	10:40:49	2:40:23	0:24:11	3:20:00	17:05:23
September	0:00:00	2:09:32	2:38:32	5:43:19	12:52:42	0:00:40	0:34:12	23:58:57
October	0:21:08	8:31:38	0:48:50	10:47:16	0:43:07	16:51:05	5:02:17	43:05:21
November	0:00:00	0:00:00	0:00:00	20:50:24	3:30:44	0:11:10	0:50:23	25:22:41
December	0:00:00	0:03:39	0:00:00	11:01:16	3:02:58	0:00:00	1:31:56	15:39:49
2019	**0:00:00**	**2:06:18**	**0:23:42**	**21:33:54**	**18:19:11**	**19:05:57**	**18:35:59**	**80:05:01**
January	0:00:00	2:06:18	0:23:42	21:07:47	13:38:51	19:05:57	18:26:59	74:49:34
February	0:00:00	0:00:00	0:00:00	0:26:07	4:40:20	0:00:00	0:09:00	5:15:27
Grand Total	**60:18:10**	**26:03:06**	**26:11:19**	**85:34:54**	**69:47:24**	**68:47:10**	**72:13:58**	**408:56:01**

Figure 18. Down Time heatmap for both CRI and CRII Turbines

VI. Conclusions

Wind energy is typically associated with stronger winter season generation. Hence, this research focused on analyzing wind energy's performance during the summer months. Although, the winter generation is stronger for all the analyzed wind turbines through out the span of three years, the contribution to summer demands cannot be ignored. Especially, in the summer months of June and September, the capacity factors are over 45% consistently. In the additional two summer months of July and August, the wind power generation is comparatively lower than other months, yet, the capacity factor is well over 30%. Besides, wind power being produced during coincidental peak hours could be a huge benefit for both the distribution utility and their wholesale power provider. It was also noticed that wind power generated during load control hours provides an additional revenue stream for the rural PPD. Additional auxiliary benefits such as rectifying grid power factor, addressing local grid resiliency, transmission congestion issues etc. puts forth a strong case for distribution grid connected wind power.

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