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Potential Effect and Analysis of High Residential Solar Photovoltaic (PV) Systems Penetration to an Electric Distribution Utility (DU)

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ABSTRACT. The Renewable Energy Act of 2008 in the Philippines provided an impetus for residential owners to explore solar PV installations at their own rooftops through the Net-Metering policy. The Net-Metering implementation through the law however presented some concerns with inexperienced electric DU on the potential effect of high residential solar PV system installations. It was not known how a high degree of solar integration to the grid can possibly affect the operations of the electric DU in terms of energy load management. The primary objective of this study was to help the local electric DU in the analysis of the potential effect of high residential solar PV system penetration to the supply and demand load profile in an electric distribution utility (DU) grid in the province of Agusan del Norte, Philippines. The energy consumption profiles in the year 2015 were obtained from the electric DU operating in the area. An average daily energy demand load profile was obtained from 0-hr to the 24th hour of the day based from the figures provided by the electric DU. The assessment part of the potential effect of high solar PV system integration assumed four potential total capacities from 10 Mega Watts (MW) to 40 MW generated by all subscribers in the area under study at a 10 MW interval. The effect of these capacities were measured and analyzed with respect to the average daily load profile of the DU. Results of this study showed that a combined installation beyond 20 MWp coming from all subscribers is not viable for the local electric DU based on their current energy demand or load profile. Based from the results obtained, the electric DU can make better decisions in the management of high capacity penetration of solar PV systems in the future, including investment in storage systems when extra capacities are generated.

Keywords: residential solar PV system, solar photovoltaic (PV) system penetration, net-metering, energy demand, load profile

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1. Introduction

The global energy demand situation is expected to increase by 56% between the years 2010 to 2040. The US Energy Information Agency reports that among this increase is from the fast growing economies that includes countries in Asia, particularly China and India (USEIA 2013).

While Renewable energy is one of the two (the other one being the nuclear power) fastest-growing energy source, fossil fuels remain as the leading supply for the world energy requirement through 2040 (USEIA 2013). In the power sector, coal emerges as the fuel of choice for electricity generation primarily because of its abundance and affordability. It is expected that the use of coal in electricity generation from today to the year 2035 will increase from less than 33% to 50% share (IEA 2013).

The power sector in the Philippines faces the same dilemma as with other Asian countries. Rene Almendras, then Secretary of the Department of Energy (DoE), reported on March 2012 that there is a total deficit of 170MW for the peak demand and reserve requirements in Mindanao (Almendras, 2012, DOE 2008).

The country's DOE has approved in the last two years four coal-fired power plants in Mindanao for installations totaling to 1,300MW capacity to address the lack of electric power supply in Mindanao, from the total 4,552MW of the sixteen approved coal-fired power plants nationwide (Green Peace International 2014). If this strategy by the DOE which is to install more coal-fired power plants in the years ahead, it has been

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estimated that 90% of the total electricity generated would be coming from coal-fired power plants in the year 2020 (ADB 2009).

The ever-increasing use of coal as the preferred fuel for electric power generation in the country and abroad however presents disturbing environmental concerns in terms of the carbon emission to the environment (Kolhe 2015, Munnik *et. al.* 2010, Grean Peace Int'l., 2005). Carbon dioxide (CO_2) is one of the three Green House Gases (GHGs) that have increased in the atmosphere since the pre-industrial times and is verified to be the cause of climate change (IPCC 2013, IPCC 2014, USEPA 2012). Many countries, including countries in Asia, are the most vulnerable and have already felt the ill-effects brought about by the climate change, especially the effects of extreme weather events such that of super typhoon Yolanda that hit the Philippines in 2013 (Köppinger 2014).

Republic Act 9154 or otherwise known as the Renewable Energy Act of 2008 was passed into law in the Philippines on December 2008. It is the first law in the country that introduced non-fiscal incentives which allows residential owners to implement or generate their own electricity from renewable energy (RE) sources through the Net-Metering policy (Dellosa 2015).

The implementation of Net-Metering allowing the interconnections of solar photovoltaic (PV) installations, however, have yet to fully progress in the country, except for areas in Metro Manila. Several electric cooperatives in the country have yet to implement the new policy pending more understanding on the effects of high degree integration of solar PV systems to their operations, especially on the supply and demand as reflected in their daily energy load profile.

Renewable energy production is considered to play a significant role to lower the preference on the use of coal as fuel for electricity generation around the world (Zwickel *et. al.* 2012). Renewable energy generation suppresses the increasing amount of CO_2 in the atmosphere with the use of these environment-friendly energy sources (Latour *et al*. 2013).

Solar photovoltaic (PV) power, one of the renewable energy sources, harness available sunlight and convert them to usable electricity. In many countries around the world, solar PV power has already been established as the leading renewable technology that is becoming a primary source of electricity (Latour *et al*., 2013, Panzer *et. al.* 2016). Many developing countries including the Philippines, however, have a lot to progress with regards to renewable energy generation, especially at the residential levels. But the country finally produced a law on renewable energy known as the "Renewable Energy Act of 2008" which encourages home and business owners to engage in renewable energy generation in the form of wind, solar and even biomass among others (Legarda 2008).

Electric distribution utilities (DUs) were required by law to make the renewable energy systems from its qualified subscribers to be connected to their power system (Legarda 2008). Even with the RE law passed by the government, the expectation that it will progress dramatically was not realized and a lot of issues with regards to the RE implementations are still being clarified (Liss 2013). The rules enabling the interconnections of the solar PV and other RE systems were finally approved only on May 2013 (Ducut 2013).

Many electric DUs in the country have yet to integrate solar PV systems to their own power systems, since, one of the major issues that confront these electric DUs is the uncertainty and unknown implications of the RE systems integration . The electric DU in the province of Agusan del Norte has yet to determine the implications of the solar PV systems integration (Damiel, 2014).

While the Philippines is lagging behind in the analysis and investigation of PV grid integration, studies on the potential effects of the high PV systems integration were carried out extensively in different locations around the world (Tselepis and Neris, 2006, Katiraei *et. al.* 2007, Rabbee *et. al.* 2013, Jimenez *et. al.* 2006, Byrne *et. al.* 2016, Elliot *et. al.* 2014, Mather *et. al.* 2016, Thoma *et. al.* 2004).

This study, therefore, was carried out to assess & analyze and determine the potential effect of the residential solar PV system integration with high combined capacities to the energy demand and load management of the electric DU in the province of Agusan del Norte.

2. Methodology

2.1 Energy Consumption profile

To obtain a realistic effect of the high solar PV system penetration coming from residential owners, data were needed on the energy consumption profile from the local electric DU.

Consultation meetings were made with some members of the management personnel of the local electric DU to obtain the needed information such that the potential effect of the solar PV systems integration on the utility's energy demand (or load) profile can be analyzed. Amongst the critical information sought were: 1. Energy consumption per subscriber classification and 2. Their actual average energy demand load profile showing their base load, intermediate and peak loads.

The energy consumption per subscriber classification will determine what percent of the contribution residential users provide with respect to the total energy demand.

The data obtained were summarized and displayed with the provision of a table. Also, the data obtained on the actual average energy demand per hour and its profile was plotted from 0-hr to the 24th hour.

2.2 Analysis on High Solar PV Capacities

In this study, it was assumed that there will be combined capacities of 10 Mega Watt-peak (MWp) to 40 MWp of total solar PV systems coming from residential owners, at a 10 MW interval. The selection of the 40 MWp as the maximum total solar PV system capacity is based on the initial information that the usual or average hourly demand from subscribers is at 40 MWp. However, it is not clear what particular hour of the day and for how long the 40 MW demand does exist. Meanwhile, the 10 MWp interval will provide enough differences to distinguish the effect of one capacity to the next capacity.

The consideration of each capacity i.e. a 10 MWp solar PV system, is assumed to have its peak at 12 NN where this is the hottest hour of the day in the country. At this hour, it is assumed that the solar PV system will harvest 100% of the 10 MW capacities. The solar PV system will begin to generate electricity from 6AM, which is the usual time of sunrise in the country. The system stops harvesting at 6PM when the sun is no longer available. It was also assumed that the total generated energy for a day of any of the four defined solar PV system capacities is defined below:

$$TEh = SPVSC\ (MW) \times 6\ (hr) \tag{1}$$

where:

- TEh is the Total Energy harvested (MW-hr),
- SPVSC is the Solar PV System Capacity.

From the given formula in (1), it can be computed that a 10 MWp solar PV system capacity will have a 60 MWhr total energy harvested in a given day. On the other hand, the 20 MWp, 30 MWp and 40 MWp systems will have total generated outputs of 120 MW-hr, 180 MW-hr and 240 MW-hr respectively.

Using the Microsoft Excel tools, graphs were generated over the 24-hour period reflecting the energy demand from the subscribers, the different solar PV system capacity from all subscribers and the net load profile. The net load profile reflects the net amount of energy from the subscribers' total demand and the contribution of the solar PV systems.

The generated graphs were then analyzed as to how much of the peak and base load demand especially during peak hours were curtailed. The information obtained was then used to analyze the potential capacity reduced from diesel and coal-fired power plant. Consultations were also made with the management of the local electric DU and their technical personnel on their feedback on the different generated outputs from the effect of the 10 MWp to 40 MWp combined solar PV system capacity integration.

3. Results and Discussions

3.1 Data Collected from the Electric DU

Data on the hourly average consumption from all subscribers from the electric DU were obtained and can be observed from Table 1.

Table 1
Actual average hourly energy use or demand in Agusan del Norte

Hour	Energy Demand (in MW)	Equivalent Time of the Day
1	31.41	1 AM
2	30.36	2 AM
3	29.23	3 AM
4	28.65	4 AM
5	28.86	5 AM
6	30.45	6 AM
7	28.89	7 AM
8	28.53	8 AM
9	35.29	9 AM
10	40.50	10 AM
11	44.44	11 AM
12	46.09	12 NN
13	44.72	1 PM
14	47.96	2 PM
15	48.00	3 PM
16	46.50	4 PM
17	42.59	5 PM
18	46.36	6 PM
19	50.19	7 PM
20	48.20	8 PM
21	46.93	9 PM
22	44.05	10 PM
23	39.40	11 PM
24	35.07	12 MN

Source: Electric Distribution Utility in Agusan del Norte Province

It can be noted in Table 1 the highest energy consumed by all subscribers is at 19th hour or at 7 p.m. The peak energy consumption on the average was at 50.19 MW on this given hour, while the least energy consumption on the average was at seven to eight in the morning. Based from the table, it was determined that indeed, the average energy consumption per hour by all subscribers is at 39.27 MW.

It was confirmed by the management of the electric DU that energy consumption begins to increase from 8AM onwards due to several establishments that are opening and are using air-conditioning (AC) system. It was also confirmed that around seven in the evening, most if not thousands of residential owners are back at home and uses AC systems along with their television

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sets and other electrical systems, hence the high energy demand during these hours.

Fig. 1 below is the load profile plotted using the Microsoft Excel software obtained from the electric DU based from the numbers as provided in Table 1.

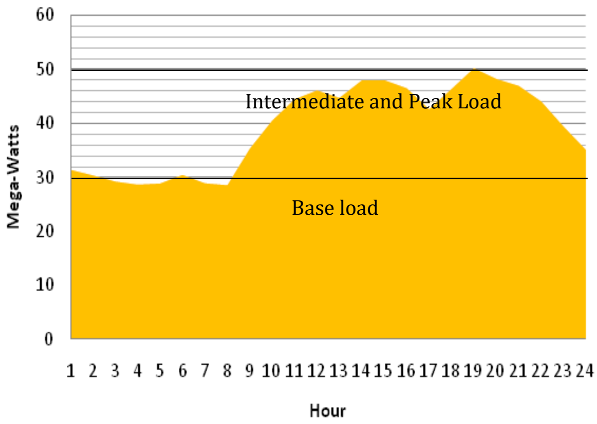

Fig. 1 Average energy consumption of all subscribers in the province of Agusan del Norte Philippines.

Shown in Fig. 1 also is the base load of the electric DU at 30 MW. It is also shown the peak load at 50 MW. Based on the discussion with the management of the electric DU, the base load requirements are being supplied primarily by both geothermal and hydroelectric power plants, all renewable energy sources. However, the intermediate and peak load demands were supplied by coal-fired and diesel power plants based upon the discussion with the management of the electric DU. This means that whenever the demand from all subscribers increases beyond the 30 MW, the energy requirement will be supplied by non-renewable energy sources such as the diesel and coal-fired power plants. This means that beyond the base load supply of the electric DU, the use of coal-fired and diesel power plants are prevailing.

Fig. 2 shows the contribution of the residential to the total annual energy demand from all subscriber type in Agusan del Norte in one year. The residential consumption accounts for 44% and is the highest among all categories. This simply means that residential owners can play a very significant role in putting renewable energy sources to the grid and prevent further reliance of energy sources which are from diesel and coal-fired power plants which are served during the intermediate and peak hours.

Demand from industrial and the rest of the subscribers having a total of 42% share can be augmented as well, if industrial companies in the province such as plywood factories will invest in solar PV system or other forms of renewable energy. Energy consumption from the commercial establishments having a 14% share are equally capable of similar reductions with RE sources deployments.

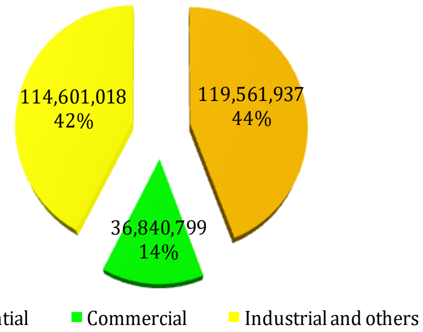

Fig. 2 Actual energy consumption of the different type of subscribers in Agusan del Norte Philippines in one year.

3.2 Impact of High Solar PV Penetration

Figure 3 shows an output of a 30 MWp Solar PV System. It is assumed that the system begins harvesting at 6 AM and ends at 6 PM and the peak reaches 30 MW at noon time for all combined residential systems with 100% system efficiency. The total harvest was approximated at 180 MWhr in a day using Equation 1.

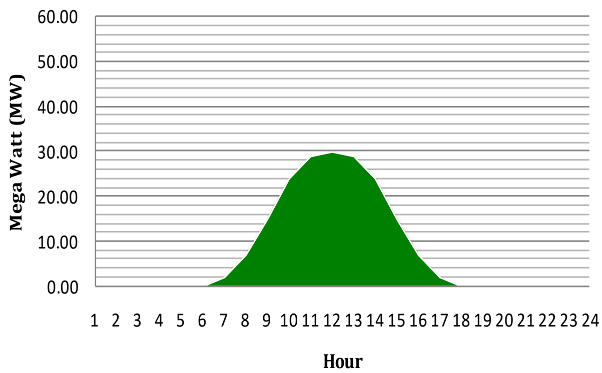

Fig. 3 Generated total output of 30 MWp Solar PV systems.

Fig. 4 shows the generated output of the four assumed PV system sizes from 10 MWp to 40 MWp systems, which is the subject of this study. Shown are the peak outputs at 100% efficiency. Each of these graphs were then used to determine the impact of each capacity to the existing and actual energy demand or load profile of the local electric DU as shown in Fig. 1.

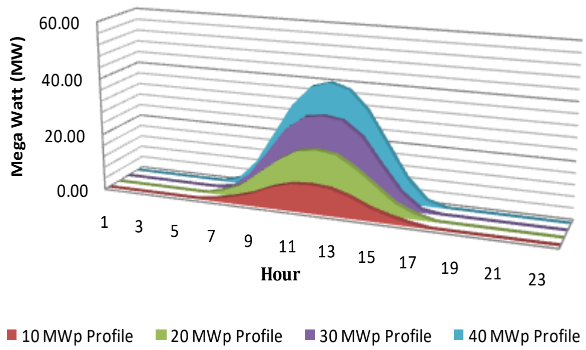

Fig. 4 Generated output of 10, 20, 30 and 40 MWp Solar PV systems.

Fig. 5 shows what it would look like when a 10 MWp combined capacity of solar PV system from residential owners affect the existing load profile of the local electric DU. A 10 MWp capacity would stave off partially the intermediate and peak load (orange graph) with the resulting net output in the yellow graph. The impact of this combined capacity can be viewed as moderately significant. However, discussions with representatives from the local electric DU viewed this as favorable to their operations as there is a gradual decrease of load from 6 AM to 8 AM and a gradual increase from 8 AM onwards.

Electric DU also preferred the absence of steep changes of load, downward or upward changes, from one hour to the next hour. This is due to the cost implications and the supply from grid suppliers to the demand of the subscribers according to the management of the local electric DU.

From equation 1, the total potential load reduction during the day with a 10 MW system is at 60 MW-hrs. This would reduce the demand at 2.5 MW per hour on the average (60 MW-hr/24 hours in a day).

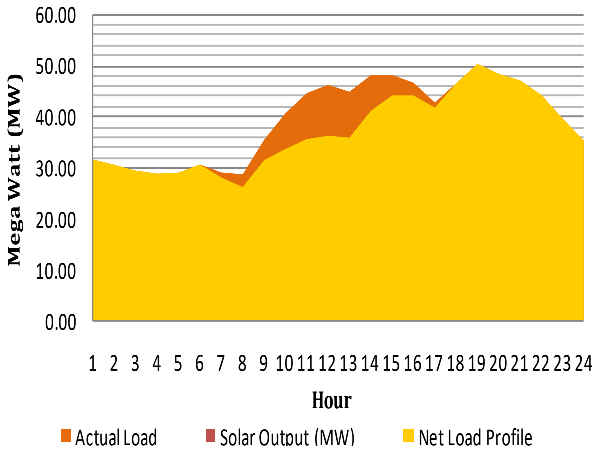

Fig. 5 Generated total output of 20 MWp Solar PV systems

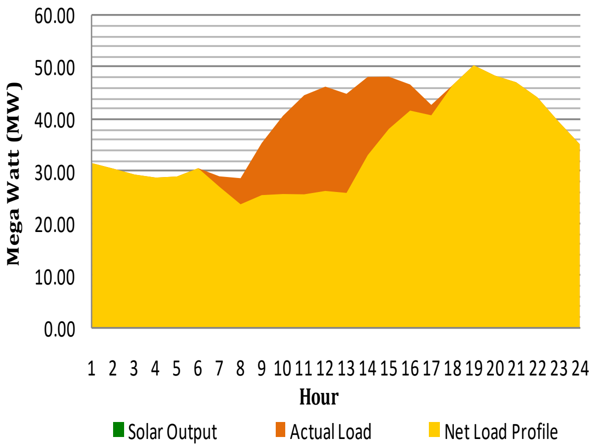

Fig. 6 Generated total output of 20 MWp Solar PV systems

Fig. 6 shows the potential output of a 20 MWp combined capacity integrated to the actual energy load profile of the electric DU. It can be observed from the graph that a huge quantity of the intermediate and peak load was reduced from 8 AM towards 4 PM. This would translate to the reduction of demand from coal-fired and diesel power plants to supply beyond the energy requirement beyond the base load during the day.

The effect of the 20 MWp combined capacity would have a stable load period from 8 AM towards 1 PM and slowly ramps up towards the intermediate and peak load from 1 PM and onwards. According to representatives from the local electric DU, the resulting load profile with 20 MW is likewise acceptable and favorable with regards to the energy demand and load management. The resulting figure did not show steep changes of energy demand.

With a 20 MWp capacity, the total potential load reduction during the day would be around 120 MW-hrs as obtained using equation 1. This would also translate to a reduction of demand from its residential subscribers at 5 MW per hour on the average.

Fig. 7 and Fig. 8 show generated outputs with 30 MWp and 40 MWp solar PV system capacities respectively.

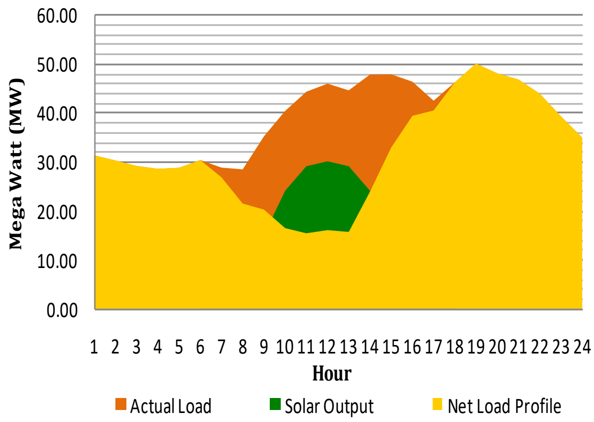

Fig. 7 Generated total output of 30 MWp Solar PV systems

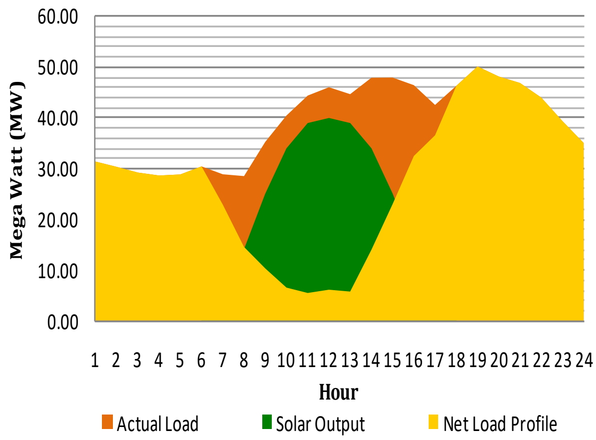

Fig. 8 Generated total output of 40 MWp Solar PV systems

Unlike the two previous generated outputs, the 30 MWp capacity staved off significant portions of the intermediate and peak load but at the same time clipped the demand at the base load during the day. The same thing is evident in Fig. 4 where the base load was curtailed and resulted to a net demand of 5 to 8 MW between the hours of 10 AM to 1 PM.

While the results shown in Fig. 7 and Fig. 8 should be favorable having renewable sources supplying the intermediate and peak loads including the base load, however, for the local electric DU this is not their preferred situation. The presence of steep changes of demand from 6AM to 10PM and then from 1PM onwards revealed undesirable load management scenario according to them.

For the 30 MWp and 40 MWp systems, harvests of 180 MW-hr and 240 MW-hr are expected throughout the day, using the formula in equation 1. These are based on the assumptions that all the systems are operating at 100% efficiency. It was also assumed at the same time that the weather during the day is favorable with the sun available from sunrise to sunset. These assumptions can be considered appropriate to measure the worst-case scenario how combined capacities impact the energy demand profile of the local electric DU.

Based from the discussions with the management of the local electric DU, the preferred and acceptable load profile is up to a combined capacity of 20 MWp from all residential subscribers in terms of non-complex energy demand and load management. The presence of steep changes from the 30 MWp and 40 MWp systems discouraged the electric DU because of its potential difficulties in energy sourcing from its suppliers. However, if the combined capacities will indeed exceed 20 MWp in the future, the local electric DU will prepare proactive actions to facilitate the renewable energy sources integration to their grid.

7. Conclusion

The objective of this paper was to investigate the potential effect of the high solar PV system penetration to the local electric DU in the province of Agusan del Norte through the conduct of analysis using actual data on the energy demand and load profile of the electric DU.

It was determined from this study that a combined capacity of 20 MWp from all residential subscribers was the preferred choice of the local electric DU with regards to how the energy demand and sourcing is concern. The absence of the steep changes from this load profile was the preferred advantage. However, the electric DU confirmed that proactive actions will be planned to accommodate additional renewable energy sources to be integrated in the grid if it exceeds the combined capacity of 20 MWp.

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