Shifting Generation of Energy of Solar PV Using OPTANG Method-Case Study Sandwip Area

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***Abstract*—The objective of this paper is to discover the amount of shifted energy produced by solar photovoltaic panel from lower demand period to higher demand period using the optimum tilt angle method. When the incident ray is at right angles to the panel plane, the output of a panel is highest. For maximum generation, the alignment of the panel should be changed according to the sun's position due to variations in the locus of the sun over the year. However, solar tracking system may not be suitable for this purpose as it requires high cost, maintenance and space. For an isolated area demand profile and generation profile may not be same and hence surplus or shortage will be occurred. It is hardly possible to use surplus energy considering certain demand profile constraints. Even, it is not possible to store the surplus energy of a season to any device for long time to use it for another season. Optimum tilt angle (OPTANG) method has been analysed for an isolated island of Bangladesh and shown that it is possible to shift the surplus energy to shortage season from surplus season.**

Keywords— Solar PV; micro-grid; optimization; penetration; tilt angle.

I. INTRODUCTION

There are many kind of renewable energy resources in which Solar PV is widely used in Bangladesh. The output power of a Solar panel is depended on angle between the incident ray and the panel plane. The maximum output of a Solar panel is obtained when the incident ray is perpendicular to the Solar panel plane. Moving sun causes changes in locus thus the angle of the panel should be changed according to the sun position for maximum generation. To change the tilt angle of the panel, single axis or double axes tracker is needed which becomes costly for maintenance; therefore not much appropriate. The default tilt angle may be termed as the average tilt angle at which solar panel is kept perpendicular for the maximum time. The maximum generation can be provided at the default tilt angle although the power generation from solar panel varies over the year as well as the consumption of an area is also varies.

A research has been done to optimize the tilt angle in such a way that the panel could be utilized as a shading device thus saving energy [3]. To achieve the maximum energy of sun, several types of tracker have been designed for PV panel, water heater, solar box oven and other as well considering the shading, raining and other climate factor [4]. A new approach to extract solar energy under cloudy conditions has been discussed in [5]. Another method to achieve the Optimal PV panel tilt angle based on solar radiation prediction has been articulate in [6]. Rather than using daily movement of the panel, monthly movement of panel is offered in [7]. Neural genetic algorithm based tilt angle optimization has modelled in [8].

The amount of generation and demand may not be linear relationship. Sometimes generation may be high but demand may be less. For an isolated area, it is hardly possible to use surplus energy considering certain demand profile constraint. Even, it is not possible to store the surfeit energy of a season to any device for long time to use it for another season.. However, by changing the tilt angle of a PV panel, energy transfer from surplus season to shortage season can be achieved. Different tilt angle will provide different pattern of generation over the year. Application of OPTANG [1] [2] method will not maximize the generation of energy over the year rather it will optimize the demand by shifting the energy to shortage season from surplus season.

II. SOLAR PV

The light and heat energy comes from the sun as a form of sunlight. What we experience as sunlight is actually solar radiation. It is the radiation and heat from the sun in the form of electromagnetic waves. Electromagnetic radiation reaches on earth as visible, ultraviolet and infrared light. In our daily life both light and heat of solar radiation can be utilized in many ways such as drying grains, drying clothes, generation of electricity, direct heating of water etc. Generation of electricity may be obtained by using the heat energy as a source to boil the steam for a steam turbine or by directly converting the light into electricity. Solar power can be classified into two categories, namely, solar thermal and solar photovoltaic (PV). However, only solar PV will be discussed in this paper for generating solar power. By using the principle of photovoltaic effect, solar cell produces electricity. Mobile charged particles are induced in the semiconductor by the incident energy of light which are then isolated by the device structure thus electricity is produced. The solar cells are being made from different materials and different structure in the quest of maximum power with minimum cost. However, the efficiency of commercial cells is less than half of the value tested at laboratories. Among the several types of solar cell, poly-crystalline and mono-crystalline solar cells are mostly available [9].

The effect of different load profiles on the optimum tilt angle is also investigated in [1] [2]. Using daily optimal tilt angle can increase the energy received than using optimal monthly tilt angle. Since altering the panel angle daily costs more effort so trade-off need to be made. In this investigation, it is found that, the maximum demand for an isolated grid is not met at the default tilt angle of solar panel;

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rather, it is subject to the demand profile as well as the generation profile. The idea about the best matching pattern of generation at different tilt angles with the demand profile could be best comprehended from their correlation coefficients.

III. IMPACTS OF ANGLE OF INCIDENCE

The numbers of incident photons become maximum when the incident ray is perpendicular to the plane of the solar panel. The number of incident photons become utmost Thus, the angle of incidence is a vital component. This can be described by the following equation [1].

$$I = I_o \cos(\alpha) \tag{1}$$

where,

α is the tilt angle, the angle between the incident ray and the area vector of the panel plane,

I_o= received irradiance when $\alpha=0^o$ and

I= received irradiance when α=other than 0^o

As the locus of the sun keeps on changing round the year so the incident angle varies accordingly. Therefore, this is another reason for the change of the incident angle of the ray. Very often maximum power point tracker is used to get maximum power output. Single axis sun tracker has been developed for better daily performance and dual axis sun tracker has been developed for better yearly performance. However, the expenses related with the sun tracker and the requirement of additional space has abolished the better performance of the sun tracker.

IV. THE OPTANG METHOD

OPTANG is a MATLAB based optimization routine which has been developped to find out the optimum tilt angle, where the demand will be met to its best possible match. The following key features were adopted in formulating the optimization routine [1].

Step 1*:* The total yearly demand profile and generation profile for veious tilt angle has been compared

Step 2: When demand is greater than the generation, it is considered shortage otherwise it is surplus. Thus both shortage and surplus are found for various tilt angles.

Step 3: The maximum demand is met when the shortage is minimum. The tilt angle for which the maximum demand is met is then found out.

Step 4: For a more real approximation, a random function is included for both the demand profile and generaion profile as follows:

$$\text{random\_demand} = \text{demand}*(1\text{-r} + 2*\text{r}*\ \text{rand}()) \tag{2}$$

$$\text{random\_generation} = \text{generation}*(1\text{-r} + 2*\text{r}*\text{rand}()) \tag{3}$$

These will assign +r% to –r% value of the demand or generation given at the look up table.

Step 5: Owing to the insertion of a random factor, the tilt angle at which the maximum demand is met, now varies slightly in random fashion.

Step 6: This iteration runs for n (Here n=1000) times.

Step 7: The frequency of satisfying the condition for meeting the maximum demand is found for various tilt angles.

The panel is ideally kept at a tilt angle equal to its latitude, which is about 23.5^0 for Bangladesh. This gives an overall higher output for electricity generation. For acquiring overall higher output electricity generation the solar panel is ideally kept at a tilt angle equal to its latitude, which is about 23.5^0 for Bangladesh. However, considering the load profile over the year, the best performance may not be found at the default latitude angle. This is an important analysis for maximizing the utilization of the output. For smaller and isolated system, the surplus energy is not utilized normally. On the other hand, shortages are to be met by an alternate approach. By changing the tilt angle, it is possible, to some extent, feasibility increases to shift the surplus energy for the season when there is shortage. The following analysis is targeted to have the minimum shortage for the isolated systems.

As the system is assumed to be isolated, there is no scope of utilizing the surplus, and the shortage must be met by an alternative source. The surplus energy can not be stored for long time for seasonal use. The analysed figure shows that during November to April of a year has a surplus and June to July has a remarkable shortage. However, it is technically and economically not feasible to store surplus of one season to use it for another season. It has been found that, by changing the tilt angle, it is possible to shift the curve to a suitable position, where the met energy demand will be maximum.

It has been noticed that the generation is lower in June to September and higher in October to May. By changinng the tilt angle it is possible to have higher generation during June to September, where the demand is higher, thus the shortage can be minimized. However, the surplus will also become less, but it is not a factor for an isolated system at all. The choice of a suitable tilt angle for erecting the solar panel is discussed here. The winter has a shorter day than night and the summer, a longer day. The winter should have the lower generation and summer should have the higher generation. However, the output also depends on the tilt angle. If the tilt angle is greater ($>23^0$) than the default tilt angle (latitude), the PV panel will generate more energy at winter and less energy at summer than those for the default tilt angle. For an angle smaller than ($<23^0$) the default tilt angle (latitude), the the PV panel will generate less enerrgy at winter and more energy at summer than those for the default tilt angle. By changing the tilt angle, it is possible to have closer generation pattern to that of the demand pattern.

V. ANALYSIS FOR SANDWIP - AN ISOLATED ISLAND

The results of this analysis for Sandwip based on method OPTANG are shown in Fig. 1 to 10. Fig. 1 shows the total consumption of few types of the customer in the existing microgrid of Sandip for the last three years 2011, 2012 and 2013 [10] [11]. The months are indicated by the index of the months from 1 to 36.

In this context, the location has been chosen as Sandwip, Chittagong, an isolated island. Analysis of this grid will provide more acceptable result for this program. In this analysis, the demand profile of several types of users of currrently running solar PV-diesel hybrid microgrid in Sandwip has been taken in account. The results of these analyses are shown in Fig. 1 to 10. Fig. 1 shows the consumption pattern of several types of user for the last three years (2011, 2012 and 2013).

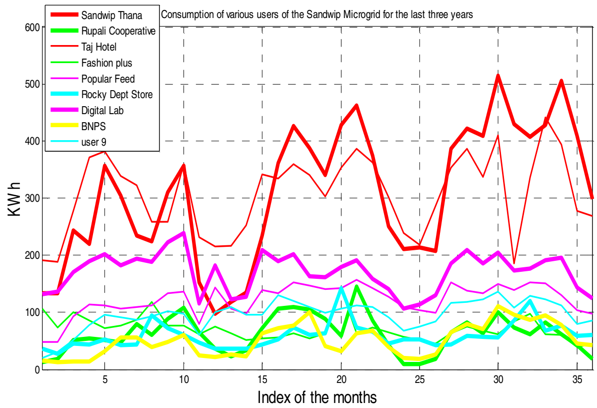

Fig.1 The consumption pattern of several types of user for the last three years (2011, 2012 and 2013)

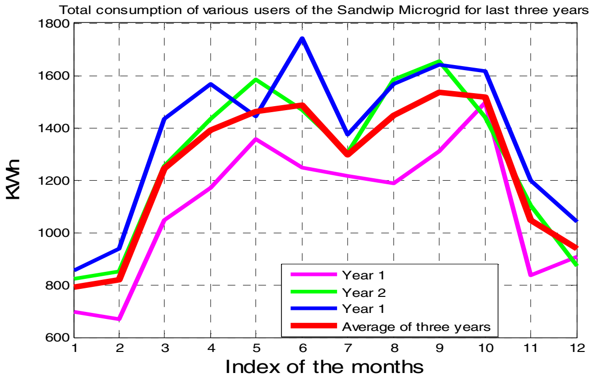

Fig.2: The total and average consumption of those users for the last three years (2011~2013).

Fig.3 shows the average consumption of the users for the last three years (2011, 2012 and 2013) as a separate figure for a clearer view.

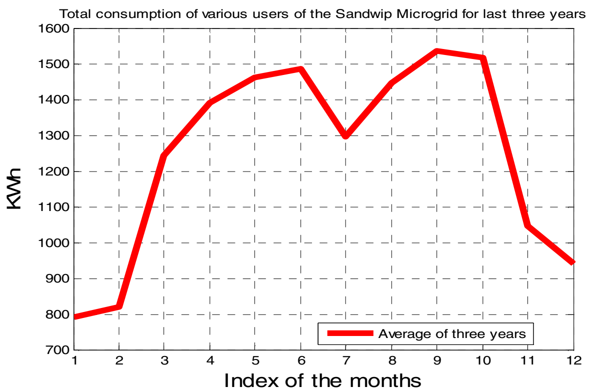

Fig.3: The average consumption of those users for the last three years (2011~2013).

This figure shows the approximate demand profile of 9 users of Sandwip microgrid. The actual demand profile is thus expected to be similar to Fig.3. Therefore, the actual demand of the microgrid will be a scaled-up version of Fig.3.

For avoiding complexity, the demand profile scaled up in such a way that it will have similar scale of previous analysis in [1] around 6500KWh of consumption per month. As the scale of demand profile is similar to the previous analysis, the scale of the generation profile thus, would be similar to that of the previous analysis. 50KW$_p$ of Solar PV panel is being considered at this analysis like the previous one. The output of the panel at Sandwip for the default tilt is shown in Fig.4 as well as the demand profile. Fig.4 shows the scaled up representation of the average consumption of the users for the last three years (2011, 2012 and 2013) have a closer range of demand pattern like that of the national demand analysis.

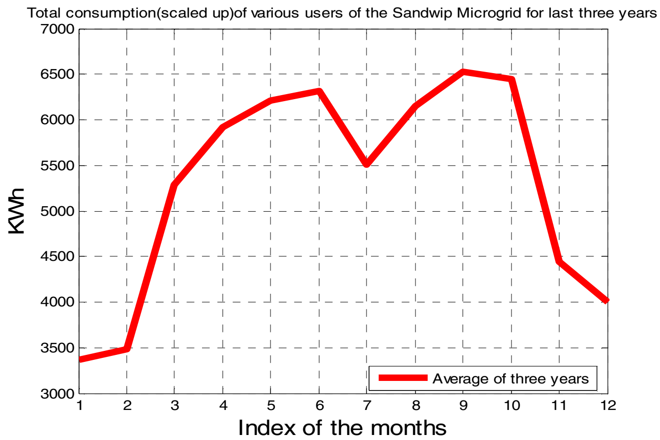

Fig.4: The scaled up representation of Fig.3.

The default tilt, optimum tilt, maximum generation of energy, maximum utilization of energy, random variation and the relationships among these have been discussed at the previous analysis. In the analysis of Sandwip, only the results are shown here. Fig.5 to Fig.10 show the results when the random variation is 0.01%, 0.1%, 1%, 2%, 5% and 10% respectively.

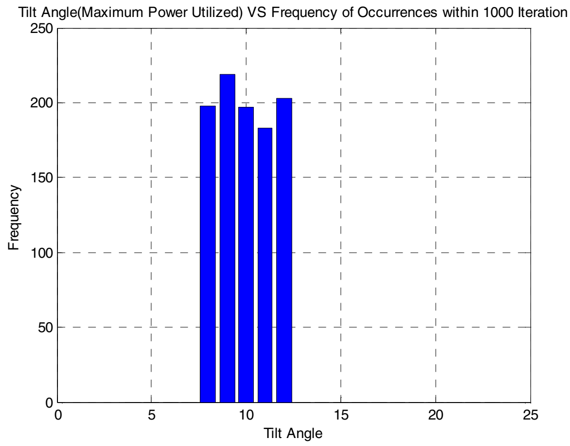

Fig.5: The number of maximum occurrence of minimum shortage for r=0.01% (tilt angle vs frequency of occurrences).

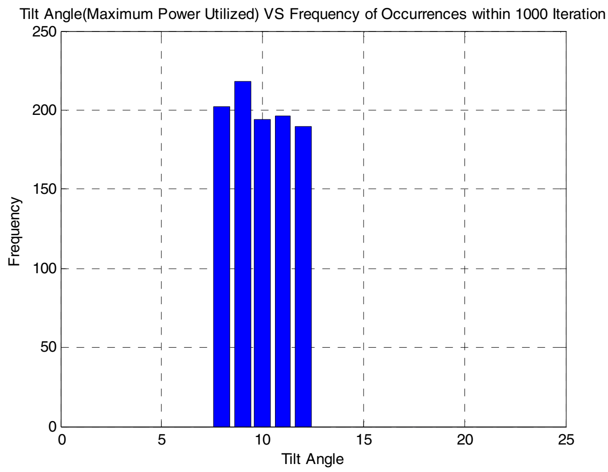

Fig.6: The number of maximum occurrence of minimum shortage for r=0.1% (tilt angle vs frequency of occurrences).

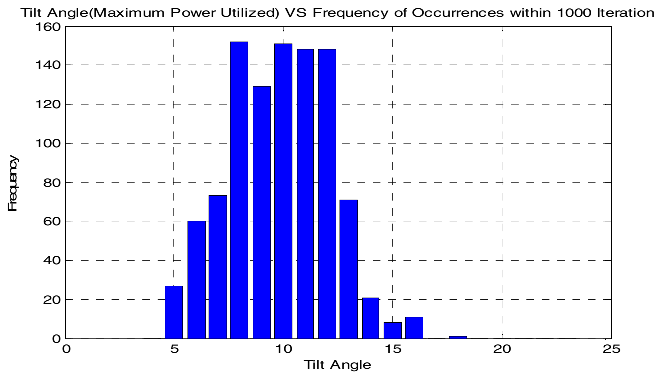

Fig.7: The number of maximum occurrence of minimum shortage for r=1% (tilt angle vs Frequency of occurrences).

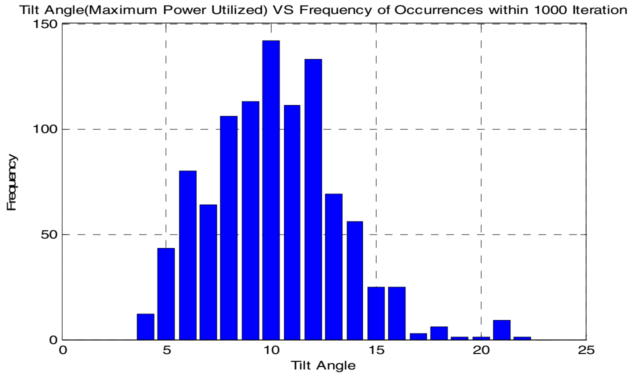

Fig.8: The number of maximum occurrence of minimum shortage for r=2% (tilt angle vs Frequency of occurrences).

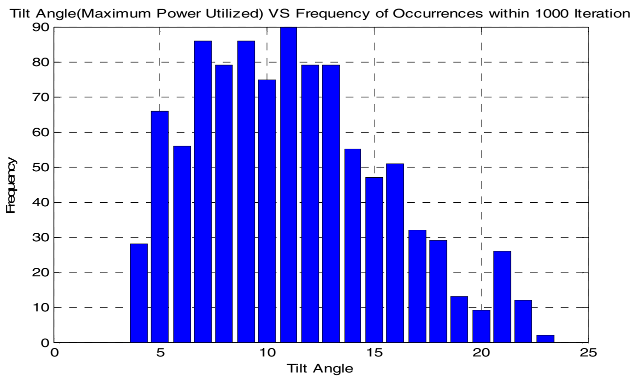

Fig.9: The number of maximum occurrence of minimum shortage for r=5% (tilt angle vs Frequency of occurrences).

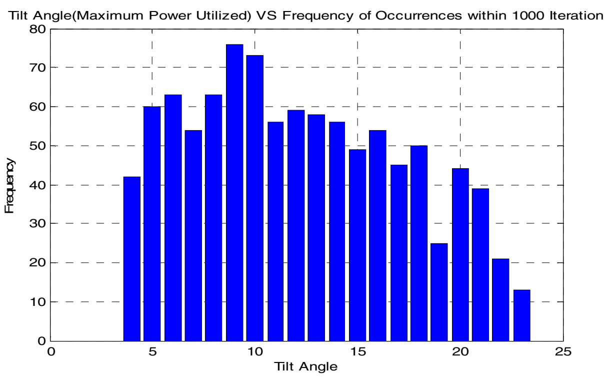

Fig.10: The number of maximum occurrence of minimum shortage for r=10% (tilt angle vs Frequency of occurrences).

For 0.01%, 0.1%, 1% and 2% of the random variation, in most of the cases, the minimum shortage occurance appears at the tilt angle of 8^0 to 12^0. In case of larger variation of the demand and generation such as for r = 5% and 10% the number of maximum occurance is still found to be around 7^0 and 13^0. These are shown in Fig.9 and Fig.10.

From the above analysis, it can be deduced that utilization of maximum power for a region may not be generated at a tilt angle of the default latitude. The default latitude will produce the maximum energy over the year, but maximum utilization of power will depend on tilt angle as well as the demand profile over the year. For a demand profile of microgrid in Sandwip and generation profile of Sandwip, the minimum shortage occurs for most of the time is at a tilt angle of 9^0 and around it. The demand, generation and surplus/shortage for default tilt (23^0) and optimum tilt (9^0) angles are shown in Fig.11.

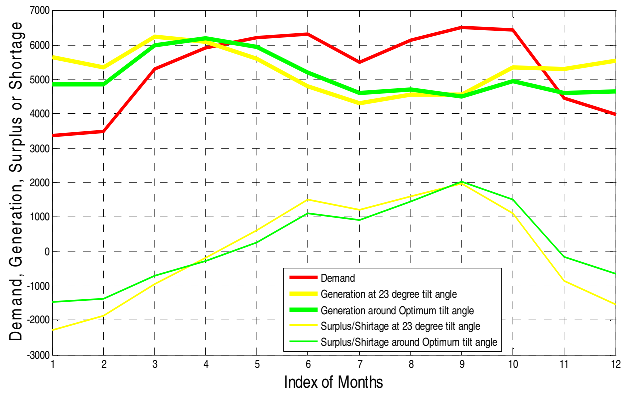

Fig.11 The demand, generation and surplus/shortage for 23^0 and 9^0 tilt angle.

Though the difference in output is not significant in percentage between the default tilt angle and optimum tilt angle, the amount will be larger for a larger system. It is however be noted that the change of tilt angle will not maximize the output of the PV panel, rather, it will minimize the shortage and maximize the demand met.

VI. RESULTS

The analyses have been done for the national demand profile considering the generation profile of Dhaka provided by the analysis of PVwatt, which is available at [12]supported by National Renewable Energy Lab (NREL). The result of the analysis for the demand profile of the microgrid of Sandwip and considering the generation profile of Chittagong is given here. The tilt optimum angle for this case is found around 9^0 tilt. Demand and generation for the default tilt angle (23^0) and optimum tilt angle (9^0) for the national load profile have been shown in Fig.12.

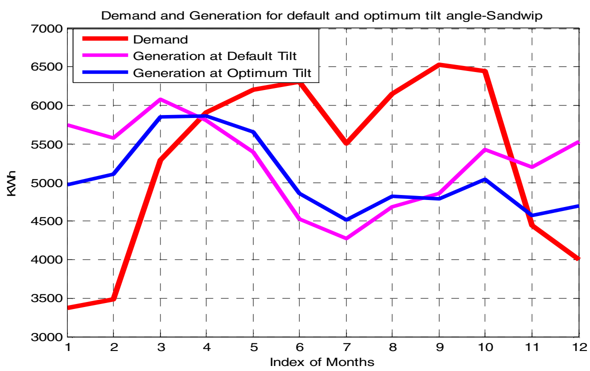

Fig.12: Demand and generation for the default tilt angle (23^0) and optimum tilt angle (9^0)-case study Sandwip.

It is also true for Sandwip microgrid that, the demand is higher from May to October over the year. At this period, the demand cannot be met by the solar panel, alternate resources of energy is needed. However, the curve for the optimum tilt is closer to the demand curve than that for the default tilt angle. Thus the demand met at optimum tilt will be more than that at default tilt. These are shown in Fig.13.

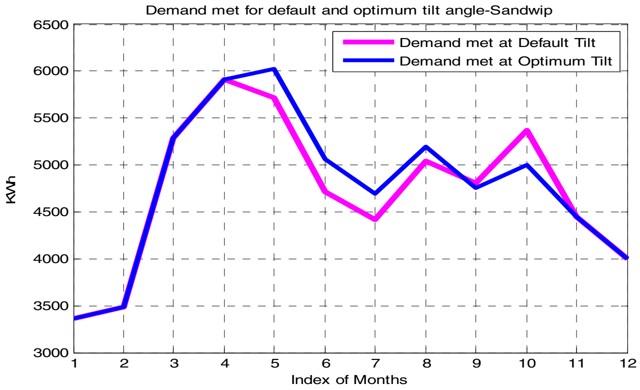

Fig.13: Demand met for optimum and default tilt angle-case study Sandwip.

As the demand cannot be met by solar panel for a period over the year, there would be shortage at that period. Shortage will be less for the optimum tilt. This is shown in Fig.14

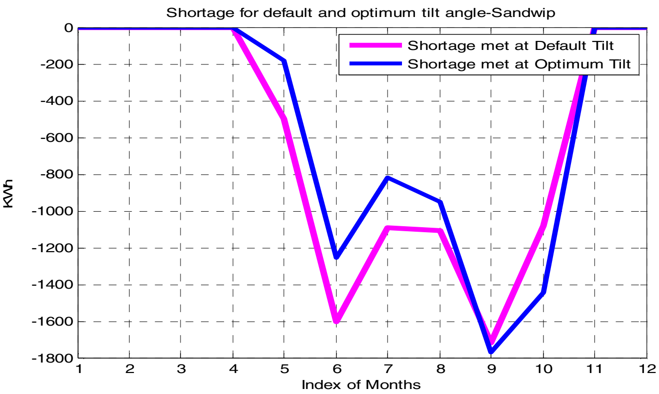

Fig.14: Shortage at default tilt and optimum tilt angle-case study Sandwip.

The results are summarised in numerical figures as follows:

(a) Yearly total demand: 63,641 KWh

(b) Yearly total Generation at 23^0 tilt angle: 66,244 KWh

(c) Yearly total Generation at 9^0 tilt angle: 63,844 KWh

(d) Yearly total shortage at 23^0 tilt angle: 70,95.5 KWh

(e) Yearly total shortage at 9^0 tilt angle: 64,14KWh

(f) Yearly demand met 23^0 tilt angle: 56,546KWh

(g) Yearly demand met 9^0 tilt angle: 57,227KWh

Although there is a trivial difference between the optimum tilt angle and the default tilt angle in percentage, for a larger system the difference will be significant.

VII. CONCLUSION

Like the previous analysis [1], here it is found that, the maximum demand for an isolated grid is not met at the default tilt angle of solar panel; rather, it depends on the demand pattern as well as the generation pattern. In July and near it the demand is higher and in November to February the demand is lower. However, the production pattern of electricity from solar PV does not match with the demand pattern. The idea about the best matching pattern of generation at different tilt angles with the demand profile could be best comprehended from their correlation coefficients. It is however, be noted that the change of tilt angle will not maximize the output of the PV panel, rather, it will minimize the shortage and maximize the demand met. This should be implemented in several isolated islands.

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