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Study of harmonic contents of appliances in various combinations and their appropriateness for use in solar mini grid ac power systems.

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ABSTRACT:*Solar photovoltaic (PV) based mini-grid systems have the potential to be an environmentally friendly and sustainable long term solution for electricity access in Bangladesh. However, to be a successful and cost effective solution, the longevity of these mini-grids with its expensive components is a vital issue. In this paper, we have investigated the potential problems those could hamper the performance of the ac mini-grid system using dc appliances.Specifically the problems those may arise due to harmonic injection from the load side and can eventually reduce the longevity. The investigation is based on a practical design of a solar PV-Diesel-Battery hybrid minigrid to be deployed atNoonertekisland, under Narayanganj district, Bangladesh. A miniature prototype capable of serving a single consumer has been built and measurement for different load combinations comprising of 7.5 and 9 watt LED bulbs, 25 watt DC fans and 14" ac color TV are carried out using DSO(Digital Storage Oscilloscope) and PQA(Power Quality Analyzer). The DC Fans appear to be the highest contributors of harmonic contents and recommended to be replaced by AC Fans.*

Keywords: *Harmonic distortion, Harmonic contents, Solar mini grid, Solar PV-Diesel-Battery hybridminigrid.*

I. INTRODUCTION

In recent years, Bangladesh has made a good progress in power generation sector. However, in spite of recent progress still only 74 percent of the total population of Bangladesh has access to electricity and per capita generation being 371 kWh [1]. The remaining 26 percent of the population is yet to get the benefit of electricity to improve their livelihood. In the fuel mix, major share is occupied by natural gas and imported oil. Bangladesh has a small amount of natural gas reserve which is expected to be depleted in a few years time. Under the current geo-political situation in the Middle East, oil is becoming more of a strategic product and its supply chain is becoming vulnerable. For ensuring its energy security and to reduce dependency on imported oil, Bangladesh is forced to explore the potential of renewable energy resources available in the country. Renewable Energy Policy of Bangladesh sets targets for developing renewable energy resources to meet 5 percent of the total power demand by 2015 and 10 percent by 2020 [2]. Among all other renewable resource, energy from the sun promises to be the most dependable and promising option.

The country is blessed by considerable solar radiation. Bangladesh receives an average daily solar radiation of 4-6.5 kWh/m^2 [3]. Solar photovoltaic (PV) are gaining acceptance for providing electricity to households and small businesses in rural areas. Development of off-grid solar home solutions has achieved international benchmark. According to a survey, there is an existing market size of 6 million households for Solar Home Systems (SHS) on a fee-for-service basis in the off-grid areas of Bangladesh [3]. Nearly 10,000 rural markets and commercial centres in the country is still out of grid which are excellent market for centralized solar photovoltaic plants.

Several fiscal incentives have been extended by the government to Renewable Energy project developers and investors. Dedicated funding support has also been extended through government financial institutions like Bangladesh Bank and IDCOL (Infrastructure Development Company Limited) as well as through private commercial banks. Moreover, the government has extended fiscal incentives including duty exemption or some sort of relief on certain renewable energy products, e.g. solar panels, inverters, LED light, solar operated light and wind power plant. At present, national capacity of renewable energy based power is approximately 403 MW; 165 MW is from Solar [3].

The government of Bangladesh in its "500 MW solar Program" has set the target to generate 25 MW of electricity from solar mini grid. 30 remote areas for implementations have already been identified for this purpose. Most of these projects are in planning stage. In some areas there is no viability of grid expansion in next 15-20 years. According to some literature solar mini grid can be proven as most efficient model for rural electrification[4].Considering technical and business issues, solar mini grid has been found as viable option for Bangladesh[5].

With the financial assistance from the international agencies like WB, JICA, DFID, GPOBA, USAID, ADB and KfW the government of Bangladesh through IDCOL is supporting the implementation of the solar mini grid projects in Bangladesh. IDCOL has a target to finance 50 solar mini grid projects by year 2017 [6].

Recently, a Solar Mini-grid in Noonertek island, under Narayanganj district, Bangladesh has been designed. The proposed project will cater to around 600 residential users, where the maximum load will be from lights, fans and other household appliances like TV, refrigerators, etc. The night time load contributed by lamps and fans (during most of the year) will be very high compared to day time use. It is expected that in the rainy season and summer about 500 fans will be used at any one time over 6-8 hours at least. In order to keep the total load for the system to a minimum, it was initially proposed that low power consuming 25 W DC fans shall be used by the consumers. The ordinary AC ceiling fans available in the market usually consume 65-90W, but cost nearly half of that of DC fans. Before taking any final decision, it was decided to investigate the harmonic contents from these fans and LED bulbs and its overall impact on the performance of the mini grid.
This paper presents the potential problem with non linear loads in section II. In section III the experimental setup for testing is described. The results are presented and also analyzed in section IV. Finally the conclusion is drawn in section V.

II. THE PROBLEM

On scrutinizing the power characteristics of DC fans available in the local market, which use adapters for conversion from AC to DC, it was found that there was a prominent problem of harmonic distortion. This was a concern for the design team because use of these fans would make the plant size smaller, but the impact on the quality of power could be disastrous. A similar problem was faced by Bangladesh Power Development Board's (BPDB) Design Directorate when millions of low quality CFL lamps were allowed to be used in the national grid, although the effect was not visible to all because of the thousands of MW of total supply capacity involved.
For off-grid minigrids the problem may also not be visible at first because the consumers usually take time to get the connections once a plant starts its operations. However, there seems to be a great problem at hand for which a solution is required before allowing large scale use of the DC fans.
According to the recommendations of IEEE standard 519-1992, Total Harmonic Distortion should be kept below 5% at the point of common coupling (PCC). Generally Solar PV inverters are designed to handle harmonic distortion of less than 3%.

III. EXPERIMENTAL SETUP AND THE TEST PROCEDURE.

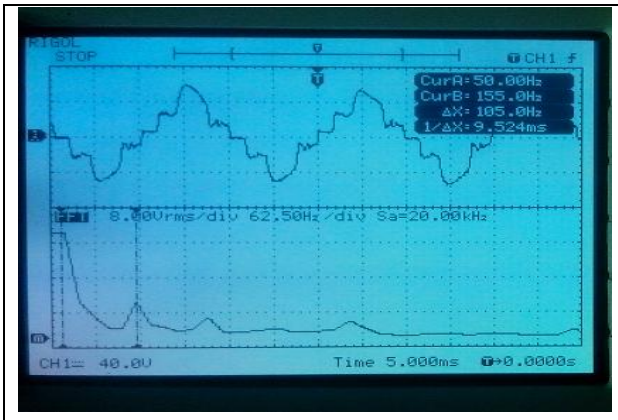
To estimate the effect of harmonics generated by these non-linear loads, a test bed was designed using the components listed in table 1.
This combination (Package-2) is envisaged to be used by more than 300 households at the project area. Initially the harmonic contents were measured using a Digital Storage Oscilloscope with FFT capability on April 04, 2014. The observation showed the presence of prominent harmonic component.

Table 1: List of loads used for observing the harmonic distortion

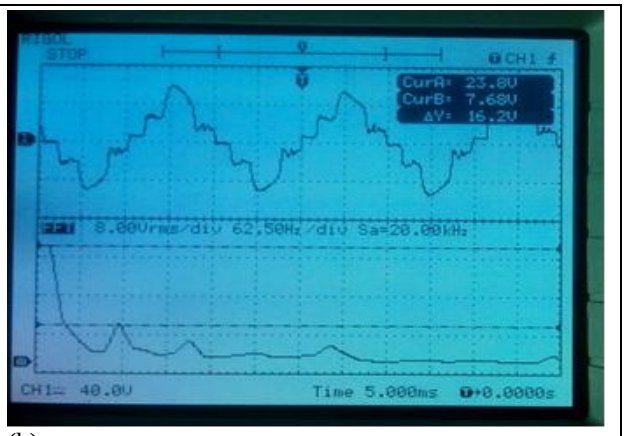
Sl.	Load	Wattage	Quantity
1.	LED bulbs	7.5 W	4
2.	DC Fan	22 W	2
3.	14 Inch colour TV	65 W	1

3.1Output from Digital Storage Oscilloscope with FFT capability:

During the test, snapshots of wave forms generated by the **Digital Storage Oscilloscope** (RIGOL DS 5022M) showed a high percent of higher harmonics. However magnitude of individual harmonic contents had to be determined manually. Moreover, some of the harmonics could have been missed due to errors in measurements resulting from human interventions. So, it was decided to use a more advanced digital harmonic analyzer.



(a)



(b)

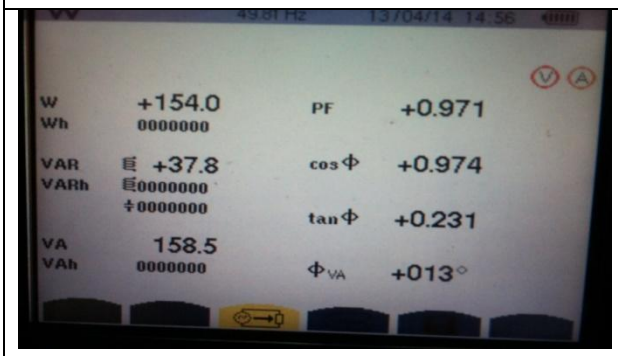
Figure 1. (a) and (b) :the upper half of these pictures show waveforms in the time domain, whereas the bottom half shows the same in the frequency domain.

In the frequency domain we can easily see the presence of a number of higher harmonics. It is obvious that measuring all the harmonics manually from this curve will be rather difficult and prone to errors. So, we decided to use Power Quality Analyzer to get accurate results.

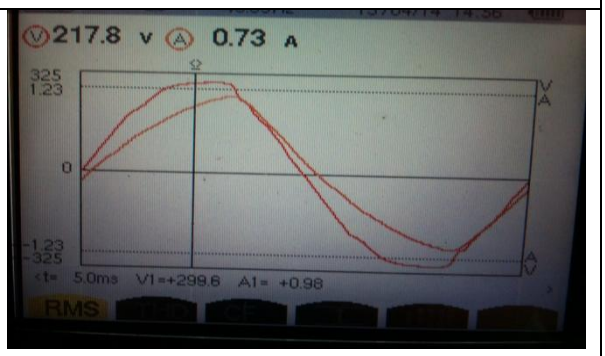
3.2 Test results using Automatic Harmonic Analyzer:

On 13th April 2014 a set of analysis was carried out using a Power Quality Analyzer (KRYKARD ALM 35), which can pick up upto 25th harmonics automatically).This is a very sophisticated equipment which could pick up all the harmonic components which was not possible to detect manually with the digital oscilloscope. The following snapshots show the results of the experiment for 3 setups.

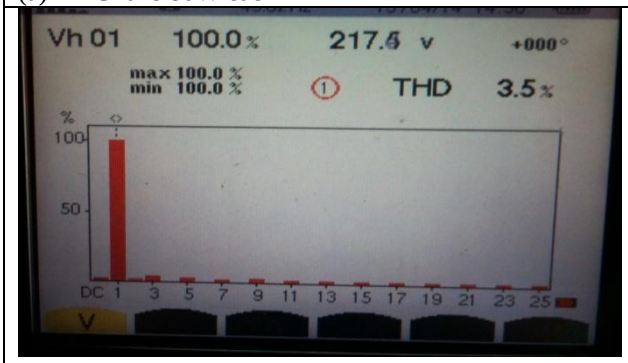
I. Setup 1: Appliances - 2 AC fans 80W each
II. Setup 2: Appliances - 2 DC fans 25W each
III. Setup 3: Appliances - 4 LED lamps, 2 DC fans 25W, and 1 TV 65W



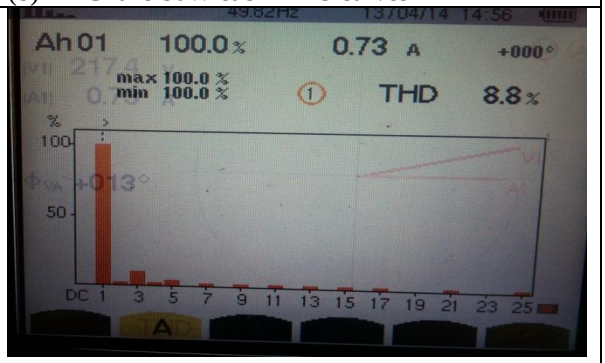
(a) 2 AC fans 80W each-PF



(b) 2 AC fans 80W each-RMS curves

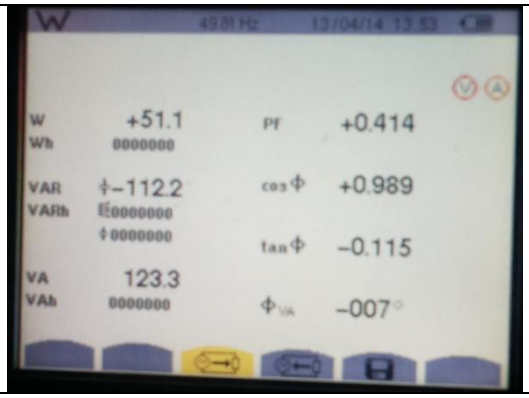


(c) 2AC fans 80W each THDv Bars

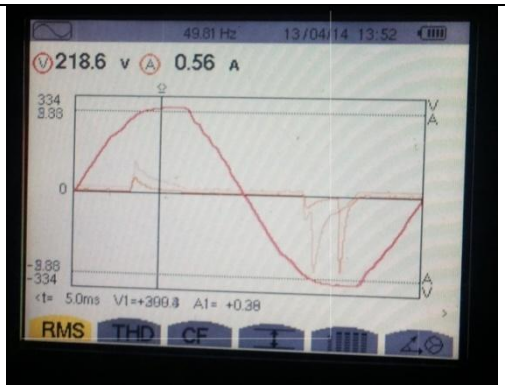


(d) 2 AC fans 80W each THDi Bars

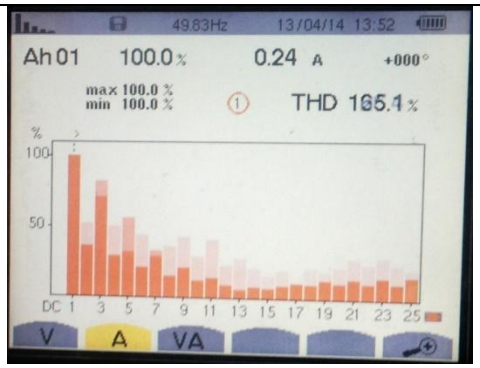
Figure 2: Setup 1- Appliances - 2 AC fans 80W each



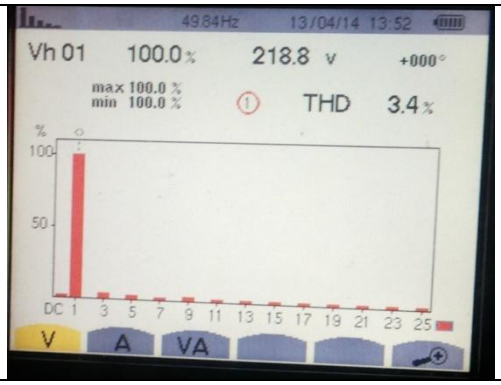
(a) 2 DC Fan: Power factor of these combined loads is +0.414



(b) 2 DC fans 80W each-RMS curves



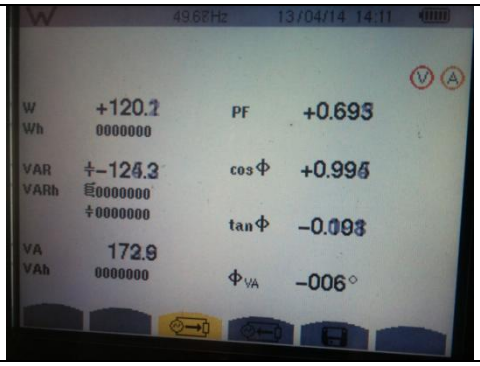
(c)2 DC fans 25W THDi bars



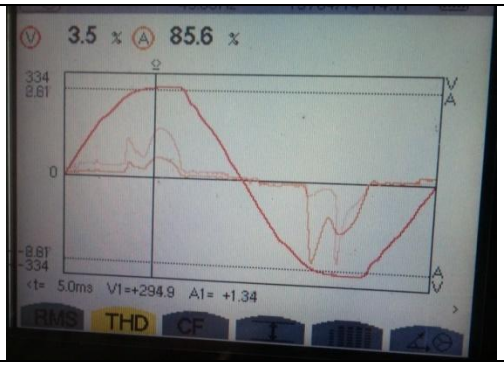
(c) 2 DC fans 25W THDv Bars

Figure3:-Setup 2 Appliances - 2 DC fans 25W each

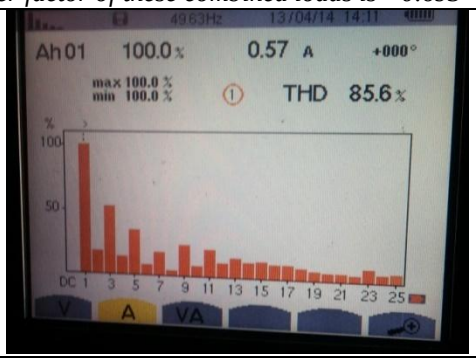
In Figure 3 significant distortion of voltage and current is observed with a very low power factor.



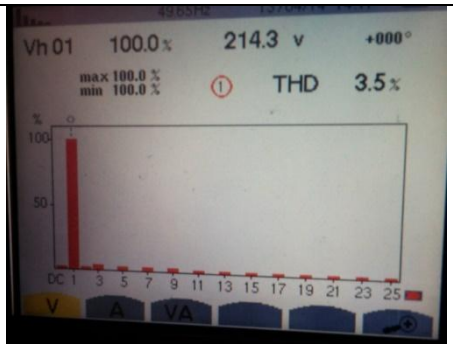
(a) 4 LED, 2 DC fans 25W, 1 TV 65W,-PF: *Power factor of these combined loads is +0.693*



(b) 4 LED, 2 DC fans 25W, 1 TV 65W,-THD curves



(c)4 LED, 2 DC fans 25W, 1 TV 65W,-THDi Bars



(d) 4 LED, 2 DC fans 25W, 1 TV 65W,-THDv Bars

Figure 4: Setup 3- Appliances 4 LED lamps, 2 DC fans 25W, 1 TV 65W

From observations in Figure 3 and 4 significant distortions of voltage and current is evident when the DC fans are used as loads. In both the cases the power factor is found to be very low. The data obtained from the observations are further analyzed in the foregoing section in details.

IV. ANALYSIS OF THE RESULTS

For quantitative analysis of harmonic distortion of both voltage and current, the parameter Total Harmonic Distortion (THD) has been used. It is calculated as follows:

$$THDi = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + ...}}{I_1} x\,100\ \%$$

$$THDv = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2 + ...}}{V_1} x\,100\ \%$$

Where,
THDi - Total Harmonic Current Distortion.
THDv – Total Harmonic Voltage Distortion.

Test results using KRYKARD ALM 35 Automatic Harmonic Analyzer

Experimental setups	Appliances	THDv	THDi	Power Factor	
Setup 1	2x80W AC Fans	3.5	8.8	+0.971	
Setup 2	2x25W DC Fans	3.4	165.1	+0.414	
Setup 3	4 x 7.5 W LED 2 x 22 W DC Fan 1 x 60 W TV	3.5	85.6	+0.693	

The DC Fans appear to be the highest contributors of harmonic contents. The most likely cause may be the presence of higher rated capacitors in their adapter circuits. Capacitors are required to get pure DC voltage wave form at the output. Power factor is also very low.

IV.I Probable effects of harmonic distortion in the proposed PV power plant at Noonertek

Harmonics in power system, especially in mini-grid system can introduce many problems [7-9]. Some of these are presented below:

- The first effect of input harmonic currents is to cause an increase in the RMS content of that current. This increase in RMS current can cause overheating of electrical distribution system wiring, and may affect the operation of sensitive electronic equipment like inverters especially in photovoltaic AC systems;
- Harmonic currents can cause false circuit breaker tripping;
- The greater the harmonic content the lower the true power factor becomes;
- Harmonic distortion in general will lower the efficiency of inverters. The issue of harmonic distortion is more important especially for smaller power systems like the mini grid under design (168 kWp);
- The inverter may malfunction and shorten equipment service life.

V. CONCLUSIONS

From the above analysis we can see that,

- The total harmonic distortion of the voltage wave form is 3.5% and the current waveform is in the range of85.6% which is far beyond the specified limit of 5% as recommended by IEEE (IEEE-519-1992). Please note that the tests were carried out with power supply from the national grid which has a huge generation capacity (above 10,000 MW). The effects of harmonics on the voltage were already around 3.5%. Besides, total harmonic distortion of the load current is 85.6%, which is also very high. We need to remember that in the power grid of Bangladesh, the share of non-linear appliances is negligibly small and hence its effects are not much reflected on the operation of the grid and the generating stations. However, in the case of Noonertek solar mini grid project, the plant capacity is very small (168kWp) and the system would be entirely loaded (almost 100%) with these types of loads (with built-in electronics in them)

generating harmonics. It should be investigated what would be the THDv and THDi when the loads are connected to the inverters and whether these inverters would be able to handle these harmonics.

- The DC Fans appear to be the highest contributors of harmonic contents.
- The low power factor (leading) is also a matter of great concern which should be properly addressed before taking decision on design capacity of a plant. Otherwise may not be possibleto utilize full power generated from PVs and generator.

The results found are quite noteworthy and alarming. If the potentialproblem due to harmonic distortionis not dealt with, and significant importance and preventive measures are not taken, it may have adverse effect on the performance and life of the mini grid. In that case it is recommended that adapters for use with DC fans available in the market are selected and properly tested before being allowed to be used in anySolar mini-grid to ensure longevityof the system and warranty requirements of the inverters.

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