POWER QUALITY ANALYSIS OF LOW VOLTAGE GRID-TIED NETWORK WITH PV SYSTEM

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Abstract

Power quality analysis (PQA) in power systems has become important to consider since there has been an increase in distributed energy resources installed on the existing grid, particularly in the area of renewable energy generation. South Africa is primarily depending on generating electricity from fossil fuel, as a result, the shortage of fossil fuel in the country has influenced the increase in electricity tariff. On the other hand, market price for installing photovoltaic (PV) system is decreasing, hence low voltage (LV) customers are beginning to utilise the advantage. Concerns have been raised about the power quality of grid-tied PV system because PV systems incorporate devices such as inverters for power conversion. Inverters have been regarded as a possible source of power quality problems according to many previous studies published. PQA of a low voltage South African network connected with PV system will be addressed in the paper. This paper analyses the level of harmonic distortions measured in the low voltage grid network the presence of PV system and compares the measured Total Harmonics Distortion on current (THD_I) with the NRS 097 standard to verify if the network with PV system meets the requirements.

Keywords: PQA: PV system: Harmonics: Inverter: THD_I: NRS 097

1. **Introduction**

The deployment of a photovoltaic system to the low voltage grid is increasing in South Africa (SA) and is expected to increase in the next decade. However, SA as a country that is depending on fossil fuel to generate electricity should see renewables energy (including solar energy) as a solution to reduce it emissions problem while meeting its electricity demand [1]. In the country, low voltage customers have started to install PV system on the premise. It indicates that people have seen the availability of this large resource at low cost [2]. As the deployment of PV system at the LV networks increases in the country, power quality analysis needs to be performed to check the compliant with the standards.

The sinusoidal voltage at 50Hz was chosen because it is the shape that guaranteed to remain constant from the output of generators at the power station to the loads at customer's premises, provided the loads are non-distorted [3]. The power electronics devices such as nonlinear loads that customers connect at the LV network can cause current and voltage distortion that is outside the standard limits [4], [5]. The increase in small-scale embedded generation (SSEG) (which include solar PV system) that are connected to the LV grid introduces significant changes in the power distribution [4]. These changes affect the power quality of the network.

PV inverter is one of the main component found in PV system this component converts the DC power from the solar panel to AC power, the conversion process occurs at high switching frequency [3]. However, at the inverter output (AC side) harmonics could occur due to the switching process [6]. PQ problems reported in [7] was not regarded as being caused by the rooftop PV System, instead, it was regarded as the cause of poor historical management. Utility standards including the NSR 097 and manufactures data sheets are only considering the full load condition when performing PQA. As for LV grid-connected with PV system the THD_I observed is higher at low solar irradiance as the PV inverter operates under light loads [8]. Solar irradiance predominantly affects the output power of the inverter, hence during higher solar irradiance, the inverter output is also higher and the THD_I's are lower [4].

Good power quality ensures that the equipment connected to the network can be maintained without coursing any damage in the system, whereas poor power quality may cause failure in medical equipment during surgery in a hospital. Major power quality issues can be threats to human lives and can lead to millions of Rands of equipment damage [9].

2. Methodology

The implementation of the research involves the collection of weather data from a recently calibrated weather station base at Energy Centre CSIR Pretoria Campus in Southern Africa. Solar insulation and ambient temperature are monitored 24 hours by pyranometer in the station. Global Horizontal Irradiance (GHI) data collected during the month of August 2019 is used in this work for showing a full sunny day during weekend and weekday. The study does not cover a moderately cloudy day and a full cloudy day because in South Africa, particularly the Gauteng region does not have rainfall in August hence, winter season [10].

Measurement of a grid-tied photovoltaic system was captured at the CSIR outdoor solar PV testing facility which comprises of two rooftop systems of 3kWp capacity connected to the same local distribution board.

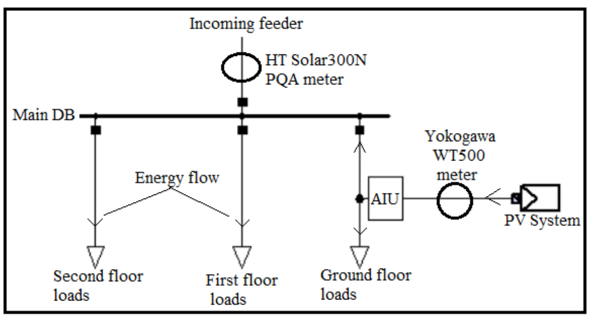

Fig. 1. Single line diagram of the Low Voltage network with PV System

Yokogawa WT500 and HT Solar300N power quality analysers (PQA) were used to measure the power quality parameters at the incoming feeder line of the building and at the inverter output as shown in **Fig. 1**. The PV system is connected at the Domestic Board (DB) in the ground floor, between the DB and the PV system the is a protective unit called Automatic Isolation Unit (AIU) that is used for disconnecting or connecting all the PV generation unit from the grid. WT500 PQA was connected between the AIU and the PV system to measure PQ on the output of the inverter. On the other hand, HT Solar300N PQA was connected at the incoming feeder to measure PQ of all the loads in the building. Both PQA were synchronised to measure and record simultaneously. However, the PQAs were recording at 15 minutes' intervals.

The grid-tied PV system network under investigation is a four-wire system with three live lines and a neutral line. All the four lines supply each floor of the three store-office building. Line 1 (L1), Line (L2), and Line 3 (L3) are labelled red phase, yellow phase and blue phase respectively. L1 is connected to an inverter with battery storage (inverter_1), L2 connected to energy recovery loads (ERLs) and L3 is connected to inverter with a battery with storage (inverter_2). Point of common connection (PCC) of this grid-tied PV system is at the DB in ground floor of the building. **Fig. 2** shows one of the PQA meters that has been used during measurement.

Fig. 2. HT Solar300N PQA connected at the main DB of the building

3. Results and analysis

3.1. Harmonics

The results that were collected during a weekday on 20 August 2019 and weekend 7 August 2019 are shown in Error! Reference source not found., Error! Reference source not found. and Error! Reference source not found.. From the results all the three phases (L1, L2 and L3) show that the maximum odd harmonics current (3, 5, 7, 9, 11, 13, 17, 19, 21, 23, 27 and 29) that occurs at the incomer are higher in magnitude than the maximum odd harmonics occurring at the output of PV system, however, the maximum even harmonic current (2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 25, 26, 28 and 30) at output of PV system are higher in magnitude than the even harmonics current at the incomer feeder.

The degree of odd harmonics is higher than the degree of even harmonics. The maximum current harmonic order 5 in L1, L2 and L3 during weekend is higher than during weekdays. At the incomer, the 7th harmonic in L2 and L3 appears to be higher on weekend than during the week and is also more than the 3rd harmonic. The 3rd harmonic in L1 at the incomer reaches a maximum of 3% on weekend and reaches a maximum of 2.4% on weekday. The maximum harmonic current at the output PV system was always below 0.5% during the weekday and weekend. All the individual maximum harmonics current (odd and even) meet the NRS 097-2-1:2010 South African standard at less than 1% for 2nd to 8th, < 0.5% for 10th to 32nd, < 4% for 3rd to 9th, < 2% for 11th to 15th and < 1.5% for 17th to 21st .

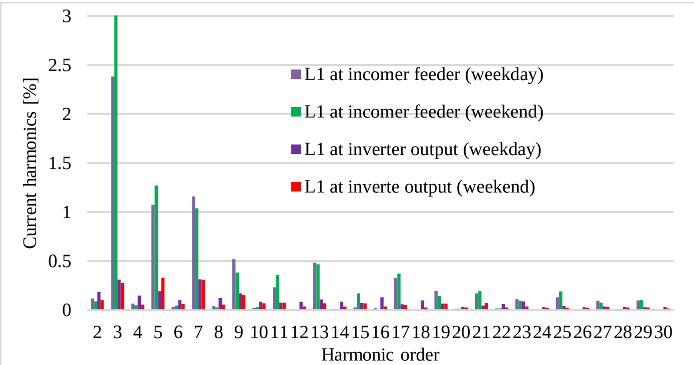

Fig. 3. Maximum Harmonics Current occurs in line one (L1) during weekday and weekend

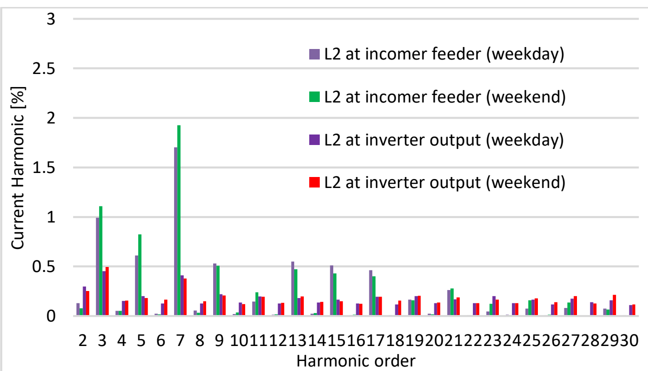

Fig. 4. Maximum Harmonics Current occurs in line two (L1) during weekday and weekend

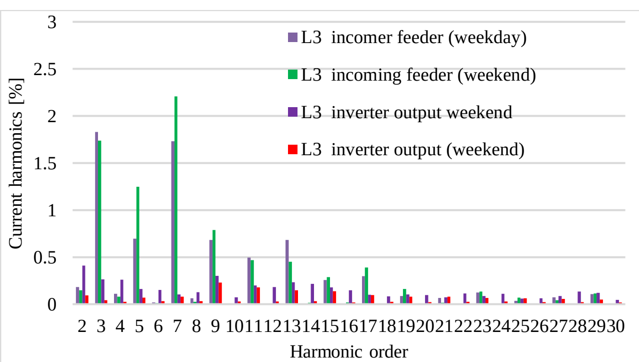

Fig. 5. Maximum Harmonics Current occurs in line three (L3) during weekday and weekend

3.2. Total Harmonic Distortion

Current total harmonic distortion (iTHD) of the network was also captured for a weekday (20 August 2019) and for a weekend (11 August 2019). THD gives the measure of harmonic distortion occurring in a signal. According to NRS-2-1 standard THD is defined as the ratio of the R.M.S. value of the harmonics to the R.M.S. value of the fundamental.

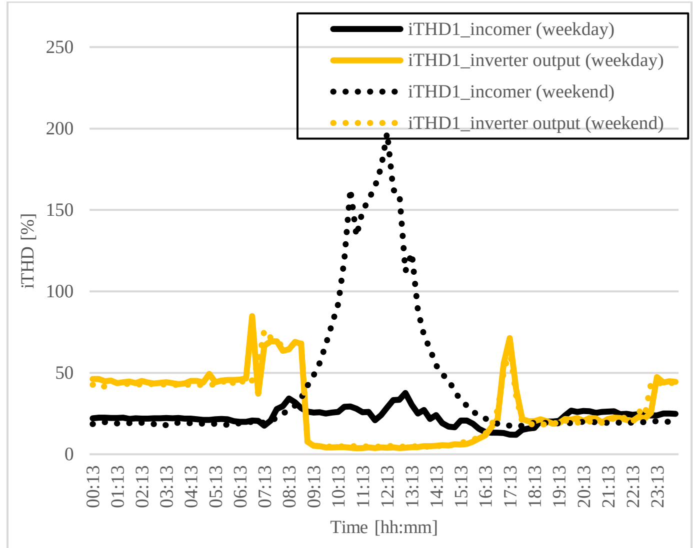

Fig. 6. Current THD of phase 1

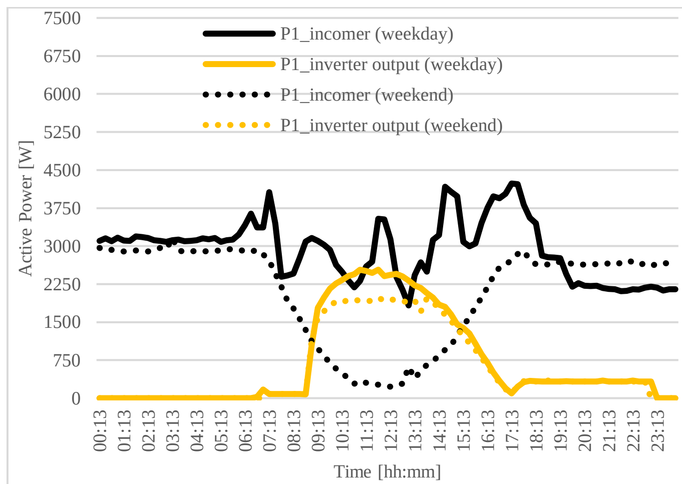

Fig. 7. Phase 1 active power

The results in **Fig. 6**, and **Fig. 7** shows iTHD and active power of phase 1 respectively, it is noted that between 9:13AM and 15:13PM the active power developed at inverter output is above 1500W for both days (weekday and weekend), however, iTHD1 reaches standard limits at less than 5%, between 6:58AM and 8:58AM iTHD1 is above 64% since, the active power produced by the inverter is low, again, at 16:58 PM iTHD1 is more than 55%. iTHD1 at the incomer feeder for both days exceed the standard limits. At the incomer iTHD1 weekday is less than iTHD1 weekend because the power developed at the incomer during weekend from 7:58 AM until 16:13PM is less than active power of weekday. Before 6:28AM and after 11:13PM iTHD1 at the inverter output rest at +/- 43% while the active power is

0W for both days, on the other hand, between 6:13 PM and 11:13 PM iTHD1 is constant at +/- 20%, while the active power reaches +/-330W because during time the battery is supplying the inverter.

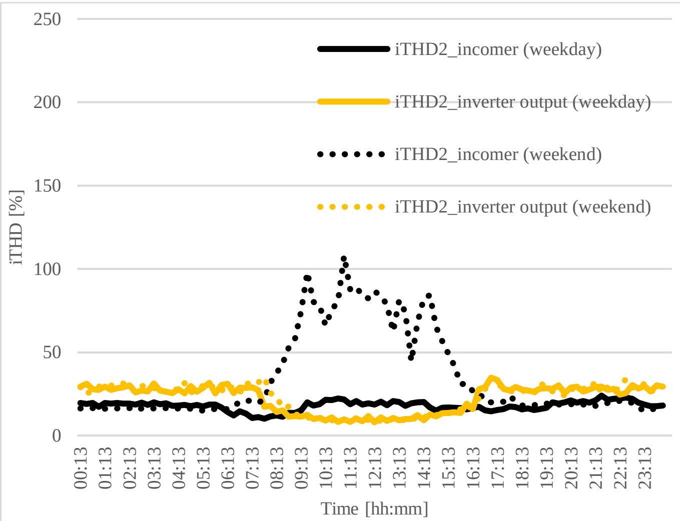

Fig. 8. Phase 2 current THD

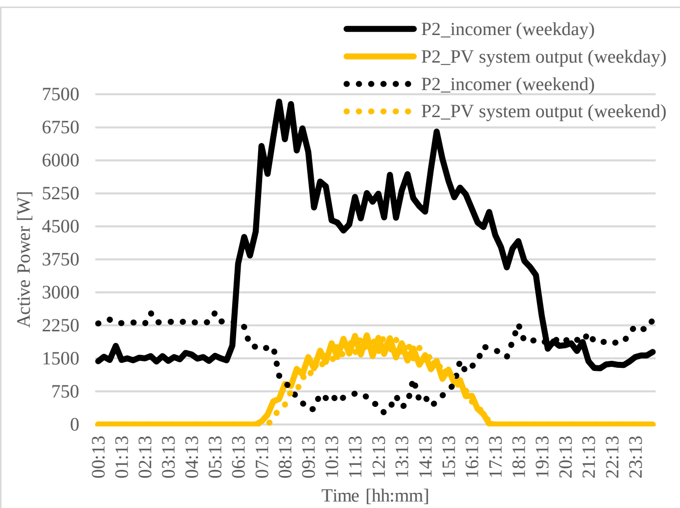

Fig. 9. Phase 2 active power

Phase 2 of the network is connected to energy recovery loads (ERLs) which supply power to the phase. The ERLs is mainly using for maximum power point tracking (MPPT). **Fig. 8** and **Fig. 9** shows the iTHD and active power of phase 2 respectively. The series of graphs shows an imbalance in the 'power from grid' across the three phases. Phase 2 shows a clear increase in load over the weekday. The apparent imbalance is mostly due to the lower output of the PV on this phase. The ERLs feed power to Phase 2 and the output of the ERLs is about half that of the string inverters. However, the iTHD2 at the PV system output is +/- 8% of which it is twice as iTHD1 and iTHD3 inverter output between 8:13 AM and 15:58. It can be seen that L2 with the ERLs is missing the big spikes seen in L1 and L3 with string inverters. L2 has 15 loads, one for each module, and then turn on point is likely staggered, unlike the string inverters where there is a big shock to the system when the inverter turns on/off.

Fig. 10. Phase 3 current THD

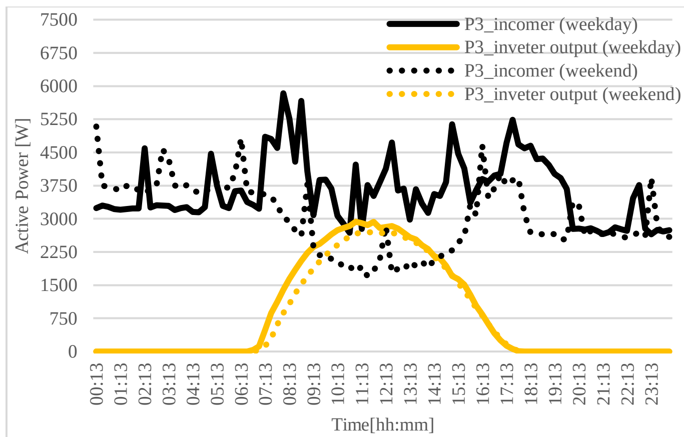

Fig. 11. Phase 3 active power

The iTHD and active power for phase 3 are indicated in **Fig. 10** and **Fig. 11** respectively. The iTHD3 at the inverter output during weekday and weekend meet the standard limits at +/-2.5 between 8:13 AM and 15:58PM and the active power developed at inverter output is above 500W for both days (weekday and weekend). At 6:58 AM and 17:43 PM, iTHD3 indicate high spike reaching 91% for both days, while the active power produced by the inverter is lower at 37W and 70W respectively. iTHD3 at the incomer feeder for both days exceed the 5% iTHD standard limits by reaching a maximum of 40% on weekday and

44% on weekend and a minimum of 11% on weekday and 17% on weekend.

3. Conclusion

The maximum individual current harmonics of the LV network discussed in this work meet the NRS 097 standard limit at less than 4% from the 3rd through 9th and less than 1% from 2nd through 8th, odd and even harmonics respectively. The current total harmonic distortion (iTHD) of the network to meet the standard limits at the PV system output (inverter output) when the active power produced by the inverter is above 500W. The iTHD at the inverter output can be maintained within the standard limits (iTHD at less than 5%) if the inverters can stop sending power to the grid when its output power is 20% less than it installed rated power. The iTHD that were measured at the incomer (grid side) does not meet the standard. During weekdays at the incomer the maximum iTHD reached was 40.88%, as for weekend it is as high as 197%. It has been noted that at low active power iTHD becomes higher on both sides at the inverter output and at the grid incomer, however, the spikes in iTHD measured are measurement artefacts due to the low active power levels at the time of measurement. It also noted that the loading in the building is less during weekend that during weekdays, however, the power generated from the PV system supply more power to the loads than the grid. The data support that the PV system does not increase the iTHD as measured at the incomer so their risk to the grid from the grid-tie PV systems is minimal.

4. References

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