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Power Quality Performance Analysis of grid tied PV fed Parallel Pumping System under Normal and Vibrating Condition

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Abstract

The aim of this paper is to perform the relative study of power quality problems in a grid tied solar PV system, with and without vibration connected to a parallel pumping system at 1.0 bar set pressure by using two control techniques such as VVC+ & V/f. In case of vibrations, the effect of motor vibration problems on the dynamic performance and electrical power quality of water pumping system will be observed. Vibrations are introduced in the pumping system by loosening the base plate of the pumps. During motor vibrations, the instantaneous flicker values become high which leads to variation in the supply voltage and torque imbalance. The effect of power quality parameters in a solar feeder during normal conditions and vibrating conditions are analysed. In normal condition, the THD increases and the flicker is high only during transient period due to sudden voltage variations. A comparison has been made to observe the appropriate control method for pumping system with and without vibrations in a solar PV-grid connected system.

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Keywords: Centrifugal pumps; Control Techniques;Normal condition; Power Quality; Variable speed drives; Vibrations.

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1. Introduction

Pumps constitute around 25% of the global energy demand in industries [1]. The centrifugal pumps are the large used member from the pump family, covering 80% of total pumps installed [2]-[3]. So, pumping system has the large energy enhancement opportunities when compared with the other consumers [4]-[5]. Power quality is becoming a significant issue nowadays due to advancements in power electronics devices. The quality of power is verified by measuring the voltage and current signals to find THD and harmonic contents. Various critical problems were occurred due to harmonics injections such as torque pulsation, acoustic noise and high power losses [6]-[7]. In recent days, major harmonic contents are used to measured and calculate with the help of modern PQ analysis that includes 5th, 7th harmonics etc. Additionally, it is also used to calculate THD (Total Harmonic Distortions).

Nomenclature

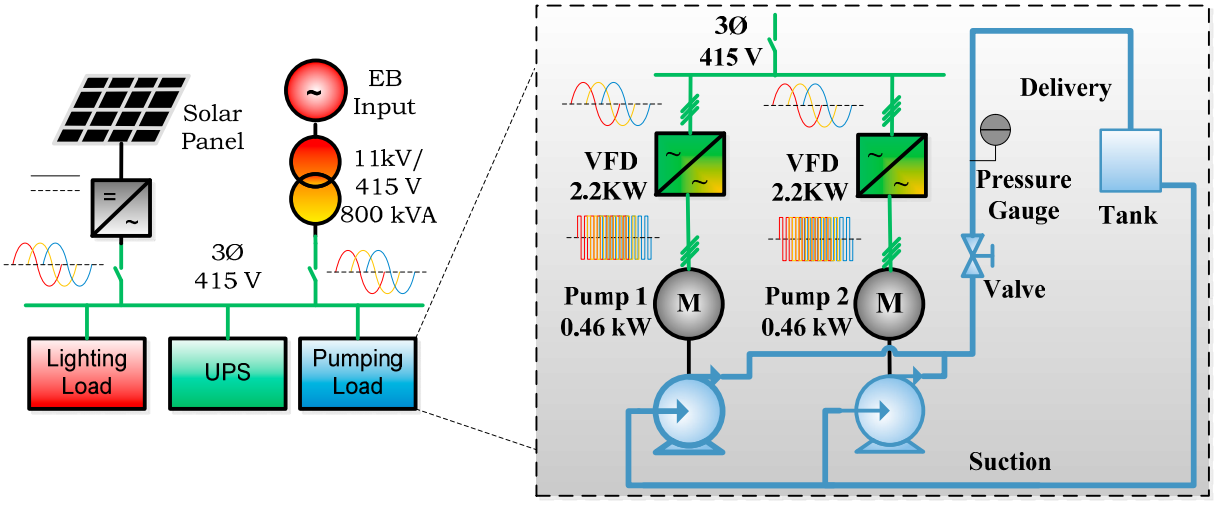
Abbreviations

N	Rotational Speed of pump [rpm]	E	Energy consumption
Q	Flow rate [m3/hr]	VFD	Variable Frequency Drive
H	Head developed [m]	V/f	Voltage / Frequency
V	Voltage	VVC	Voltage Vector Control
I	Current	FO	Fully Open
P	Real Power	SO/ SC	Semi Open/ Semi Closed
Q	Reactive Power	FC	Fully Closed
		t	Time [sec]

In this paper both the normal and vibrating condition of individual pumps in a parallel pumping system with grid tied solar PV are discussed with two control methods (VVC+ and V/f). The base plate of the motors is loosened to achieve the vibration test results for the pumping system [8]-[9]. The power quality issues analysis have been performed with/without vibration at a specific set pressure with two control methods.

2. Experimental results

The pressure/ flow rate control of pumps is performed by using variable frequency drives (VFDs) [10]-[18]. The Figure 1 shows the block diagram and the hardware setup of the parallel pumping system.



(a)

(b)

Fig. 1. Multi pump system in parallel (a) Block diagram (b) Experimental setup

Under normal and vibrating conditions, measurements were done with two control methods (VVC+ & V/f) and three operating valve positions such as fully open, semi-closed and fully-closed at a constant pressure of 1.0 bar. Firstly, power quality issues such as THD, unbalance in voltage, flicker, 5th and 7th harmonics etc., were measured with normal and vibrating condition. The power quality analyzer (PQ Box - 200) and Fluke 430 II is used to measure all the electrical signals. The experimental specification and the IEEE limits of the parallel pumping system are given in Table 1 and Table 2 respectively.

Table 1. System Parameters

Particular	Values	Particular	Values
Solar panel	3 kW	Pump type	Centrifugal
V_{oc}	20 V	I_{sc}	3.3 A
Rated Power	0.55 kW	Head	23.5 m (18 ~ 25m)
Rated Voltage	415 V	Discharge	2000 LPH
Frequency	50 Hz	Stator Resistance	11.134 Ω
Rated Current	1.7 A	Rotor Resistance	8.18 Ω
Nominal Speed	2800 RPM	Leakage Reactance	14.094 Ω

Table 2. THD limits for voltage level (IEEE 519). [11]

Bus Voltage at PCC	Individual Voltage Harmonic Distortion (%)	VTHD (%)
Vg ≤ 69kv	3.0	5.0
69kv < Vg ≤ 161kv	1.5	2.5
Vg > 161kv	1.0	1.5

2.1. Normal conditions

In case of the normal conditions, base plates to motor are tightened and the measurements were carried out on the pumping unit for electrical signal. Under all operation cases the THD at PCC in a solar feeder has resulted approximately 3%. For 5th harmonic it is around 2 to 2.5% and for 7th harmonic its 1.2 to 1.5% for both V/f and VVC+ methods respectively (see Fig. 2(a), and Fig. 2(b)). Furthermore, voltage is around 230V under unbalanced positive, negative and zero conditions. Sudden pump operations cause unexpected changes in solar feeder voltage at transition intervals further causing instantaneous flickers that are negligible as shown in Fig. 2(c), and Fig. 2(d).

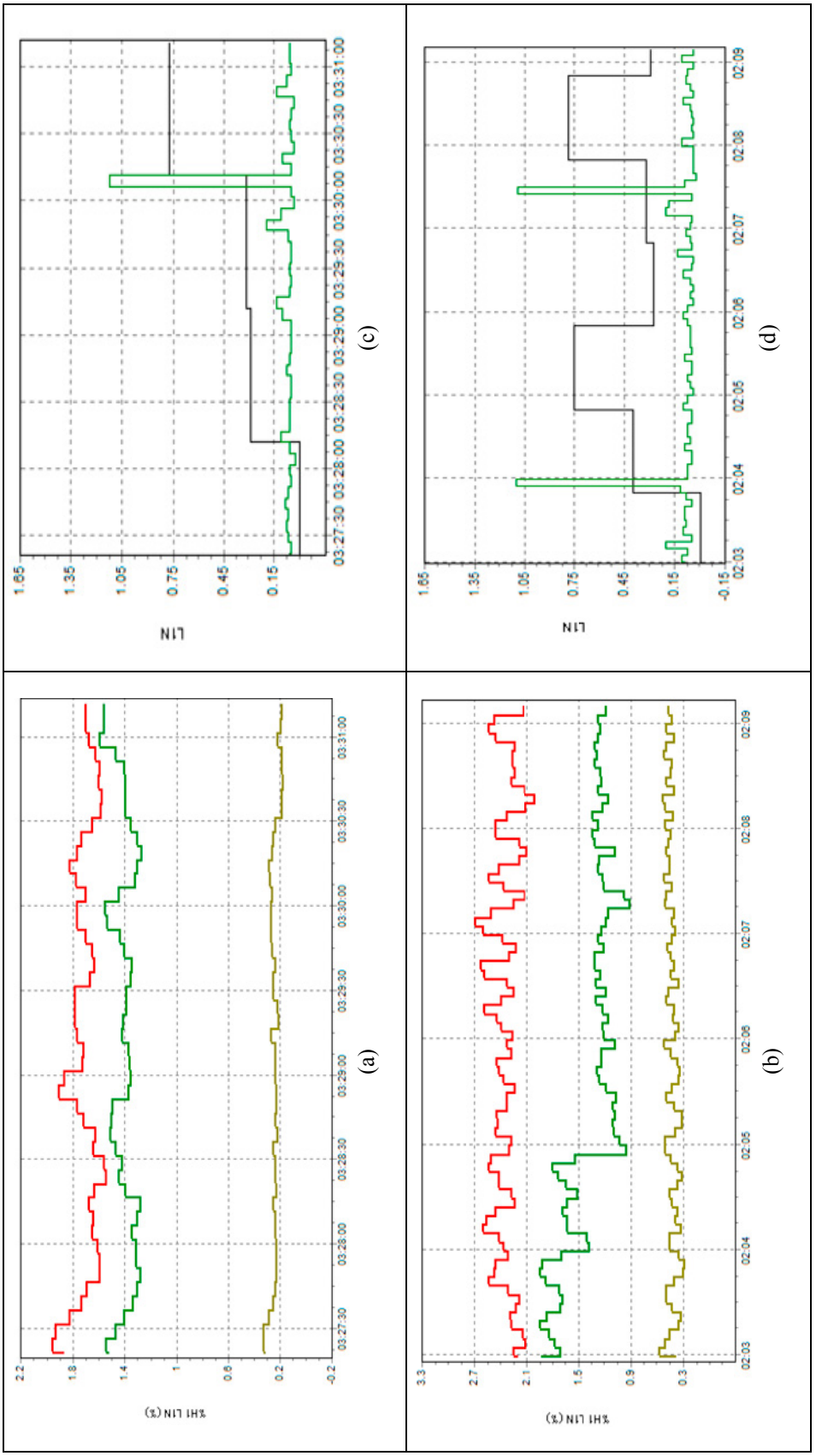


Fig. 2. Normal condition (a) V_{THD} (5th, 7th and 11th order) for V/f method, (b) V_{THD} (5th, 7th and 11th order) for VVC+ method, (c) Voltage Flicker for V/f method, (b) Voltage Flicker for VVC+ method

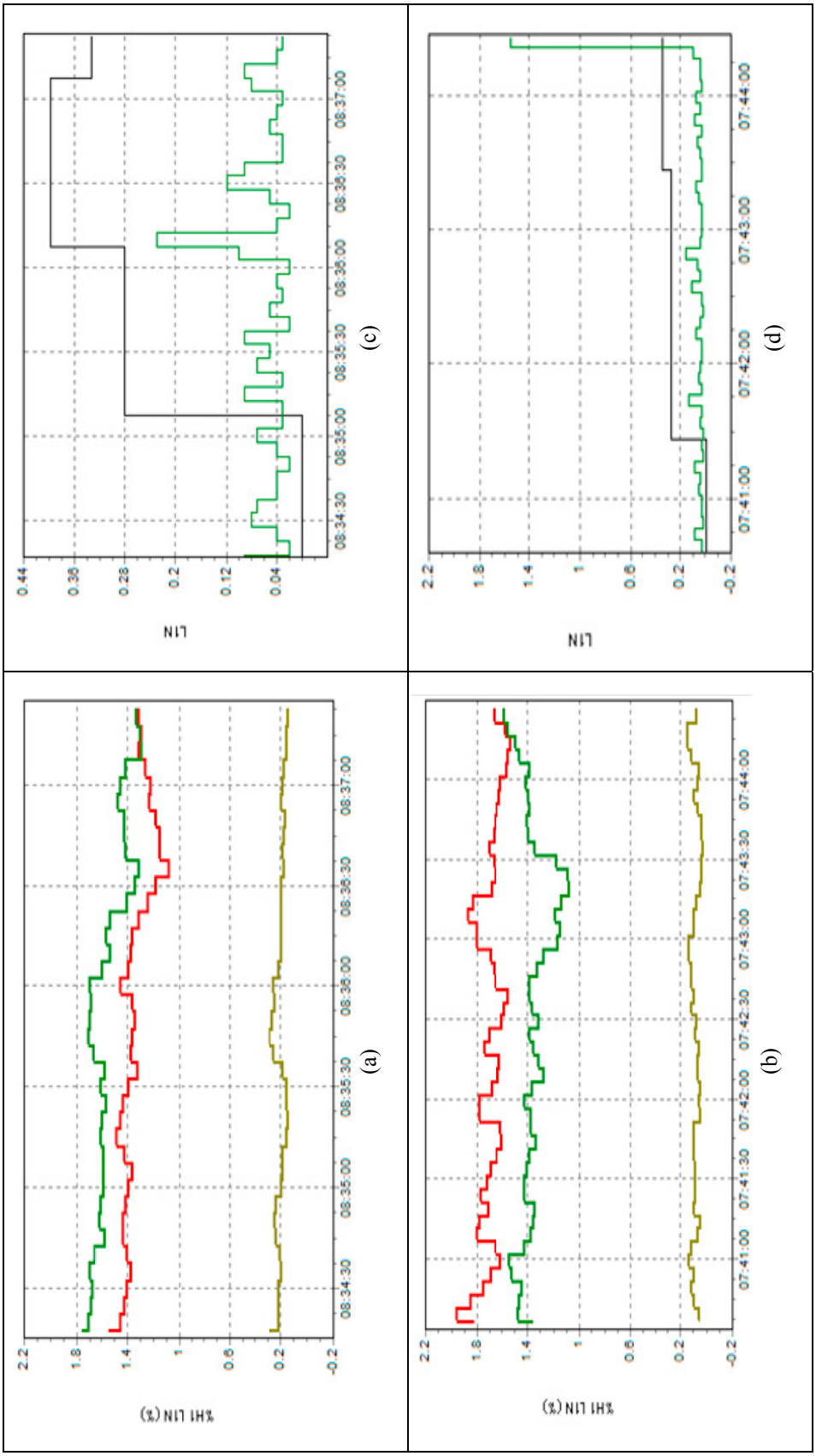


Fig. 3. Vibration condition (a) V_{THD} (5th, 7th and 11th order) for V/f method, (b) V_{THD} (5th, 7th and 11th order) for VVC+ method, (c) Voltage Flicker for V/f method, (b) Voltage Flicker for VVC+ method

2.2. Vibrating conditions

For the operation of motor with vibrations, 5th, 7th and instantaneous THD values (see Fig. 3(a), and Fig. 3(b)) of flicker are depicted in Fig. 3(c), and Fig. 3(d). It is inferred that about 3 to 4.5% of changes in the THD value has occurred based on the number of units operation. However these values are nearest to the permissible limits which are shown in Table 2 but their values should not exceed these limits. Further observations in solar feeder power quality results in contents being higher 5th and 7th harmonics. This is due to torque operation being unbalanced which is a result of motor vibration causing supply voltage to fluctuate [13]-[18].

In table 3, the comparison has been done under normal and vibrating conditions for both control methods. From this comparison, it is observed that THD increases about 3% to 3.1% under vibrating conditions by using VVC+ method and 2.7 to 2.8 % under V/f method. Additionally, 5th harmonic values are also increased by 1.5 to 1.7% by VVC+ method under vibrating conditions and 1.2 to 1.4% by V/f method. Moreover, the instantaneous flicker has no values under normal conditions in solar connected line; only at transition period, it has a value due to sudden voltage variations. So, the comparison represents that all harmonic contents and the flicker values increases under vibration mode results in vibrations which causes unbalanced torque.

Table 3. Performance Comparison

Control Method	VVC+ Control		V/f Control	
Case	Without Vibration	With Vibration	Without Vibration	With Vibration
THD	About 3%	3.5-4%	2.5-3%	Greater than 3%
5^{th} harmonics	1.5-2%	2.2-2.3%	2-2.5%	About 3%
7^{th} harmonics	1.3-1.4%	1.5-2%	About 1.2%	About 1.5%
Flicker(at 1min)	Small flicker value	High flicker value	No flicker value	More flicker value
Unbalance V_{POS}	About 230V	Greater than 230V	About 230V	235-240V
Unbalance V_{NEG}	0.5-1V	Greater than 1V	1-1.6V	1.7-2V
Unbalance V_{ZERO}	3.5-4.5V	About 7V	4-4.7V	Greater than 5V

3. Conclusion

The analysis of the dynamic measurements and power quality showed that; motor vibrations affect dynamic performance and electrical power quality in a grid connected PV system. A comparison between electrical power quality analysis and dynamic performance in the two cases; normal mode and vibration mode is done and the following results; such vertical big pumps should be connected to the foundation through strong supports. A poor fixing or weakness of base plate or foundation leads to high levels of vibration. The THD increases by about 3% to 3.1% under vibrating conditions by using VVC+ method and 2.7 to 2.8 % under V/f method and the harmonics content 5th and 7^{th} increased 1.5 to 1.7% by VVC+ method under vibrating conditions and 1.2 to 1.4% by V/f method. A full load condition creates other sources of high vibration of level due to misalignment and pump bearings problems for the pump units in a solar feeder. Finally the effect flicker did not occur in case of normal conditions connected with solar feeder but its values were higher in vibrating conditions. Hence, V/f method is better than VVC+ for operating in vibrating conditions when the pumps are operated in a grid tied solar feeder.

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