Power Quality Behavior of Single Phase Fed Adjustable Speed Drive Supplied from Grid of PV Generation

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***Abstract*--- Power quality behavior on connecting single phase fed adjustable speed drives to a grid which photovoltaic as the power generation is studied in this paper. A MATLAB/Simulink simulations are performed to investigate the existence of power quality parameter and the system problems that may be resulted from operation of this type of load. The results indicate a potential serious power quality problem with the connected adjustable speed drives, which requires consideration during operation of PV generation which a number of this dynamic load.**

***Keywords*--- power quality, PV generation, adjustable speed drives**

I. INTRODUCTION

The increasing of energy consumption, electricity demand and environmental issue have pushed more effort to produce more electricity. The renewable energy source such as wind, solar, fuel cells, small hydro and wave energy tend to be exploited significantly [1]. Solar energy that converted via photovoltaic cells conversion is one among promising renewable energy source and with wind energy become dominant renewable source being exploited [2-3]. Simplicity for build in any place, time for realization and flexibility for built in wide range capacity cause this technology more and more used.

PV generation system can be operated in grid connected mode and with other generation system, can perform distributed generation system. In isolated area, where electrical consumers can not reached by the utility grid, PV generation are built and operated in isolated mode [4]. The problem facing by application of PV generation and other renewable energy source generation is quality of electrical power quantity. Power density of renewable energy resource (i.e. irradiance level and temperature in PV conversion) that vary over the time potentially cause voltage and frequency variation or sag/swell pattern on the grid. Also, application of power converter as interface between energy source and grid and their interaction with other system components may cause high harmonics distortion [5].

Beside from source side, power quality problem can also be created from load side, power quality behaviors in this case are combination from both side of the system. Trend application of electrical equipment based on power electronic devices and mode operation of equipment can cause significantly power quality problem in the grid [6], their connection to the grid both single or three phase are also one of factors that affects power quality parameter on the grid. Adjustable Speed Drive (ASD) is one among such equipment. Along with fast growing application and demand of ASDs that have proven has capability in energy consumed reduction and ability to fulfill torque and speed pattern needed by motor load, it causes increasing production of various type of ASDs (topology and control method) [7]. This various production offer many features in operation and installation to the main.

This paper presents study of power quality behavior in operation three phase induction motor and its ASD fed from grid of PV generation trough single phase connection. Such connection is found on residential connection or home industrial that supplied from the main trough single phase line. The study is focused on observation of line harmonics on supplying phase created during steady state operation of ASDS and their effect on other phase of the grid. Power quality behavior of system component during power quality event when motor is starting and accelerating/decelerating are observed and analyzed. The study is done by modeling and simulation the system using MATLAB/Simulink.

II. SYSTEM DESCRIPTION

A. Photovoltaic array and PV inverter

In a photovoltaic generation, sun energy in form of irradiance and is convert to DC electrical energy trough cells in photovoltaic module or array. As other renewable energy sources, the power from the sun that indicates by irradiation and temperature are time varying. In other hand, photovoltaic cells as conversion equipment shows non linearity in electrical parameters: current and voltage, due to irradiation and temperature. Photovoltaic

cell characteristic shows that the higher the irradiation, the higher current output created and the higher temperature the lower voltage developed. This characteristic follows the well known voltage-current relationship of photovoltaic cell's one diode model as [8]:

$$I = I_{SC} - I_o\left[e^{(q(V+I.R_S)/A_o kT)} - 1\right] - \frac{(V+I.R_S)}{R_{sh}} \qquad (1)$$

Where I_{SC} is short circuit current, I_o is dark saturation current, q is electric charge = 1.6022x10-19 C, k = 1.3807x10-23 JK-1 is Boltzmann's constant, A_o is ideality factor of photovoltaic cell and T is the absolute temperature. R_s and R_{sh} are photovoltaic cell serial and shunt resistance respectively. The V-I photovoltaic cell's characteristic dependence due temperature and irradiance is illustrated on Fig. 1 and 2.

Power electronics converter, in this case, PV inverter is used to interface the varying power density generated by photovoltaic to utility level of electrical power. In a PV inverter, some function are employed: adjusting the voltage level of photovoltaic output to meet voltage operation of inverter; tracking the voltage /current point where maximum power can be extracted and creating sinusoidal ac power. If the PV inverter is used as grid tied PV inverter, it must be completed by synchronizing and power flow control mechanism when the inverter to be connected to the grid. Reliable protection, such as anti islanding to protect the inverter from over load must be added. Also, cause of it is considered as power source for utility, grid tied inverter must be fulfil tight standard of power quality like IEEE 1547 [9].

In the market, PV inverter are met in three phase and single phase types, in both isolated and grid tied connection. Three phase PV inverters is produced in relatively high capacity and used for large application such central inverter in a PV generation plant. Meanwhile single phase inverters that produced generally as string inverter in lower capacity is used in small application, such as in building photovoltaic system or in individually residential photovoltaic electricity.

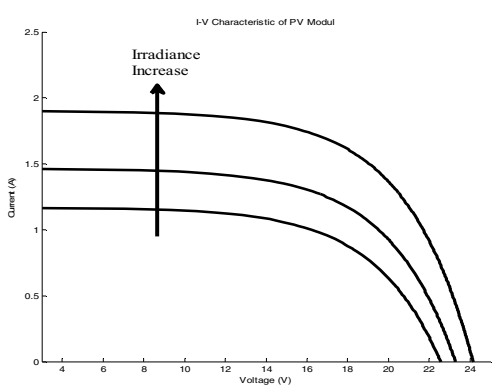

Figure 1. Dependence of V- I characteristic of a PV module due to irradiance variation

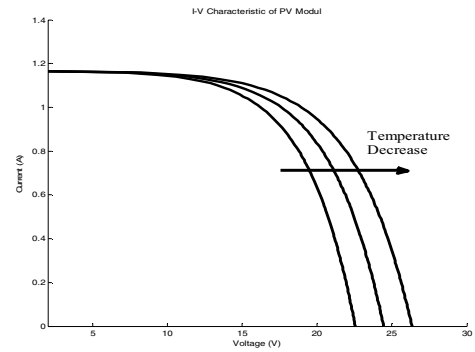

Figure 1. Dependence of V- I characteristic of a PV module due to Temperature variation

In a PV generation plant using single phase inverter, enlarging capacity is done by implementing a number of PV inverters and connecting them to form three phase connection.

As the point of power flow control, power quality aspects of PV generation are highly depend on performance of PV inverter. The problem arise from connecting PV inverter as power source to grid can be in form of voltage and current distortion caused by harmonics produced, voltage variation in form of over or under voltage, unbalance voltage between phase and degradation of power factor.

B. Adjustable speed drives

An adjustable speed drive (ASD) is an electrical device that used to provide continuous range process speed control of electrical motor. Other term concerning to this equipment are variable speed drives, adjustable frequency drives or variable frequency inverters. The latter two term only refers to a certain ac system.

Generic ASD contains rectifier and inverter. The rectifier is a circuit used to converts fixed ac voltage power from the line to either fixed or adjustable voltage dc. The dc power than convert to variable ac voltage and frequency by the inverter. Conversion process in both rectifier and inverter accomplished by electronic switch that work under control schema so that the desired dc voltage level, ac voltage and frequency can be reached. Three basic types of inverter that widely used in ASDs application are voltage source inverter, current source inverter and the most commonly used due to power quality: pulse-width modulated inverter.

According to input voltage, in market, for three phase motor ASD is met also in single phase and three phase input. Three phase input ASD generally used in industrial application meanwhile single phase input ASD met in other relatively small industry and household application (refrigeration, washing machines, etc) which their electricity supplied from utility using single phase connection.

Even though in capacity, single phase ASD individually seen not significant, but because its application spread in large number of user, then their operation may cause significant effect to power system behavior especially in power quality. Single phase input mean that the ASD employ single phase rectifier which known creates rich triplen harmonics current. Magnification of this current resulting from superposition between phases as nature of this type of harmonics current, may causes over heating in neutral line conductor and shifting the neutral point. Excessive unbalance loading is also one among aspects that may appear in application of single phase load. Unbalance loading in three phase system may further cause unbalance voltage between phase in three phase system, one phase may experiences over voltage and the other experiences under voltage condition.

As generally drive characteristic, dynamic operation such as starting, acceleration and deceleration of single phase fed ASD is also give effect in form of voltage sag and swell on the grid.

III. SIMULATION

In order to observe the power quality behavior of connecting single phase fed ASDs, a simulation was built and run with MATLAB/Simulink. A PV generation plant contains PV array and three phase PV inverter supply the single phase fed ASD and three phase resistive load. A delta-wye transformer is used as distribution transformer, secondary neutral connection is set up to allow neutral parameter measurement. Varying input dc power for PV inverter is done by adjusting irradiance of PV array. Circuit breaker are employed in each single phase ASD in order to observe grid voltage and current during connection and disconnection. The ASD is operated in several speed level by adjusting the ac side ASD's inverter frequency, the motor load is from a type of load that its torque is function of square of speed. The simplified simulation diagram is shown in Fig. 3. Using the simulation diagram, some power quality behavior during ASD operation is reviewed and analyzed, they are:

A. Connecting the single phase ASD to the grid.

Initially the PV generation runs in normal condition supplying a resistive load. At time t = 1, the single phase fed ASD is connected, the motor start till reach its nominal speed. Motor and grid parameter are shown on Fig. 4.

During starting, the ASD input current change rapidly for supplying starting current of the motor until reach its nominal speed. Current shape shows typical high distortion single phase rectifier waveform used in ASD. In the same time, grid phase voltage where single phase fed ASD is connected experiences voltage drop meanwhile other phase shown over voltage resulting unbalance voltage between phase. This condition may affect the surrounding customers connected to same

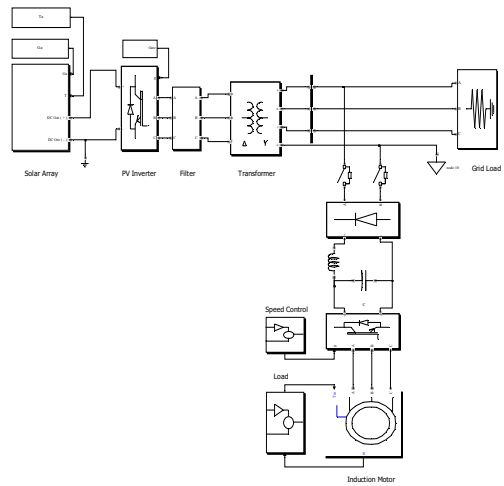

Figure 3. Simulation diagram

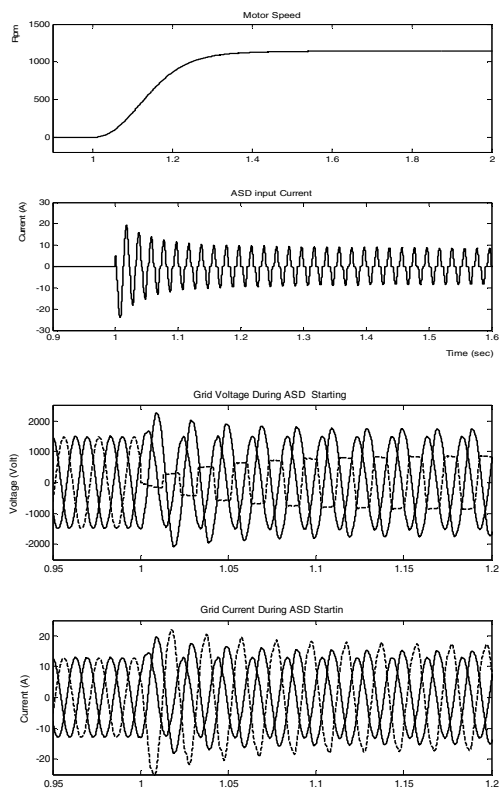

Figure 4. ASD input and grid parameter during ASD operation

coupling point, three phase customers equipment will experience an unbalance supply on their terminal as well as single phase customers load will supplied by under or over voltage.

Fig. 5 shows appearance of neutral current during operation of ASD, this figure is taken by connecting three single phase fed ASDs on each grid phase in the same capacity and loading condition so that the grid is experienced balance load. Cause of triplen harmonics created by each ASD, even in

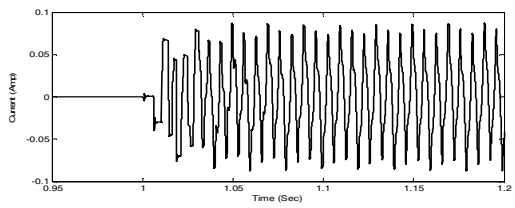

Figure 5. Neutral current

balance loading, the neutral current still appears. Neutral current become more important in a grid with large number single phase load in unbalance connection and the loads are from non linear type such as rectifier.

B. Loading effect of ASD to THD

Speed variation of ASD is done by varying operation frequency of input voltage to the motor from inverter in ASD. In this simulation, frequency is taken in several frequency, total harmonics distortion (THD) on grid voltage during ASD frequency 50 Hz is shown in Fig.6. Trend of voltage distortion on some frequencies and loading level of ASD are shown in Fig. 7.

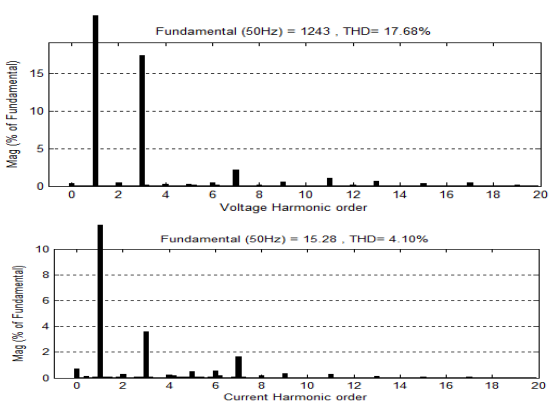

Figure 6. Grid distortion during single phase ASD operation

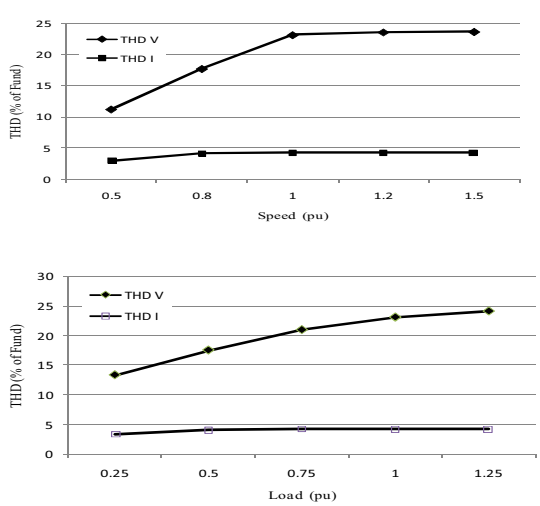

Figure 7. Trend of voltage distortion in varying operation speed and loading level of ASD

Dependence of power output of PV array to irradiance condition are simulated and the result are shown in Fig. 8. Three irradiance level are applied with initially 800 W.m^{-2} and than at certain time it is changed to 500 and 900 W.m^{-2}, during these condition, ASD is switch on and effect to ASD is observed. Fig.9 shows input voltage and speed of ASD at the events.

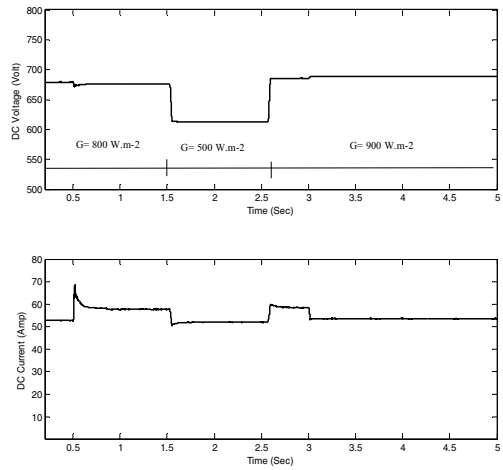

Figure 8. DC output of PV array when irradiance is adjusted

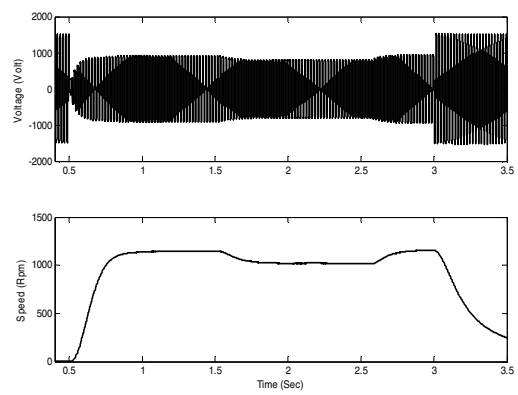

Figure 9. ASD Input voltage and motor speed when irradiance is adjusted as Fig. 8.

IV. CONCLUSION

Application of single phase fed ASDs leads to severe power quality problems such as high contents of triplen harmonics especially harmonics and voltage dip during dynamic operation of ASD. It was also shown the effect of varying speed and loading level of ASD to harmonics content fed to the grid and effect of variation input power to PV array that cause parameter changing both in grid and ASD performance.

ACKNOWLEDGMENT

The authors thank the Malaysian Government, Ministry of Science, Technology and Innovation (MOSTI) and Universiti Teknologi Malaysia for the E-Science Fund Grant, Vot. No. 79140.

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