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MODELING OF UNBALANCED RADIAL DISTRIBUTION SYSTEM

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ABSTRACT:
This paper presents a simulation based unbalanced radial distribution system. The distribution system is consisting of a three phase induction machine load, a single phase photovoltaic, a three phase power factor correction capacitor, and a load. The single phase photovoltaic is interconnected to grid through a voltage source inverter. The single phase photovoltaic model includes maximum power point tracking, proportional resonance controller, and a phase locked loop. This model is demonstrated by three case studies. The devolved model is used to identify variety of stability, harmonic issues in distribution system and also effect of unbalance on the system. The system dynamic performance is investigated using this model. The complete analysis is carried out in MATLAB/SimPowerSystems environment.

Keywords: *Photo Voltaic, Distribution System, Maximum Power Pont Tracking, Proportional Resonance Controller.*

1. INTRODUCTION

Increasing efficiency and decreasing cost of solar technology Promotes substantial growth of the photovoltaic (PV) power integration in modern power systems. PV has shared a favorable amount of renewable energy penetration in micro grids where the PV power supplies electrical loads for local communities [3]. New government policies and incentives encourage more and single phase PV systems to be connected. In addition, induction machine loads are dominant in distribution systems. The unbalanced redial distribution system consists of all three phase lines except the PV line is single phase. Since the PV array is dc source, an inverter is required to convert the dc power to normal ac power. The PV array supplies the single phase ac power into the grid. This will introduce the unbalance in the distribution system. PV system has a more complicated control system.

Control of the interfacing dc to ac converter including PR controller, PLL and MPPT will all be modeled in MATLAB/SIM Power Systems. The control strategy driving the dc to ac converter is essential for the maximum dc power extraction and its proper transfer to the grid. Different types of maximum power point tracking (MPPT) algorithms have been proposed in the recent years, e.g., hill climbing (HC) [3,4], perturb and observe(PO) [5], and incremental conductance (IC) [6,7]. Among these algorithms, HC and PO are two commonly used methods because of their simple control structures. The disadvantages related to these methods are more losses at the steady state because of large perturbation around maximum power point, reduced dynamic performance when there is a change in irradiance or at any other sudden dynamic event [8], and large oscillations around the maximum point [8]. IC algorithm has a number of advantages compared with the PO method. It can exactly determine when the maximum power point is reached. In PO method, there are oscillations around the maximum power point. The IC method is more accurate in maximum power tracking or responding to the irradiance changes is more than that of the PO method. The ripple content in the output power is reduced in the IC method compared with the PO method [8]. And finally dynamic performance of the incremental conductance based methods is faster when an operating point is changes in the system [8].increased complexity is one of the disadvantage of the IC algorithm when compared with the HC and PO algorithms[9]. In Ref [8], it is demonstrated if a proportional integral controller is used, the dynamic response of IC method is improved.

The main objective of this paper is to model, analyze and simulate an unbalanced distribution system with both complex loads such as induction machine (IM) and renewable such as inverter interfaced PVs. This model can be used in micro grid studies such as power quality, harmonic mitigation or resonance issues. The detailed PV model consists of a single phase synchronizing phase locked loop (PLL), proportional resonance (PR) controller, and maximum power point tracking unit.

The reaming of the paper is described as follows. In Section 2 the system configuration is described. PV control composed of PR controller and MPPT and PLL are described in Section 3. Different cases are considered for analyzing the system with varying irradiance and unbalance level have been described in Section 4. Section 5 is the conclusions.

2. SYSTEM CONFIGURATION

The power system which is used in this paper is an unbalanced distribution system including a three phase induction machine, a power factor correction (PFC) capacitor, a load, and a single phase PV. Fig.1 is the single line diagram of the system which is to be studied. All the elements are connected at the point of common coupling. The system parameters are given in the appendix. The Fig.1 shown all the lines of network are three phase balanced, and the PV line is single phase line.

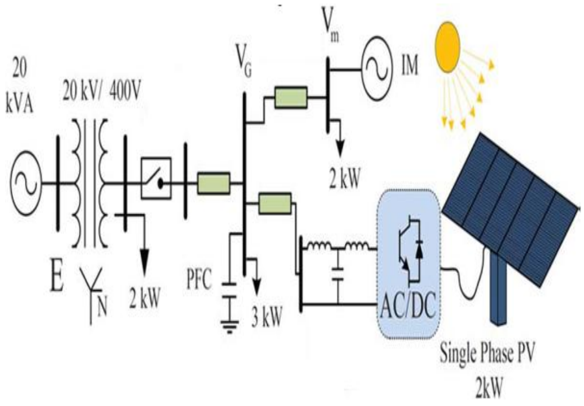

Fig.1. Single line diagram of photovoltaic system.

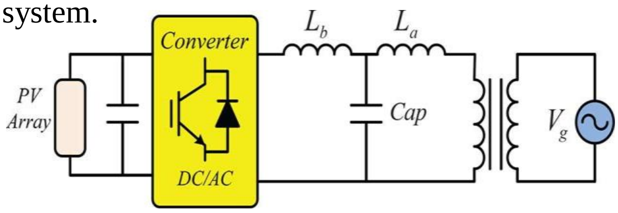

Fig.2. Basic configuration of photovoltaic system

Traditionally, two-stage converters (a dc to ac converter after a dc to dc converter) have been used for PV systems. Two-stage converters need additional devices compared with single stage converters. Therefore, single stage converters have been used in PV grid integration. The basic configuration of a single phase PV is illustrated in Fig.2. The main elements of the single stage PV are the proportional resonance (PR) controller and the output LCL filters. Fig.2 shows the basic configuration of an LCL filter in a single phase PV. It consists of two inductances and one capacitor connected to the grid though transformer. This LCL filter reduces unwanted harmonics injected to the grid.

3. PHOTOVOLTAIC CONTROL

The main block diagram of PV control is illustrated in Fig.3.The inputs of the MPPT block are the measurements from the PV angel (I_{dc}, V_{dc}). The output of MPPT block is then modified to shape the reference PV AC current magnitude. The measured AC current from the grid is then compared with the reference signal and the error will be sent to the PR controller. The output of the PR controller is sent to the pulse width modulation (PWM) generator block to generate the pulses for the PV inverter. A phase locked loop (PLL) is used to synchronize the PV reference current with the AC grid in Fig. 3. The PV control structure is explained with MPPT control, PR controller, and PLL.

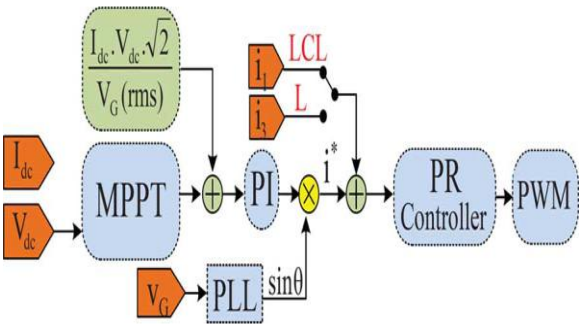

Fig.3. Control of photovoltaic system

1. MPPT Control

The MPPT is the main art in the photovoltaic systems which can ensure the maximum captured power from the PV array. To achieve this objective, a MPPT strategy is used regardless of weather conditions or load profiles, the MPPT should guarantee a PV is providing the maximum power. In this study, the incremental conductance algorithm has been used. The output current and voltage of the photovoltaic panel are used to calculate the conductance and incremental conductance. The basic approach is to compare the conductance (I_{dc}/V_{dc}) with the incremental conductance (dI_{dc}/dV_{dc}) and to decide whether to increase or decrease the PV current in order to reach the maximum power point. Considering P = V.I. At the maximum power point, the derivative of P against V should be zero.

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V\frac{dI}{dV} = 0 \quad (1)$$

$$\frac{dI}{dV} = \frac{-I}{V} \quad (2)$$

The above equations indicates that, the power captured by the PV is maximum when the conductance is equal to the incremental conductance

2. PR Controller

The main objective of the PR controller is to track a sinusoidal signal reference. So that PR controller is adopted for this objective. The transfer function of PR controller is expressed as

$$F_{PR}=K_p+K_r \frac{s}{s^2+w^2} \quad (3)$$

PR controller provides an infinite gain in a very narrow band-width that is at the resonance frequency. As a result, steady-state error is eliminated at the resonance frequency. It can be concluded that, PR has reached to very high gain around the resonance frequency. When the gain is maximum or infinite at the resonance frequency, the steady state error reaches zero. Therefore PR controller is used to track designed frequency signals. So that the PR controller for single phase PV has been designed to reduce the higher order frequencies like 3^{rd}, 5^{th}, 7^{th} and 9^{th}. The PR controller aims to control the grid side AC current. To achieve this objective, the error of the reference PV current and measured PV current will be used as the input for the PR controller. The magnitude of the reference current generated from the output of the MPPT block will be synchronized with the grid voltage before sending to the PR controller. The synchronization steps will be conducted in a single phase PLL block. The output generated from the PR controller is the voltage reference which will be directly given to the pulse width modulation (PWM) generation unit.

3. Single Phase PLL

The aim of phase locked loop is to provide a reference phase signal synchronized with the AC systems. Later the reference phase is used to generate a carrier waveform for firing pulses in control circuits of converters. The PLL can dynamically change the reference phase due to any dynamic change in AC systems, ensuring synchronization of the converter's output with the AC system. The input of the PLL is AC voltage from the grid, and the out-put is the frequency or angle which is synchronized with the grid.

4. CASE STUDIES

The study system was built in MATLAB/SIM Power Systems based on the physical circuit connection in the Fig.1.The MATLAB/SIM Power Systems model captures power electronic switching details therefore is considered high-fidelity simulation model. The dynamic performance of the unbalanced distribution `system is demonstrated with the three cases as follows.

- In the first case, a step change in load torque is applied to the induction machine.
- In the second case, the effect of unbalanced level is investigated by applying a ramp change in irradiance of the PV. This dynamic event emulates the cloud effect on a PV and a distribution system.
- In the third case, stability of the system is investigated by change in grid line length.

The three cases are explained as given below with help of the suitable simulation results in MATLAB/SIM Power Systems environment.

Case Study 1: A Step Change in Load Torque

A single-phase PV is connected to the phase of the system at the point of common coupling as shown as in Fig. 1. The initial torque of the IM has considered as 22 N.M. A torque change form 22 N.M to 20 N.M will be applied to the IM at time t=4 sec and the results of simulation have been illustrated in Fig.4.

In the Fig .4, the two waveforms shows the change in electromagnetic torque and the rotor speed of induction machine for the applied step change in load torque.

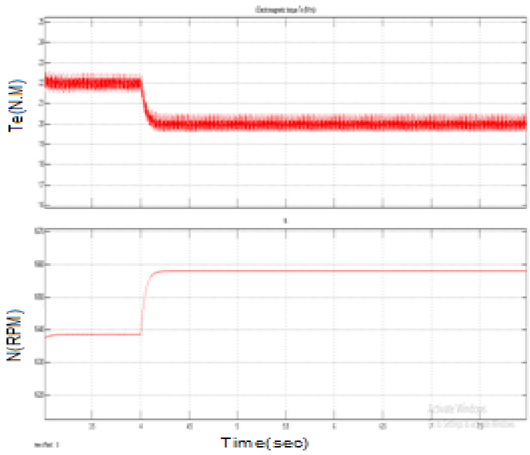

Fig.4. Simulation results of torque and rotor speed, due to a step change in mechanical torque (from 22 N.M to 20 N.M)

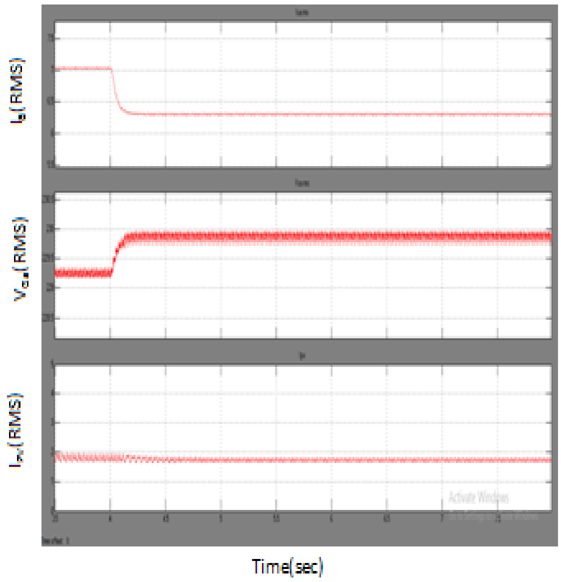

Fig.5.Simulation results of the IM line current, line voltage and PV current.

Case Study 2: PV Irradiation Change

In this part, the PV irradiance change will be simulated in MATLAB/SIM Power systems. The PV irradiance was set to 1000 W/M^2 previously. A ramp change will be applied at t=4sec to decrease the irradiance to 200 W/M^2.Then after some time the irradiance will be set back to 1000 W/M^2 at t=6 sec.

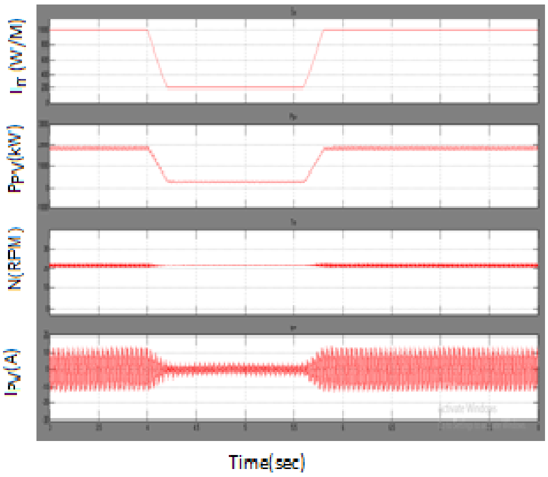

Fig.6. Simulation results for the change in irradiation level.

The change of irradiance has been illustrated in detail in the Fig. 6. The PV power wave form shows that, it follows the irradiance command. It is noticed that the maximum power level (2 kW) is obtained when the irradiance is set to 1000 W/M^2. The electrical torque of the induction machine shows that the thickness of the waveform size is reduced when the irradiance is decreased due to clouds; the PV power level is decreased, which leads to the decrease in the unbalance injection level to the system. The magnitude of the ripple also decreased during the interval of 4 to 6 sec. The last wave form show the PV current, which has been decreased due to the irradiance change.

Case Study 3 Increase in Line Length

In the third case the system stability was investigated by changing the grid line length. That means the length of the line is changed suddenly. This can cause voltage instability of the system. The grid line length from 3 km to 30 km was triggered with help of breaker at t=4sec.due to this the effective line impedance increases suddenly.

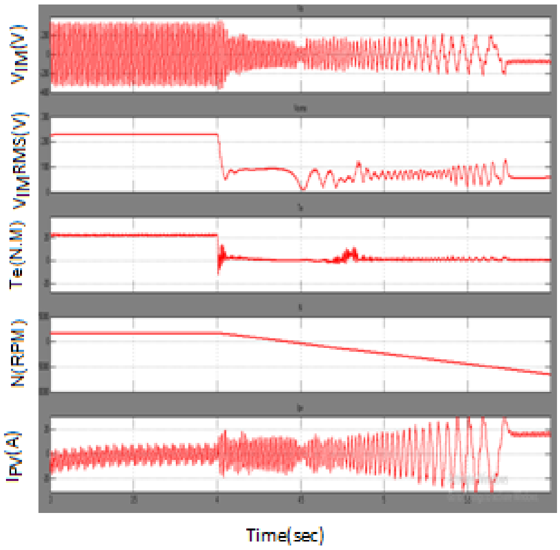

Fig.7. Simulations results of IM stator voltage, torque, speed, and instantaneous PV current due to the grid line length increase.

5. CONCLUSIONS

This paper presents a simulation based model of an unbalanced radial distribution system. The system consists of a single phase PV, a three phase induction machine, a power factor correction capacitor unit, and load. The control structure of the PV array also presented. The effect of the unbalanced on dynamic performance and the impact of line length on system stability were investigated.

APPENDIX

The network parameters of the system shown in Fig.1 are presented in Tables 1-3. Table 1 is the induction machine Table 2 is the PV system parameters, and Table 3 is the line data of the network.

Table 1
Induction Machine Parameters

Total Capacity	5.5 kVA
Nominal Voltage	400 V
Frequency	60 Hz
R_s	2.52 Ω
R_r	2.67 Ω
X_{ls}	3.39 Ω
X_{lr}	3.39 Ω
X_m	197 Ω
J	0.486 $kg.m^2$
P(poles)	4

Table 2
PV System Parameters

Total Capacity	2000 W
Frequency	60 Hz
L_a	0.01H
L_b	0.02H
C_{ab}	3 μH
K_p(PLL)	180
K_i(PLL)	3200
K_p(PR)	200
K_r(PR)	1500

Table 3
Line data of the network

Line No	Line Type	Z(Ω/km)	Length(m)
1	Z_{GRID}	0.579+j1.75	105
2	Z_{IM}	0.497+j2.47	105
3	Z_{PV}	0.462+j0.564	30

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