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A Review on Modeling of Unbalanced Radial Distribution Systems Based on Dynamic Phase



J.Rakesh Sharan, M.Tech
Associate Professor
Department of EEE
Sri Indu College of Engineering And Technology (Autonomous)
Hyderabad,Telangana.

Vangala Sandeep Reddy
M.Tech Student
Department of EEE
Sri Indu College of Engineering And Technology (Autonomous)
Hyderabad,Telangana.

Prof. M.Shiva Kumar
HoD & Professor
Department of EEE
Sri Indu College of Engineering And Technology (Autonomous)
Hyderabad,Telangana.

Abstract

Radial Distribution Systems is a system whereby power is received at the utility supply voltage level by a single, incoming substation. Through a series of step downs and splits, the power is converted for individual end-use equipment. There are 3 type of power distribution namely loop, network and radial.

This paper develops an analytical model of an unbalanced radial distribution system consisting of a single-phase photovoltaic (PV), a three-phase induction machine load, a three-phase power factor correction capacitor (PFC), and a load. The analytical model is based on dynamic phasors (DP) for phases. The single-phase PV model includes inverter current control [proportional resonance (PR) controller], an L, or an LCL filter. The induction machine model is based on positive-, negative-, and zero sequence components' dynamic phasors. The sequence-based induction machine model was converted to the DP- reference frame and interconnected with other grid components. The developed analytical model is capable of small-signal analysis and can be used to identify variety of stability and/or harmonic issues in distribution networks, e.g., instability due to weak grid. Impact of unbalance on system dynamic performance can also be investigated using this model. The analytical model is benchmarked with a high-fidelity model built in Matlab/SimPowerSystems where power electronic switching details are included. The small-signal analysis results are validated via Matlab/SimPowerSystems timedomain simulations.

***Index Terms*—Dynamic phasor (DP), induction machine, singlephase photovoltaic, small-signal analysis.**

INTRODUCTION

Increasing efficiency and decreasing cost of solar technology promotes substantial growth of photovoltaic (PV). Power integration in modern power systems. The total capacity of grid connected PV systems has increased from 300 MW in 2000 to 21 GW in 2010 . PV has shared a fair amount of renewable energy penetration in micro grids where the PV power supplies electrical loads for local communities.

New government policies and incentives encourage more and more single phase PV systems to be connected. In addition, induction machine based loads are dominant in distribution systems. Analytical models of such unbalanced distribution systems would provide insights of the system and further be used for small signal and large signal stability analysis. The analysis will help identify stability issues and mitigate related problems.

For unbalanced systems, abc frame based dynamic models can be used for dynamic performance examination. Simulation packages such as PSCAD and Matlab/Sim Power Systems are based on simulation models with instantaneous variables, e.g., instantaneous voltages and currents in three phases. Conventional linearization at an operating condition cannot be applied to these models due to the periodic varying state variables. The necessary condition for small signal analysis is to have constant values for state variables at steady state. Transforming the models to a synchronous rotating reference frame is the most common technique utilized to overcome the above problem. However the negative sequence components presented in an unbalance system will be converted to 120 Hz ac variables in a reference frame. Hence, reference frame based models do not offer the capability of small signal analysis under unbalanced topology and operating conditions.

On the other hand, dynamic phasor (DP) based modeling, an averaging technique, has been demonstrated to be capable of converting periodic varying state variables into dc state variables. It has been used in electrical machines analysis, dc/dc converter analysis, distribution system analysis, and HVDC and FACTS system modeling and analysis . For example, presents an averaged model of LCC based HVDC system which is capable of representing low frequency dynamics of the converters at both AC and DC sides. DP models make small signal analysis feasible. DP modeling technique also provides very ac curate simulations for larger time steps.

Moreover, DP based modeling can take into consideration of unbalance. For example in an induction machine (IM) model as well as a permanent magnet synchronous generator (PMSG) model in unbalanced conditions have been developed based on positive, negative, and zero (pnz) variables. In the dynamic phasor based modeling technique is used to model the unified power flow controller (UPFC). The model is ex pressed in pnz variables and can be used to study the effect of unbalanced operation. presents a DP based model taking into consideration of positive , negative, and zero sequence elements of a synchronous generator and its voltage controls. Tests on a single machine infinite bus system is conducted.

The above mentioned references consider only unbalanced operation instead of unbalanced topology. The objective of this project is to model, analyze and simulate an unbalanced distribution system with both complex loads such as IM and renewable such as inverter interfaced PVs. To the authors' best knowledge, the literature lacks a comprehensive modeling approach for unbalanced distribution systems that is suitable for both small signal analysis and nonlinear time domain simulation.

An effort has been taken in to model a distribution system with unbalanced topology. The system model is expressed by DPs of fundamental frequency in frame and the system contains a synchronous generator and a single phase inverter. Our proposed work will improve the modeling strategy in two aspects and therefore tackle comprehensive dynamic phenomena of unbalanced distribution systems.

A more comprehensive inverter control will be modeled in this project. The inverter is modeled in as a PQ controlled voltage source. Current controls are ignored. Inter actions between the current controls of inverters and the grid can lead to resonances. Therefore, ignoring current controls of a grid connected inverter will lead to the omission of certain dynamics. The current controls of a PV inverter will be modeled in our project.

A more comprehensive system model will be pursued in this project. The network model is treated as algebraic equations in and with dynamics of inductors and capacitors ignored. Each source in the system is treated as a voltage source. The sources are interfaced through voltage/ current algebraic relationship derived based on the network model. In our project, a different modeling strategy is adopted. Each source is modeled as a current source. The sources are then interfaced

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through network dynamics. Using this strategy, the network dynamics due to inductors and capacitors will not be omitted.

SOLAR ENERGY

Increasing efforts are being made nowadays to use renewable energy sources. Processing the energy obtained from sun, wind or water is coming to the fore. The energy supplied by these sources does not have constant values, but fluctuates according to the surrounding conditions (intensity of sun rays, water flow, etc.). These supplies are therefore supplemented by additional converters. The most used types are inverters or DC/DC converters. The area of high power converters for solar application is already covered by industrial manufacturers. However, the area of low power devices is not fully covered. These converters are mostly built from commercially produced parts that can perform demanded functions, but they are not developed for this type of application and therefore the efficiency of the whole system is low. Low power devices are important in applications where there is no voltage grid present and electric power is required.

The simplified block structure of the investigated system is shown in block diagram of the solar system. A DC/DC converter with an MPPT (Maximum Power Point Tracker) is connected to the solar array. A second DC/DC converter is connected to the output of this converter. The second converter raises the voltage acquired from the solar system to the voltage level demanded by the VSI

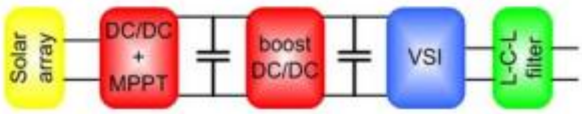

Fig 2.1 block diagram of the solar system

Solar photovoltaic (PV) energy has witnessed double digit growth in the past decade. The penetration of PV systems as distributed generators in low voltage grids has also seen significant attention. In addition, the need for higher overall grid efficiency and reliability has boosted the interest in the micro grid concept. High efficiency PV based micro grids require maximum power point tracking (MPPT) controllers to maximize the harvested energy due to the nonlinearity in PV module characteristics. Perturb and observe (P&O) techniques, although thoroughly investigated in previous research, still suffer from several disadvantages, such as sustained oscillation around the MPP, fast tracking versus oscillation tradeoffs, and user pre defined constants. In this project, a modified P&O MPPT technique, applicable for PV systems, is presented. The proposed technique achieves: first, adaptive tracking; second, no steady state oscillations around the MPP; and lastly, no need for predefined system dependent constants, hence provides a generic design core. A design example is presented by experimental implementation of the proposed technique. Practical results for the implemented setup at different irradiance levels are illustrated to validate the proposed technique.

MODELLING OF CASE STUDIES

The distributed system consists of a single phase PV station installed in phase of the system, a 3 phase induction machine, a 3 phase PFC, and a 3 phase load. this was shown below

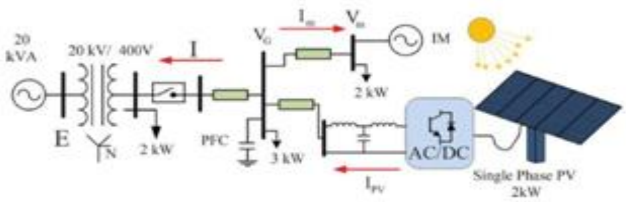

Fig 5.1 study system

The pv array generated dc power has to converted in to single phase IGBT inverter. the AC side of the converter bridge is connected to the filter circuit which consisting of series inductors and shunt capacitors to filter out the harmonics on AC side of converter this AC power is boosted to the grid voltage Vg by using transformers this was shown in Basic configuration of PV system and the filters LCL and L type filters used in AC side of the converter is shown in Basic configuration of PV system.

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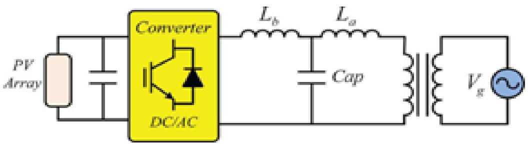

Fig 5.2 Basic configuration of PV system

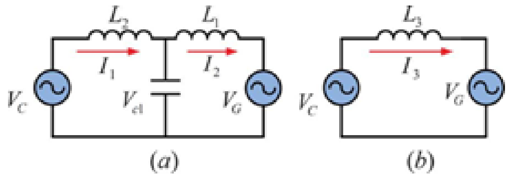

Fig. 5.3. Simplified PV model with different filters. (a) LCL filter. (b) L filter.

Case Study 1

In this part, A single phase PV is connected to the phase of the system at the point of common coupling (PCC) At , the induction machine's mechanical torque was applied a step change from 28 N.M to 23 N.M. The PV current from Sim Power Systems simulation has dynamics related to MPPT control and the dc side capacitor. In the analytical model, MPPT effect and dc side dynamics are neglected.

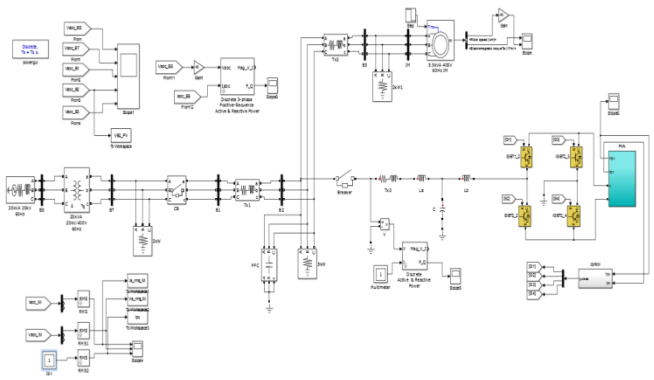

Fig 6.9 case 1 simulation diagram

Case Study 2

PV Irradiance Change

In this part, the effect of PV irradiance change will be simulated in both Matlab/Simulink and Matlab/SimPowersystems. the PV irradiance was set to 1000 W/m^2 previously. A ramp change will be applied at t = 4s to decrease the irradiance to 200 W/m^2 in 0.2 s. Then after 1.4 s, the irradiance will be set back to 1000 W/m^2.

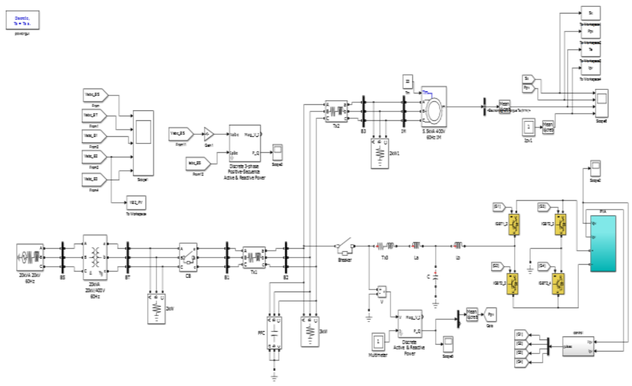

Fig 6.10 case 2 simulation diagram.

Case Study 3

In this impact of line length on system stability was investigated by time domain simulation in Matlab/SimPowerSystems. The grid line length has been changed from 3km to15km in order to observe its effect on dynamics. It is worth mentioning that increasing the line length more than 15km causes non convergence of the sweeping method for initialization. Therefore the results are only shown for the initial conditions where the system is able to converge. This can cause voltage instability of the system. In time domain simulations, a dynamic event to increase the grid line from 3 km to 30 km was triggered. Initially the grid connection consists of two parallel lines. At , a breaker of one line is opened so the effective line impedance increases suddenly

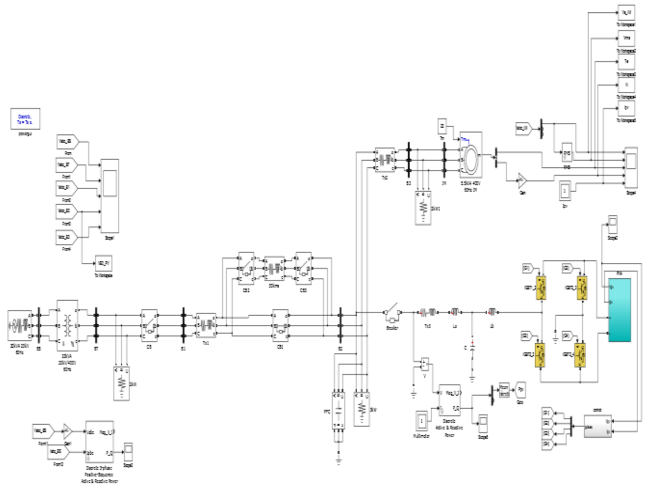

Fig.6.11case 3 simulation diagram

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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 6.1 parameters of induction machine

Total capacity	2000 W
Frequency	60Hz
L_a	0.01 H
L_b	0.02 H
Cap	3 μH
$K_p(PLL)$	180
$K_i(PLL)$	3200
$K_p(PR)$	200
$K_i(PR)$	1500

Table 6.2 parameters of pv

RESULTS

Results for case1

The analytical model based simulation results are compared with the Matlab/Sim Power Systems model based simulation results (in short, Sim power).

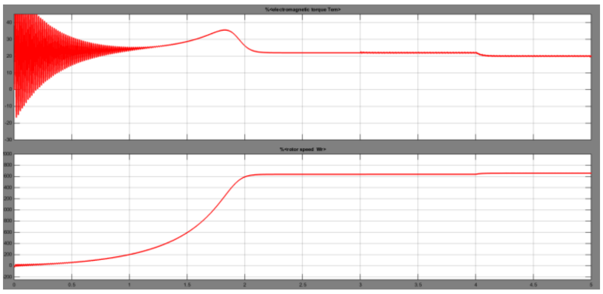

Fig 7.1 The simulation results of the electromagnetic torque and the rotor speed of the induction machine for step change in electromagnetic torque.

In the above shown simulation result electromagnetic torque Tem a step change in mechanical torque from 36 N.M to 21 N.M we can observe it in the time interval of 1.5 sec to 2.5 sec. as torque goes to a sudden step change this will affect the other system parameters like speed of the induction motor, induction motor stator stator current ,stator voltage and current of solar grid i.e photo voltaic current Ipv. as electromagnetic torque is suddenly decreasing the speed of induction motor will increase, stator current of induction machine is decreases, stator voltage is increses and finally the photo voltaic current will changes.

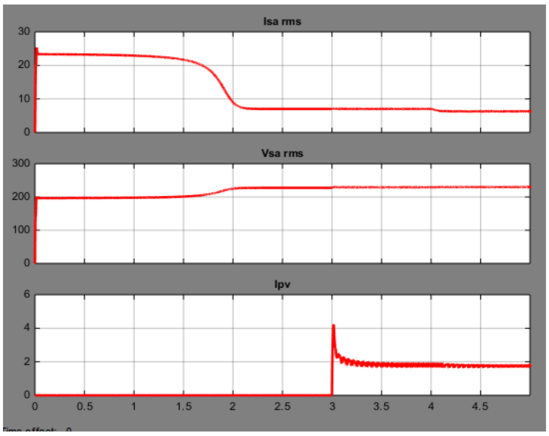

Fig 7.2 simulation results of the IM stator current, stator voltage and PV current due to step change in mechanical torque

The dynamic responses from the two models match each other well. The simulation results for the line current, the line voltage and the PV current The results of the line current and the line voltage from both models match well, which demonstrates the accuracy of the analytical model derived in this project. While the PV power is constant and has negligible variation, therefore the PV current of the analytical model is almost constant

Results for case2

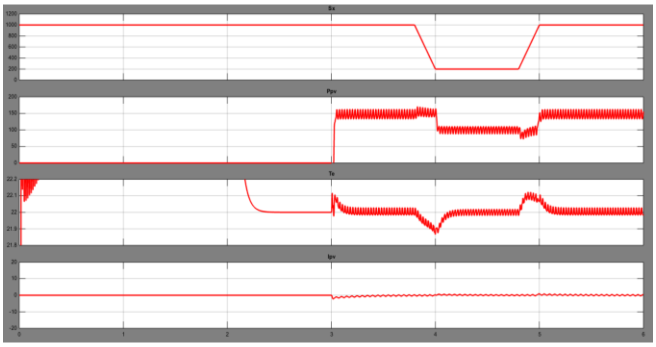

Fig 7.3 simulation results for the effect of irradiance change

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The results the change of irradiance has been illustrated in detail in the above simulation result. the first one shows change in light intensity irradiation from 1000 W/m^2 to 200 W/m^2 in 0.2 sec after 1.4 sec the intensity set to 1000 W/m^2 . The second on shows the PV power which follows the irradiance command. The PV power of the analytical model is set to follow the change of the irradiance. It is noticed that the maximum power level (2 kW) is obtained when the irradiance is set to W/m^2 in 0.2 s.

Then after 1.4 s, the irradiance will be set back to 1000 W/m^2.The third figure shows the electrical torque of the induction machine. When the irradiance is decreased due to clouds, the PV power is decreased, which leads to the decrease in the unbalance injection level to the system. The magnitude of the 120 Hz ripple has been decreased during the interval of 4 to 6 s. The last figure shows the PV current which has been decreased due to the irradiance change.

Results for case 3

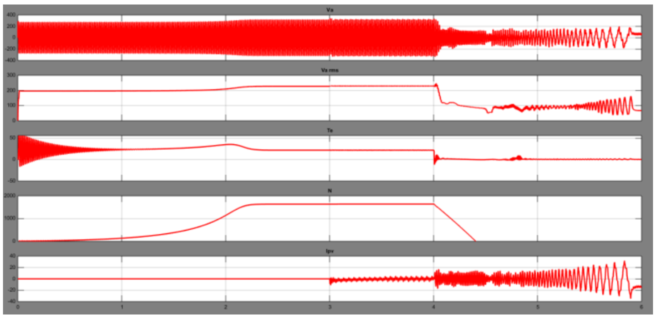

Fig 7.4 simulation results for stator voltage, rms voltage, torque, rotating speed, instantaneous current fom pv for increse in grid line leangth from 3Km to 30 Km

Above simulation results for the dynamic event to increase the grid line from 3 km to 30 km was triggered. The stator voltage of the induction machine decreases significantly as shown above simulation resut presents the dynamic response of the RMS value from 3.5s to 6s, which clearly shows the decline of the voltage magnitude. Due to the decrease of the stator voltage and system voltage magnitude, for the induction machine, its electromagnetic torque will decrease and its rotor speed will decrease as shown the first one shows the results for maximum startor voltage change the second one shows the results for rms startor voltage .the third one shows the result for electromagnetic torque of induction motor. fourth one shows the result for rotating speed of induction motor. fifth one shows the result for instantaneous current from PV

CONCLUSION

In this project, a dynamic phasor based dynamic model was derived for an unbalanced distribution system consisting of a single phase PV, a three phase induction machine and a three phase power factor correction capacitor. The model is capable of fast time domain simulation and small signal analysis. The model's accuracy in capturing time domain dynamics has been validated by Matlab/SimPowerSystems based simulation. The model's capability of small signal analysis was also demonstrated.

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