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A Method To Analyse Unbalanced Distribution System Using Dynamic Phasor Modeling

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Abstract: *Thispaperdevelopsananalyticalmodelofanunbal-ancedradialdistributionsystemconsistingofasingle-phasephoto-voltaic(PV),athree-phaseinductionmachineload,athree-phasepowerfactorcorrectioncapacitor(PFC),andaload.Theanalyt-icalmodelisbasedondynamicphasors(DP)forphases.Thesingle-phasePVmodelincludesinvertercurrentcontrol[propor-tionalresonance(PR)controller],anL,oranLCLfilter.Thein-ductionmachinemodelisbasedonpositive-,negative-,andzero-sequencecomponents'dynamicphasors.Thesequence-basedin-ductionmachinemodelwasconvertedtotheDP-referenceframeandinterconnectedwithothergridcomponents.Thede-velopedanalyticalmodeliscapableofsmall-signalanalysisandcanbeusedtoidentifyvarietyofstabilityand/orharmonicissuesindistributionnetworks,e.g.,instabilityduetoweakgrid.Im-pactofunbalanceonsystemdynamicperformancecanalsobein-vestigatedusingthismodel.Theanalyticalmodelisbenchmarkedwithahigh-fidelitymodelbuiltinMatlab/SimPowerSystemswherepowerelectronicswitchingdetailsareincluded.Thesmall-signalanalysisresultsarevalidatedviaMatlab/SimPowerSystemstime-domainsimulations.*

I. Introduction

The analysis of power distribution systems is an important area of research activities due to the vital role of distribution systems as the final link between the bulk power system and consumers. There are 3 type of power distribution namely loop, network and radial.distribution system is highly radial in nature. 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. Due to radial nature, there is consecutive increase in voltage drop from source bus to end buses.

In the last few years, generating electricity from clean and environment friendly resources is the world-wide trend to develop the future power grid. Photovoltaic (PV) power can be considered as a most promising and faster growing renewable source because of their low generation cost and minimum environmental impact. The PV system are planned and installed in distribution system to supply consumer directly. Therefore the distribution system is facing new challenge on its dynamic behavior with addition of PV. In addition induction machine based load are dominant in distribution system. The analytical model of such unbalanced distribution system provides the capacity to gain an accurate and deep understanding of the system. The objective of this dissertation is to model, analyze and simulate an unbalanced distribution system with both complex loads such as induction machine and also renewable such as inverter interfaced PVs. Proposed work improves the modeling strategy in two aspects and therefore tackle comprehensive dynamic phenomena of unbalanced distribution systems.

- A more comprehensive current control of PV inverter will be modeled. If current controls are ignored, interactions 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.
- Each source is modeled as a current source. The sources are then interfaced through network dynamics. Using this strategy, the network dynamics due to inductors and capacitors will not be omitted.

The dynamic performance of the unbalanced distribution system will be demonstrated with the three cases as follows:

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

To demonstrated the above cases the study system will be built in Matlab/SimPowerSystems based on physical circuit connection.

System under Study

shows the basic configuration of an LCL filter in a single-phase PV. It is composed of two inductances and one capacitor connected to the grid through a single-phase transformer.

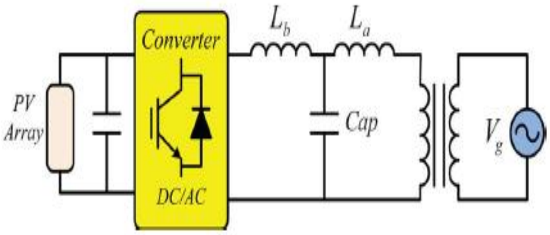

Fig : Basic configuration of PV system.

For unbalanced systems, frame-based dynamic models can be used for dynamic performanceexamination. Simulation packages such as PSCAD andMatlab/SimPowerSystems [are based on simulationmodels 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 [7]. Transforming

the models to a synchronous rotating reference frame is the most common technique utilized to overcome the above problem [7]. 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.

OBJECTIVES

DP-based modeling can take into consideration of unbalance. For example, in [9], 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.

The objective of this proposed system is to

1. model, analyze and simulate an unbalanced distribution system with both complex loads such as Induction Motor
2. model, analyze and simulate an unbalanced distribution system renewable such as inverter interfaced PVs.

DESCRIPTION OF THE PROPOSED WORK

Our proposed technique involves investigates comprehensive modeling of unbalanced distribution systems using dynamic phasors. The system consists of a three-phase induction machine load, threephase resistive loads, a PFC and a single-phase PV system. The three-phase induction machine, will be modeled based on dynamic phasors and then be converted to phasors. A single-phase PV system at phase will be modeled in phase phasors. The entire system model will be obtained through a current source-based integration technique. The major contributions of this paper include a comprehensive dynamic modeling approach for unbalanced radial distribution systems. Applications of the model will be demonstrated in small-signal analysis and fast and accurate simulation.

II. Methodologies

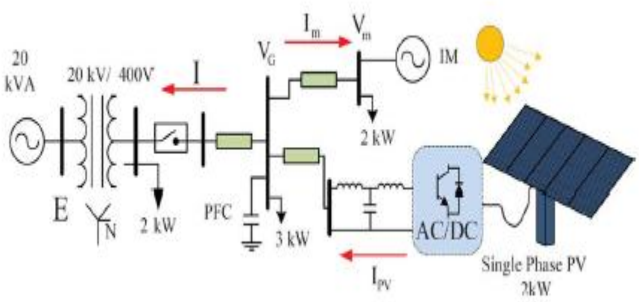

Fig: system fig.

The parameters presented are utilized for the proposed study system shown in Fig. The distributed system consists of a single-phase PV station installed in phase othe system, a 3-phase induction machine, a 3-phase PFC, and a 3-phase load. Traditionally, two-stage converters (a DC-AC converter after a DC-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 implemented in PV grid integration. The basic configuration of a single-phase PV is illustrated in Fig. The main elements of the single-stage PV are the proportional resonant (PR) current controller and the output filter.

. The analytical model for the entire distribution system has been derived in Section III. The model was been builtinMatlab/Simulink. The nonlinear analytical model can be linearized based on a certain operating point using Matlab function “linmod”. Small-signal analysis can then be carried out for the linearized model. The same study system was also built in Matlab/SimPower Systems based on the physical circuit connection. TheMatlab/SimPower Systems model captures power electronic switching details and therefore is considered high-fidelity simulation model.

Three case studies have been carried out.

• In the *first* case, the analytical model in Simulink is benchmarked with the high-fidelity model in Sim Power Systems Dynamic simulation results are compared for the same dynamic
event: a step change in load torque of the induction machine.

• In the *second* case, the effect of unbalance on the dynamic performance 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, the effect of the grid-line length on stability is investigated. Small-signal analysis and time-domain simulation are carried out.

Design Of PV Array

PV arrays are built up with combined series/parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model such as the one given in Fig. 1 and/or by an equation as in (1).

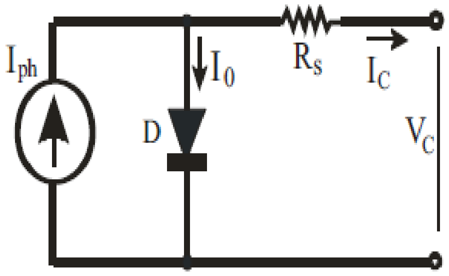

Fig. 1. Simplified-equivalent circuit of photovoltaic cell.

$$V_C = \frac{AkT_C}{e} \ln\left(\frac{I_{ph} + I_0 - I_C}{I_0}\right) - R_S I_C \qquad (1)$$

Where the symbols are defined as follows:
e: electron charge (1.602 × 10-19 C).
k: Boltzmann constant (1.38 × 10-23 J/oK).
Ic: cell output current, A.
Iph: photocurrent, function of irradiation level and junction temperature (5 A).
I0: reverse saturation current of diode (0.0002 A).
Rs: series resistance of cell (0.001 Ω).
Tc: reference cell operating temperature (20 °C).
Vc: cell output voltage,

Where, Bt = 0.004 and Yt = 0.06 for the cell used and Ta=20 oC is the ambient temperature during the cell testing. This is used to obtain the modified model of the cell for another ambient temperature Tx. Even if the ambient temperature does not change significantly during the daytime, the solar irradiation level changes depending on the amount of sunlight and clouds. A change in solar irradiation level causes a change in the cell photocurrent and operating temperature, which in turn affects the cell output voltage. If the solar irradiation level increases from Sx1 to Sx2, the cell operating temperature and the photocurrent will also increase from Tx1 to Tx2 and from Iphl to Iph2, respectively. Thus the change in the operating temperature and in the photocurrent due to variation in the solar irradiation level can be expressed via two constants, CSV and CSI, which are the correction factors for changes in cell output voltage VC and photocurrent Iph, respectively

$$C_{TV} = 1 + \beta_T (T_a - T_x) \qquad (2)$$

$$C_{TI} = 1 + \frac{\gamma_T}{S_C}(T_x - T_a) \qquad (3)$$

Both k and Tc should have the same temperature unit, either Kelvin or Celsius. The curve fitting factor A is used to adjust the I-V characteristics of the cell obtained from (1) to the actual characteristics obtained by testing. Eq. (1) gives the

voltage of a single solar cell which is then multiplied by thenumber of the cells connected in series to calculate the full array voltage. Since the array current is the sum of the currents flowing through the cells in parallel branches, the cell current IC is obtained by dividing the array current by the number of the cells connected in parallel before being used in (1), which is only valid for a certain cell operating temperature Tc with its corresponding solar irradiation level Sc. If the temperature and solar irradiation levels change, the voltage and current outputs of the PV array will follow this change. Hence, the effects of the changes in temperature and solar irradiation levels should also be included in the final PV array model. A method to include these effects in the PV array modeling is given by Buresch [1]. According to his method, for a known temperature and a known solar irradiation level, a model is obtained and then this model is modified to handle different cases of temperature and irradiation levels..

Let (1) be the benchmark model for the known operating temperature Tc and known solar irradiation level Sc as given in the specification. When the ambient temperature and irradiation levels change ,the cell operating temperature also changes, resulting in a new output voltage and a new photocurrent value. The solar cell operating temperature varies as a function of solar irradiationlevel and ambient temperature. The variable ambient temperature Ta affects the cell output voltage and cell photocurrent. These effects are represented in the model by the temperature coefficients CTV and CTI for cell output voltage and cell photocurrent, respectively, as:

$$C_{SV} = 1 + \beta_T \alpha_S \left(S_x - S_C \right) \quad (4)$$

$$C_{SI} = 1 + \frac{1}{S_C} \left(S_x - S_C \right) \quad (5)$$

where SC is the benchmark reference solar irradiation level during the cell testing to obtain the modified cell model. Sx is the new level of the solar irradiation. The temperature change, ΔTC, occurs due to the change in the solar irradiation level and is obtained using. Using correction factors CTV, CTI, CSV and CSI, the new values of the cell output voltage VCX and photocurrent Iphx are obtained for the new temperature Tx and solar irradiation Sx asfollows:

$$V_{CX} = C_{TV} C_{SV} V_C \quad (7)$$

$$I_{phx} = C_{TI} C_{SI} I_{ph} \quad (8)$$

VC and Iph are the benchmark reference cell output voltage and reference cell photocurrent, respectively. The resulting I-V and P V curves for various temperature and solar irradiation levels were discussed and shown in [6, 8, 9], therefore they are not going to be given here again

III. Conclusion

Dynamic phasor-based dynamic model would 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/SimPower Systems-based simulation. The model's capability of small-signal analysis was also demonstrated. The analysis results corroborate with time-domain simulation results in Matlab/SimPower Systems.

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