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Grid Integration of DG using Synchronous Reference Frame Theory

Ahmed Mohammed Mohsin Alzubaidi, P. V. Ramana Rao

Abstract*: *Emission of carbon and other flue gases into atmosphere is the main drawback of conventional power plants with fossil fuels as source. Renewable energy sources are trending in power generation sector due to global constraints. This paper presents the analysis of grid integration of renewable energy source. The power generated from renewable source is fed to grid. Square wave (conventional two-level) inverter acts as an interface between distributed generation (DG) (from renewable source) and grid. Power switches of square wave inverter are triggered by the pulses generated from synchronous reference theory. The system is validated with fixed current reference condition and variable current reference condition. Proposed system is developed and the result analysis is presented using MATLAB/SIMULINK software

Index Terms*: *Grid; integration; DG; square wave inverter; current reference

I. INTRODUCTION

Integration of renewable energy source in power system is becoming trendy as global countries are concerned much on global warming. Power generated from renewable sources at distribution level is called distributed generation (DG) [1-4]. Generally, these DG's are rated from 50MW to 100MW and are not centrally dispatched. Distributed generation facilitates their connection of small generation at any point in the distribution system. The units of distributed generation generate power on the customer side (close to the load) and can feed distribution system to meet load demands. Distributed generation evolution took place mainly due to recent innovations in technology and environment regulatory conditions. Limitations on erection of new transmission lines and increased load demand also contribute to the development of distributed generation [5-7].

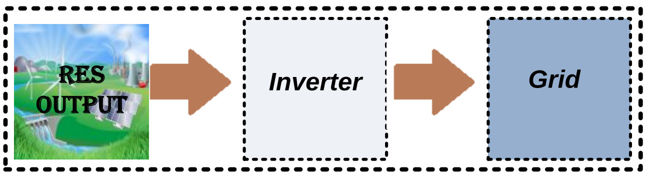

Figure 1: Block flow diagram of DG integration to grid

There is a tremendous growth in share of DG's having distributed generation, renewable generation, storage units and controllable loads these days because of reliable supply requirements and environmental issues. Profitable and beneficial integration of distributed generation to grid can throw up substantial confronts to the already existing methods in operation, planning and software tools. To successfully integrate DG to grid, planning and strategies of operation plays a vital role. Wide spectrum of operating policies is needed for the energy management of decentralized power and the analysis of active power system. Also, heavy penetration of distributed generation to power distribution system might eventually change the conventional structure of the system and this insists for new solutions due to all new economical and technical issues.The flow structure of grid integrated distributed generation is shown in figure 1. The power generated from DG is fed to inverter which converts DC power to AC type. The output from the inverter is fed to grid through interfacing filters. DG integration to grid [8-10] stabilizes the grid during peak load condition. Photo-voltaic (PV) systems, wind systems, fuel cell technology constitute to distributed generation. PV system and fuel cell technology produces low voltage DC power which insists for inverter to feed grid or loads. Distributed generation operates in two modes: grid connected mode and standalone mode. Grid connected mode of DG integrates power from DG to grid while in standalone mode, DG directly feeds the local loads.

This paper presents the analysis of grid integration of renewable energy source. Square wave (conventional two-level) inverter acts as an interface between distributed generation (DG) (from renewable source) and grid. Power switches of square wave inverter are triggered by the pulses generated from synchronous reference theory. The system is validated with fixed current reference condition and variable current reference condition.

II. GRID INTEGRATION OF DISTRIBUTED GENERATION

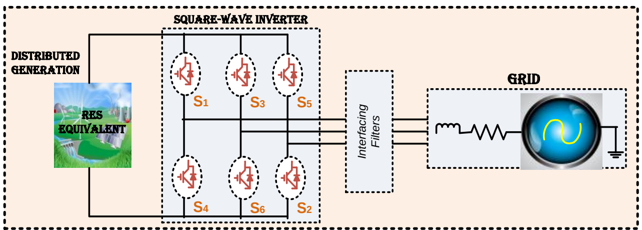

Figure 2: Grid interfacing scheme of DG

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* Correspondence Author
Ahmed Mohammed Mohsin Alzubaidi*, Research Scholar, EEE Department, Acharya Nagarjuna University, Guntur, India
Prof. P. V. Ramana Rao, Professor & Head of EEE, Acharya Nagarjuna University, Guntur, India

Distributed energy sources (power from renewable source) are sporadic and integrating scheme of Distributed generation to power grid is a tough task. Maintaining power quality (limiting harmonics and maintaining power factor) while integrating DG to grid is an exigent task for power engineers. Protection of DG from faults in power system is also challenging issue while integrating DG to grid. Placing of DG's while integrating DG to grid is vital. Rapid growth in power electronic technology has realized the integration of distributed generation to power grid and power electronic technology plays a key role in integration process. In the recent years, major development in power electronics led to development of power switches which can handle high frequency switching and high power.

Grid connected distributed generations is becoming familiar these days due to incentive schemes from government. Grid connected system permits customers to provide required energy for their own loads while the surplus power is fed to power grid with buy back scheme. These days grid interfacing scheme has been part of utility system. Figure 2 depicts grid interfacing scheme of distributed generation. The power generated from DG is fed to inverter which converts DC power to AC type. The output from the inverter is fed to grid through interfacing filters. The power grid accepts active power from DG.

Generally many kinds of renewable sources produce DC kind of power which insists to be converted to AC type to feed loads. However, the amount of power delivered from the distributed source dictates the quantity of active power to power grid. With this phenomenon, an inverter is demanded by the system of DG integration to power grid. The proposed system is developed in such a way that the DC kind of power generated from renewable source is directly fed to a (square-wave) inverter. The output of the inverter is connected to power grid where loads are connected to grid. Inverter is controlled by triggering oulses from control algorithm.

III. CONTROL OF PARALLEL DSTATCOM

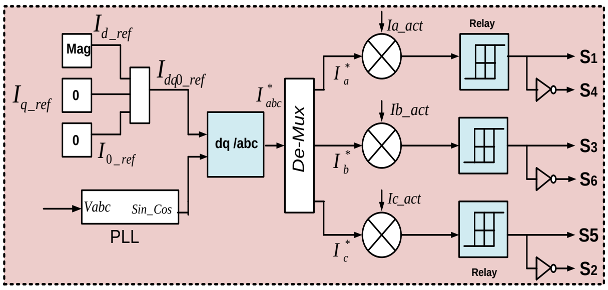

Figure 3: Control algorithm for inverter

Figure 3 illustrates the control algorithm to produce triggering gate pulses to power switches of square-wave inverter. This control algorithm takes voltage feedback from grid which is fed to phase locked-loop (PLL) to give out phase angle of grid. The control algorithm takes 'd'-component of current with some magnitude depending on power requirement. The 'q' component and zero-sequence current components are kept zero. Combining the'd' and 'q' components along with zero-sequence components yields reference 'dq' component of current. The reference 'dq' component of current along with phase angle obtained from PLL is fed to Clarke's inverse transformation to generate reference current signal in 'abc' co-ordinates as in equation (1).

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_0^* \\ i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} \quad (1)$$

The obtained reference current signals are compared to actual currents from grid and are processed to pulse generation block where controlled pulses to inverter switches are generated.

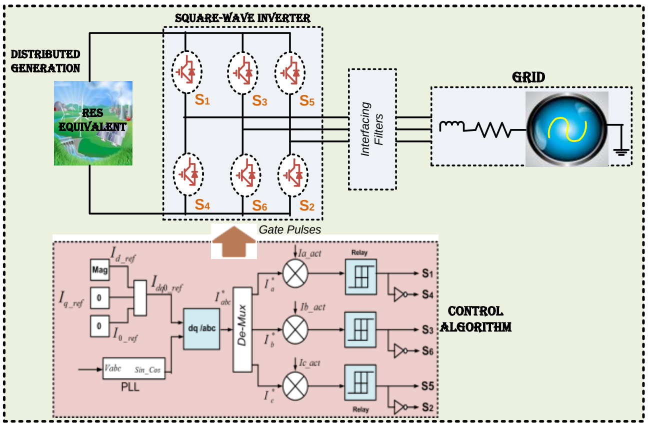

Figure 4: Grid integrated DG with control algorithm

In the event that the real current surpasses the HB, the upper gadget of the half-connect is killed and the lower gadget is turned on. As the current rots and crosses the lower band, the lower gadget is killed and the upper gadget is turned on. In the event that the HB is diminished, the consonant nature of the wave will improve, however the exchanging recurrence will build, which will thusly cause higher exchanging misfortunes. Figure 4 shows complete schematic of Grid integrated DG with control algorithm. Table I depicts the system parameters used to develop MATLAB/SIMULINK models and for simulation analysis.

Table I: System Parameters

Parameter	Value
DG Output	800 V
Inverter filter	7.5 mH
Grid Ph-Ph RMS Voltage	440 V, 50 Hz

IV. SIMULATION ANALYSIS

A. Simulation analysis with fixed current reference signal

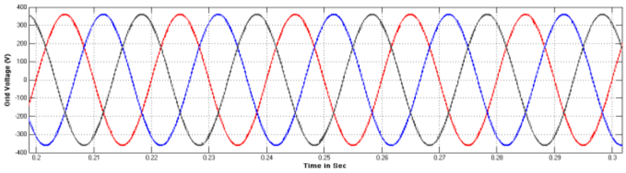

Figure 5: Three-phase grid voltage

Three-phase voltages fed to grid from DG are shown in figure 5. Grid voltages (induced from DG) are with constant magnitude and sinusoidal in shape.

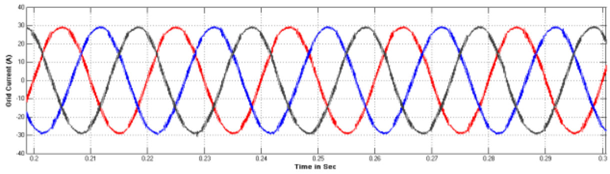

Figure 6: Three-phase grid currents

Three-phase currents fed to grid from DG are shown in figure 6. Grid currents are with constant 30A magnitude and sinusoidal in shape

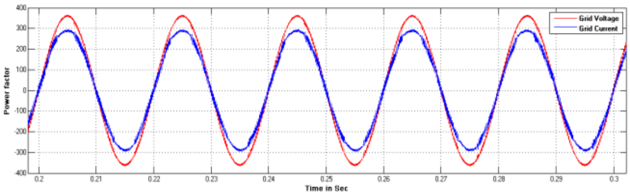

Figure 7: Power factor in grid

Power factor in grid is shown in figure 7. There is minute angle difference between induced voltage to grid and current waves tending to make power factor (cosine of angle between voltage and current) to be nearer unity. Current waveform is added with gain for better appearance.

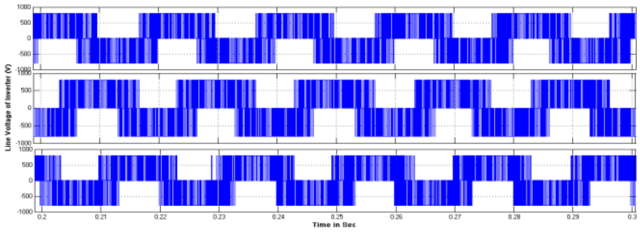

Figure 8: Line voltage of inverter

Figure 8 shows the line voltage output of inverter. DG power is fed to inverter and line voltage is 2-level (square-wave) output in shape.

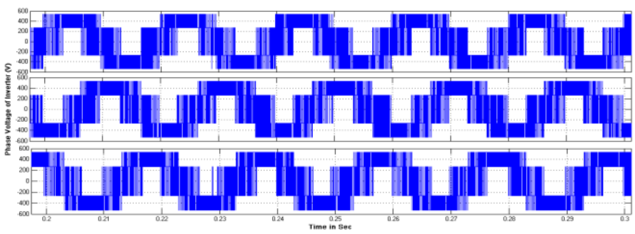

Figure 9: Phase voltage of inverter

Figure 9 shows the phase voltage output of inverter. DG power is fed to inverter and phase voltage output shape is shown in figure 9.

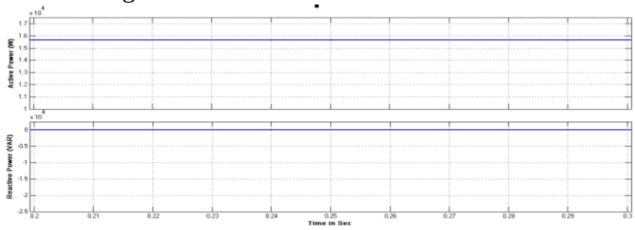

Figure 10: Active and reactive powers of grid

Figure 10 illustrates the active power and the reactive power fed to grid. 15.6KW of active power is fed to grid from DG, while there is no reactive power exchange in the process of grid integration and hence reactive power is zero.

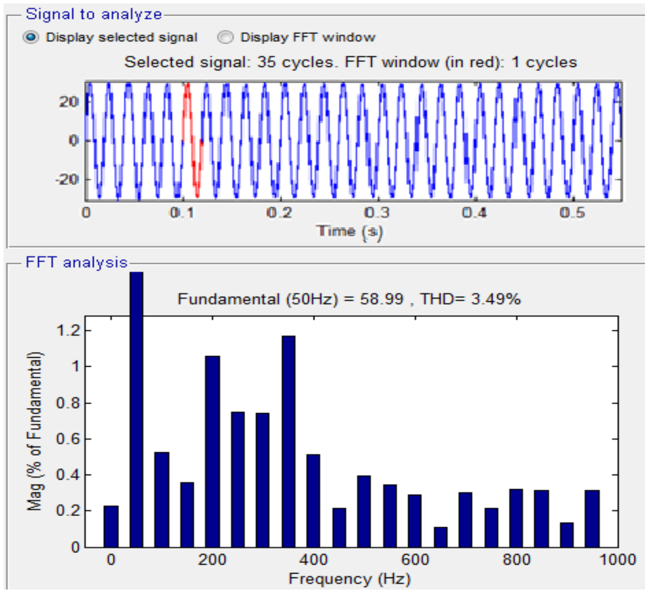

Figure 11: THD of grid current

Figure 11 shows the FFT window of harmonic analysis in grid currents. Grid currents induced from DG through inverter are distorted by 3.49% and is well below nominal limit. Less the distortion, closer the current wave to be in sinusoidal shape.

B. Simulation analysis with variable current reference signal

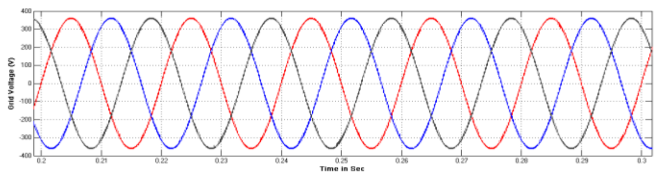

Figure 12: Three-phase grid voltage

Three-phase voltages fed to grid from DG are shown in figure 12 with variable current reference signal condition of the system. Grid voltages (induced from DG) are with constant magnitude and sinusoidal in shape.

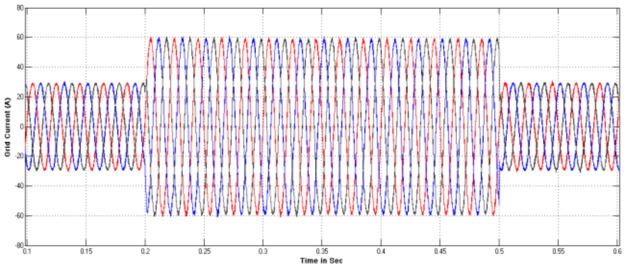

Figure 13: Three-phase grid currents

Three-phase currents fed to grid from DG are shown in figure 13. Current reference signal is varied from 0.2 sec to 0.5 sec. Grid currents are with constant 30A magnitude until the current reference is varied. After current reference variation, grid currents are increased to 60A magnitude till 0.5 sec and restored to normal 30A magnitude after variation duration. Grid currents are sinusoidal in shape.

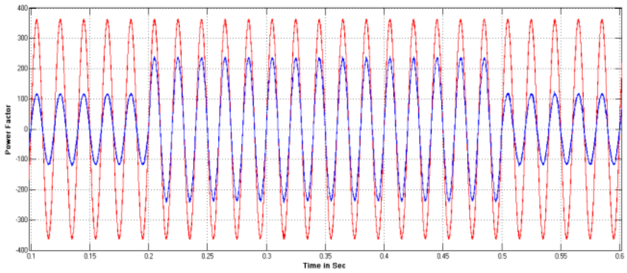

Figure 14: Power factor in grid

Power factor in grid is shown in figure 14. There is minute angle difference between induced voltage to grid and current waves tending to make power factor (cosine of angle between voltage and current) to be nearer unity with variable current reference. Current waveform is added with gain for better appearance.

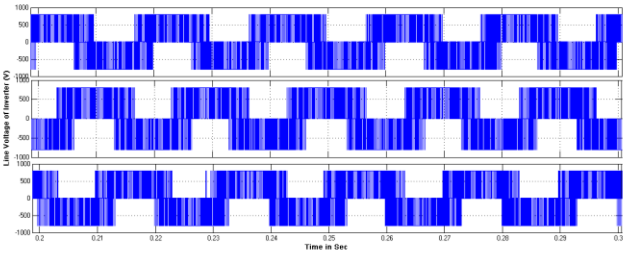

Figure 15: Line voltage of inverter

Figure 15 shows the line voltage output of inverter. DG power is fed to inverter and line voltage is 2-level (square-wave) output in shape with variable current reference.

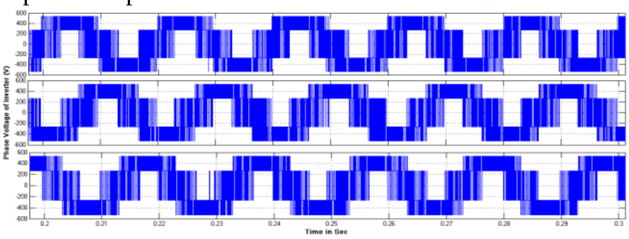

Figure 16: Phase voltage of inverter

Figure 16 shows the phase voltage output of inverter. DG power is fed to inverter and phase voltage output shape is shown in figure 16 with variable current reference.

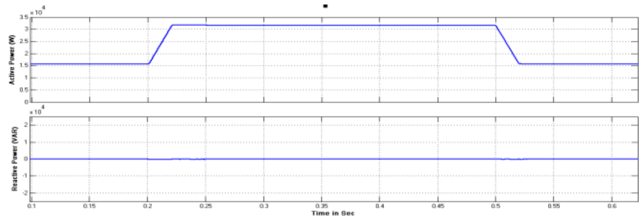

Figure 17: Active and reactive powers of grid

Figure 17 illustrates the active power and the reactive power fed to grid. 15.6KW of active power is fed to grid from DG initially, while there is no reactive power exchange in the process of grid integration and hence reactive power is zero. At 0.2 sec when reference current is varied, the active power increases to 3.2KW and drops back to original after restoring the current reference signal.

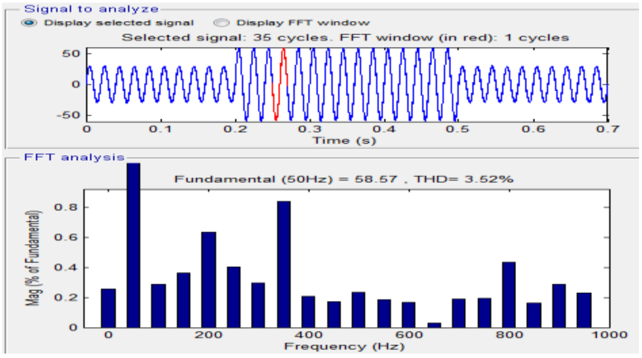

Figure 18: THD of grid current

Figure 18 sows the FFT window of harmonic analysis in grid currents. Grid currents induced from DG through inverter are distorted by 3.52% and is well below nominal limit. Less the distortion, closer the current wave to be in sinusoidal shape. Table II illustrates the harmonic distortion analysis with fixed and variable reference current signal conditions.

Table II: Harmonic distortion analysis

THD	Grid Current
Fixed Iref	3.49%
Variable Iref	3.52%

Harmonic distortion analysis in table II illustrates the effectiveness of control strategy to deliver qualified power to grid in different working conditions in power system.

V. CONCLUSION

The paper presents scheme of integrating DG to grid. The power generated from DG is fed to grid to feed loads which are connected to grid. An inverter (square-wave inverter) is employed as an interface of DG and grid inverting the DC supply from DG to AC type required for the grid conditions. The system is validated with fixed reference current signal condition and variable reference current signal condition and the active power fed to grid in both the conditions along with voltage, current and power factor are illustrated in result analysis. Harmonic distortion in grid current is well within nominal limits as tabulated. This provides a platform to integrate DG to grid to feed grid to meet load demands in mere future with less pollution

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