

Design of Inverter Voltage Mode Controller by Backstepping Technique for Nonlinear Power System Model

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Abstract

Modelling systems are a new sort of electrical network that can be easily adapted. Dispersed generators are linked to a microgrid using voltage source inverters. Nonlinear modelling systems are used in this study to create an inverter voltage mode controller for power systems to control power supply volatility. Controller for a nonlinear inverter that operates in voltage control mode is proposed. The primary goal is to ensure that the output voltage of the system matches a predetermined standard. Once the system model is completed, the controller is constructed using the backstepping method. After the control law is developed, several simulations are run to test the proposed controller's performance. According to simulation findings and formal analysis, the output voltage matches the reference voltage with global asymptotic stability. The accomplishment of this work is that the controller built, works in both grid-connected and inverter voltage modes of microgrid operation.

Keywords: Power system, nonlinear modeling, inverter voltage controller, micro grid, PI controller

1. Introduction

Distribution Generation (DG) has seen a dramatic rise in the recent two decades. A DG unit is a power production facility that can generate energy close to its use. Photovoltaic systems, wind turbines, microturbines, fuel cells etc., may all be found in DG. At its most basic, an island-style microgrid may be operated in two ways, either connected with the primary utility grid or completely independent of it. In a grid failure, the microgrid may run independently disconnecting from the significant grid and serve its local loads by opening the isolation mechanism. A microgrid's most significant considerations are voltage and frequency

regulation, the use of several DG units in islanded mode, power quality difficulties, implementation, and protection, as covered in many research publications. One existing option for supplying energy at distant places is stand-alone microgrid systems, also known as Hybrid Renewable-Based Systems (HRBS) [1]. The stand-alone microgrids aim to give people in remote locations, energy based on green technology, thus improving their productivity and quality of life [2, 3]. Because of advancements in renewable energy technology, it is now feasible to establish electricity-producing facilities at distant places, to benefit and cover areas that are not networked [4-7].

The majority of the world's electricity is still generated and delivered through centralized generation. Nuclear, hydroelectric, and thermoelectric power plants and other large-scale sources are linked by a system of high-voltage transmission lines, which distribute electricity in a single direction to far-flung consumers in heavily populated regions. However, rural and inaccessible areas cannot benefit from this service due to the high expense of transportation [8-12].

Power electronics converters are responsible for controlling the power flow among the sources, storage systems, and loads, and they link each component of the system to the DC grid. These linkages may be made with the use of power electronics converters. There are three main goals for power flow regulation in hybrid systems: maximizing renewable energy extraction and optimally using storage systems [13].

2. Organization of the Research

The remaining portions of the research are grouped as follows: Section 3 discusses related efforts on the design of voltage-mode controllers for hybrid power systems. Section 4 discusses the recommended voltage mode controller design parameters. Section 5 explains the collected findings and how they are used. Section 6 concludes the investigation.

3. Preliminaries

Design and cost model analysis of a stand-alone solar PV system utilizing intuitive and numerical approaches were suggested by Okoye et al. and examined at three important cities in Nigeria: Onitsha, Kano, and Lagos [14].

An off-grid PV system design solution given by Akinyele and Rayudu was modelled and analysed using HOMER software, to study and evaluate the PV system and its cost. As a

case study, the energy use of two families in Gwagwalada, Abuja, with modest loads, were analysed. MATLAB and HOMER tools were used to generate daily load profiles for the two houses based on the home appliances' average loads and operating hours [15].

For the remote northern regions of Nigeria, the feasibility analysis of an integrated PV solar-diesel power system was provided by Adaramola and colleagues. Jos and its surrounding area in Plateau State were used as a case study for this research. Rural regions with a population of 1,500 were given a daily peak load of 236kW and average daily energy consumption was one kilowatt-hour (kWh) as the basis, thus assumed that each family used 1 kWh of electricity per day [16].

Jank and colleagues (2017) investigated a single-phase half-bridge Pulse-Width Modulation (PWM) inverter with changing switching frequencies and inductor current ripples applied to the PID controllers. When designing a controller, switching frequency and inductor current ripple are critical factors [17]. Additionally, Chen et al. (2020) devised a repeated control for a dual-buck full-bridge single-phase inverter to assure steady-state performance and adaptive PI control to speed up the system's dynamic reaction process [18].

Using a PID-based repeating control method, Chen et al. (2020) demonstrated following a predetermined periodic reference signal. It is a technique that is utilized to reduce the current harmonic components induced by non-ideal circumstances. Permanent Magnet Synchronous Linear Motors (PMSLM) current harmonics were concentrated using a novel PID controller called R-2DOF PID controller in the PMSLM control system in a small microsecond laser cutting system [19].

3.1 Research Gap

Estimated energy requirements for hybrid/PV systems have been calculated by calculating the power needs of each household appliance and determining the approximate number of hours each instrument needs electricity each day. In this situation, the assessment of total harmonic distortion has been presented. However, when designing a PV system, this technique doesn't take into account the position and size of electrical appliances, building materials, orientation and dimensions of a home, as well as the heat loss via walls, windows, doors, and roofs for any nonlinear approach.

4. Methodologies

4.1 Proposed Backstepping nonlinear control

DC energy storage, PWM inverter, filter, and the series voltage injection transformer are the key components of the dynamic voltage restorer depicted in Fig.1. Detecting voltage sag/swell in the power line and injecting the needed balancing voltage from nonlinear voltage controller is the major function of the proposed system. Here, active and reactive power may be absorbed or injected to accomplish.

4.2 Multilevel inverter

The voltage source inverter which is based on an H-bridge multilevel inverter with space vector modulation is used primarily to mitigate voltage sag. This device injects a voltage with the correct phase and amplitude into the load when a failure occurs. When voltage saturation occurs, the compensator modifies the voltage equal to load current, which angularly displaces the voltage from its current equivalent. The limiter is activated during the operation in order to shut off the current or frequency at a certain level.

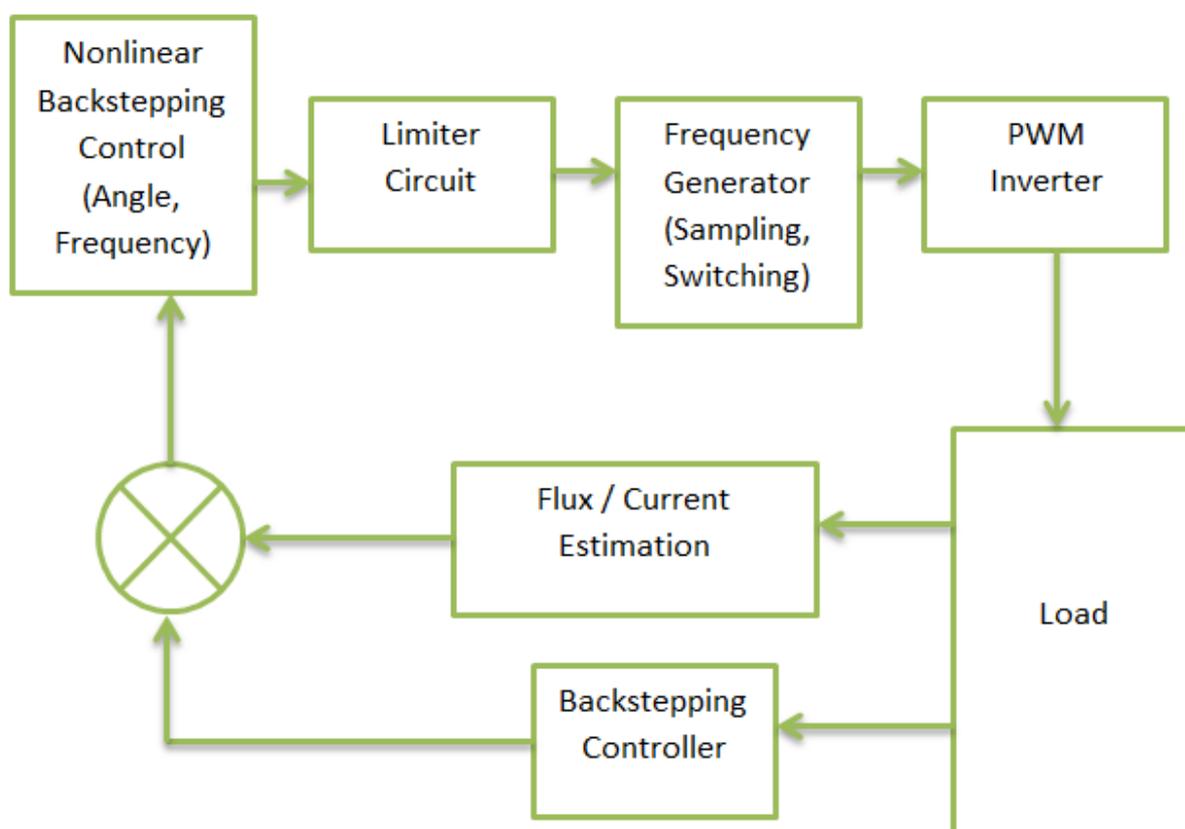


Figure 1. Block diagram of proposed backstepping for nonlinear control

The voltage source inverter must inject both active and reactive power to restore the magnitude and phase of the load voltage to the pre-fault circumstances [20-25]. Therefore, the System Static Synchronous (SSC) dynamic and reactive fuel injection during voltage drop mitigation is comparable if the load voltage and current in pre-fault cases are equal to unit defined as,

$$P_{Modify} = 1 - \left\{ \frac{V_{Saturate}(\cos(\theta + const))}{V_t(\cos\theta)} \right\} P_{output}$$

$$Q_{modify} = 1 - \left\{ \frac{V_{Saturate}(\sin(\theta + const))}{V_t(\sin\theta)} \right\} Q_{output}$$

A recursive design style, the backstepping approach takes a step backward. It requires the methodical design of both feedback control rules and related Lyapunov functions. At no point in the design process does the controller reach a level above the system order. Compensatory voltage must be enforced in order to keep up with a predetermined voltage differential. Direct output voltage control isn't possible because of the power converter's lack of minimum phase [26-29]. A more indirect method is used to deal with the issue of management. It is the goal of the control system to make the compensatory voltage range larger. It is necessary to design a controller in two steps by employing the backstepping technique, since a second-order control system is used.

Step 1

The output error should be minimized by differential function as shown in the below equation.

Output = input – control feedback output

$$\frac{dy_1}{dt} = \frac{dx_1}{dt} - \frac{du}{dt}$$

Step 2

The investigation of the error for next output, for example y_2 ,

$$\frac{dy_2}{dt} = \frac{1}{LC} x_1 + \frac{1}{LC} v_i - bias\ value$$

Step 3

$$\text{Bias value} = \beta_1^2 y_1 - \beta_1 y_2 + \frac{1}{C} i_N + \frac{d^2 u}{dt^2}$$

Finally, the controlled law is framed as follows,

$$v_{\text{instantaneous}} = \text{input}_1 + LC(\beta_2^2 - 1)\text{ouptut}_1 - LC(\beta_1 + \beta_2)y_2 + Li_N + LC \frac{d^2 u}{dt^2}$$

The instantaneous voltage is adopted for inverter voltage function with modulation index for the output controller.

5. Results and Discussion

In this section, the suggested backstepping approach is based on the nonlinear controller, and three levels of voltage source inverter are simulated using MATLAB/Simulink. Figure 2 shows some spectrum of harmonic distortion at various sampling frequency.

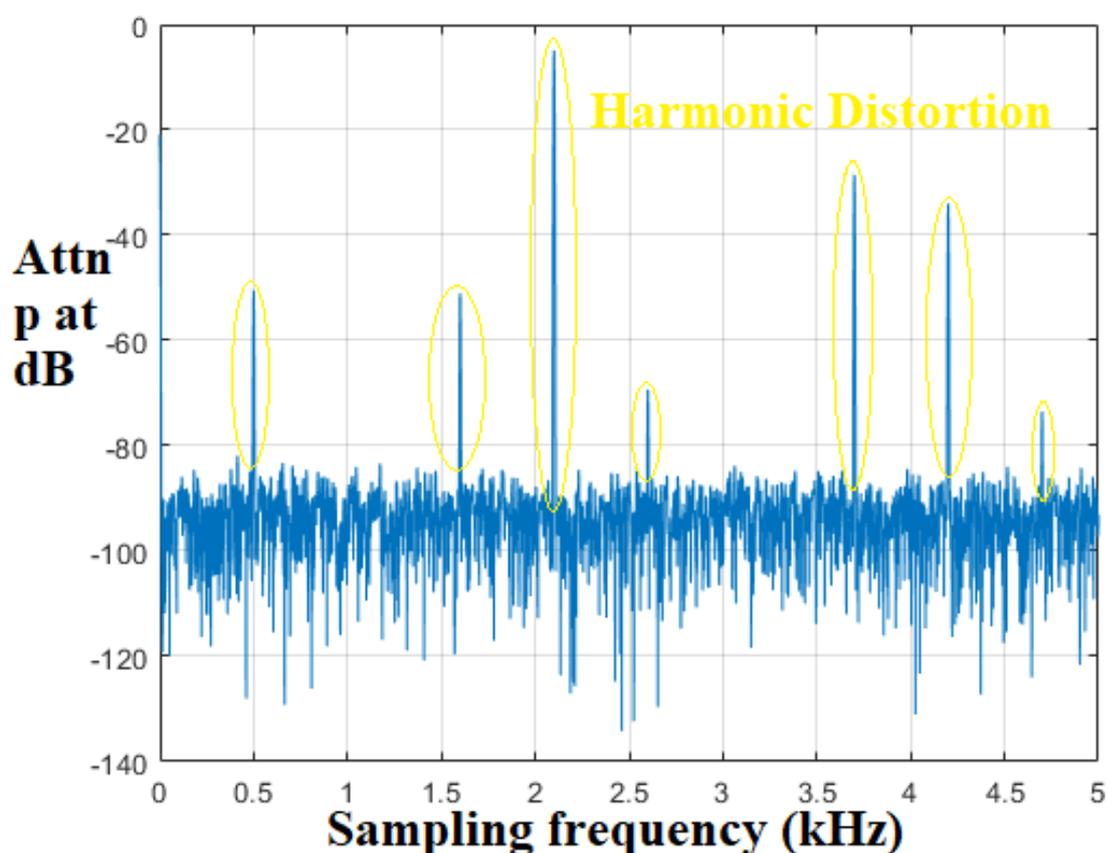


Figure 2. Harmonic distortion at various sampling frequency

One phase of the voltage sag is maintained at a minimum while the other two phases drop to 80 percentages in this scenario. This hang down lasts around 100 msec. On the inverter with three stages of switching, at 5 Hz the load voltage is adjusted. The waveforms generated via simulation using the complete proposed model, including the PWM process, reveals good performance with a balanced and nominal amplitude sinusoidal waveform [30, 31]. The figure 2 depicts the inaccuracy in the corrected load voltage for various sampling frequency.

Table 1. System parameter for the proposed design

S.No	Parameter	Value	Unit
1	Grid voltage	450	Voltage
2	Grid current	19	Ampere
3	Grid frequency	50	Hertz
4	Filter Resistance	1	Ohm
5	Filter Inductance	2.7	milliHenry
6	Filter Capacitance	55	Micro Farad
7	Sampling time	4	milliSeconds
8	Frequency	4.5 (Variable)	kiloHertz

The designed parameters are tabulated in a spreadsheet for grid and filter system design as shown in Table 1. The Total Harmonic Distortion (THD) analysis for various switching frequencies and levels are given in table 2.

Table 2. Harmonic distortion analysis at various level

S.No	Total Harmonic Distortion level	THD at Switching Frequency (kHz)			
		2	5	8	10
1	1 st level	40dB	31dB	25dB	22dB
2	3 rd level	10dB	15dB	20dB	23dB
3	5 th level	12dB	10dB	9dB	8dB
4	7 th level	8dB	7dB	6.9dB	6.8dB

This THD is a minimum value at a higher level (7th level) than the other preliminary levels, making it a more significant minimum value. The graph of THD is likewise presented in figure 3.

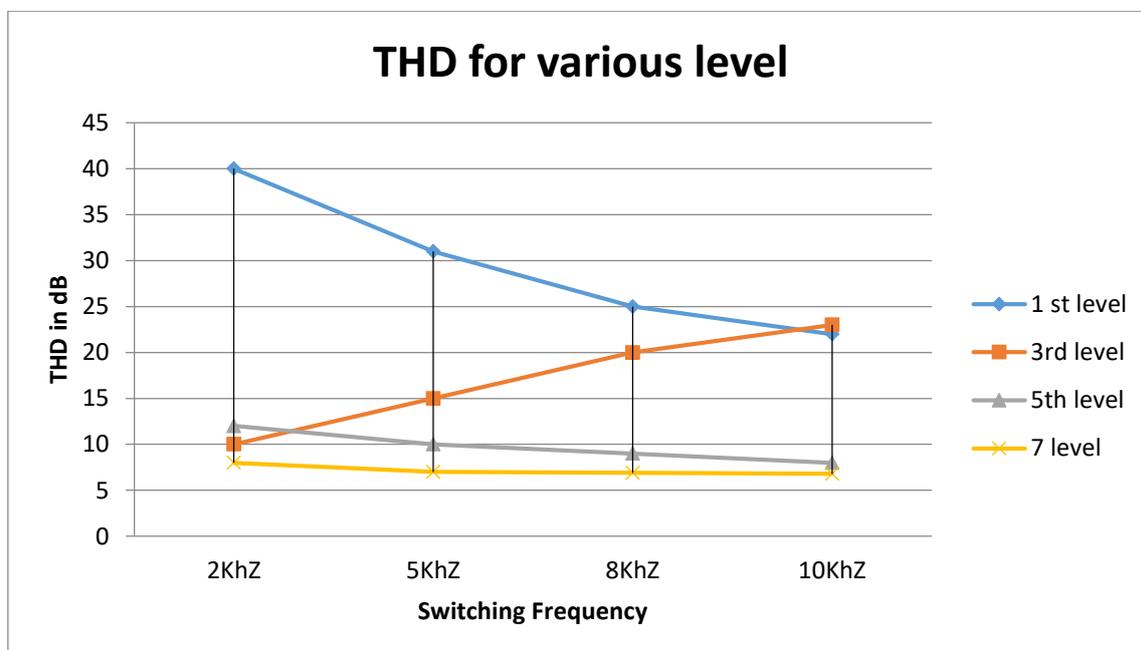


Figure 3. Performance graph for the obtained THD parameters

The three-phase voltage represents the adjusted load voltage for an induction motor driving load. The oscillograms generated by the simulation shows that the system behaved well under motor loads. Using induction motor drive load switching frequencies between 1 and 10 kHz, the error amplitude is calculated for two, three, five, and seven-level converters.

6. Conclusion

As a result, the harmonic distortion in the tabular data is tested using this backstepping approach to operate the systematic nonlinear controller. The suggested design guarantees that the load voltage of the device is within the projected standard specification. Therefore, the developed controller is extensively accepted by backstepping method, resulting in excellent reaction time for the user. Following the system design development, the controller design's performance is assessed and tested using harmonic distortion to determine the asymptotic stability results. As a result of this investigation, the following suggestions for the future have been made: Direct power control of DC-AC converters in constant power load applications has to be developed; Robust controllers for weak three-phase distribution networks with

unbalanced and nonlinear loads must be developed; The advantages of passivity-based control designs may be combined with virtual inertia emulators; To increase the dynamic performance of the suggested PI-PBC approach in applications with considerable fluctuations in the load terminals, sophisticated methods for effective adjustment of PI control gains employing active and passive strategies should be used.

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