A New Smart Controller Model Using Feedback and Feedforward for Three Phase Inverter

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Abstract. This paper aims to discussing three-phase inverter design and Control using feedback and feedforward controllers. These inverters convert direct current to sinusoidal voltages and currents in three phases. The behavior of feedback, feedforward controller, is addressed in the presence of DC source input disturbances. These disturbances cause by the direct current source (PV, batteries, etc.). After conducting the study and simulation, it establishes that the feedback controller is ineffective at stabilizing the system when the input disturbances happen; hence, the feedforward controller is used to achieve this objective. This review aims to establish a stable and controllable approach for a three-phase voltage source inverter that supplies the most frequently used applications (RL load) and investigates the behavior of feedback and feedforward controllers. Finally, the paper developed an optimization method for improving the performance of a realistic inverter under any load condition.

Keywords: Three phase inverter · Feedback controller · Feedforward controller · Smart controller

1 Introduction

Power converters use to convert alternating current (AC) to direct current. David Prince wrote an article entitled "The Inverter" It was supposed to be equipment that acts as a rectifier but in a reversed method, hence an inverter. Only after the invention of the thyristors in 1950 that the inverter and rectifier started to achieve their highest possible level of productivity [1].

The development of pulse width modulated (PWM) converters has helped promote small-scale DC power sources that provide power in direct current. However, to supplement the traditional grid, the DC/AC power converters must transfer the delivered power from these DC sources to AC sources [2]. The study of power electronics entails examining electronic circuits designed to regulate the flow of electrical energy. These circuits can withstand even more power than the individual devices are rate to [3].

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The voltage-source inverter drive technology use in many diverse applications such as UPS (Uninterrupted Power Supply), AC machines, and AC battery-powered devices.in standard Outputs according to the switching modes, we have square wave used in some low-performance systems; also, we can use PWM or a Sinusoidal signal for AC or DC drives [4].

Also, the voltage source inverter has uses in renewable energy; the real worry about higher energy costs, the exhaustion of conventional fuels, and the recent adoption of clean energy sources for generating electricity have encouraged the industry to produce more renewable electricity.

Additionally, the cost of PV cells became feasible where the wind turbines became sophisticated; unlike typical sinusoidal electricity, renewable sources do not generate conventional sinusoidal voltage, and the current cannot be stored, therefore inverter used in these systems to convert the output into AC waveform to connect them to a grid or to keep current in DC batteries.

Based on the definition of the linear system, we can automatically define the nonlinear system as the system which breaks the principle of superposition. The system, which has parameters changing with time, belongs to the time-varying system; otherwise, the system will be a time-invariant system.

Control can be found in many applications in our life such as an automobile with the position of the paddle as input and the speed as output, a traffic light whose input is the color of the light and production is the traffic flow, and the bank accounts with fund deposited as input and the interest generated as the output [5–7].

Two main types of control systems are considering in applying controllers to the systems [8, 9]. An open-loop system controls its outputs without needing a feedback loop. This method does not allow a comparison between the input and the output; therefore, this system is also known as Non-Feedback System.

The output should be driven ideally by the reference signal, and that could be possible only if the controller has been designed based on the complete knowledge of the plant. However, if any change in the plant happened, caused by a disturbance occurrence, the controller in the open-loop will not be effective anymore, and errors will emerge.

The closed-loop control system uses feedback to adjust the system's output. Since the output and input have been comparing, we have a system that may make errors known as an error signal. In such system, there is a connection between the output and the controller. Any disturbance that causes the plant to change would result in a rise in the error value on the controller side. Thus, the controller can take action to compensate for the disturbance. The problem that has been demonstrating in the open-lope scheme will be solved using the closed-loop structure.

This control system expects it to have an optimum output that serves the system's primary function for any scenario. If we conclude that dynamic performance behavior is critical, finding it must be a significant part of any scheme. The placement of the controller, which needs in any device, depends on the user's commands. We need to define the relationship between the plant and the controller in any controlled system, using an open-loop control system or a closed-loop control system [5–7].

A proportional-integral-derivative controller (PID controller) is commonly using as a feedback mechanism in industrial control systems. It utilizes a PID controller to identify a mismatch between a measured value and a target value calculated by a set point. It tries to correct the error by using a controllable variable.

PID controller consists of three terms; proportional to the current value of the error (P), the term which reflects the past value of the error using the integrator (I), and the estimator term of the future value of the error using the deviation (D). All PID controller terms can tune by using the changeable gain (K) [8, 9].

They presented a multi-path feedforward controller designed in the discrete-time domain for a three-phase inverter with a step-up transformer. They tested their model under resistive inductive and nonlinear loads. The findings indicate that the proposed model enhances the steady-state and dynamic behavior of the system. The technique suggested based on the assumption that it would reduce system impedance to avoid voltage drop [10].

Introduced a detailed description of a simple feedforward approach to stabilize the three-phase voltage source inverter system, which fed squirrel cage induction motor with LC filter by subtracting the feedforward term from d-q current component overcome the resonant that produce between the LC filter and rotor–flux oriented Control. The result shows that the stability analysis of the drive with Feedforward validates at different set points, and the overall system became more efficient [11].

The effectiveness of the implementation of voltage feedforward on-grid tide inverter has adversely affected the voltage feedforward in the weak grid. The author proposed proportional voltage feedforward to improve system stability and power quality also eliminate the harmonics in the grid by adding proportional coefficient 'k' in the feedforward path. The Theories and actual findings confirm the efficacy of the system.

It is common knowledge that specific switching devices operate between the source and load. The amount of switching devices is constrained by the complexity, though, so we can only choose the simplest. Also, the most complicated circuit has at least one switch as an input/output link. A converter has a certain amount of 'n' inputs and a certain amount of 'm' outputs, so the number of switching devices needed for electrical energy conversion is equal to 'm $\times$ n' [12].

Also, for example, to understand conversion from single-phase to DC, suppose we have three terminals on the single-phase side (input), and the DC has three terminals (output); thus, a total of '$3 \times 3 = 9$' switches are required.

2 The Developed Feedback and Feedforward Model

We have various controller structures and will implement the proportional-integral (PI) controller, which will be using in our design.

The following formula can use to formulate the PI controller:

$$PI(s) = K1 + \frac{K2}{S}$$

where:

K1: represents the proportional gain, K2: represents the integral gain.

The FB structure shows in Fig. 1 based on the structure, we must select the gains K1 and K2 to modify the system's dynamic response; in this case, we can use the PID tuning MATLAB software determine those gains. The configuration of the closed-loop control system would be as follows:

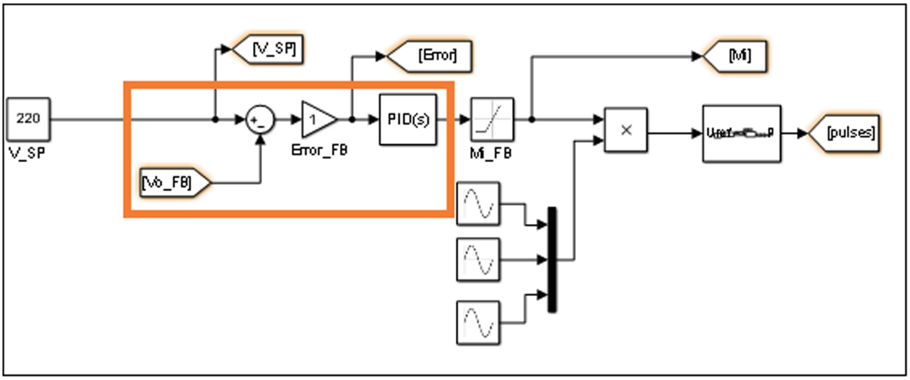

Fig. 1. The FB structure for voltage source inverter.

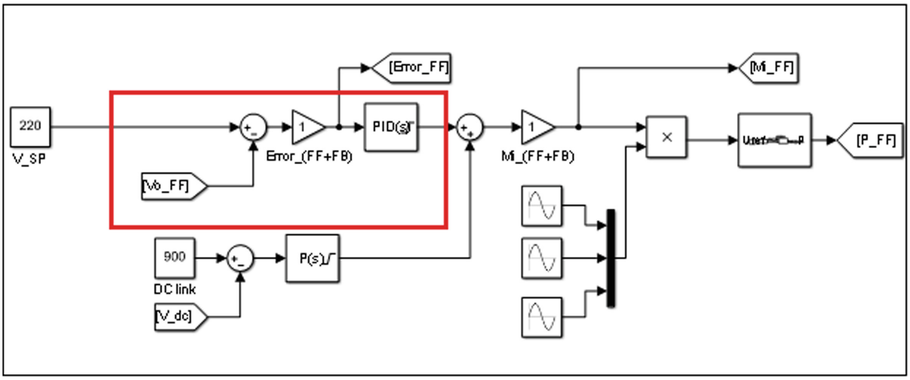

Fig. 2. The voltage source inverter FB and FF structures.

When we were using just the feedback controller, the input disturbances cannot be modified when the input contains abrupt jumps. Consequently, the input should be controllable to modify in response to the input's sudden jumps. This aim was meeting by the implementation of a feedforward controller into the system. Thus the system will continuously update the input variance and proactive in taking action before these variation signals appear on the output. As shown in Fig. 2, the structure that provides us with this method is called the feedforward (FF) structure.

To calculate the operation cost of different stations to feed all the loads with inverter, the system will then be ascending order the stations depending on the cost by using fuzzy logic control [13]. Then it chooses the station which have lower operating cost. After arranging the stations, the station will be automatically loaded and the system will sense if the load is greater than the capacity of the selected station or not, if yes load sharing will do to feed the reminder of load all this will be by using fuzzy logic control Fig. 3 shows chart flow for principle of work of the intelligent model.

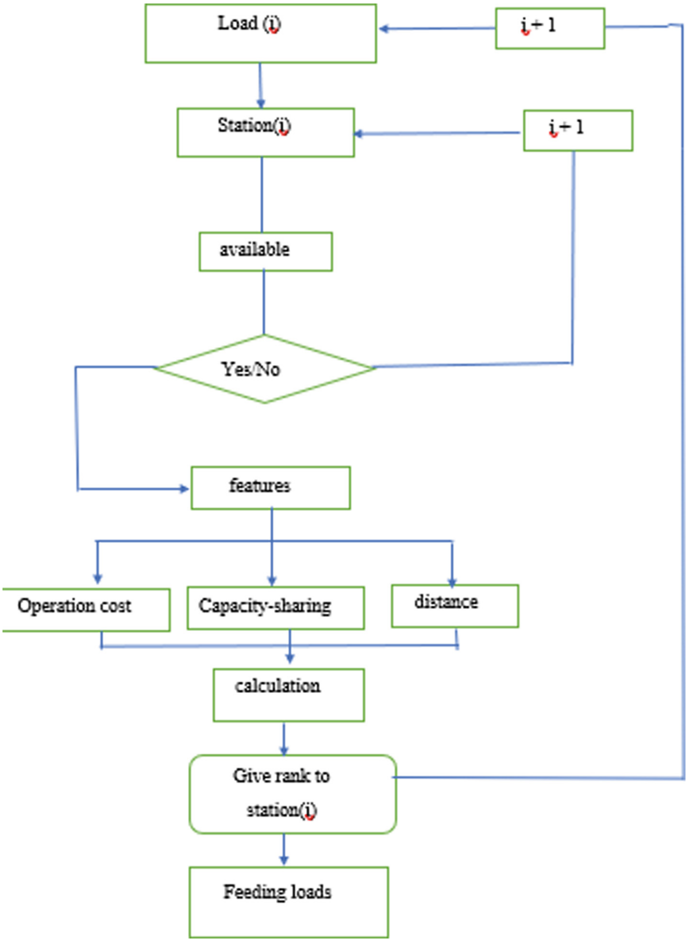

Fig. 3. Chart flow for intelligent model.

3 Results and Discussion

This chapter introduced and explained the achieved results of the feedback and feedforward/feedback controller's responses under various DC link voltage disturbances and load conditions. The disturbance signal was divided into three parts as shown below in Fig. 4 first positive edge, first negative edge, and second positive edge, where the response of the two controllers to be studied was recorded, and the readings were then analyzed accordingly.

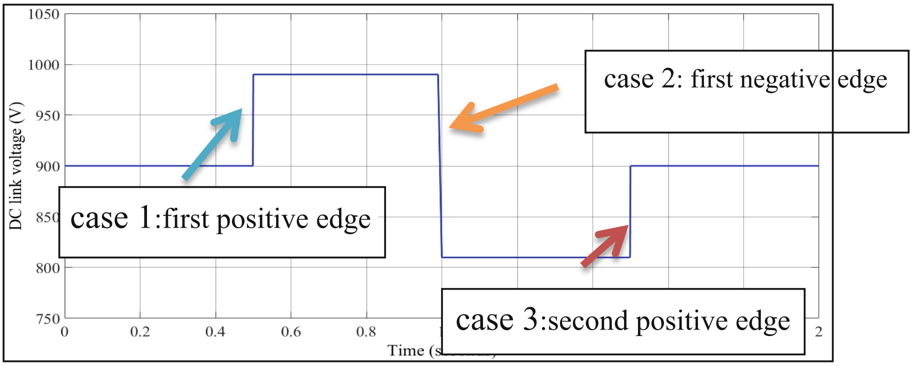

Fig. 4. DC link disturbance shows three disturbance cases.

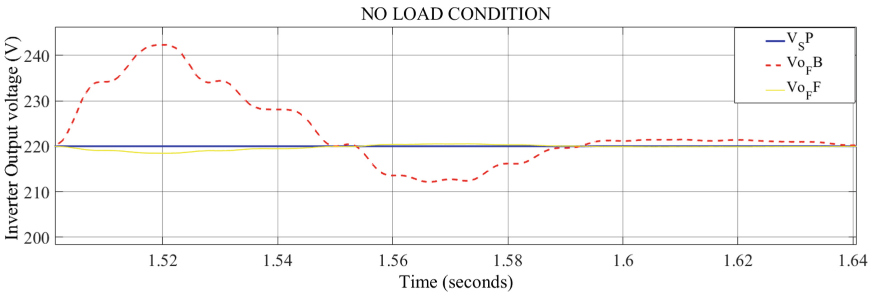

Fig. 5. Output voltage responses at 10% disturbance - No load condition.

In this case, the following parameters of VSI circuit shown in will be used, then the disturbance in DC link input by -10% around the set point will be applied. The second positive edge analysis from Figs. 5, 6, 7 and 8 and Table 1 showed that load increment has a positive effect on the rise time and the settling time, and at the same time it has a negative effect on the overshoot values. It is also noticeable that the proposed control system scored the minimum overshoot value, which means the generation of a fixed and stable voltage signal.

The developed system can be use in many applications such as electrical vehicles, vehicle to vehicle-to-vehicle communication systems, prediction systems, and energy management systems [14–17].

4 Conclusion

This paper proposes an optimal feedforward controller for compensating for the abrupt changes in the input voltage of a three-phase voltage source inverter. The results indicate that, due to the inherently unstable existence of DC sources such as a photovoltaic device or a battery, the feedback controller cannot tolerate input jumps. The monitoring and noise rejection shortcomings of the proposed system with the Feedback controller can be addressed only by adding Feedforward to the system. The feedforward scheme represents

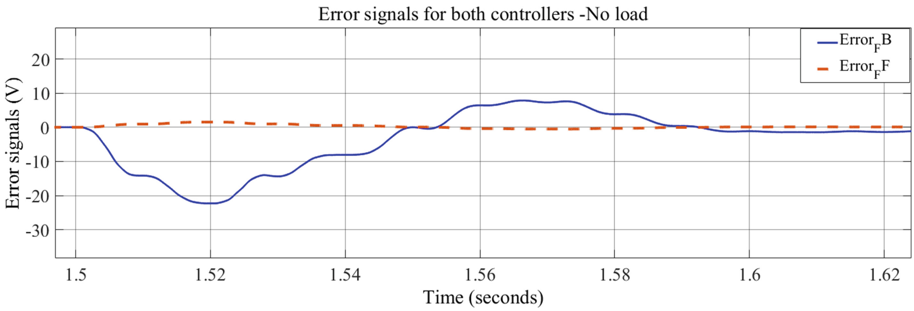

Fig. 6. Error signals of both controllers at 10% disturbance - No load condition.

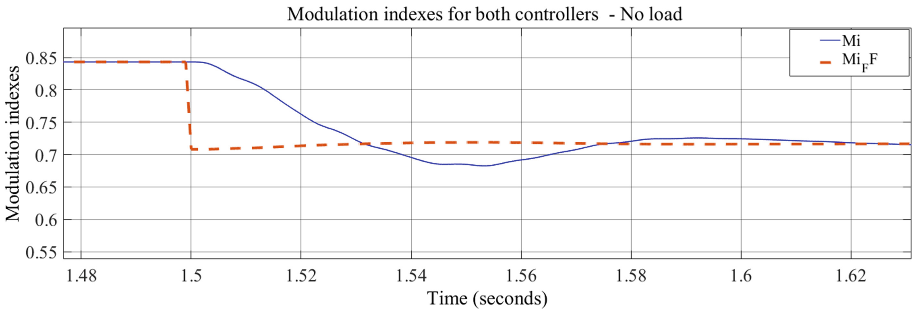

Fig. 7. Modulation indexes of both controllers at 10% disturbance - No load condition.

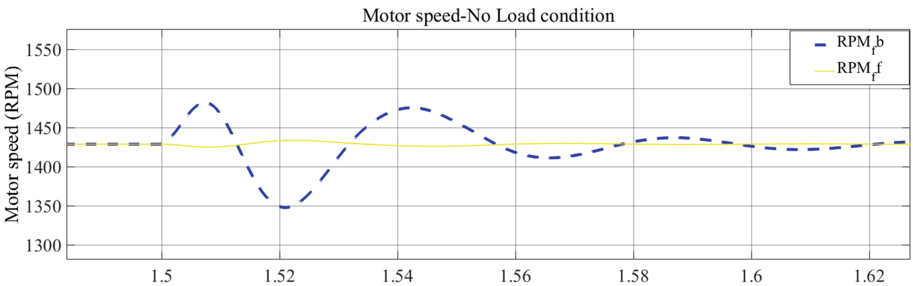

Fig. 8. Motor speed of both controllers at 10% disturbance - No load condition.

good performance and stabilizes the system, especially in the first negative edge; also, in the second positive edge. The overall system overshot and rise time becomes more amelioration with the feedforward controller; furthermore, significantly improves the accuracy of fundamental voltage and current components and the measurement efficiency of inverter simulations.

Table 1. Second positive edge analysis with 10% disturbance.

Comparison criterion	No load measurements		Full load measurements	
	FB	FF + FB	FB	FF + FB
Disturbance	**10%**		**10%**	
Rise time	2.69E-05	2.45E-05	2.64E-04	3.42E-04
Settling time	0.1928	0.1990	0.1789	0.1820
Settling Min	212.1462	218.4726	213.7508	218.7520
Settling Max	242.3014	220.5213	243.6854	220.3296
Over shoot	22.3014	0.5213	23.6854	0.3296
Under shoot	7.8538	1.5274	6.2492	1.2480
Peak	242.3014	220.5213	243.6854	220.3296
Peak time	0.0464	0.0990	0.0340	0.0865

References

1. Owen, E.L.: History [origin of the inverter]. IEEE Ind. Appl. Mag. **2**(1), 64–66 (1996). https://doi.org/10.1109/2943.476602
2. Prince, D.C.: "The Inverter," GE Review, vol. 28, no. 10, pp. 676–681 (1925). A Sarkar- 2015 -repository.asu.edu, Modeling and Control of a Three Phase Voltage Source Inverter with an LCL Filter
3. Llorente, R.M.: Practical control of electric machines. In: Advances in Industrial Control, Springer, Cham (2020). https://doi.org/10.1007/978-3-030-34758-1
4. Boeing, G.: Visual analysis of nonlinear dynamical systems: chaos, fractals, self-similarity and the limits of prediction. Systems **4**(4), 37 (2016). https://doi.org/10.3390/systems4040037
5. Ogata, K.: Discrete-Time Control Systems. Prentice-Hall, Upper Saddle River, NJ (1987)
6. Lin, F.: Robust Control Design. Wiley, Chichester (2007). Araki, M. "PID Control" (PDF)
7. https://www.motioncontroltips.com/faq-what-are-pid-gains-and-feed-forward-gains/
8. Bowei, L., Li, P., Ke, X.: A multi path feedforward control of load current for three-phase inverter with transformer. In: 2019 IEEE 28th International Symposium (2019)
9. Mishra, P., Maheshwari, R.: A simple feed-forward approach to stabilize VSI-fed induction motor with filter in RFOC. In: IEEE Transactions on Industrial Electronics (2019)
10. Wang, G., Du, X., Sun, P., Tai, H.-M., Ji, Y.: Analysis and design of voltage feedforward for stability and power quality of grid-tied inverter. In: IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society (2017)
11. Liu, T., Hao, X., Yang, X., Zhao, M., Xiong, L.S.: A novel grid voltage feedforward control strategy for grid-connected inverters in weak grid. In: IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society (2017). https://doi.org/10.1109/iecon.2017.8216109
12. Cho, H.Y., Santi, E.: Modeling and stability analysis in multi-converter systems including positive feedforward control. In: 2008 34th Annual Conference of IEEE Industrial Electronics (2008). https://doi.org/10.1109/iecon.2008.4758062
13. Obeidat, M.A., Qawaqneh, M., Mansour, A.M., Abdallah, J.: Smart distribution system using fuzzy logic control. In: 2021 12th International Renewable Engineering IEEE Conference (IREC), pp. 1–5 (2021). https://doi.org/10.1109/IREC51415.2021.9427799

14. Obeidat, M.A., et al.: Effect of electric vehicles charging loads on realistic residential distribution system in Aqaba-Jordan. World Electr. Veh. J. **12**(4), 218 (2021). https://doi.org/10.3390/wevj12040218
15. Mansour, A.M., Almutairi, A., Alyami, S., Obeidat, M.A., Almkahles, D., Sathik, J.: A unique unified wind speed approach to decision-making for dispersed locations. Sustainability **13**(16), 9340 (2021). https://doi.org/10.3390/su13169340
16. Obeidat, M.A., Al Anani, M., Mansour, A.M.: Online parameter estimation of DC-DC converter through OPC communication channel. Int. J. Adv. Comput. Sci. Appl. **12**(5), 102–114 (2021). https://doi.org/10.14569/IJACSA.2021.0120514
17. Obeidat, M.A.: Real-time DC servomotor identification and control of mechanical braking system for vehicle to vehicle communication. Int. J. Comput. Appl. **182**(40), 20–30 (2019)