Reducing the Fluctuations Effect of the DC Supply on the Three Phase Inverter using Intelligent Inverter Control

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Abstract: - In this paper, an Intelligent inverter control is used to reduce the noise, disturbances, and sudden jumps in DC bus voltage of the grid supplies a three-phase inverter. The system is modelled using Matlab/Simulink 2020. Many reasons cause fluctuations in a DC supply such as loose, corroded connections, or unregulated supply. The paper proposes a solution for fluctuations in DC supply of three phase voltage source inverter using two degree of freedom controllers Feeback (FB) and Feedforward (FF). The results show that FB only can't solve the disturbances and sudden jumps of the DC voltage. Using both controllers FB and FF solve this problem and the performance such as overshoot, rise time, peak time, and settling time parameters are improved under different load conditions for ±15% fluctuation in DC supply

Key-Words:- Intelligent Controller, Fluctuations, Three-phase inverter, Feedback Controller, Feedforward controller.

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1 Introduction

Three-phase inverters are very important to drive AC machines such as: induction and synchronous machines. Reducing disturbances and improving input tracking under sudden grid input change are needed to enhance AC machine drive system. Feedback controller can be used to improve input tracking, but it can’t solve disturbance and system noise problem coming from sudden change in the DC grid input. Using both feedforward and feedback controllers enhance the AC drive system and decrease the effect of grid input fluctuation and noise.

In [1], the authors presented a multi-path feedforward controller designed in the discrete-time domain for a three-phase inverter with a step-up transformer. The authors 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.

A detailed description of a simple feedforward approach to stabilize the three-phase voltage source inverter system is introduced in [2], 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.

The effectiveness of the implementation of voltage feedforward on-grid tide inverter has adversely affected the voltage feedforward in the weak grid as described in [3]. 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 as shown in fig.3; the Theories and actual findings confirm the efficacy of the system.

In [4], the author described a low-pass filter design that could be Embedded in the voltage feedforward circuit to generate improvements that help the grid's capability, effectively solving high-frequency current harmonics when The LCL filter exists in a weak grid linked with an inverter. these harmonics caused malformation in system current, experimental and theoretical interpretation of outcomes confirmed by the modeling and results obtained.

The classical negative feedback system is applying for the newer positive feedforward Control. A voltage control analysis of the system's interactions between subsystems has been performing. Without any significant physical change, the author raising the step margin in multi-converter applications by utilizing low-bandwidth connections. It seems that in low-frequency, both control feedforward and feedback have the same behavior, but at high frequency, feedforward became an active filter that raises system input stability as in [5].

The Control and stabilizing systems for both VSC and CSC have been discussed elaborately. The transient response and the best steady-state performance have been improving by proper damping of LC resonance as in [6], it can be done using a control signal-shaping approach combination with virtual harmonic damper, the LC resonance adequately is demoralized because it considers the variations in grid voltage, which is especially important in a grid-interfacing converter system.

The grid current harmonics issue could be solved using the feedforward approach under the d-q rotating frame, these harmonics caused by the distortion from grid voltage in the grid tide inverter (voltage source inverter) with LCCL filter. Both simulations and experiments have substantiated the efficacy of this approach. This novel approach which presented in [7] does not require additional sensors, where the author takes an experimental case in a grid-connected solar cell (100kw) inverter with a high-speed controller DSP.

The author compares discrete and continuous as a control reference in grid-connected inverter with LCL filter [8], where the voltage feedforward mainly uses the continuous controller. The continuous approach cannot be applied to discrete controllers because it relies on grid voltage as a feedforward control strategy. Hence, the author suggests the full grid-voltage feedforward that conceivably uses in the discrete state-space controller. The discrete Control bandwidth is higher with state-space controllers, and state-space technology inverter control offers exceptional stability for widely deployed LCL-type grid-connected inverters.

The author described Negative PLL behavior that may cause whenever a three-phase voltage source connects to a low grid impedance system. The negative consequences of PLL can partially reduce with a novel q-axis feedforward voltage control technique is proposed. In [9] A vital advantage of this approach is that it incorporates these features: It does not affect the steady-state operation of the voltage source inverter as a result, simple, PLL not be changed, the dynamic response of the PLL is reserved, after successful implementation of a three-phase (VSI) control in the system, the results confirm the method used.

In [10] the paper presented a generalized state-space averaging method to formalization the three-phase voltage source inverter that considers the dead-time effect of this method. It is in agreement with simulated and actual devices which Using the conventional method of state-averaging, More critical it provides a powerful means for closed-loop Control. The accuracy and effectiveness of this model validate through actual and functional models used in simulation and experiment, respectively, furthermore is potentially used in parallel inverter connections and circumference computation.

As in [11] authors presented a new model of voltage source inverters, which considers the dead time and modulation effects by a modified small-signal model. The analysis was performing with a comparison with a 2kw prototype experiment and with a full-scale model.

The combinations between the feedback and feedforward controller in Three-Phase Voltage Source Inverter connected with a DC voltage source to stabilize the system and obtain exceptional performance as in [12]. The system has been subjected to in detail to analyze and determine its overall stability, where the system has an interlinkage problem between the VSI and DC voltage source cause limited Thévenin impedance.

In [13] the authors provide a detailed review of stability in DC Distribution Systems, thoroughly summarizes all the criteria employed in the design of DC systems in the field; for perfect DC power systems, performance and stability are needs. so the author suggests the Passivity-Based Stability Criterion (PBSC) by passivity dominant on the DC bus, where The Performance and stability ensure with a passivity criterion, where the simulation has been using to clarify this theory; in the end, the paper offers a summary of the research on these various stability studies.

[14] presented that, the grid voltage feedforward positively impacts grid voltage; the inverter impedance derives from an accurate small-signal model that approximates the target impedances in the d-q domain, the instabilities created by interaction between the model can employ to predict the effects of instability.

A detailed description for simulating a three-phase voltage source with dSPACE 1104 control circuitry will allow future use of dSPACE Controller in photovoltaic projects is introduced in [15]. There is a substantial improvement in the inverter voltage output. As stated in this paper, this controller can be built using the dSPACE board as a design tool. The model provides a 2.83% total harmonic distortion value rather than approximately 37%; the simulation test demonstrates that the hardware implementation corresponds to the simulation model.

An entire feedforward approach to eliminate grid harmonics caused by the grid voltages in grid-connected inverter with LCL filter is presented in [16]. The author proposed a scheme able to control three reference frames (stationary, synchronous, decupled synchronous) rather than the proportional feedforward. the Transient response to changing further limits by feedforward signal amplitude; the results obtained show that the suggested feedforward schemas are effective.

[17] presented the outstanding result for The suggested feedforward control voltage has experimentally shown to obtain steady-state and dynamic responses. because transformer impedance affects voltage fineness, the author proposition feedforward approach on the output current To cancel the impact of voltage drop and reposition the transformer after the filter(LC) to obtain the compact size.

The author proposed in [18] a control technique for a three-phase grid-connected inverter in a PV system. Using the feedforward decoupling method, the mathematical model built, and the case applied to a 5KW solar cell system that This control strategy is effective and efficient through experimentation. It has been shown that the system is stable and dynamic.

Disturbance rejection for DC-DC converters such as buck, boost, and buck/boost converters is proposed in [19-21]. The authors used feedback and feedforward controllers to improve input tracking and reducing disturbance impact due to sudden jumps of DC input grid.

In this paper a three-phase voltage source inverter is developed and modeled using Matlab/Simulink, then a feedback controller is applied to control the fluctuation of dc input voltage that appears in the bus of the grid. The experiments show that feedback controller only cannot solve the disturbance problem properly, after that, a new feedforward controller with feedback can be applied to eliminate the disturbance and track the dc voltage source without affecting the overall system.

Adding Feedforward controller with feedback controller improve the system tracking and reduce the disturbance at the input of the three-phase inverter under different loads. This methodology is different from other research studies in that, it solved the problem of disturbance in the dc bus voltage for two periods of disturbance input signal, i.e. for first positive edge, first negative edge, and second positive edge for different loads. Using control strategies have the benefits of decreasing the number of power electronics devices and switches which can be used to solve such problem.

2 Intelligent Inverter Control Architecture and Design

The three-phase full-bridge voltage source inverter is shown in Figure 1.

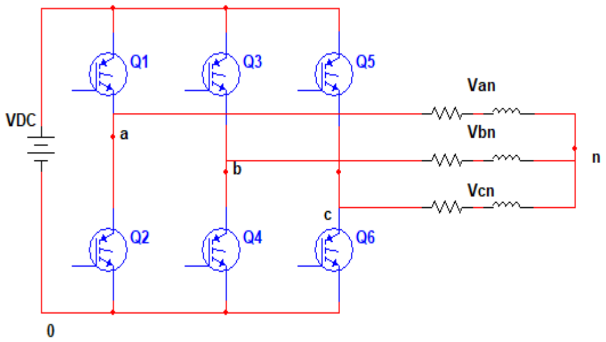

Fig. 1: Three-phase Full –Bridge Inverter

Figure 2 illustrates the overall MATLAB/Simulink system.

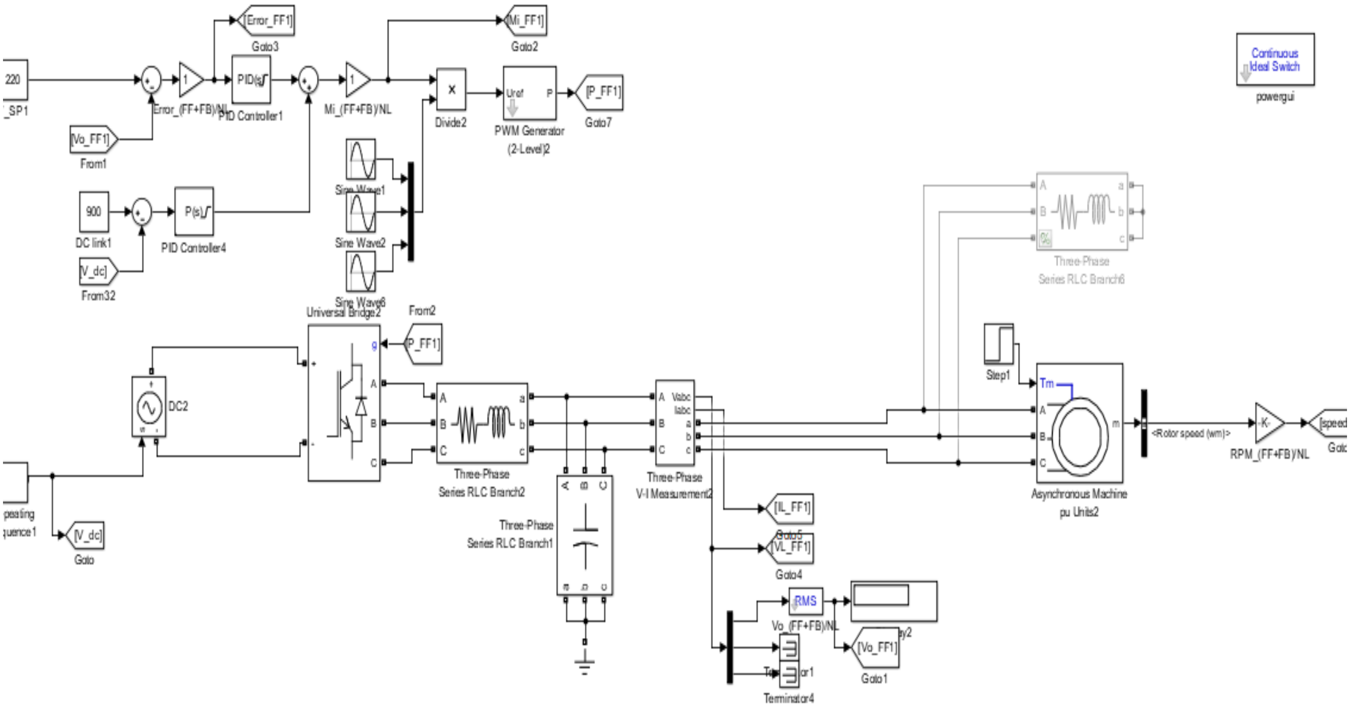

Fig. 2: Overall MATLAB/Simulink system

The output of three phase inverter is shown in Figure 3.

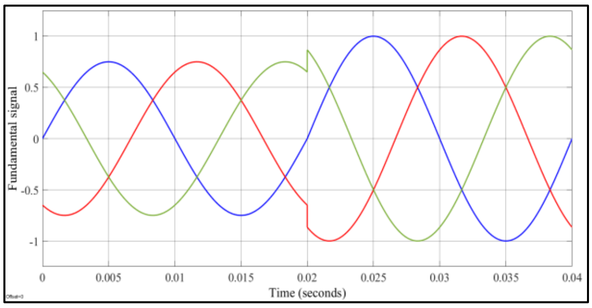

Fig. 3: Fundamental waveforms.

In this control system, the set point voltage (V_SP) was the only reference to generate the required pulses and the voltage waveform.

After that step, the controller using the tuned internal parameters starts to produce a modulation index (Mi) signal (0.2 - 1) to estimate the peak values of the reference sinusoidal waves. A limiter uses to make sure that the controller output is within the required boundary. Moreover, the pulse generator sensed the features of the three-phase reference waveforms and provided an appropriate six pulses to the inverter switching devices.

For this type of Control, the disturbance of the DC link was not taken into consideration and the controller performance depending on the output voltage only.

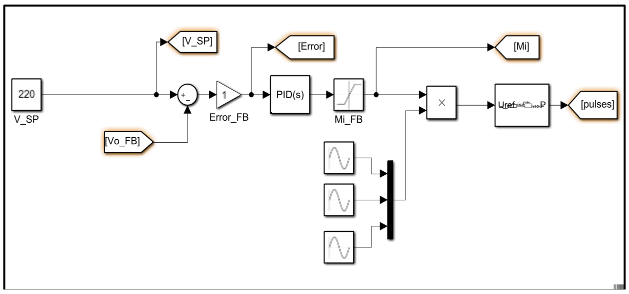

Fig. 4: Feedback control for pulse generation.

The control system shown in Figure 4, set point voltage (V_SP) and DC link voltage were considered as reference signals to generate the required pulses and, in doing so, the voltage waveform. There are two differential points and two control loops for set point and DC link voltage. The first differential compared the set point with the produced output voltage, and the error will be estimated. Simultaneously, the second differential provides another error signal based on the disturbance of the DC input. After that step, the combined signal of both controllers uses to produce a modulation index (Mi) signal (0.2 - 1) to estimate the peak values of the reference sinusoidal waves. A limiter uses to make sure that the controller output is within the required boundary. Moreover, the pulse generator sensed the features of the three-phase reference waveforms and provided an appropriate six pulses to the inverter switching devices.

3 Simulation Results and Discussion

This section introduces and explained the achieved results of the feedback and feedforward/feedback controller's responses under DC link voltage disturbances and load conditions. The response of three cases: first positive edge, first negative edge, and second positive edge, for both feedback and feedforward controllers are obtained. The results obtained from Matlab/Simulink is stated below on the figures and tables that have to compare the No-load case with a full-load case with DC link voltage disturbance, this compression made by three cases each case have DC link disturbance signal at 15% the anlayzed data contains the main properties of the figures [Rise time, Settling time, Settling Min, Settling Max, Over shoot, Under shoot, Peak ,Peak time], Figure 5 illustrate the shape of DC link disturbance signal at 15%.

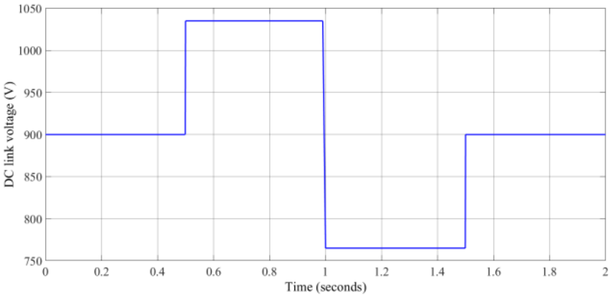

Fig. 5: DC link disturbance signal at 15%.

The following parameters of the overall system shown in Table 1 will be uses in Matlab/Simulink.

Table 1. Parameters of the overall system used in Matlab/Simulink.

parameter	values
VDC (set point)	900 v
Motor	4W,400V,50HZ,1430RPM
RLC Filter (ohms, Henry, Farad)	R=0.2,L= 10e-3,C= 20e-6.
Inverter (snubber resistance, ohms)	Rs= 1e7
Inverter (snubber capacitance, Farad)	Cs=∞
Inverter(The internal resistance Ron, ohms)	RON= 1e-3

In this case, the parameters of VSI system will be used, then the disturbance in DC link input by + 15% around the set point will be applied.

3.1 Case 1: First Positive Edge

The results obtained from first positive edge Figures (6 - 9) and Table 2 showed that both controllers recorded the same readings at the 15% disturbances with no load condition. Moreover, the analysis of the first positive edge showed a small variation in overshoot and settling time with full load condition.

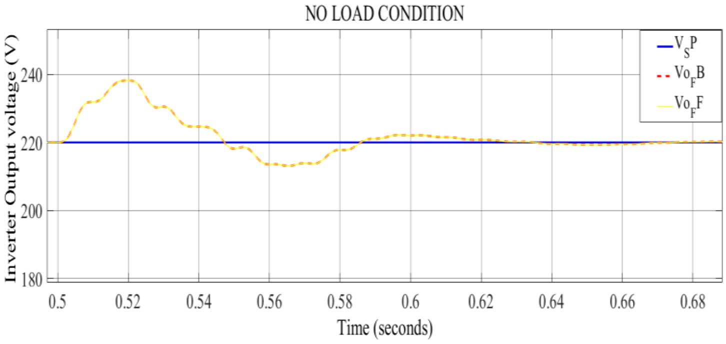

Fig. 6: Output voltage responses at 15% disturbance - No load condition.

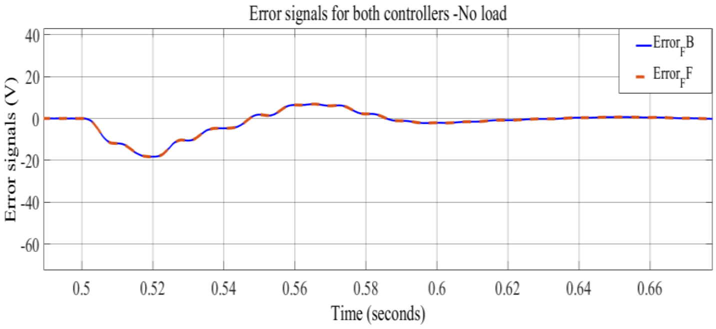

Fig. 7: Error signals of both controllers at 15% disturbance - No load condition.

Table 2. First positive edge analysis with 15% disturbance

Comparison Criterion	No load measurements		Full load measurements	
	FB	FF+FB	FB	FF+FB
Disturbance	15%		15%	
Rise time	7.87E-04	8E-04	7.87E-04	8E-04
Settling time	0.1670	0.17	0.1664	0.167
Settling Min	213.1440	213	212.8042	212.8
Settling Max	238.2372	238	237.9726	237.97
Over shoot	18.2372	18	17.9726	17.97
Under shoot	6.8560	6.85	7.1958	7.2
Peak	238.2372	238	237.9726	238
Peak time	0.02	0.02	0.02	0.02

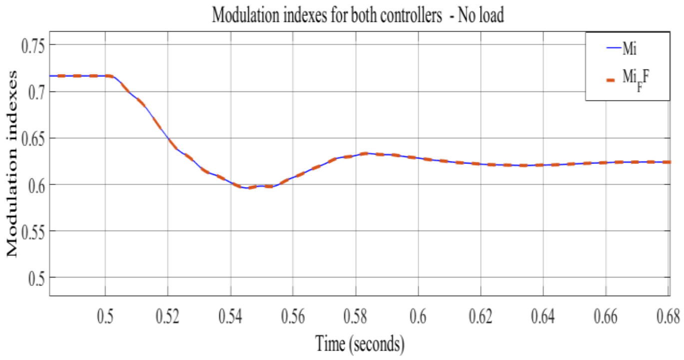

Fig. 8: Modulation indexes of both controllers at 15% disturbance - No load condition.

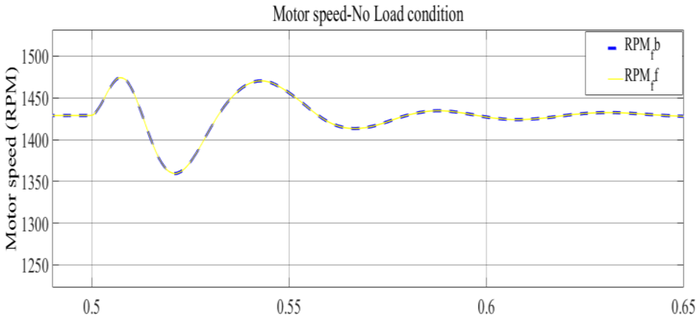

Fig. 9: Motor speed of both controllers at 15% disturbance - No load condition

3.2 Case 2: First Negative Edge

In this case, the parameters of VSI system shown in Table 1 will be used, then the disturbance of DC link input is -15% around the set point will be applied.

The first negative edge analysis from Figures (10-13) and Table 3 proved that load increment has a positive effect on the rise time and overshoot values, and at the same time it has a negative effect on the settling time. It is also noticeable that the proposed control system (FB+FF) overcame the increased disturbance and load effect. Moreover, it produced stable voltage with faster response than the feedback control system.

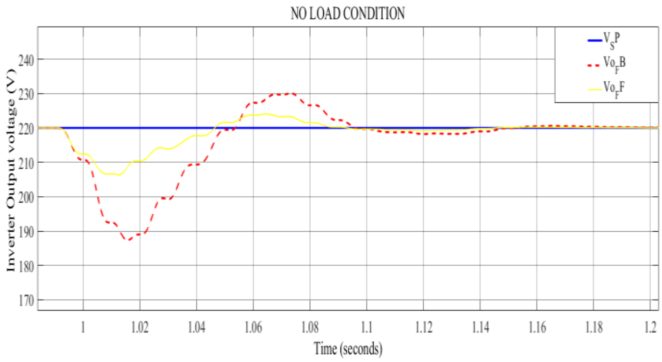

Fig. 10: Output voltage responses at 15% disturbance - No load condition.

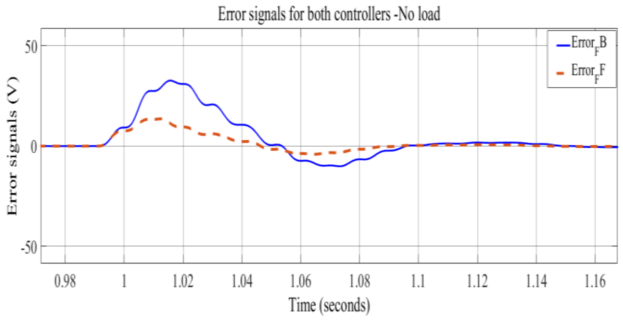

Fig. 11: Error signals of both controllers at 15% disturbance - No load condition.

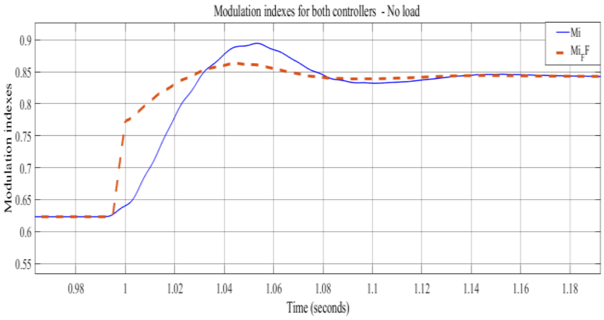

Fig. 12: Modulation indexes of both controllers at 15% disturbance - No load condition.

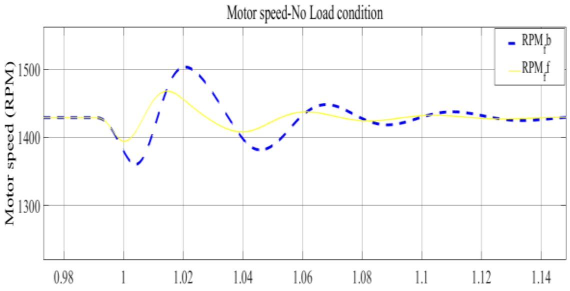

Fig. 13: Motor speed of both controllers at 15% disturbance - No load condition

Table 3. First negative edge analysis with 15% disturbance

Comparison Criterion	No load measurements		Full load measurements	
	FB	FF+FB	FB	FF+FB
Disturbance	15%		15%	
Rise time	1E-04	1E-04	1E-05	1E-05
Settling time	0.1606	0.1525	0.172	0.16
Settling Min	187	206.3785	184	204.9
Settling Max	230	224.0762	229	223.5
Over shoot	10	4.0762	9.2	3.5
Under shoot	32.7	13.6215	36.3	15.1
Peak	230	224.0762	229	223.52
Peak time	0.0886	0.0797	0.1	0.09

3.3 Case 3: Second Positive Edge

In this case, the same parameters of VSI circuit will be used, then the disturbance in DC link input by +15% around the set point will be applied. The second positive edge analysis from Figures (14-17) and Table 4 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.

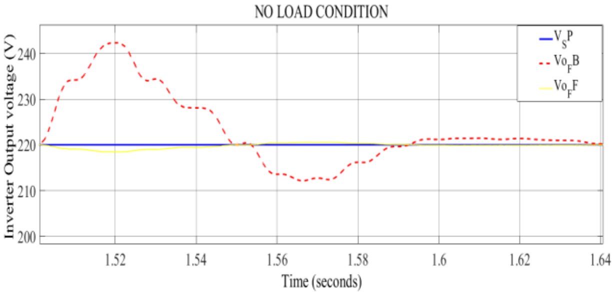

Fig. 14: Output voltage responses at 15% disturbance - No load condition.

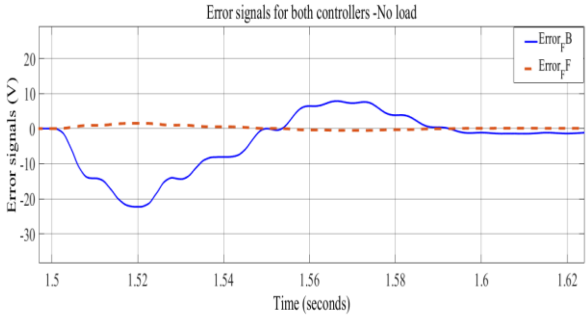

Fig. 15: Error signals of both controllers at 15% disturbance - No load condition.

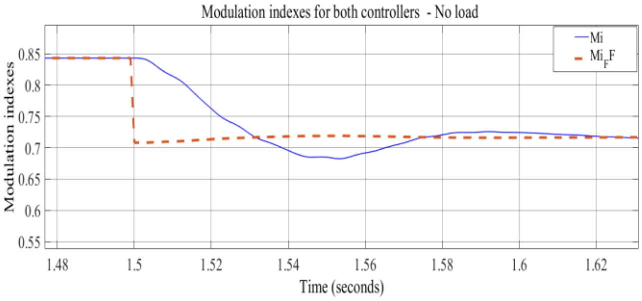

Fig. 16: Modulation indexes of both controllers at 15% disturbance - No load condition.

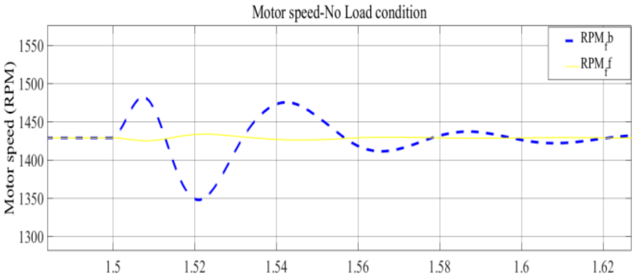

Fig. 17: Motor speed of both controllers at 15% disturbance - No load condition

Table 4. Second positive edge analysis with 15% disturbance

Comparison Criterion	No load measurements		Full load measurements	
	FB	FF+FB	FB	FF+FB
Disturbance	15%		15%	
Rise time	2E-5	2E-05	2E-4	3.E-04
Settling time	0.19	0.2	0.18	0.18
Settling Min	212.0	218.5	213.	218.
Settling Max	242.3	220.6	243.7	220.3
Over shoot	22.30	0.52	23.7	0.33
Under shoot	7.85	1.53	6.25	1.248
Peak	242.3	220.5	243.7	220.4
Peak time	0.046	0.099	0.034	0.086

3.4 Overall System Analysis:

Figure 18 illustrated the output voltage responses of the studied systems under no load condition. It can be seen that the disturbance increment produced a larger overshoot especially at the first positive and negative edges for feedforward/feedback control compared to a high overshoot in all edges for the second control system.

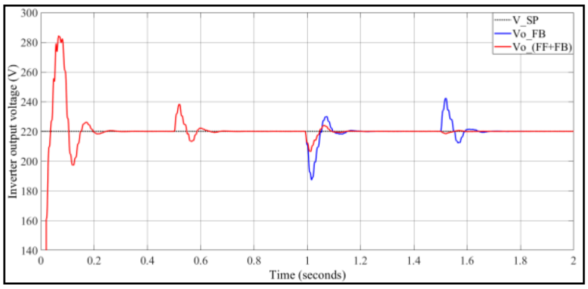

Fig. 18: overall system Output voltage responses at 15% disturbance - No load condition.

The error signal of both control system under no load condition were shown in Figure 19. The relationship between the error overshoot and the disturbance is proportional and as a result, the need for more compensation to reduce it to zero. Both controllers had the ability to do so, but the scored error of the proposed system was in smaller range compared to the feedback system.

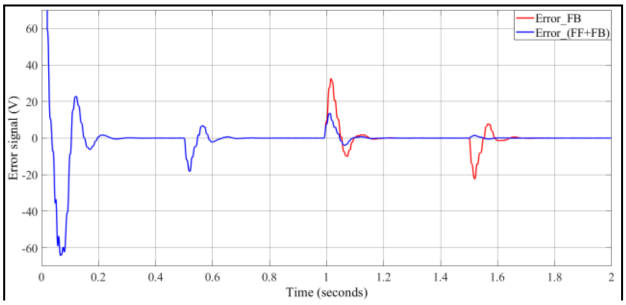

Fig. 19: Error signals of both controllers at 15% disturbance - No load condition.

Figure 20 illustrated the modulation index performance of both systems under no load condition. It can be observed that the relation between the DC link voltage and the modulation index is inverse one. Moreover, the proportional relationship was observed between the modulation index and the disturbance. On the other hand, the proposed approach recorded better index response compared to the second system.

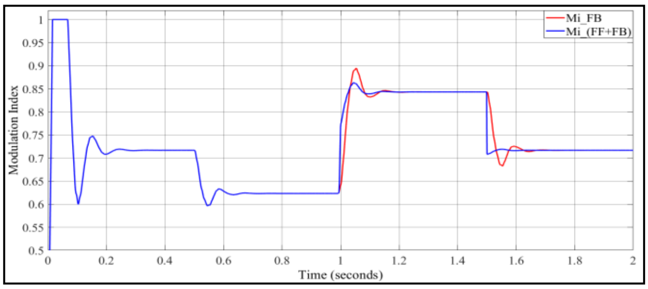

Fig. 20: Modulation indexes of both controllers at 15% disturbance - No load condition.

Figure 21 showed the motor speed responses under disturbance variation with no load condition. It can be seen that the speed oscillation will increase with higher disturbances. The proposed system overcame the oscillation issue with better performance.

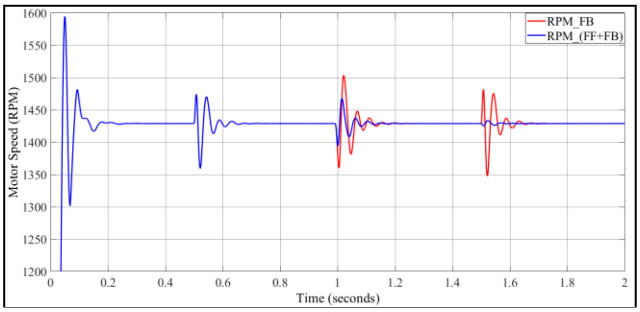

Fig. 21: Motor speed of both controllers at 15% disturbance - No load condition.

It can be seen from achieved results that the proposed control system has recorded the better performance in terms of rise time, settling time and overshoot aspects under disturbance- load variation, the feedforward with feedback controller achieved the expected result in which the system outcomes stabilize and observe good response.

Figure 22 showed the generated output voltage of both systems in time domain at the second positive edge. The supremacy of the proposed system was observed. Figure 23 showed the generated output current of both systems in time domain at the second positive edge. The excellence of the proposed approach was obvious.

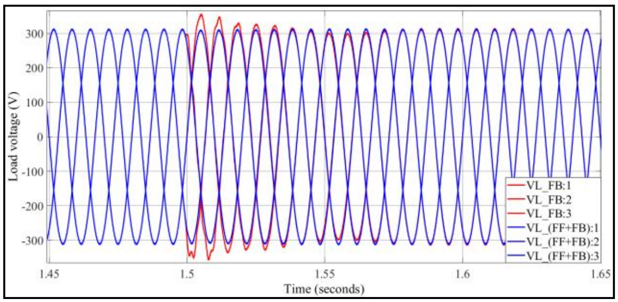

Fig. 22: Load voltage at 2nd positive edge with 15% disturbance - No load condition.

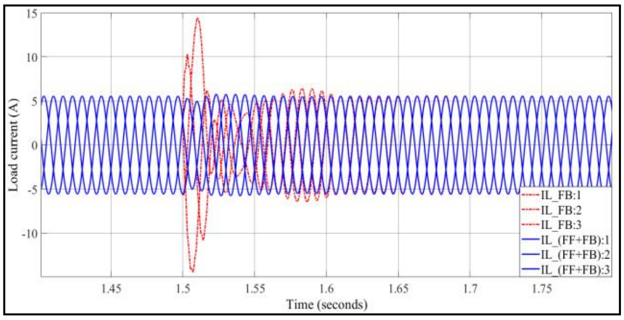

Fig. 23: Load current at 2nd positive edge with 15% disturbance - No load condition.

Figure 24 explained the feedforward/feedback controller behaviour under various conditions (10% and 15% disturbances at different load conditions). It can be observed that the controller performed better responses at full load conditions, in spite of the disturbance increment. In order to achieve that in the case of full load condition, the modulation index was increased as shown in Figure 25.

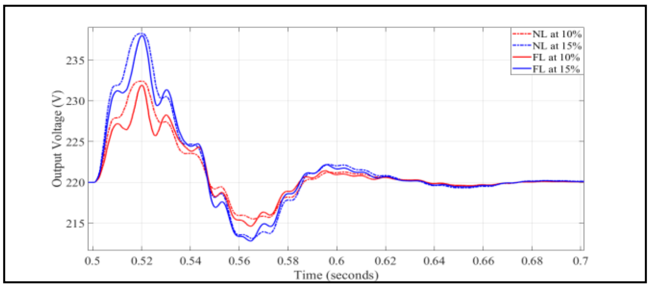

Fig. 24: Output voltage responses of FF/FB control with different loading – disturbances.

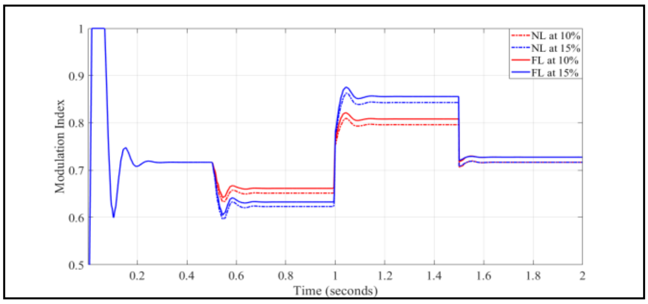

Fig. 25: Modulation index responses of FF/FB control with different loading – disturbances.

The speed response of the proposed controller under full load condition was illustrated in Figure 26, It can be seen that the speed oscillation was reduced in small time in both loading cases.

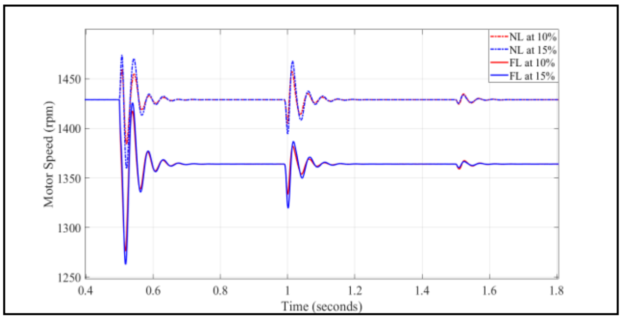

Fig. 26: Motor speed responses of FF/FB control with different loading – disturbances.

4 Conclusion

This paper proposes an optimal feedforward controller to compensate sudden input voltage changes fed 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. Monitoring and noise rejection in the system can be addressed only by adding both Feedforward and feedback controllers. Adding feedforward scheme represents good performance and stabilizes the system, especially in the first negative edge; also, in the second positive edge. The overshot and rise time of the system is enhanced. furthermore, it improves the accuracy of the fundamental voltage and current components and the measurement efficiency of inverter simulations.

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