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# Analysis of Performance Parameter In Terms Of THD and Time-Delay

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***ABSTRACT :***
*Recent progress in the area of digital signal processing has made it possible for grid-connected inverters to use digital microprocessors to run them. For the other hand, the phase lag that comes from gaps in time makes it harder to use digital technologies effectively. This phase delay is used to test how stable and reliable the inverter driver is. This paper looks at all of the time-delay correction methods for both model-free (MF) and model-based (MB) inverter controls when connected to the grid. A lot of the time, proportional-integral and proportional resonance controls are used in MF methods. It is also possible to shorten the length of the wait by using certain tactics. For MB, these are some of the most common control methods that are used. This piece goes over a lot of similar methods that have been taken from other studies to cut down on delays. It also talks about some important problems that have to do with the MF and MB processes. This study comes up with an idea about the current method and suggests a mixed method that combines the MF and MB steps. This study also lays the groundwork for more research to come.*
***Keywords:*** *Performance Parameter, Time Delay, Total Harmonic Distortion, Digital Signal Processing.*

## I. INTRODUCTION

In order to keep up with the growing demand for energy around the world, traditional power systems have been going through some changes in how they normally work. So, if we want to keep up with the world's growing demand, networks need to be opened up to include green energy sources like solar and wind. It is possible that these green energy sources could make a big difference in the main grid's power supply if they are fully collected and used in a controlled way. To meet this need, distributed generation (DG) is being used. Grid-connected inverters, which are pieces of power electronics, are used in this method to connect DG systems in a way that makes them work like a microgrid. Connecting different distributed generation (DG) units makes the system more flexible, which is good for many things, such as controlling power quality, protecting it, and making it work better. Safety during operation, power quality, and security against islanding are all set by new, strict standards in [2]. Why is this the case? Because machines that connect with the grid face special problems, especially when things aren't going well [1]. New technologies, like real-time controllers that can run complicated control algorithms and power electronic devices that can manage a lot of power and switch quickly [3], have brought these interconnection problems to people's attention, which has caused a lot of research to be done. There are many problems with real-time controllers, such as the control loop lag and delays during the changes between grid-connected and islanding modes. It is possible for a material system to respond to an outside input with an impact that happens later. This is called time-delay [4]. This skill is shown by the system's ability to react. Sending energy or control messages from one place to another always takes some time because of delay. This lag is called propagation. The transmission delay depends on how fast the information is being sent and what kind of material it is going through. When the inverter's digital control loop has a long delay, either when moving between grid-connected and island modes or when designing and putting it together, it makes controller tasks more difficult. Because of this, changes in power and frequency stand out a lot more. Several types of remedial techniques can be used to fix a small delay. When connected to the grid, inverters can use LCL filters and either an inner-loop or an outer-loop design with a voltage, current, direct power processor, or a mix of these. You can also use these controls in a different order. A lot of study has used inner current control because it can accurately track current, has a large control bandwidth, and responds quickly to changes. On the other hand, voltage source inverters (VSIs) use the driver that is already in place to let the inverter work as a current booster within the current loop span [5]. In an outer-loop design, the voltage processor, on the other hand, protects the system from grid and input source problems so that power passes through it. For all methods, the control loop adds a delay that limits the controller's ability to handle many things at once, especially for digital ones. The use of digital microprocessors to manage grid-connected transformers is another new idea that came about because of progress in digital signal processing [6]. The digital method gives you more control options, faster system reprogramming, and more reliable performance compared to the traditional method. Out of all the problems with this digital technology, the phase lag caused by the control loop's time delay is the most noticeable. When more control loops are added, this lag will be much more obvious. Before looking at the different common ways to fix time delays in the control loop of a grid-connected inverter, it's important to fully understand the main reasons for them. Digital controller rollout delays are mostly caused by the time it takes to do calculations, deal with the zero-order hold effect of digital pulse-width modulation, and sample and update voltage and current data for control purposes. Because of this, it might be hard to get good performance when the control loop is having big time delays. This makes the controller's crossover frequency low-gain, which in turn lowers its rapid response, raises overshoot (because there isn't enough phase buffer), and lowers its control bandwidth.

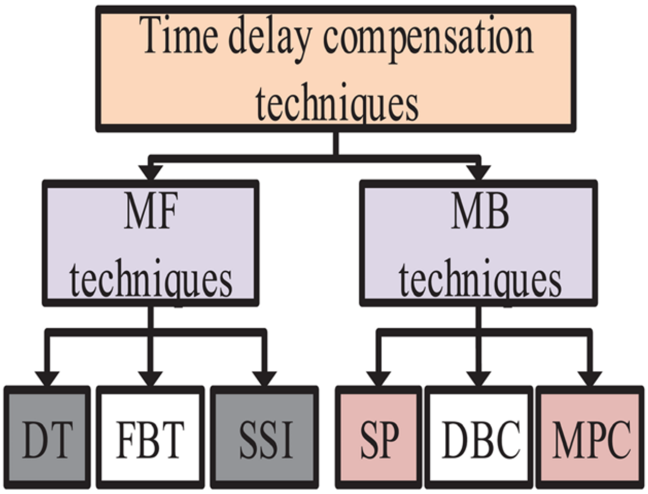


**Fig 1 : Common time-delay compensation techniques for grid connected inverter**

The controller will not work as well overall, and it will have many bad effects, such as becoming unstable. These effects might be lessened or eliminated completely if compensators are used, which cut down on or get rid of delays. A lot of different time-delay pay plans have been written about in scholarly papers. One thing that helps put these methods into groups is whether they use models or not [6]. In Figure 1, you can see the two main groups. Maximal likelihood (MF) methods are not as accurate, but they don't care about how good the model is. Maximum likelihood (MB)-based methods, on the other hand, are more accurate, though they depend a lot on the model. Two different kinds of MB time-delay compensation systems are Smith predictors (SP) and modified Smith predictors (MSP). There are also deadbeat controllers (DBCs) and model predictive controllers (MPCs). Some of the MF methods that were used to compare them were the filter-based technique (FBT), the changing the sampling instant (SSI) of the control variable, and the damping technique (DT). The goal of this research is to find problems and possible answers that can make time delay less of an issue in the control loop of grid-connected inverters. Another important thing it does is open the door for more study into the subject of reducing delays.

## II. PERFORMANCE PARAMETER

In order to meet the world's energy needs, different kinds of power electronic devices are being used to connect green energy sources to the main grid. Renewable energy sources can provide power to the main grid, but if the quality of the power they send is poor, the grid gets crowded, which has major effects on the power system and equipment at the user end. Grid voltage distortion, grid impedance change, and time delay in the control loop can all have a big effect on the output current of grid-connected inverters, especially those that are rated for a lot of power but have low switching and sampling frequencies. In addition, if the current that green energy sources send into the grid has a lot of harmonics, the grid voltage distortion and time-delay effect in the control loop will get worse. This makes the system less efficient and the controller less effective.

## III. SUMMARY ON RESULTS OF PERFORMANCE PARAMETER

The quality of the electricity sent to the grid has been judged by the amount of overall harmonic distortion in the current and voltage. Because of this, IEEE Standard 1547:2003 says that the total harmonic distortion (THD) for both the current and the voltage should be less than 5%. It is important to remember that current THD is opposite to switching frequency. It takes more work to get low current total harmonic distortion (CTHD) and low time delay in a high-power system, which is always the case for grid-connected inverters with a switching frequency less than 5 kHz and a low inductance of less than 0.5 mH. In Table 1, you can see a summary of the performance parameters of the model-free techniques we talked about earlier. The switching frequency ranges from 2 to 16 kHz, and the sampling frequency ranges from 5 to 20 kHz, which means that the maximum time delay is 200 to 50 µs.

The CTHD numbers from the studies that were looked at are mostly within the appropriate range. But the minimum CTHD number could be lowered even more by using the different methods described to cut down on the time delay even more. Regarding the shortest possible delay, as seen in Tables 1 and 2, most of the study papers did not show the shortest delay that could be achieved with the compensation method they used. This means that there will be less time to decide which method has the smallest time delay. Also, not having this knowledge will make it harder to imagine doing more study to make what has already been done even better. Finally, it might be helpful to explain how to intuitively measure time-delay in a grid-connected control loop using the model-free methods described in this work. This could be a topic for future research.

**Table 1:** Summary of the performance parameters of model-free techniques

| S/No | Author | Type of inverter | Disturbances | CTHD (%) | Time-delay | Switching frequency | Sampling frequency |
|---|---|---|---|---|---|---|---|
| Single loop techniques | | | | | | | |
| 1 | [10] | 1 ϕ, 3 kW | GCV | *2.73 | N/A | 16 kHz | 16 kHz |
| 2 | [28] | N/A | N/A | N/A | N/A | N/A | N/A |
| Extending stable region techniques | | | | | | | |
| 1 | [13] | N/A | GVV | 2.23 | N/A | 9.6 kHz | N/A |
| 2 | [15] | 3 ϕ, 500 kW | GIV | 0.66 | 75 $\mu$s | N/A | N/A |
| 3 | [26] | 1 ϕ, 5 kW | GIV | N/A | N/A | 10 kHz | N/A |
| 4 | [36] | 3 ϕ, 500 kW | GIV | N/A | N/A | 10 kHz | 20 kHz |
| 5 | [33] | N/A | GIV, GVV | N/A | 4.7 $\mu$s | 10 kHz | 10 kHz |
| 6 | [35] | 3 ϕ, 250 kVA | GVV | *3.43 | N/A | 5 kHz | 10 kHz |
| 7 | [37] | 1 ϕ, 6 kW | GIV | 1.82 | N/A | 15 kHz | 30 kHz |
| 8 | [34] | 3 ϕ, 30 kVA | FIV, GIV | 1.96 | N/A | 16 kHz | 16 kHz |
| Filter based techniques | | | | | | | |
| 1 | [14] | N/A | FIV, GIV | N/A | N/A | 10 kHz | 10 kHz |
| 2 | [6] | 3 ϕ, 10 kW | RCV | N/A | N/A | 10 kHz | 10 kHz |
| 3 | [40] | 3 ϕ, N/A | GCV | N/A | N/A | 10 kHz | 10 kHz |
| 4 | [17] | 3 ϕ, 2.5 kW | N/A | N/A | N/A | 8 kHz | 8 kHz |
| 5 | [18] | 3 ϕ, 10 kVA | FIV | 10.8 | N/A | 2.5 kHz | 5 kHz |
| 6 | [19] | 3 ϕ, 2 kW | FIV, FCV | N/A | N/A | 8 kHz | 8 kHz |
| 7 | [38] | 1 ϕ, 10 kW | FIV | *0.9 | 45 $\mu$s | 10 kHz | N/A |
| 8 | [44] | 1 ϕ, 10 kW | MM | 2.8 | N/A | 3 kHz | N/A |
| 9 | [41] | 3 ϕ, N/A | FCV, IIV | N/A | N/A | 10 kHz | 10 kHz |
| 10 | [42] | 3 ϕ, 10 kW | GVV, $V_{DC}$V | 0.4 | 25 $\mu$s | 10 kHz | N/A |
| Different sampling and updating techniques | | | | | | | |
| 1 | [11] | N/A | N/A | *3.3 | N/A | *16.4 kHz | N/A |
| 2 | [12] | 3 ϕ, 3 kW | N/A | N/A | N/A | 10 kHz | N/A |
| 3 | [22] | 3 ϕ, 50 kW | GIV | 1.56 | N/A | N/A | N/A |
| 4 | [24] | 3 ϕ, 5 kW | N/A | 2.26 | N/A | 2 kHz | N/A |
| 5 | [43] | N/A | GVV, GIV | 2.71 | N/A | 15 kHz | 15 kHz |
| 6 | [45] | 1 ϕ, 6 kW | GIV, GCV | 1.4 | N/A | 10 kHz | 20 kHz |
| 7 | [49] | 1 ϕ, N/A | GCV, GVV | N/A | N/A | 1.25 kHz | N/A |
| 8 | [51] | N/A | N/A | N/A | N/A | 15 kHz | 15 kHz |

Table 2 shows a summary of the performance factors of the model-based time-delay correction methods. Table 2 shows that the sampling frequency is between 2 and 30 kHz and the change frequency is between 2.5 and 28 kHz. The table shows that the smallest CTHD is reached when time delay is taken into account in both the system modeling and controller design, compared to when it is not taken into account. When it comes to time delay, there isn't a clear-cut way to measure it, and most of the study that's been looked at doesn't give an exact number for the smallest delay that can be achieved by using a certain correction method. In the material that has been looked at, there is always a general comment that time delay has been lessened or removed. Using the CTHD as a measure, the writers come to the conclusion that the shortest time delay in the control loop is achieved by deadbeat control using the multi-sampling, multi-updating method.

**Table 2**: Summary of performance parameters of MBT

| S/No | Author | Type of inverter | Disturbances | CTHD (%) | Time-delay | Switching frequency | Sampling frequency |
|---|---|---|---|---|---|---|---|
| Summary with a time-delay effect | | | | | | | |
| 1 | [5] | N/A | LIV, LRV, BEMF | 0.93 | N/A | 6.7 kHz | N/A |
| 2 | [20] | 3 ϕ, 50 kW | GCV, FIV | 2.4 | 30.7 μs | 10 kHz | 10 kHz |
| 3 | [52] | 1 ϕ, 10 kW | GVV, MM | N/A | 50 μs | 10 kHz | N/A |
| 4 | [84] | 3 ϕ, 5 kW | N/A | N/A | N/A | 28 kHz | N/A |
| 5 | [85] | 3 ϕ, 75 MW | MM, RCV | N/A | *23 ms | N/A | N/A |
| 6 | [96] | 1 ϕ, 2 kVA | LV, RCV | 4.1 | N/A | 15 kHz | 30 kHz |
| 7 | [71] | 3 ϕ, 10 kVA | LIV | 0.95 | N/A | 6.7 kHz | 8.16 kHz |
| 8 | [95] | 1 ϕ, 3 kVA | PRCV, ARCV | <1 | N/A | 20 kHz | N/A |
| 9 | [59] | 1 ϕ, 3 kVA | RCV | <1 | N/A | 20 kHz | N/A |
| 10 | [97] | 3 ϕ, 3 kW | ARCV, GSC | 1.2 | N/A | 20 kHz | 20 kHz |
| 11 | [98] | 1 ϕ, 1.5 kW | PE, PAS | 7.03 | N/A | N/A | 2 kHz |
| 12 | [94] | 3 ϕ, 1.5 kW | SCA | N/A | N/A | 3 kHz | N/A |
| Summary without time-delay | | | | | | | |
| 1 | [89] | 3 ϕ, 300 kVA | FE, PJ, AE | N/A | N/A | 2.5 kHz | 5 kHz |
| 2 | [87] | 1 ϕ, 3.3 kW | HIC | 5.00 | N/A | 10 kHz | N/A |
| 3 | [88] | 3 ϕ, 100 kW | LIV, LRV | *2.01 | N/A | 10 kHz | N/A |
| 4 | [90] | 3 ϕ, 1.5 kW | P, QV | *9.66 | N/A | N/A | 2 kHz |
| 5 | [86] | 1 ϕ, 1 kW | LIV, LRV | 4.96 | N/A | 3.3 kHz | 5 kHz |
| 6 | [91] | N/A | GVV | 1.4 | N/A | N/A | N/A |
| 7 | [92] | 1 ϕ, N/A | GVV | N/A | N/A | N/A | N/A |
| 8 | [93] | 1 ϕ, 1.5 kW | RCV, MM, GVV, $V_{DC}$V | 3.38 | N/A | 20 kHz | N/A |

## IV. CONCLUSIONS

This paper gives a short overview of the mathematical work that has been done on grid-connected inverter control loops using time-delay compensation methods. Even though there were problems with system stability in both inverter-side and grid-side designs, MF was picked as the best method because it was relatively easy to use and performed about averagely. Two types of controller-dependent systems are looked at in this paper: MF and MB. Let us now look at the models side by side. They wouldn't be able to do their jobs if they were connected to a grid that wasn't dependable or if they were hacked in some other way. Many ideas have been put forward for using fewer and easier controls to make systems more stable and cut down on time delays. However, these controllers may not be very strong. It was the Smith predictor and the modified Smith predictor that were first used to balance time and delay in standard PID controls after model-based methods were looked at. This is what happened when the Smith prediction was first used. This method doesn't work as well for grid-connected inverters because their controls can't handle signals that change over time or block out enough disturbances. But DBC has become more common because it has many useful properties, such as the ability to quickly check current, block interruptions, make up for time delays, and have no steady-state mistake. This piece divides this approach into two groups based on whether the time delay effect is taken into account when designing the controller. Many tests of time delays were done with the assumption that both the DC-link and the grid power were always on. The outside loop wasn't planned into the controller. This work suggests that researchers use a mix of DBC and several MF time-delay correction methods. For example, they could use DBC in the inner loop and MPC in the outer loop, and they could use fuzzy logic with QSQU in the outer loop.

The total harmonic distortion of this hybrid controller is low, and it has a good output current, a fast transient and dynamic reaction, and a short control-loop time-delay. An LCL output filter keeps the system stable. The review of the literature shows that these limits are not present.

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