Reviewer #1 (Required Remarks for the Author):   
  
Authors are proposing models for synchrophasor with step discontinuities in magnitude and phase. The work provides a possible solution for calibration of PMUs under such transients by including data during the transient.   
While the proposed parameters were estimated and results presented both from simulations and measured results, the proposed paper has the following major issues:   
  
I. INTRODUCTION   
UTC is Universal Time Coordinated and a time base could be synchronous with the UTC, not centered in.

Ok, changed text.

II. MATHEMATICAL BACKGROUND   
Equations (1) and (2) both define y(t), but they describe different models. Please use different designation for each model.

Done

B. Reference phasor values   
Here Ve is defined but its estimation performance is not reported elswhere in the paper.

Tables II shows the intermediate magnitude estimation performance, Table III shows the intermediate phase estimation performance. It is now more explicit in the tables.

The only results are those presented in the Fig. 7 and 8, but not in the Fig. 11 and 12..

Fig. 11 and 12 are intended to show the quantities supposed to be constant, but for practical reasons are not, during the laboratory measurements. For example, during a phase step, the phase changes as shown in Fig.7, but the magnitude (which we expect to be constant) is not stable, but presents variations as shown in Fig. 11. Likewise, during a magnitude step, the magnitude changes as shown in Fig. 8, but the phase (expected to be constant) has variations shown in Fig. 12.

It is not clear what is the purpose or the benefit of using these intermediate values. How do they add to the calibration of the PMU?

The purpose of defining the intermediate values is to having well defined reference phasors to be used in the calculation of TVE during the occurrence of steps in magnitude or phase. The procedure adopted in previous works use as reference phasors the values obtained in adjacent windows with steady state signals, taken before or after the step occurrence, depending on the instant of occurrence. This procedure depends on detecting with good accuracy the instant of occurrence (\tau), and is based on the assumption that the measurements taken from adjacent windows are good estimates of the window with a step.

The step tests are prescribed to measure the time response (TR), which is the time during which the TVE, FE or RFE exceeds the limit values ​​defined in standard. For P-class PMUs, a calibration system shall give a very short estimate of TR estimate of the order of a few cycles. Some recent works indicate that these tests may be are insufficient to describe the phenomena of short-duration sags that are being observed in today's networks.

We carried out a simulation to show how important can be the definition and measurement of reference values. The TVE of a DFT-based PMU is calculated with two different methods:

1. Using the reference phasor taken from the nearest adjacent windows of 500 samples, as related in reference [x], with a Steady State estimator (SS).
2. Using intermediate reference phasor calculated from the parameters obtained by an LM estimator, using 1000 samples.

The PMU simulator is submitted to a signal containing a positive 10% magnitude step, SNR = 50dB. The PMU window takes 1000 samples, with reporting rate of 20 frames/s.



The upper graph shows the TVE response of the DFT-PMU calculated with method 1 (black line), and method 2 (red line). The lower shows TVE calculated with method 2 alone.

If one takes the TR from the TVE calculated with method 1, TR can be overestimated (about 250 ms). On the other side with TVE calculated with method 2, the DFT-PMU never passes the standard limit. In the first case, this PMU would be rejected as a P-class, but in the second case not. It is the same PMU, the only difference is the definition of reference values. As TR is defined in function of TVE, the intermediate reference phasors can improve the accuracy of TR estimation provided by calibration systems. This can be significative for the already standardized P-class PMU tests, as well as possible more stringent TR tests for distribution PMUs in the future.

D. Model Parameters Estimation via Levenberg-Marquardt   
Please define y(k) beforehand.

OK, done.

III. NUMERICAL SIMULATIONS   
B. Parameter estimation with non-linear least squares   
Here, the simulations were caried out using SNR of 90 dB, 93 dB and 97 dB. All these SNRs are too good for any realistic measurement setup concerning PMUs. Consequently, achieved standard deviations are very small, useless for any assessment of their influence in th efinal uncertainty budget. In previous paragraph (A), a SNR of 40 dB and 75 dB were used, which are more realistic. Consider using SNR as expected or measured with the sampling system and sampling parameters used (AWG + DSVM). 

Yes, indeed.

These levels are typical levels considered for the setup used in the reference (Frigo et. al.), for calibration systems. Although these values are useful to make comparisons with our method, they are not to be used for the assessment of the setup used to make measurements in this work.

The measured SNR with AWG + DSVM are estimated to be around 60 dB, according to the references (xxx). Considering SNR = 60 dB, we carried out simulations to assess the more realistic contribution of the parameter estimation in the final uncertainty.

Refazer LM para 60dB

IV. LABORATORY MEASUREMENTS   
... Both are triggered with a 1 PPS (pulse per second) signal. Both goes for AWG and DSVM here, but only trigger to AWG is shown on Fig. 5.

Of course, the figure is corrected now.

Also, if DSVM is triggered externally, there is a time delay and timing uncertainty (likely around 400 ns +- 100 ns) involved. How was this covered in the measured results? 

The DSVM trigger time delay is one component of the overall phase error (it is indeed one of the components of the absolute phase uncertainty, which estimation is beyond the scope of this work), and its influence is part of the variations observed in the results. However, previous work indicate  time delay less than 50 ns and jitter less than 100 ps.

V. CONCLUSION   
The authors state: "The proposed approach tackles the estimation of the step discontinuities in the phasor signal observed within an analysis window, instead of dodging the problem." However, they do not give any further benefit of doing so, nor they provide any comparison to numerous previous results already published. This is the major issue of this paper - it should provide a clear comparison to the work already published and clearly depict benefits of the proposed method in comparison with previous work.

The proposed method is capable of detecting, without initial guessing, the instant of the transient with time resolution of the sampling intervals (dt) and uncertainty of a few dts. If we simply detect the transient and ignore the window, the best time resolution achieved is of a few cycles. Besides, with the models proposed, one can continuously measure the parameters that are supposed to remain constant during a step change, and check if they really are.

Frigo et al. provides a very detailed comparison of the accuracy of an LM estimator (incorporating a model for the transient) with other representative estimators (IP-DFT and CS-TFM). They also mention that the TVE metric is less appropriate to assess the accuracy of PMUs under step conditions and introduce a further metric. As they use only 3 parameters (magnitude, frequency and phase, the others are supposed known *a priori*) for the LM estimator, we propose, as an enhancement, a TVE-compatible approach (with intermediate phasors) and a hybrid estimator with 5 parameters, one taken from a Hilbert-based detector (HLM).

Comparison with the results reported by Frigo under step conditions show that HLM4 estimator has a performance similar to LM3, with the advantage of estimating more parameters of the underlying model.

For the assessment of PMU calibration systems, the proposed method that can bring more information about the system components, especially for the cases when one needs to investigate the behavior of the measurements during a few cycles.

Benefits:

1 – estimation of tau without any a priori information

2 – assessment of a hybrid estimator HLM under step conditions including

a) uncertainties in tau estimation;

b) LM with 4 parameters (Frigo uses 3 parameters).

c) considering lower levels of SNR (60dB)

Also, what would be the deficit of the measurement if the 5th window shown in Fig. 6 would be excluded from the analysis, related to the calibration outcome of the PMU involved? 

Recent works point out the need of a better understanding on how PMUs behave during fast transients. Events with duration of a few cycles cannot be observed if one simply ignore the widows that contain the transients. If a PMU is calibrated with a system that cannot provide a fast and accurate response during a few cycles, one cannot know what to expect from the PMU.

In addition, the paper need a thorough proofreading   
  
  
  
Reviewer #2 (Required Remarks for the Author):   
  
The language is quite ok.   
The mathematics and explanations of the mathematics and tests are quite ok.   
The conclusions are also good.   
The problems lay in the problem definition, and reasons for the work.   
The proposed tests are for signals for which a PMUs response is undefined and as such a real calibration can not be done, since there are no requirements set in the PMU standard for these kinds of signals. In which situation/for what purpose do they propose/anticipate it to be used?

A test can still be valuable but not for calibration purposes, this should be reflected in the first section where reasons for the work is described. 

Further, the benefits of such a test is not very well described in the first section (while it is in the conclusion)   
In summary the first section lacks in clarity regarding the reason for and the practical use of the method proposed.   
  
The same responses to rev1 can be easily adapted/referred here.

Reviewer #3 (Required Remarks for the Author):   
  
(Note, due to the limitations in text formatting, mathematical symbols in this review are written in LaTex)   
  
Overview: Calibration of PMUs and PMU calibration systems is a very important topic and improvements in analysis techniques are essential for the technology to move forward since future requirements for PMU performance are expected to be more stringent than they are in the present standard. This paper is timely and important and it must be clear about what it can and cannot provide to the community.   
  
In the first paragraph of the introduction states: "Recent developments towards the calibration of PMUs for distribution grids demand lower uncertainty levels than the current systems, which were designed for the context of transmission grids [3]" This statement implies that the proposed method will provide higher uncertainty levels than existing methods. The statement must be substantiated or else state that future work is needed to determine if this method is more accurate. Accuracy is especially important in the determination of signal phase, which is assumed to be crucial parameter for distribution PMUs. 

This work improves the time resolution of \tau detection and provides one way to assess PMU calibration systems under step conditions. As distribution PMUs are subjected to poorer signal quality, their accuracy shall be tested during dynamic conditions. Under dynamic conditions, accuracy is usually worse than the ones obtained under steady state conditions, especially due to equipment behavior. This work intends to provide means of assessing PMU calibration systems during step signals.

In the forth paragraph: "...and sets the phasor estimates where the discontinuity occurs as those of obtained from the previous or following window." change: "those of obtained" to "those obtained"   
ok

Equation number 4 is skipped, equation 3 is followed by equation 5. Equation 4 appears on page 3 in section D and should be equation 14 once the numbering is corrected.   
ok

Following Figure 1, it is unclear what the author means by "intermediate phasor estimates". I think this refers to the phasor values during the rise time of the step itself. the step generally rises faster than the sampling rate so (5) and (6) can be used to find intermediate values between two samples. This is important to know as a reference value if the step occurs exactly coincident with a synchrophasor report but not exactly coincident with a sampled value. The equations work, however "T" and \tau are not the correct values to use. "T" should be "dt" and another symbol should replace "\tau" to denote the length of time following the sample time at which we are trying to interpolate the value. For example, if the sampling period "dt" is 1/5000 s and the step occurs half way between two samples then "\tau" is 1/10,000 s. "T" is used elsewhere in the paper to represent the total duration of the sampled window and \tau is the time from the beginning of the window until the step. Using these values in (5) and (6) would basically mean that the step rise time is the duration of the window. Using those values, (5) and (6) would only provide some kind of average value of amplitude or phase over the entire sampling window, which I fail to see as a useful metric. I recommend changing "T" to "dt" and providing a new symbol to represent the distance between the samples where the step actually occurred. 

The referred equations cannot provide any information during the rise time of the step. We are not trying to interpolate the samples. What we propose is an average value over the entire sampling window. It is a proposal to be used as a well defined reference phasor, to be compatible with TVE calculation, instead of using reference values from adjacent windows.

Equation 4 is mis-numbered (should be 14),

ok  
  
Top of page 5: The PMU standard does not state that synchrophasors must be obtained relative to the center of an analysis window. Synchrophasors may be obtained in any manner as long as the performance meets the requirements of the standard. 

Conclusion: Recommend mentioning that Levenburg-Marquadt initial parameter sensitivity should be studied in future work. When calibrating PMU calibration systems, actual parameters are not available to the calibrator calibration system. Some anecdotal testing has shown that due to local minima or possibly phase wrap issues, Lebenburg-Marquadt is sensitive to errors in initial phase error as small as 3 degrees: estimated parameters with a negative magnitude and phase error of pi resulted (which actually provides the same signal). Also recommend that future work be suggested to test sensitivity to \tau estimation when \tau of a magnitude step near or coincident with a zero crossing. The PMU standard says nothing about the required phase at which the steps may or may not occur but this and previous methods may not work when the step occurs at or near particular points in the phase, such as zero crossings.

We agree that in the case of poor estimates of the actual parameters this study should be extended to assess the behavior of the estimator when subjected to large errors in the initial guessing.

The sensitivity of tau estimation in special situations can be degraded with lower SNR than the ones related. However, the use of a more elaborated detector can be implemented to deal with these cases. For example, inserting a detector using instantaneous magnitude in conjunction with the instantaneous frequency can improve the detection performance.