Neural Network Compensated Microcontroller Based Frequency Synthesizer-Vector Voltmeter

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Abstract—**This work shows the development of an automated neural network compensation scheme for an originally developed microcontroller based frequency synthesizer-vector voltmeter (FSVV) system which uses the direct digital synthesis (DDS) and the synchronous detection technique. The compensator employed uses a neural network that was trained offline using real data acquired from the system to find the error and was checked online for various combination of input values.**

Keywords-Frequency synthesizer-vector voltmeter, Direct Digital Synthesis, microcontroller, neural compensation

I. INTRODUCTION

Vector voltmeters are used to measure simultaneously the magnitude and phase of an unknown voltage. We use a microcontroller based frequency synthesizer- vector voltmeter. This was indigenously developed [1] by employing direct synthesis (DDS) for the frequency synthesizer, using lookup tables and the vector voltmeter was designed to extract the in-phase and quadrature components of the fundamental of an unknown voltage, using synchronous detection technique. The actual implementation of the vector voltmeter system often suffers from the disadvantage of reduced accuracy in the system output, i.e., the magnitude and phase of the displayed voltage may differ quite significantly from the true magnitude and phase of the unknown voltage under measurement. This discrepancy in measurement arises due to the time lag between the signal generation and detection and the phase shift during signal conditioning. Thus the measured magnitude and phase of an unknown voltage can vary, with wide variations of circuit conditions/parameters and the frequency of measurement. For this, compensation of the output values is needed. We use a neural network based compensation scheme that maps the input frequency, measured voltage and phase to the error i.e. the compensation value of voltage and phase. At first ,a large dataset was obtained from real measurements of the FSVV instrument, under several experimental conditions, and the neural compensator was trained using the uncompensated FSVV readings and the corresponding true voltages under measurement. This trained neural compensator was implemented online to find the compensation on the measured magnitude and phase values of the voltage obtained.

II. FSVV MEASUREMENT

The system utilizes a PIC 18F4520 microcontroller which is a high-speed 40-pin plastic dual in-line package microcontroller, a programmable gain amplifier (MCP 6521), an MCP 3201 12-bit successive approximation type ADC, an externally connected 10-MHz quartz crystal. Though the indigenous system in [1] used a Lampex LG128641 128 × 64 graphic liquid crystal display for displaying, we interface the system with a computer. It is used both for denoting the input frequency, voltage as well as displaying the output voltage. The frequency synthesis or signal generation scheme is developed using DDS theory, where a digital frequency control word F of $(m + p)$ bits (m integer bits and p fractional bits) is used to determine the ROM lookup table (LUT) address. The output frequency of the synthesizer is f = F * $(f_c/2^m)$, where f_c is the clock frequency. Fig. 1 shows the scheme for signal generation using direct digital synthesis.

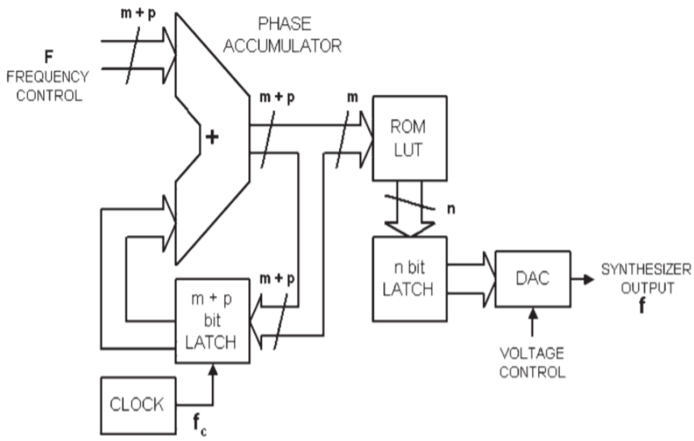


Fig. 1. Signal generation scheme employing DDS.

The measurement of voltage in vector form is carried out using the synchronous detection technique, which is popularly employed to extract fundamental of an unknown signal consisting of several harmonic components and some uncorrelated random components. The rms in-phase (I) and quadrature (Q) components of the fundamental of can be estimated as:

$$I = \sqrt{2} * \left[\frac{1}{T}\int_0^T x(t)\sin\big(w(t)\big)\,dt\right] \quad (1)$$
$$Q = \sqrt{2} * \left[\frac{1}{T}\int_0^T x(t)\cos\big(w(t)\big)\,dt\right] \quad (2)$$

where$T$ is the time period of the signal.

III. NEURAL COMPENSATION FOR FSVV SCHEME

The neural network compensator is developed to provide a three-input–two-output nonlinear function mapping:

$$[V_{m\_corr}, V_{p\_corr}] = F_{NN}\,(f, V_{m\_unc}, V_{p\_unc}) \quad (3)$$

where$f$ = excitation frequency, V_{m_unc} = uncompensated magnitude andV_{p_unc} = uncompensated phase determined by the vector voltmeter, V_{m_corr} = magnitude and V_{p_corr} = phase correction, to be provided by the compensator output, so that the compensated magnitude and phase closely approximate the true voltage under measurement . Fig. 2 shows the development of this compensator in the training phase, on the basis of a large training dataset acquired from the experimental setup for different and for outputs measured from different circuit configurations. Once trained, the vector voltmeter is implemented in real life, with the trained neural network being present in the computer.

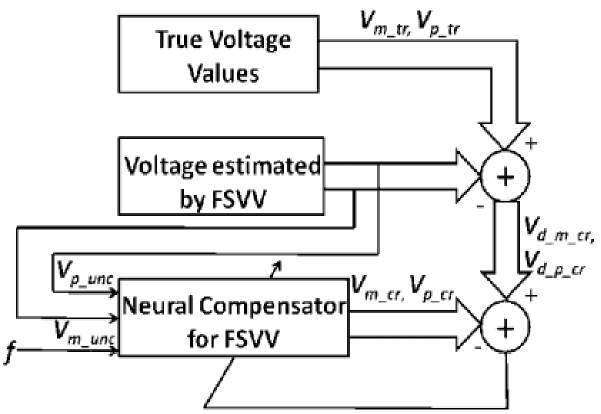


Figure 2. NN Compensator in training phase

IV. TRAINING AND EXPERIMENTAL RESULTS

To train the neural network, a large dataset was developed at first based on the experimental data output acquired from the uncompensated vector voltmeter. The outputs were taken for different circuit conditions. For each of these cases, the true value of the voltage magnitude and voltage phase was mathematically computed. These are the values that should have been attained ideally, but due to reasons mentioned previously, we find that there are large deviations in the recorded value from these. The output of the frequency synthesizer i.e. the software synthesized sine wave was used as a source and fed into an R–C series circuit.

The across the capacitance C (V_C) was separately measured by using the vector voltmeter module of the same FSVV instrument. The voltage output, both magnitude and phase was measured for a sine-wave source voltage peak-to-peak magnitude of 1.2 V. The frequency of the sinusoidal voltage was varied from 30 to 70 Hz (with a resolution of 10 Hz), while R was varied from 1 kΩ to 2kΩ with a gap of 0.2 kΩ while the capacitance varied from 0.5–1.0 µF (with a resolution of 0.1 µF). Varying these quantities in an orderly manner (i.e., for all possible combinations of each variable in their before mentioned range with their resolution steps), a data set containing 324 instances of data pairs, i.e., a matrix of 324 × 5 size, was prepared from these experiments.

Then the data instances were divided into two non-overlapping data sets, with 80% of the data kept in the training data set and the remaining 20% of the data in the testing data set.

The neural network used has 3 inputs and 2 outputs with 2 hidden layers. The hidden layers have 10 and 5 nodes respectively .There is a non linear activation layer namely the ReLu layer between the hidden units.

Then, the NN compensator was trained offline, employing gradient descent backpropagation, using the training data set. The following curve [Fig 3] shows how the loss, which was taken as a MSE loss, decreases with each epoch. It was observed that the network converged in 150 epochs.

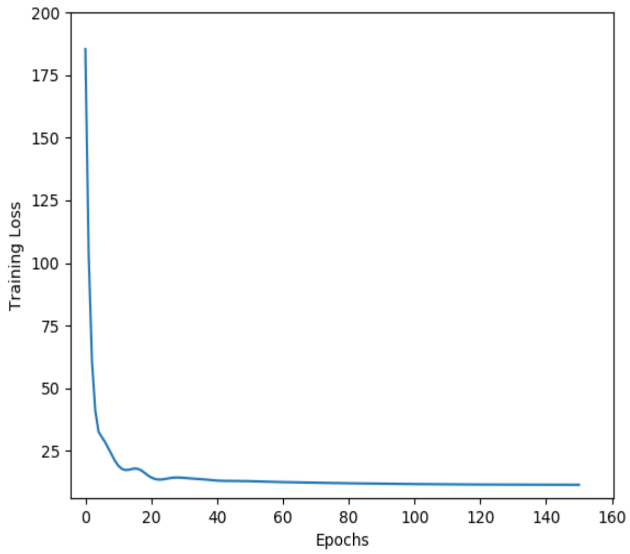


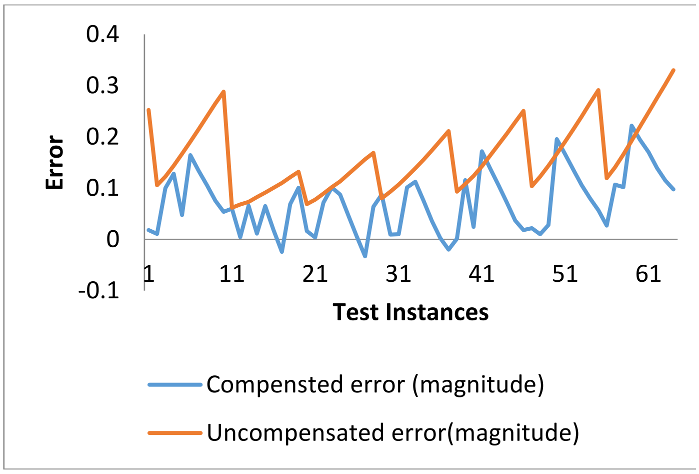
Fig 3. Training loss curve

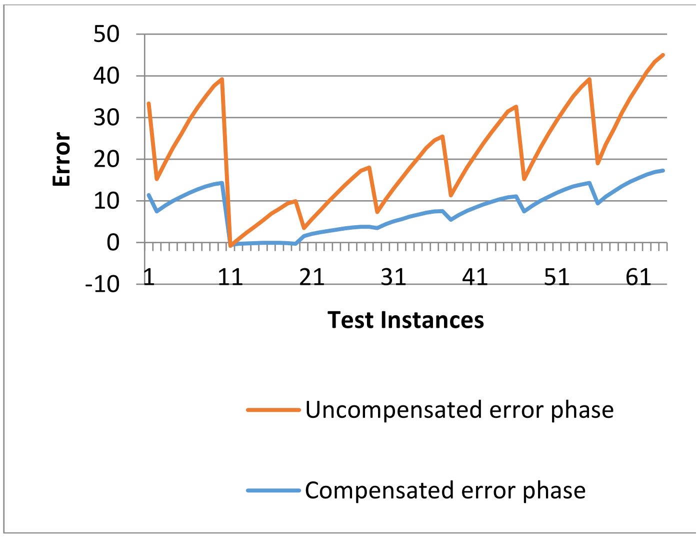
Once the training was successfully completed, the performance of the compensator was first tested using the testing data set offline, in simulation. Table I shows the performance comparison of the compensated and the uncompensated values from the voltmeter in terms of different statistical measures like mean, standard deviation..

TABLE I. PERFORMANCE COMPARISON OF NN-COMPENSATED AND UNCOMPENSATED VOLTMETERS IN TERMS OF DIFFERENT STATISTICAL MEASURES

Error	***Uncompesated-d Values***		***Compensated Values***	
	Mag.	***Phase***	***Mag.***	***Phase***
Mean	0.162	13.44	0.126	7.86
Maximum	0.325	27.74	0.257	17.26
Std. Dev.	0.067	7.044	0.054	5.118

The following graphs show a variation of error for the compensated and uncompensated magnitude and phase.





It can be seen that the proposed compensated vector voltmeter was able to enhance the performance of the uncompensated vector voltmeter significantly.

CONCLUSION

A neural network compensator has been designed for the FSVV scheme which uses DDS and synchronous detection technique. It is seen that the compensator shows good performance in providing compensations for the magnitude and phase values.

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