Simulation of Power System Transient Disturbances in MATLAB

Waqar A. Adil, Aslam P. Memon, M. Usman Keerio, Ahsan Zafar

Abstract----The power system transients (PST) can cause serious disturbances in the reliability, economy and safety of the power system network. The transient signals are the short term duration for which the frequencies as well as varying time information are compulsory known for the analysis purposes. These disturbances occur for few cycles, which are difficult to be identified and classified by digital measuring and recording instrumentations.

For the analysis and detection of PST disturbances (PSTDs) different algorithms have been developed to generate their accurate waveforms. This paper discusses and develops the different simple and efficient simulation models of PST waveforms with spectral and magnitude specifications as guided by IEC and IEEE-1159 through the numerical data. Matlab/Simulink has been utilized for the simulation of different types (like oscillatory and impulse transients) of PST to prove the applicability, validity and accuracy for the detection and analysis of PSTDs.

Index Terms — Impulse, Matlab/Simulink, Numerical model, Oscillatory, Power System Transients, , Simulation.

I. INTRODUCTION

A. Power System Transient (PST):

Nowadays, the prime focus of industries is in the field of control engineering. It concerns mainly to monitor a system continuously, detect the occurrence of fault and identify the type of fault. This is mainly done to protect the system and prevent any possible damages [1-3].

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A. Types:

Transients are classified as: oscillatory transient, the most common type caused due to the switching on secondary systems, radiated noise, lighting induced ringing and electronic equipment having impacts of high rate of oscillations with low voltage power supplies failure and short duration voltage disturbances. Impulse transient caused due to capacitor switching and tripping of adjustable speed drives (ASDs) systems having main impacts of magnification of voltage at customer capacitors [1-6].

In Electrical Power Systems (EPSs) a transition from one steady state condition to next steady state condition is known as transient. This change in steady state condition involves the changes not only in magnitudes but also in shape, and aperiodic in nature. In every proposed PST analysis work, the core part of the methodology is to have a transient signal, either by real time recording instruments or by simulation techniques.

It is very expensive to observe PST waveforms analysis and detection with transient events experimentally. One way to do so is to simulate power system models to observe transient events by predicting source values, circuit parameters and loading conditions. In [7-9] the authors presented mathematical equations to numerically model and generate transient events but it lacks in a sense that it used single exponential model to simulate impulses, and presented only µsec impulsive transient. Amany El-Zonkoly in 2004 [10] has proposed a mathematical relation for transient generator, though no results were presented about transients except for sag disturbances. In [11] the various standard waveforms like EN61000-4-4, EN61000-4-5, RTCA DO.16OD, ANSI C62.41, and 1S07637 have been examined but focused on transient test waveforms of impulsive nature type signals.

This paper proposes simulation of all the categories of PST as defined by IEC and IEEE-1159 standards, using numerical modeling in MATLAB software.

Voltage disturbances less than sags or swells are classified as transients and are caused by sudden variations in electrical power system [12].

Transient falls into disturbance class of power quality issue apart from other classes like waveform distortion, unbalance and fluctuation. Disturbance has a meaning of deviation from the steady state waveform that is non-repetitive.

If we go into physical interpretation of the problem, we come to know that the transient disturbances are produced due to ability of different components and elements of power system to store energy. This leads to transient disturbances with complex characteristics such as non-stationary, non-periodic, impulse superimposed, fast decaying and short duration components [13].

The two major sources of transients in a power system are [14]:

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1) Environment-produced transients that are the direct or indirect effect of lightning strikes.

2) Appliance-produced transients resulting from the operation of a mechanical or semiconductor switch; inrush currents during transformer energization and the effects of transformer core saturation; or faults within a piece of equipment or within the power system.

3) Table. I show the categories of transients in accordance with their responsible sources.

TABLE I: Categorization of transient based on wave shapes, causes and origin

Waveform based classification	Event based classification	Origin
Impulsive Transient	Lightning	Environment-produced
Oscillatory Transient	Line or cable switching, Transformer energization, Faults	Appliance-produced

II. SIMULATION TECHNIQUES

Every simulation work of signals starts with the question, what standards are to be followed? After answering this question the next methodological stage is implementation of the selected standards. This section presents the adopted standards, mathematical equations to implement the standards to generate PST, and some basic simulation specifications like sampling frequency, simulation time, and time samples for PST.

A. Adopted Standards

Two recognized international bodies in the field of Power quality standards are International Electrotechnical Commission IEC, and IEEE. IEC classification divides transients into two groups of unidirectional and oscillatory. The IEEE 1159 contains several additional terms related to IEC terminology [6]. Table. II shows IEEE-1159 categorization of transients and provides information regarding typical spectral content, duration, and magnitude for each category of PST [6].

TABLE II
CATEGORIES AND TYPICAL CHARACTERISTICS OF POWER SYSTEM TRANSIENTS DEFINED IN IEEE 1159

Category	Typical spectral content	Typical duration	Typical voltage magnitude
Impulsive			
Nanosecond	5-ns rise	<50 ns	---
Microsecond	1- s rise	50 ns–1 ms	---
Millisecond	0.1-ms rise	>1 ms	---
Oscillatory			---
Low frequency	<5 kHz	0.3–50 ms	0–4 pu
Medium frequency	5–500 kHz	20µs	0–8 pu
High frequency	0.5–5MHz	5µs	0–4 pu

A. Mathematical Equation

We must keep one thing in our mind that we are going to produce a wave whose particular section will be normal and remaining would be deviated from normal. Normal part will be represented by sine function, to represent $\sin(t)$ power system waveform, and abnormal part will be $a(t)$ oscillatory or impulsive function as shown in (1).

$$V_{PQ} = \sin(t) + [a(t)] \quad (1)$$

Figure.01shows the block diagram of to generate the PST waveforms from equation (1).

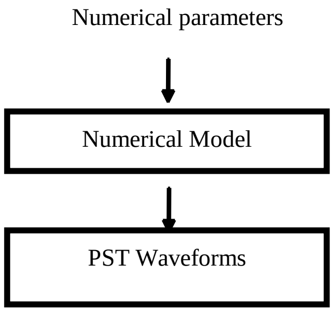

Fig.01 block diagram of to generate the PST waveforms

In other words we are adding two waveforms graphically with transient element duration less than the normal waveform part. Being in above mentioned constraints, a unit step function helps us in adding such wave shapes. The unit step function ensures the occurrence of transient in normal wave by its step time.

After sorting out the graphical aspects of transients, next question that arise is how should we write transient element mathematically? This question can be easily answered with the help of transient response of a general RLC circuit. If we consider power system with lumped parameters as Resistance (R), Capacitance (C), and Inductance (L), then for any series or parallel configurations the mathematical model for that circuit will be a second order differential equation. Equation (2) it is suitable to go through the transient response of this circuit to find the nature of the additive event function in.

The general form of differential equation for RLC circuit is:

$$\frac{dv}{dt^2}^2 + a_1\frac{dv}{dt} + a_2 v = 0 \quad (2)$$

The solution of (2) with some initial condition and real roots for over-damped and critically damped conditions contains double exponentials as shown in (3).

$$v = Ae^{s_1 t} + Be^{s_2 t} \quad (3)$$

For zero initial condition and under-damped case and with complex conjugate roots, the solution is given by (4).

$$v = e^{\sigma t} B \sin \omega t \quad (4)$$

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Oscillatory transient can be modeled as shown in (5), where is the t_s transient starting time, a is the transient magnitude, is the f_{osc} frequency of the transient element and ρ is responsible for the transient settling time.

$$V_A = \sin(2\pi f_1 t) + [u.a.\sin(2\pi f_{osc} t_S).e^{-\rho t_S}] \quad (5)$$

Impulsive transient can be modeled using double exponential functions shown in (6), where t_S is the transient starting time, a is the impulse magnitude which can be obtained by some adjustments in actual value to compensate interaction between two exponentials. The rise time is controlled by β and fall time by α.

$$V_A = \sin(2\pi f_1 t) + [u.a.(e^{-\alpha t_S} - e^{-\beta t_S})] \quad (6)$$

A. Simulation Period and Sampling Frequency

For generation as well as analysis of PST waveforms except the low frequency disturbances a fast sampling rate is required. According to Nyquist theorem (7), the sampling frequency should be at least twice the highest frequency contained in the signal [15].

$$f_s \geq 2 f_c \quad (7)$$

The time step between two time samples can be found from (8)

$$\frac{1}{f_s} = T \quad (8)$$

The total data points (time samples) are found from the relation (9)

$$\frac{t}{T} = n_T \quad (9)$$

We can conclude that if we increase the simulation period or run-time or number of cycles we shall increase the number of time samples. Slow disturbances (milliseconds) give less number of time samples when simulated for greater number of cycles as compared to fast disturbances (μsec and nsec) when they are simulated for lesser number of cycles.

III. SIMULATION RESULTS

A. Transient Disturbance Only

1) First type of impulsive transients i.e. of Milliseconds characteristics is simulated with values 0.1msec×2msec to 0.1msec×4msec.

2) Standard Lightning impulses are simulated with 1μsec×50μsec, 1.2μsec×40μsec, and 1.2μsec×40μsec.

3) Nanoseconds impulses are simulated with 4nsec×30nsec to 4nsec×50nsec.

4) Low frequency oscillatory transients with frequency ranging from 500 Hz to 1200Hz, and of duration 30 to 50 milliseconds.

5) Medium frequency oscillatory transients with frequency 0.1 MHz to 0.3 MHz and having duration 20μsec.

6) High frequency oscillatory transients having frequency 1 MHz to 1.7MHz and 5μsec duration.

The numerical parameters used to generate the transient disturbance are shown in Table III.

TABLE-III
Impulse Transient waveform constant

category	spectral content		fall constant	rise constant
	rise	duration		
Impulsive transient	4-ns rise	30-50 ns	9800000	990000000
	1μs-1.2μs rise	40μs-50μs	14000	4400000
	0.1-ms rise	2ms-4ms	180 – 370	60000

TABLE-IV
OSCILLATORY TRANSIENT WAVEFORM CONSTANTS

CATEGORY	SPECTRAL CONTENT		SETTLING RATE
	FREQUENCY	DURATION	
Oscillatory transient	<5 kHz	0.3–50 ms	90-200
	5–500 kHz	20μs	100000
	0.5–5MHz	5μs	800000

Fig. 02 to Fig. 07 is depicting a transient disturbance of various types.

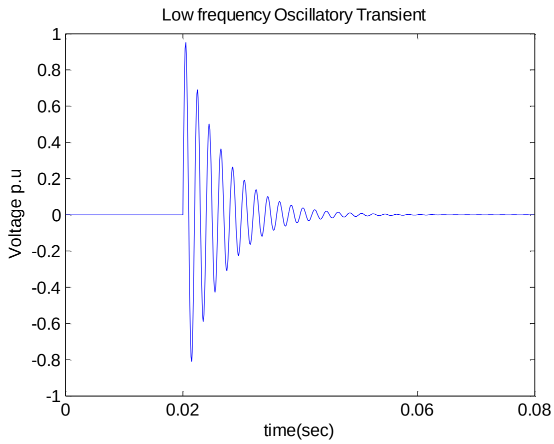

FIGURE 2 OSCILLATORY TRANSIENT DISTURBANCE SHOWING DECAY IN 40MSEC

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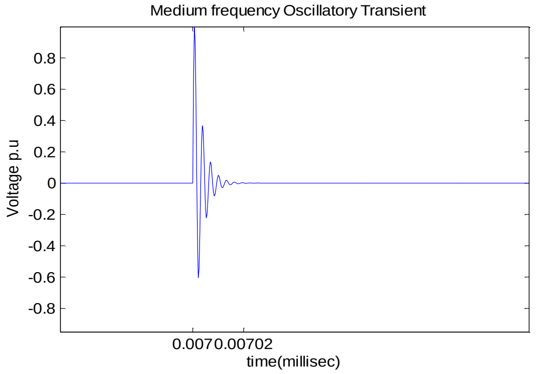

FIGURE 3 MEDIUM FREQUENCY TRANSIENT OSCILLATIONS FROM 0.007 MSEC TO 0.00702 MSEC

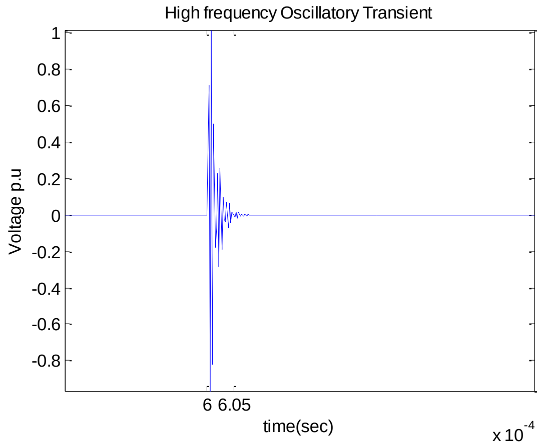

FIGURE. 4. HIGH FREQUENCY TRANSIENT DISTURBANCE FROM TIME 6×10-4 SEC TO 6.05×10-4 SEC

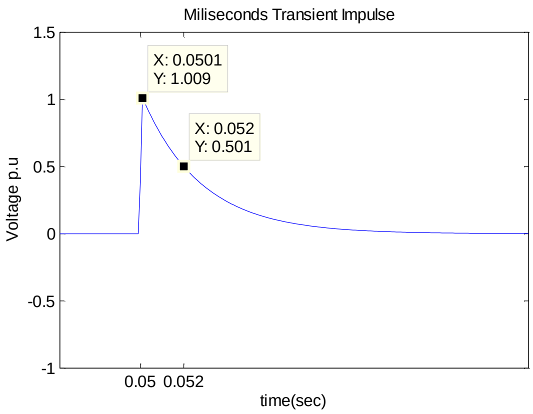

Figure 5 Impulse of Milliseconds rise. Starts to rise from 0.05sec, reaches its peak at 0.052sec and decays half of its value at 0.052 sec

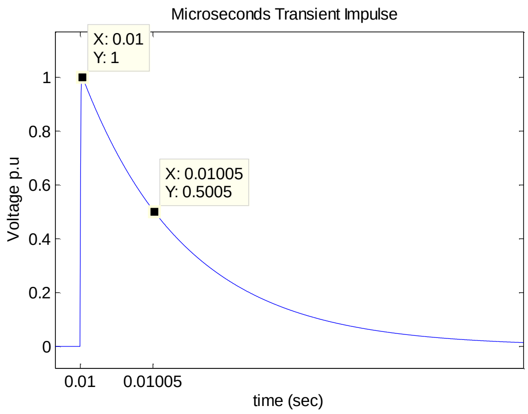

Figure 6 Impulse of Microseconds rise. Starts to rise from 0.01sec, reaches its peak at 0.01sec and decays half of its value at 0.01005 sec

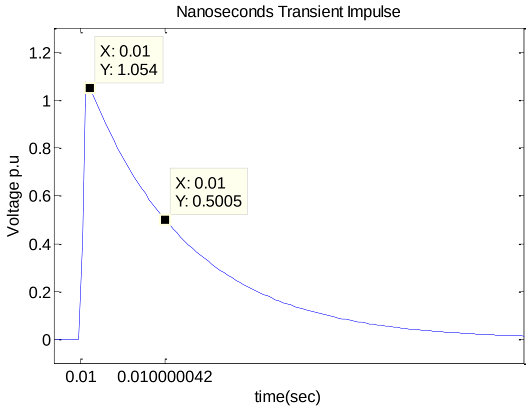

Figure 7 Impulse of Nanoseconds rise. Starts to rise from 0.01sec, reaches its peak at 0.01sec and decays half of its value at 0.010000042 sec

A. PST Disturbances superimposed on Power system voltage

Table V shows simulation period based on the time samples resulting from sampling rate.

TABLE V. PST Waveform simulation parameters

PST WAVEFORM	SAMPLING RATE	SIMULATION PERIOD	TIME SAMPLES
Low frequency	10 kHz	0.2 sec	2000
Medium frequency	1 MHz	0.02 sec	$20x10^3$
High frequency	4 MHz	0.02 sec	$80x10^3$
Milliseconds	10 kHz	0.1 sec	$1x10^3$
Microseconds	5 MHz	0.02 sec	$100x10^3$
Nanoseconds	250 MHz	0.02 sec	$5x10^6$

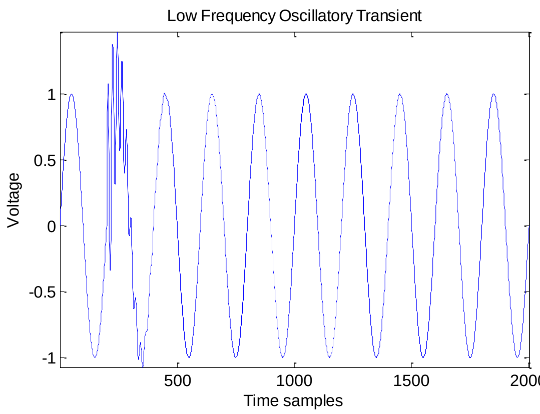

FIGURE 8. LOW FREQUENCY TRANSIENT DISTURBANCE FOR 10 POWER CYCLES GENERATING 2000 TIME SAMPLES, WITH SAMPLING FREQUENCY OF 10 KHZ

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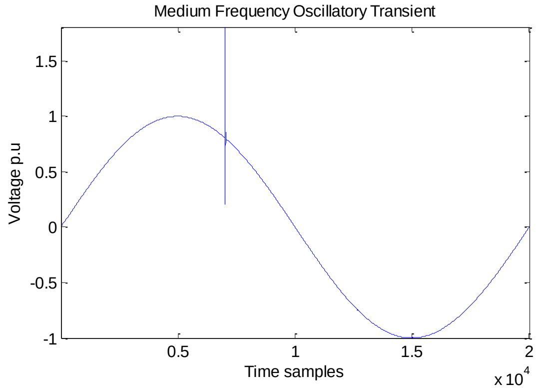

Figure 9. Medium frequency transient disturbance for one power cycle generating 20000 time samples, with sampling frequency of 1 MHz

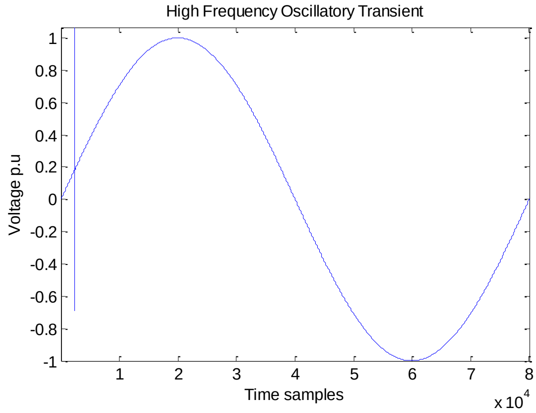

Figure 10. High frequency transient disturbance for one power frequency cycle generating 80000 time samples, with sampling frequency of 4 MHz

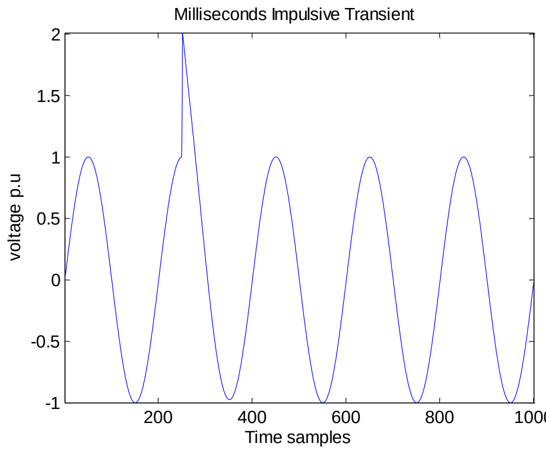

Figure 11. Millisecond impulse transient disturbance for 5 power cycles generating 1000 time samples, with sampling frequency of 10 kHz

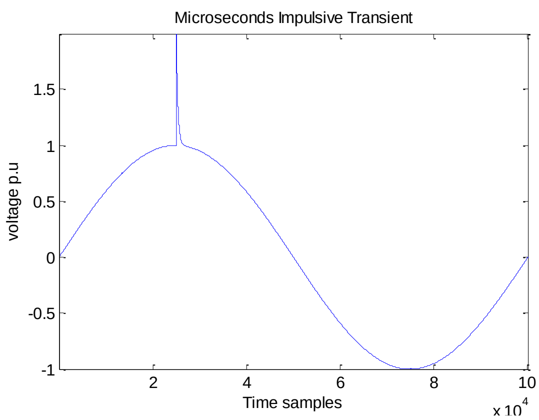

Figure 12. Microseconds transient disturbance for one power frequency cycle generating 100000 time samples with sampling frequency of 5 MHz

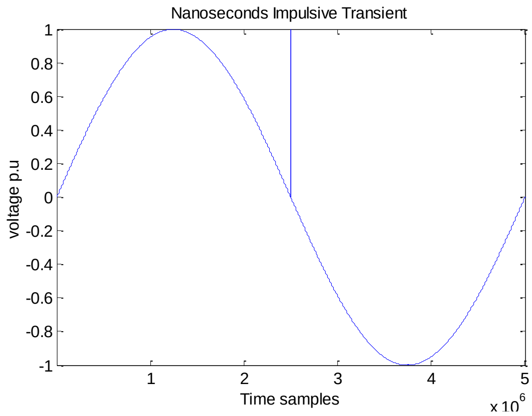

Figure 13 Nanoseconds transient disturbance for one power cycle generating 5000000 time samples with sampling frequency of 250 MHz.

IV. CONCLUSIONS

Simulation based analysis and detection of power system transients with defined standards of IEC and EEE-1159 have been discussed, successfully implemented and concluded using Matlab. It is observed that theses six simulated signals of PST with increased sampling rate produce greater number of time samples causing more computational time, thereby forcing to minimize number of power frequency cycles to be simulated. It is concluded that the numerical model approach to generate transient waveforms is simple and suitable and accurate for further investigation of power system transients like their deep investigation, characterization and classification. Further work in this area is to implement artificial intelligence with time-frequency or phase difference domain feature extractions is required which is the part of this research in future.

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