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Application of GPS for Sag Measurement of Overhead Power Transmission Line

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Abstract: Overhead conductor sag may be measured by different methods. In the paper measurement of sag of 66KV power transmission line under shut down conditions at no wind load using standard handheld GPS receiver BT 359 has done. The real time direct measurement of overhead conductor sag is needed for the operation of power transmission system. The measurement of conductor tension, temperature and ambient weather conditions are not required to monitor in this method. The digital signal processing (DSP) techniques is used to get better accuracy of GPS measurements. The Least Square Parameter Estimation (LSPE) method for the error estimation of GPS measurements is also incorporated.

Keywords: Global Positioning System, MATLAB, Power Transmission System, Digital Signal Processing, Least Square Parameter Estimation, NMEA0183.

1. Introduction

In power transmission system, overhead conductor forms its backbone. Conductor sag plays an important role in mechanical designing of transmission lines. Traditionally overhead conductor sag is measured by using indirect methods for current rating. The commercialized technique for the measurement of sag uses conductor surface temperature, which is to be measure by mounting an instrument directly on line and conductor tension is measure at the insulator support points [1]. These two parameters are used to calculate the conductor sag.

Real time direct measurement of conductor sag is needed for operation of power transmission system without requiring measurement of conductor tension, temperature and ambient weather conditions. The power system operation and reliability has improved by continuously regular monitoring of overhead conductor sag. The overhead conductor sag directly relates to the temperature of conductor. Moreover measured value of conductor sag helps in improving the reliability of the system. The available extra current capacity of transmission line [1, 2] can be computed indirectly. In fact the current capacity of transmission line depends on the ambient temperature, wind speed, wind direction, incident solar radiation, physical characteristics, and conductor configuration/geometry. The overhead line conductor loading capacity may be determined by static or dynamic method. The static method requires the knowledge of worst-case weather conditions while dynamic method requires online actual weather conditions.

This paper describes the use of GPS based system for real time measurement of sag in an overhead power transmission lines. Real time sag measurement of overhead line is used for the purpose of knowing conductor clearance so that mandatory clearance does not get violated.

2. Global Positioning System

The Global Positioning System GPS consists of 24 satellites in medium earth orbit at an altitude of 20,200 km with an orbital inclination of 55 degree [3]. The orbits of 24 GPS satellites are in such a way that at anytime, anywhere in the world GPS receiver can pick up signals from at least four satellites. The GPS system operated by U.S Air force from GPS master control station (MCS) at Falcon Air force base in Colorado Springs, Colorado. GPS satellites transmit two signals at different frequency bands L1 and L2. The L1 band frequency

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carrier (1575.42MHz) is modulated by modulo 2 sum of 1.023Mbps PN sequence called coarse/acquisition (C/A) code and navigation message of 50bps. It also carries precise (P) code as Quadrature modulation. The L2 band frequency carrier (1227.6MHz) is modulated by modulo 2 sum of 10.23Mbps PN sequence called precise (P) code and navigation message of 50bps [3, 4]. The L1 frequency band is used in civilian applications while the L2 band is used for military applications. The GPS transmission has at very low power strength and about 90-120dbm [4]. A GPS receiver at given location determines its location by analysis of signal level received from GPS satellites. Thus, a GPS receiver gives user's latitude, longitude and altitude. Typical GPS receiver has an accuracy of 20m-100m, which is appropriate for its applications in power system. There are two approaches of GPS used to increase its accuracy i.e. Differential GPS (DGPS) and Wide Area Augmentation System (WAAS). The accuracy of position measurements using the GPS receiver depend on various factors such as type of measurement made, ionospheric and tropospheric conditions, government inserted error for security measure, number of satellites in view, receiver equipment used, digital signal processing of the received signal, reflection of signals, and other factors. The table1 show sources of errors in the GPS altitude measurements [4, 5].

In order to improve the accuracy of GPS receiver, Differential GPS receiver (DGPS) may be used. In this DGPS receiver, there are two GPS receivers one is called base (primary receiver) and the second one rover (secondary receiver). The position of base station receiver is already known in advance. This receiver calculates its position also from GPS satellite data and then compare with its known position, Difference between these two is GPS signal timing error. The base station transmits this correction signal to rover station receiver using communication link. Then rover station receiver applies this error correction code to its position and timing measurements [3]. The main advantage of Differential GPS receiver is higher accuracy at the cost of two receivers and corresponding communication link between base and rover receivers.

Error Sources	**Approximate errors(m)**	
	Standard GPS	**Differential GPS**
Selective Availability (SA)	30.0	0.0
Ionospheric Variations	5.0	0.4
Inaccurate Orbital Path	2.5	0.0
Satellite Clock	1.5	0.0
Multipath Signal Error	0.6	0.6
Tropospheric Variations	0.5	0.2
Receiver Noise	0.3	0.3

Table 1. GPS Error Sources and their Contribution

3. Overhead Conductor Sag measurement using GPS (Experimental Setup)

The figure 1 shows proposed basic set up for measurement of overhead conductor sag in the 66KV NH3-PALLA power transmission line, Faridabad (Haryana), India under shut down conditions i.e. at no load.

The basic configuration of the system for the proposed GPS based sag measurement in an overhead power conductor is shown in figure 1. It consists of:

- Bluetooth GPS receiver BT359
- Laptop / PC
- Bluetooth device compatible with GPS receiver BT359
- NMEA/GPS data logging software (GPS Logger 3.0.25)

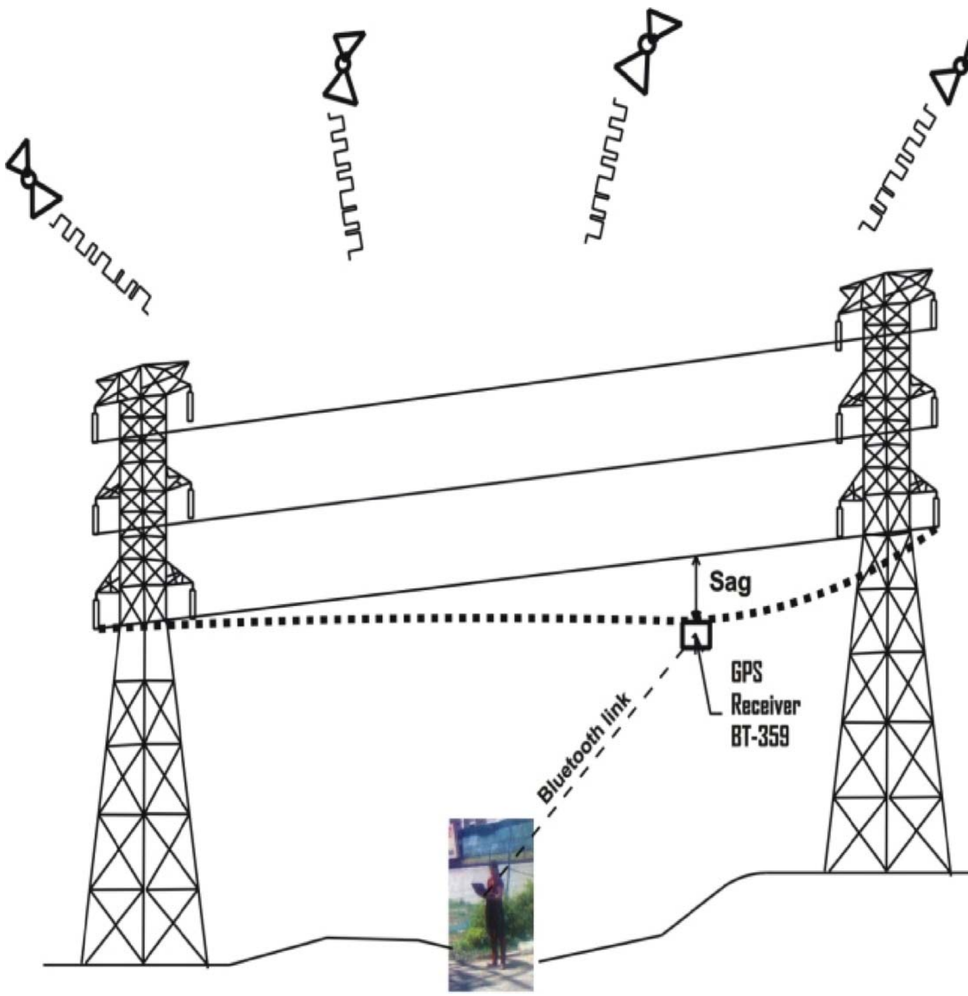

Figure 1. Basic GPS configuration for Conductor Sag Measurement

A selected number of experiments have been performed under shut down condition at no wind load on 66KV NH3-PALLA power transmission line, Faridabad, Haryana (India). The GPS data has been collected for approximately 350s. The lowermost single phase of line section is considered to perform experiments. The GPS relevant information is transferred in standard NMEA0183 sentences from GPS receiver to the laptop over Bluetooth link. Data is processed by using GPS software “GPS Logger 3.0.25” as shown in fig. 2[8].

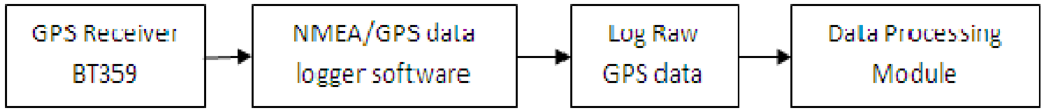

Figure 2. Conceptual Representation of GPS data logging

The obtained data gives the information of GPS receiver position in the form of latitude(x), longitude(y) and altitude (z). But our main concentration for sag measurement in overhead conductor is to measure the altitude information. Next challenge is to reduce error in GPS altitude measurements using data processing technique such as Least Square Parameter Estimation. The Altitude obtained by GPS receiver is above mean sea level. Also the altitude of conductor has been measured physically from the earth and the distance of earth from mean sea level is added to it. It gives the actual value of the conductor altitude for the estimation of error. It is required to take GPS altitude measurements at 2-3 places to reduce error in raw GPS altitude measurements at mid span. The GPS altitude measurements have been taken at mid span ant its nearby places (.1m towards left and .2m towards right). An average of approximately 350 reading has been taken at each place. From these GPS altitude measurements taken at three places, more accurate altitude measurements are used as controlled data in the LSPE method used to obtain best estimate of raw GPS altitude measurements at mid span. It has been reported by major GPS manufactures that improvement in accuracy within centimeter error range can achieve with a Differential Global Positioning System (DGPS) receiver.

4. Digital Processing of GPS Data

The pseudo range signals from GPS satellites has been digitally decoded, converted to pseudo range data and solved for position and time at the receiver. Various error sources as shown in Table1 such as ionospheric and tropospheric delays, multipath effects and dilution of precision (DOP) etc. affect accuracy of GPS measurements. Thus an attempt is made to improve accuracy of raw GPS altitude measurements for overhead conductor sag. A module has been developed in MATLAB programming environment to process observed GPS altitude measurements to obtain best estimate of GPS altitude measurements for particular time instance. Various signal-processing methods such as Bad Data Identification, Least square parameter estimation (LSPE) and Wavelet analysis may be used as post processing technique to further improve the accuracy of raw GPS altitude measurements. But in this paper Least square parameter estimation (LSPE)) method has used for the error estimation of GPS measurements for improvement of accuracy.

A. Least Square Parameter Estimation (LSPE)

This method has been used so as to improve the accuracy of raw GPS altitude measurements taken directly on overhead conductor of 66KV power transmission line, Faridabad (Haryana) India in absence of HV environment. This method is based on the utilization of measurements of the altitude position taken from the physical process to obtain parameter vector. Here the vector z is the measured altitudes using GPS. For knowing the nonlinear behavior of the error, the LSPE may be formulated as:

$$\hat{z}(n) = a0 + Az(n) + Bz^2(n) \tag{1}$$

Where

$\hat{z}(n)$: Sampled Estimated GPS altitude measurements at certain time.

$z(n)$: Sampled reading at certain time that gives the estimation of the corresponding altitude measurements of conductor.

For set of three exact places using the set of raw GPS altitude measurements, the above equation can be written in matrix form as:

$$Z_{known} = X\Theta \quad (2)$$

Where

Z_{known} : Set of actual altitude of three places.

$\Theta = [a0 \;\; A \;\; B]^T$

This Θ may be determined using the measurements corresponding to actual altitude of conductor. Therefore, the parameters $[a0 \;\; A \;\; B]$ may be determined using the Moore-Penrose pseudo inverse of the matrix X [6-7]. Hence these parameters are used to get estimated GPS altitude measurements at mid span of 66KV power transmission line.

5. Results and Discussions

Programming in MATLAB software has been done to obtain these results. The figure3,4 & 5 show data taken on 66KV NH3-PALLA power transmission line, Faridabad, Haryana (India) using GPS based overhead conductor sag measuring instrument and actual altitude of conductor at mid span and its nearby places (.1m towards left and .2m towards right). The deviation of raw GPS altitude measurements from actual altitude of conductor is error in these observed GPS altitude measurements which can be seen in following figure 3, 4 & 5. Out of these GPS altitude measurements taken at three places, GPS altitude measurements taken at place .1m towards left and .2m towards right from mid span are more accurate and used for estimation of error in LSPE method.

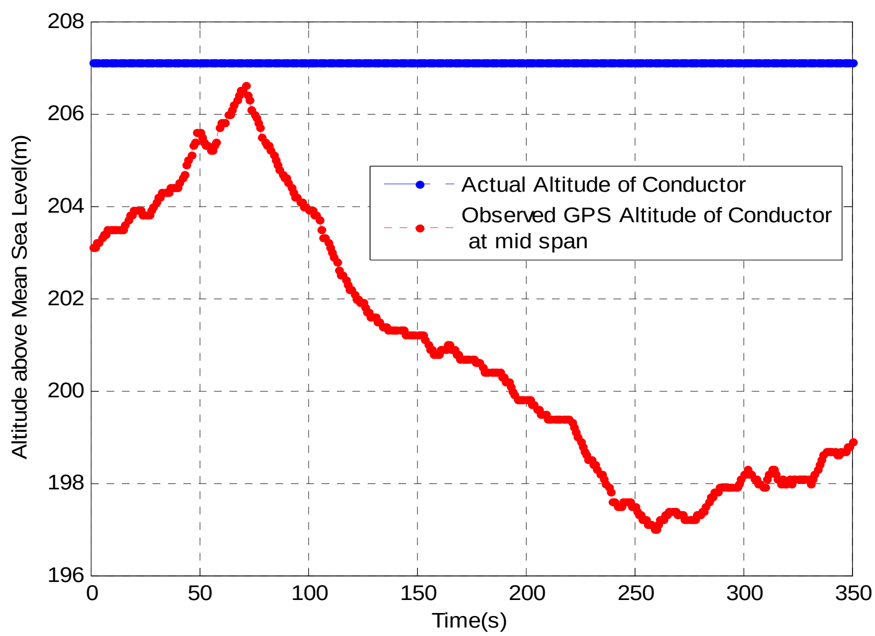

Figure 3. Comparison of Actual Altitude of Conductor and Observed GPS Altitude Measurements at mid span

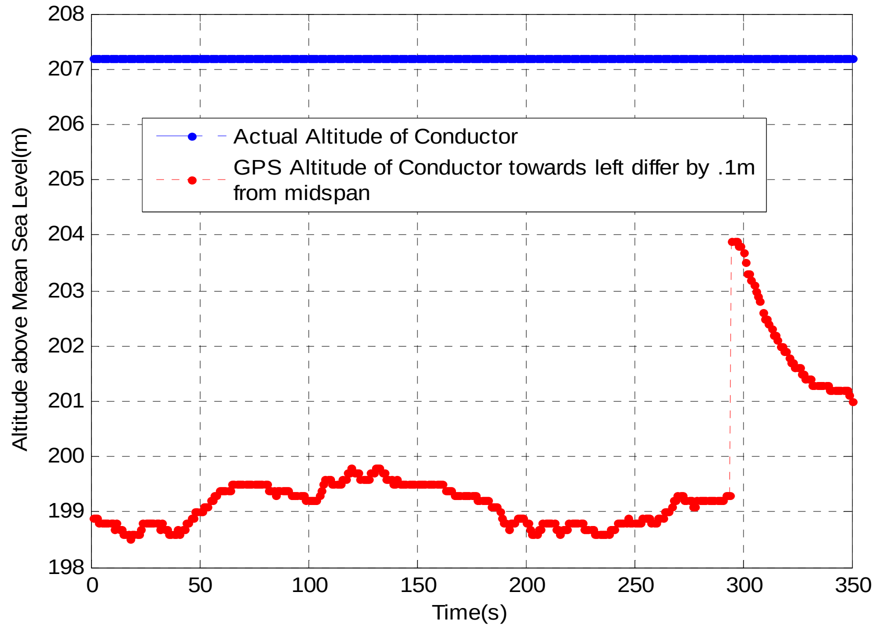

Figure 4. Comparison of Actual Altitude of Conductor and Observed GPS Altitude Measurements taken at place differ by .1m towards left from mid span

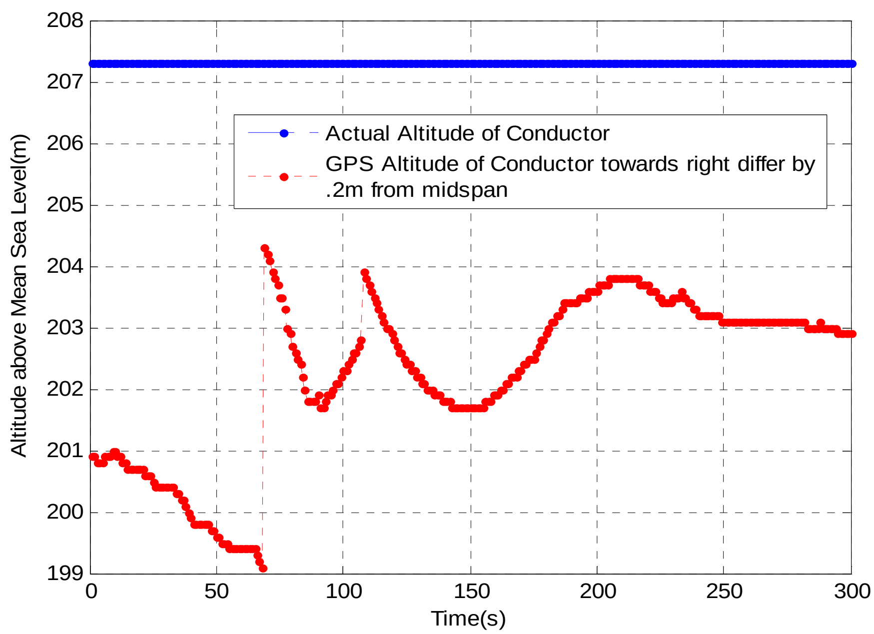

Figure 5. Comparison of Actual Altitude of Conductor and Observed GPS Altitude Measurements taken at place differ by .1m towards left from mid span

Observed GPS altitude measurements have been processed to reduce error in these measurements using LSPE method. The error in these raw GPS altitude measurements at mid pan has been reduced using LSPE method as can be seen in figure 6. Furthermore accuracy of

GPS altitude measurements is more important to evaluate sag of power transmission line. Thus LSPE method may be used to process observed GPS altitude measurements to get better accuracy of sag measurements of overhead conductor in power transmission line Thereafter we get estimated GPS altitude measurements close to the actual or true measured values as can be seen from figure 6.

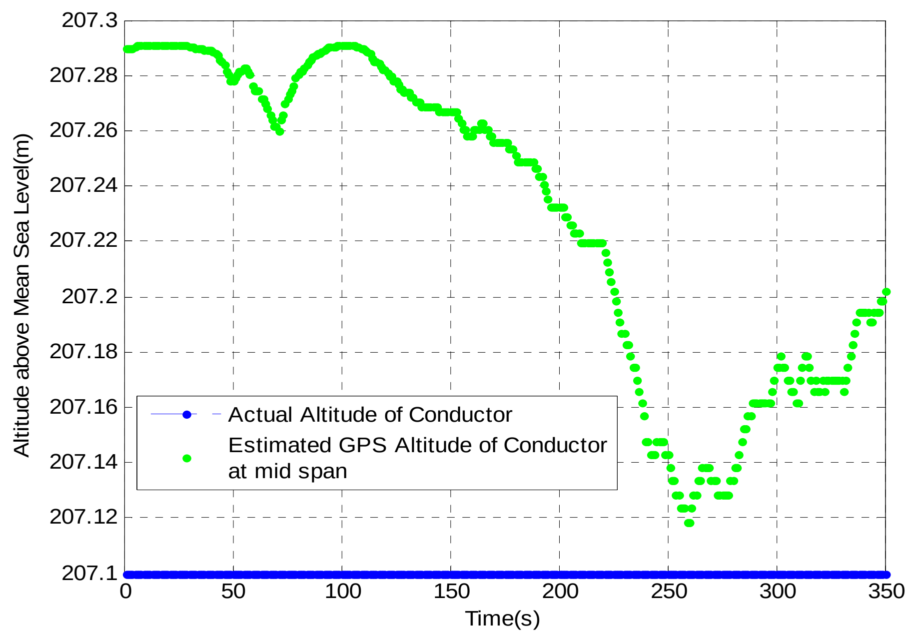

Figure 6. Comparison of Actual Altitude of Conductor and Estimated GPS Altitude Measurements

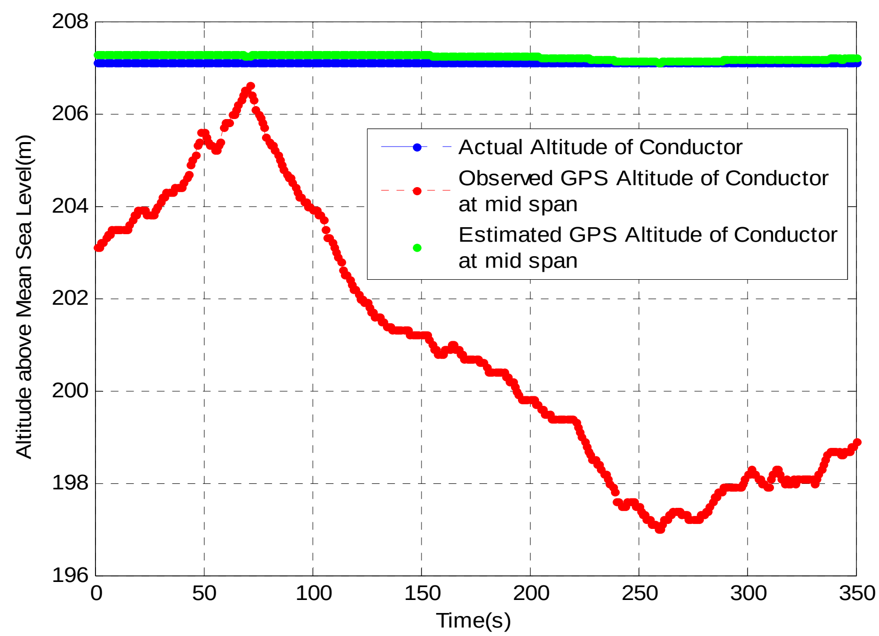

Figure 7. Comparison of Actual Altitude of Conductor, Observed and Estimated GPS Altitude Measurements at mid span

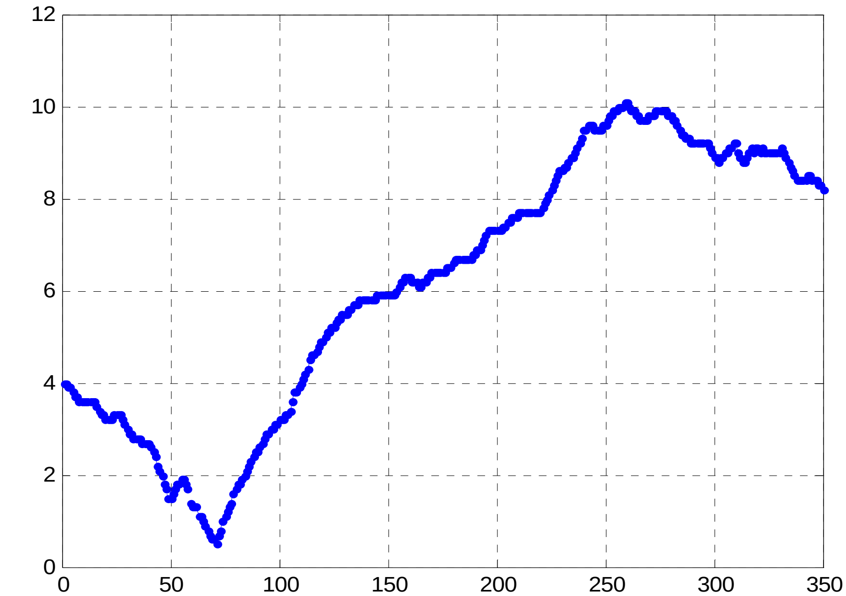

Figure 8. Error Analysis for Observed GPS Altitude Measurements

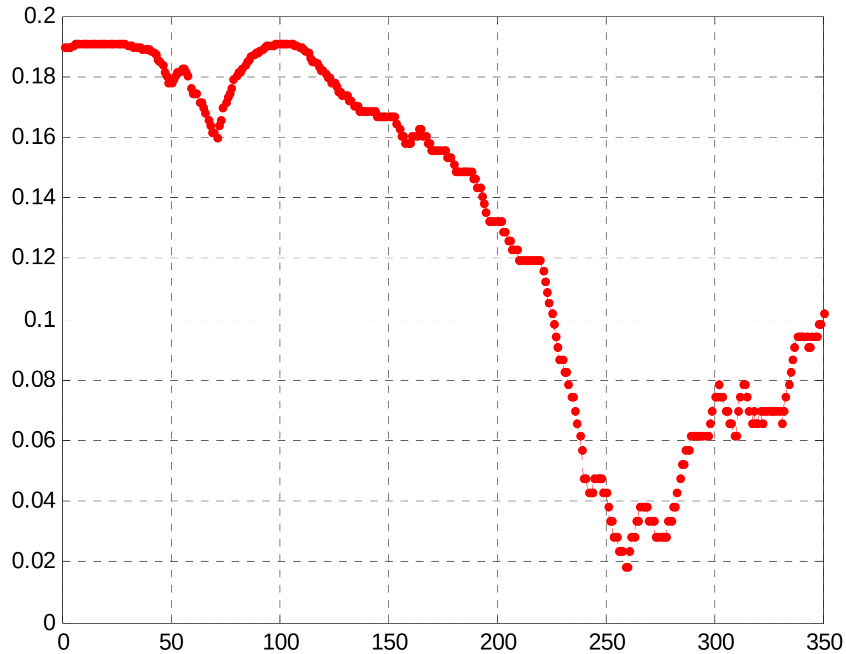

Figure 9. Error Analysis for Estimated GPS Altitude Measurements

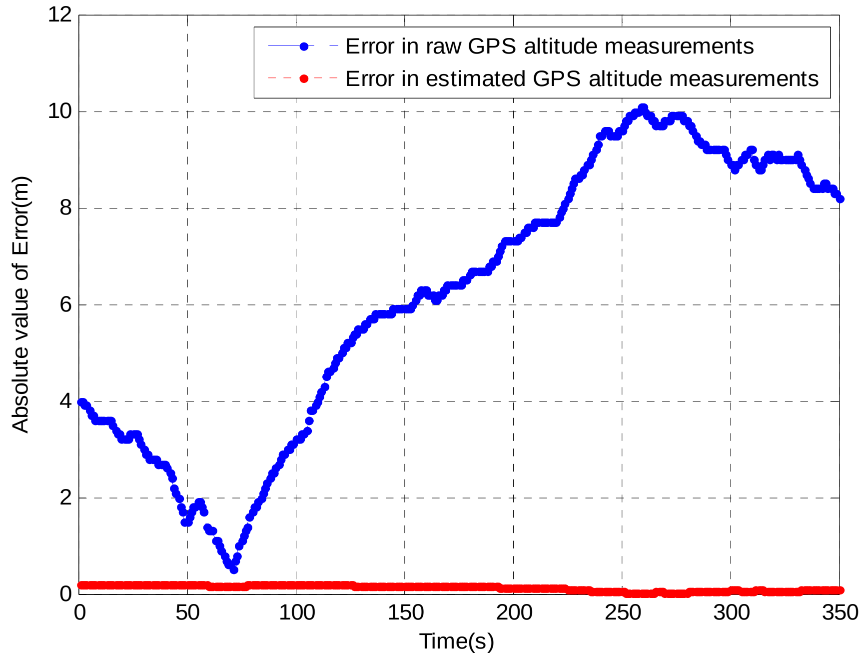

Figure 10. Error Analysis for Observed & Estimated GPS Altitude Measurements

The GPS altitude measurements obtained from LSPE method is closely matches to actual altitude as compared to observed GPS altitude measurements as can be seen from figure 7.The figure7 shows deviation of observed and estimated GPS altitude measurements from actual altitude of conductor. It shows that better accuracy has achieved by using digital signal processing technique such as Least Square Parameter Estimation method.The figure 8 shows that maximum absolute value of error (deviation of raw GPS altitude measurements from actual altitude of conductor) in observed GPS altitude measurements is 10m. These errors are due to various sources as shown in table1. In the figure9, we depict that the error has been reduced drastically to .19m by using MATLAB programming for digital signal processing technique such as Least Square Parameter Estimation (LSPE). The figure10 compares the observed and estimated error for GPS measurements. It shows that measurement error of GPS receiver gets reduced leading to better accuracy by using digital signal processing technique such as Least Square Parameter Estimation method.6. Conclusion

It can be concluded that the experiment of sag measurement using GPS has been performed successfully on 66KV power transmission line under shut down condition for approximately 350s. Further the digital signal processing technique LSPE method is used to reduce error in raw GPS altitude measurements. It is observed that estimated GPS altitude measurements have been obtained with 20% error. It indicated that standard handheld GPS receiver may be used to measure sag in overhead conductor of power transmission lines along with error estimation technique LSPE.

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