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Airwaves Prediction Model for Shallow Water Marine Control Source Electromagnetic Data

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Abstract

One of the main challenges of using Marine Control Source Electro-Magnetic (MCSEM) sounding for Hydrocarbon detection has been the airwaves phenomena. In shallow water the response from the air half-space often masks the response from the subsurface. In this paper we present a curve fitting approach to identify a mathematical function or model that best describes the pattern of the airwaves data. The identified model can serve as a prediction model for the airwaves. Synthetic data are simulated in a geologic model that is fairly representative of the area where real MCSEM data were collected. Root Mean Square Error (RMSE), Sum of Square Error (SSE) and Coefficient of determination (R^2) were used to evaluate the performance of the prediction model. The result indicates that exponential decay function can describe the airwaves data with RMSE of 3.1e-7, SSE of 1.3e-11 and R^2 of 0.990.

Keywords: Airwaves; Coefficient of Determination; Exponential Curve Fitting; Hydrocarbon; MCSEM; RMSE; SSE

1. Introduction

Marine Control Source Electro-Magnetic (MCSEM) is a technique of measuring the response of earth's subsurface structures due to the imparted alternating electric current when external electromagnetic field is applied into subsea floor formations. The CSEM technique has provide a means of remotely detecting the presence of high resistive subsea floor structures of the earth's interior such as the hydrocarbon reservoir.

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The following describes a typical MCSEM survey. Commonly in practice, an electrode refers to a Horizontal Electric Dipole (HED) which serves as electromagnetic source is disposed approximately 30 – 50m above the seabed and connected to the survey recording vessel. The electrode is being charged by the power source on the survey vessel at selected magnitude of alternating current and transmission frequency or frequencies. At a selected source receiver distance (offset), an Ultra-low (~ 0.1 – 5Hz) transmission frequency is commonly passed through the seabed into the subsurface of the earth formation. Electric and magnetic sensors/receiver designed with a voltage measuring circuit are placed strategically either on the seabed or on a different survey vessel (see Figure 1). The imparted voltages recorded by the receivers on the seabed are then analysed to presume the structural formations beneath the earth surface through their electrical properties [1 – 3].

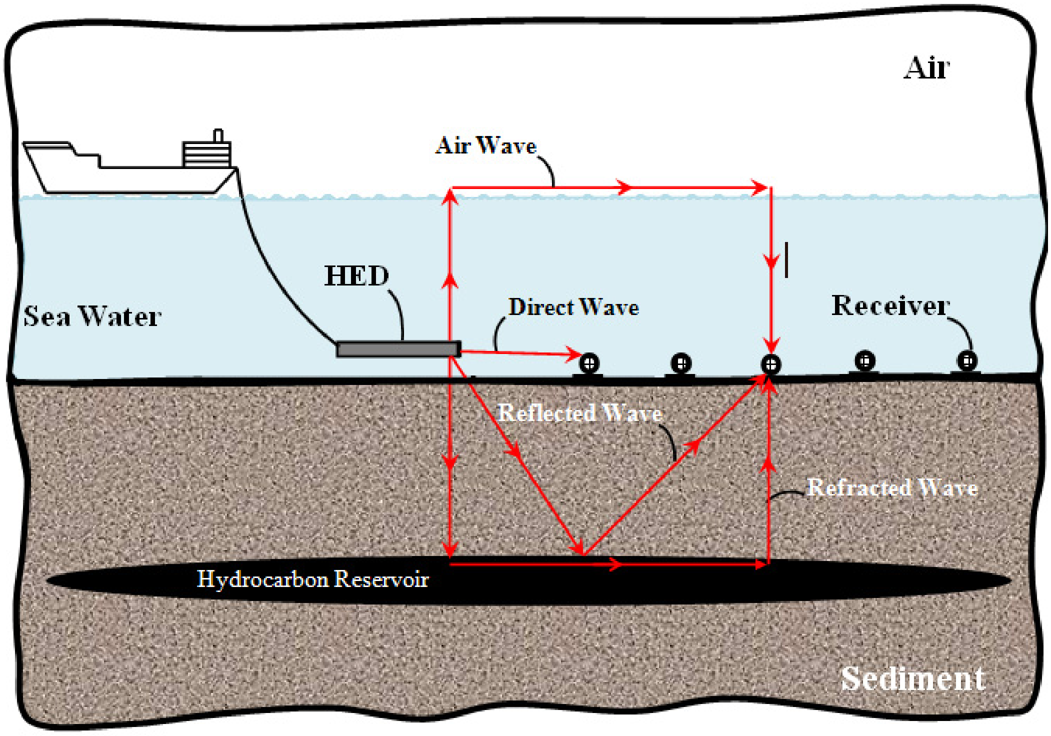


Fig. 1. A sketch of the MCSEM survey area

Theoretically, one of the main physics behind MCSEM is based on the knowledge that when an electromagnetic (EM) field is propagated through a conductive subsurface, the induced signal is mainly affected by spatial distribution of resistivity. Sediments filled with saltwater in a marine environments typically represent good conductors, whereas carbonates, hydrocarbon filled sediments, salt and volcanic rocks represent examples of resistive bodies that scatter the EM field. Part of the electromagnetic field scattered by subsurface inhomogeneities propagates back to the seafloor where the signal is recorded by receivers equipped with electric and magnetic sensors. The data recorded in shallow water CSEM survey are known to be affected by a noise called “airwaves". The noise component (airwaves) are generated predominantly by the vertically up going diffuse electromagnetic signal component that propagates in form of wave at the air/sea interface with speed of light and without attenuation before it diffuse back through the water layer vertically down where it is recorded by the electromagnetic receivers [4] as illustrated in Figure 1.

There are numerous modeling concepts developed to provide better understanding of systems having factors with nonlinear relationships like the airwaves. The numerical modeling conducted by [5] that used HED as the electromagnetic source, investigated the airwave contribution to the MCSEM data. Their study identified far offset, transmission frequency and relatively shallow seawater depths to have important effect on the airwaves component. Even though, apart from the numerical modeling, no method of computing the airwaves was given in that study. Hankel transform was used by [6] to develop another 1D model through numerical airwaves calculations that resulted into a fast algorithm. The behaviour and physical insight of how airwaves build up in the water layer was not explained by the algorithm.

Study by [4] has also shown the effect of seawater depth would be important at large source-receiver separations, low frequencies, or in relatively shallow water. It was also pointed out that in principle, the method of modeling-and-subtraction can be used to suppress the airwave component. The effect can be incorporated into the theory if both water depth and source location are accurately determined [6]. Features of the effect of the air wave on the amplitude and phase was described by [2] and reported that the range at which the air wave dominates the response, and information on seabed resistivity is lost, increases with decreasing frequency and water depth.

Furthermore, in the work of [7] and reported by [8] where the angular frequency, conductivity, and magnetic permeability were respectively represented by ω, σ, and μ, the expression defining attenuation (α) and propagation (β) constants for frequencies below 10^5Hz within the conductive medium is given by:

$$\alpha = \beta = \sqrt{\frac{\omega\mu\sigma}{2}} \tag{1}$$

Here $\mu = \mu o$ (magnetic permeability in free-space) because of nonmagnetic rocks in sedimentary basins. The research done by [4] has shown that the attenuation of electromagnetic energy depends on conductivity, transmission frequency and offset in a situation where the geometry is fixed. The low frequency electromagnetic signal in a distance x (m) experience exponential decay expressed as $e^{-x/\delta}$ where;

$$\delta = \sqrt{\frac{2 * \rho}{8 * 10^{-7} * \pi^2 * f}} \tag{2}$$

Where, ρ and f denote resistivity (Ωm) and signal frequency (Hz) respectively. The distance required to attenuate an EM signal by factor of e^{-1} is defined as skin depth and is about 551m in sea water (0.3 Ωm), 1424 m in 2 Ωm sediment and 10^8 in air (10^{11} Ωm) for a frequency of 0.25Hz.

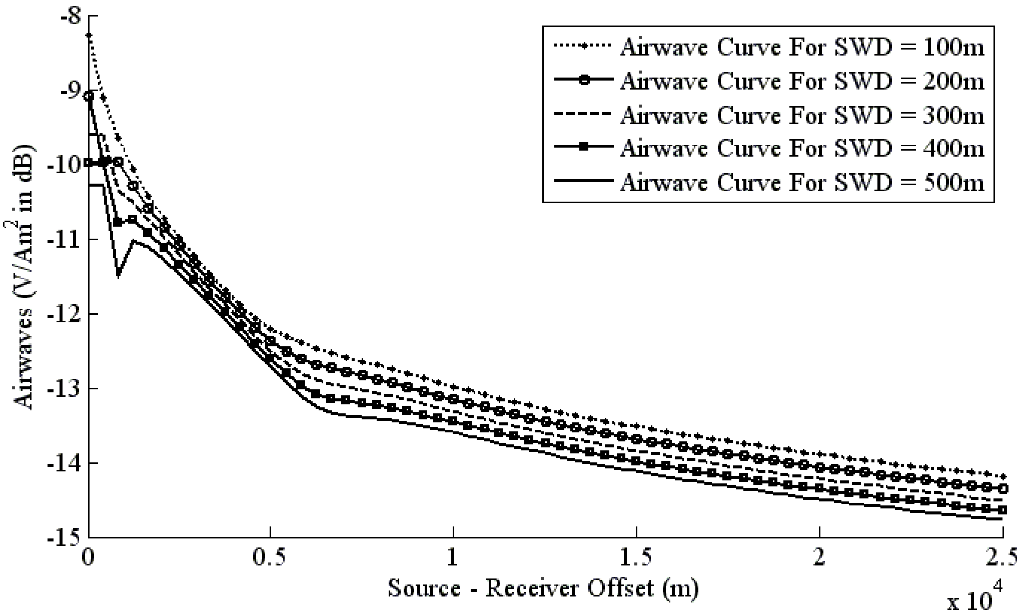


Fig. 2. Magnitude Versus Offset (MVO) plots for airwaves data in 100m – 500m seawater depth

Considering the above studies and the trend pattern of the MVO plot shown in Figure 2 which fairly suggests an exponential form of relationship motivates the authors to study the feasibility of applying exponential curve fitting method to model the airwaves data.

2. The Exponential Function

An exponential function is a widely used function in fundamental and applied sciences to model a relationship in which a constant change in the independent variable gives the same proportional change (i.e. percentage increase or decrease) in the dependent variable [9]. All forms of exponential function originate from the primitive two (2) parameter family. The variations that exist within this extended family resulted from mere transformations, shifts and stretches of the common stock defined as:

$$Y = f(x) = \alpha\beta^{x} \tag{3}$$

Where, α and β are the function parameters that represent the Y-intercept and the base for the function respectively. The random variable is denoted by x where they all determine the exponential function's input-output behaviour [10]. It is worth to note that β is always positive in order to make real and algebraic sense. This implies that β^x is also positive always. Therefore, the output values of the function $f(x)$ are either completely positive or completely negative depending respectively on whether the sign of α is positive or negative. In many different applications and indeed calculus, the common choice of base for exponential functions is $\beta = e$. This is because transformation can easily be made such that for all $\beta > 0$ there exist a constant λ so that $e^{\lambda} = \beta$ and hence equation 3 becomes:

$$f(x) = \alpha\beta^x = \alpha e^{\lambda x} \tag{4}$$

However, the term exponential function is sometimes used more generally for functions of the form $\alpha\beta^x$, where the base β is any real positive number, not necessarily e.

2.1. Algorithm of Exponential Curve Fitting

Basically, curve fitting technique is a process of determining mathematical function that has the best fit to a series of data points, possibly subject to constraints [11]. To accomplish the exponential curve fitting process, suppose that we are given the points $(x_1, y_1), (x_2, y_2), \ldots (x_n, y_n)$ and want to fit an exponential curve. We express X_i's $(i = 1, 2, \ldots, n)$ to represent the offset values and Y_i's as the corresponding magnitude of the airwaves Looking at Equation (3), the nonlinear least-squares procedure requires finding a minimum of:

$$E(\alpha, \lambda) = \sum_{i=1}^{n} \left(\alpha e^{\lambda x_i} - y_i\right)^2 \tag{5}$$

The partial derivatives of $E(\alpha, \lambda)$ with respect to α and λ are:

$$\frac{\partial E}{\partial \alpha} = 2\sum_{i=1}^{n} \left(\alpha e^{\lambda x_i} - y_i\right)\left(\alpha x_i e^{\lambda x_i}\right) \tag{6}$$

And

$$\frac{\partial E}{\partial \lambda} = 2\sum_{i=1}^{n} \left(\alpha e^{\lambda x_i} - y_i\right)\left(e^{\lambda x_i}\right) \tag{7}$$

When the partial derivatives in (6) and (7) are set equal to zero and then simplified, the resulting normal equations are:

$$\lambda\sum_{i=1}^{n} x_i e^{2\alpha x_i} - \sum_{i=1}^{n} x_i y_i e^{\alpha x_i} = 0 \tag{8}$$

And

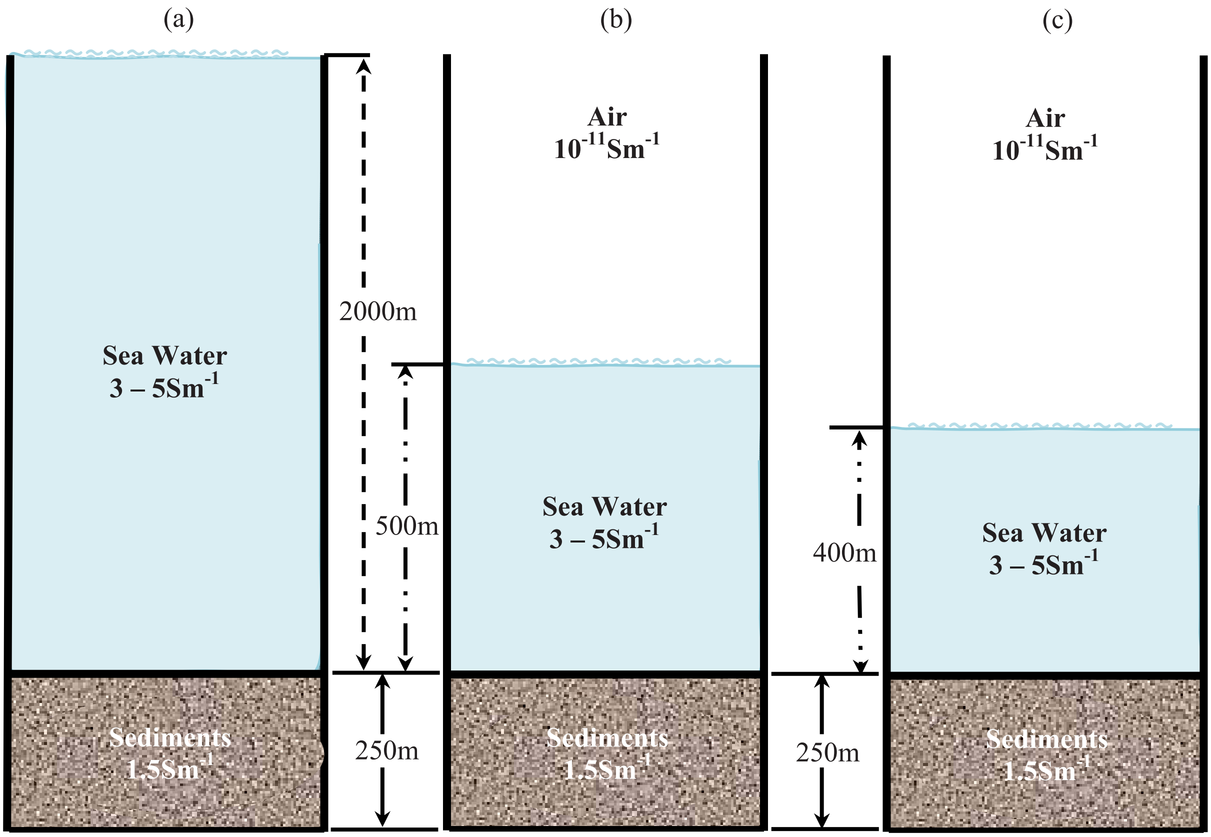
$$\lambda\sum_{i=1}^{n} e^{\alpha x_i} - \sum_{i=1}^{n} y_i e^{\alpha x_i} = 0 \tag{9}$$

Equations (8) and (9) are nonlinear in the unknowns α and λ. To avoid a time-consuming computation and the iteration involved that requires good starting values for α and λ for equations of this nature. We therefore utilize MATLAB software package which has a built-in minimization subroutine for functions of several variables to minimize $E(\alpha, \lambda)$ directly.

3. Methodology

The simulation protocols related to the study data acquisition are explained in this section. Computer Simulation Technology (CST) software was used in designing and solving the different models of MCSEM environment. The area simulated is 25Km. The transmitter is modelled as a short 1250A AC line current segment of length 270m located 30m above the sea bed. The Maxwell's electromagnetic field wave equation in vacuum in the absence of electric or magnetic sources is solved for the electric field vector E inside the computational domains.

Figure 2 (a) is a 1D MCSEM geologic model depicting "No Air Layer Model" and Figure 2 (b) – (f) are "With Air Layer Models" configurations that were simulated to obtain the airwaves data. Note that the figures are not drawn to scale in this text; but in practice all have the same area. The only difference between "No Air Layer Model" and "With Air Layer Models" is the changing of the sea water depth and replacing the space with air layer. We changed the sea water depth at interval of 100m from 2000m down to 100m in order to obtain the airwaves data. In this study, only airwaves data from sea water depth of 500m down to 100m was used. This is because a study by [12] has shown that airwaves have significant effect on the MCSEM survey data within the depth of 100m to 500m.



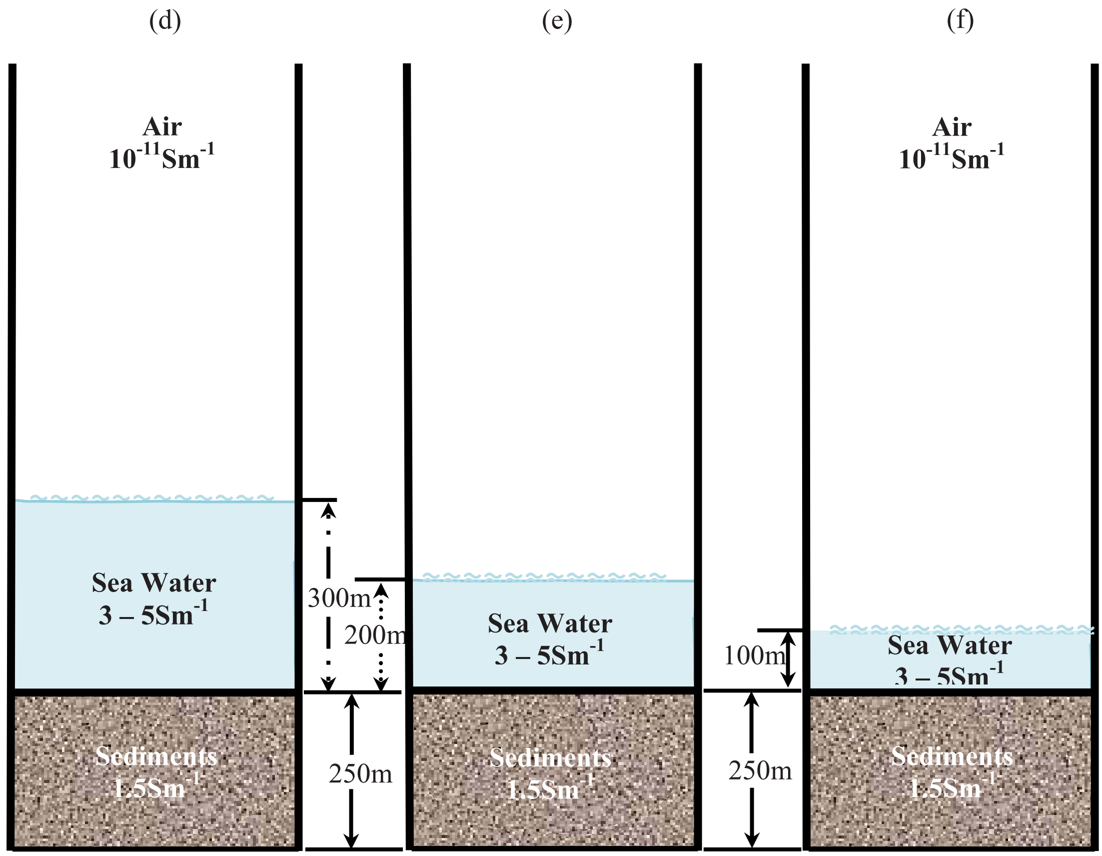


Fig. 3. Six MCSEM geologic models used to generate the study data

Table 1 present other physical values used for the simulation domains.

Table 1. Values assigned to the domains physical properties

Domain	Air	Sea Water	Sediment
Conductivity (σ)	1e-11Sm-1	[3 — 5Sm-1]	[1— 0.5Sm-1]
Material Density (ρ)	1.293kgm-3	1025kgm-3	2600kgm-3
Relative Permeability (μ_r)	1.0	0.99	1.0
Relative Permittivity (ε_r)	1.006	80	30
Thermal Conductivity	0.024 W(km)-1	0.593 W(km)-1	2W(km)-1

The contribution of the airwaves to the MCSEM data were computed by the method for removing the air wave effect as patented by [13] through the following steps:

- Constructing a MCSEM geometric model of the region having a top air layer, a middle sea water layer, and a bottom earth layer, with the model reflecting known bathymetry of the region and known conductivities of the air, seawater and earth;
- Using the model to compute the electromagnetic field at all receiver locations for each source location;
- Replacing the air layer in the model with sea water to create No-Air Layer model;
- Computing the fields for the same source-receiver geometries for the No-Air Layer model; and
- Computing the airwave effect at each seawater depth by subtracting the No-Air Layer Model fields from the corresponding fields of the With-Air Layer Models.

4. Results

Table 2 present the performance measure of the exponential curve fitting analysis with parameter values of α and λ. It can be seen from the results that even in the most shallow water depth of 100m where the airwaves is considered more than in the other deeper seawater depths. The exponential curve fitting technique has achieved the value of R^2 of 0.99. While the RMSE and SSE of as low as 3.1e-7 and 1.3e-11 respectively. Furthermore, it can be observed the value of the intercept (α) is decreasing as the seawater depth is increasing. This is because the onset of the airwaves is being affected by the depth of the seawater. The values for λ seem to be fairly the same; this might suggest the stability of the model.

Table 2. Parameter values and the performance measures

Sea Water Depth	α	λ	RMSE	SSE	R^2
100M	1.142e-5	-3.05e-4	3.1e-7	1.3e-11	0.990
200M	8.656e-6	-3.07e-4	1.6e-7	3.4e-12	0.991
300M	5.839e-6	-2.98e-4	1.5e-7	3.0e-12	0.993
400M	3.033e-6	-2.79e-4	1.6e-7	3.5e-12	0.995
500M	1.967e-6	-2.73e-4	1.3e-7	2.3e-12	0.997

5. Conclusion

Curve fitting technique was used in this study to identify a model that can serve as a shallow water air-waves prediction model. We have identified an exponential decay function of the form $f(x) = \alpha e^{\lambda x}$ to best describe the airwaves data. The study results shows that the exponential decay function can achieve R^2 of 0.995, RMSE of 1.6e-7 and SSE of 3.4e-12. The near 1.0 for the coefficient of determination the small RMSE and SSE observed indicates that this prediction model indeed fits the data well. As this study is done with simulated data, the next step is to carry out the experimental work to verify the results.

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References

[1] Constable, S., Srnka, L.J. An introduction to marine controlled-source electromagnetic methods for hydrocarbon exploration. Geophysics 72, WA3 (2007).
[2] Hesthammer, J., Boulaenko, M. The potential of CSEM technology, GeoExpro, 4, 2007, pp. 52-58, and HGS Bulletin, pp. 23-43 December, Rocksource ASA: (2007).
[3] Johansen, S.E., Amundsen, H.E.F., Røsten, T., Ellingsrud, S., Eidesmo, T. and Bhuiyan, A.H. Subsurface hydrocarbons detected by electromagnetic sounding. First Break, 23(3), 31–36, (2005).
[4] Eidesmo, T., Ellingsrud, S., MacGregor, L.M.., Constable, S., Sinha, M.C., Johansen, S., Kong, F.N., and Westerdahl, H. Sea Bed Logging (SBL), a new method for remote and direct identification of hydrocarbon filled layers in deep-water areas. First Break, March 2002, Vol. 20.3.
[5] Chave, A. D., and Cox, C. S. Theoretical numerical model study for offshore CESM exploration with a horizontal electric dipole source. Journal of Geophys. Res. 87, 5327-5338 (1982).
[6] Anderson, W.L. Numerical integration of related Hankel transforms of order 0 and 1 by adaptive digital filtering. Geophysics, 44, (1979), pp.1287–1305.
[7] Anwar B., Tor W., and Stale J. High Resistivity Anomalies at Modgunn Arch in the Norwegian Sea. Technical Article. First Break volume 24, January 2006.
[8] Muhammad A., and Afza S.,(2013). Performance Analysis of Transfer Functions in Simulating Air Waves Data. International Journal of Current Engineering and Technology, ISSN : 2277 – 4106.
[9] Goldstein, L., and Schneider, A. Brief calculus and its applications, 11th ed., Prentice-Hall, 2006.
[10] Lorentzen, L., and Waadeland, H. The exponential function: Continued Fractions. Atlantis Studies in Mathematics, page 268.
[11] Coope, I.D. (1993). Circle fitting by linear and nonlinear least squares. Journal of Optimization Theory and Applications 76 (2): 381.
[12] Muhammad A., Afza S., Noorhana Y., Radzuan R., and Wan Fatimah Wan Ahmad. A Simulation Study to Identify the Sea Water Depth for the Presence of Air Waves in Sea Bed Logging. "2nd International Conference on Fundamental and Applied Sciences" (ICFAS2012).
[13] Xinyou, L., Srnka, L.J., and Carazzone, J.J. Method for Removing Air Wave Effect from Offshore Frequency Domain Controlled-Source Electromagnetic Data, U.S. Patent 7 277 806, Oct. 2, 2007.