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Modelling and Analysis of Powerline Temperature Surveillance with Optisystem Simulation

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ABSTRACT
A periodic variation of the index of refraction of a fiber optics is known as the Fiber Bragg Grating. It works on the principle of wavelength shifts in response to the modulation of the light source as a result of change in temperature above the reference point. This paper presents the design and analysis of Fiber Bragg Grating Sensor to measure and monitor the temperature change in powerlines for a particular range of temperature. Simulation was carried out on Optisystem to determine the peak reflectivity of the Bragg wavelength. It is seen that a change in the reflected spectrum of light is proportional to the change in temperature as shown in the FBG interrogator.
***Keywords** - Fiber Bragg Grating, Temperature, Optisystem.*

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I. INTRODUCTION

The modern times have been defined by the need of power to drive virtually every sector of human life. It is an established understanding to the fact that having power is not enough but to have a constant, reliable and sustainable power supply in this 21st century.

To rely on existing infrastructure is no more applicable as there is need to always evolve and adapt to the growing demands of the populace which is steadily on the increase. Electricity is the backbone that up holds the development for both economy and technology, it has also seen rapid transformation in developing countries as an industry. But these changes are seen not to be effective as its either not evolving equivalently with the growing demands of the population or that the state of infrastructure is weaken by its age of installation. This means that break down is imminent as it cannot bear the burden of previous years.

As demand for energy increase as a result of increasing population and economic activities, pressure of over utilizing the transmission lines beyond their limit of design becomes more evident.

More power plants were installed and transmission lines increased but the need to monitor and maintain efficiency of these added asset proved critical as the fact that despite the increases, it still couldn't cater for the entire nations demand. So, load sharing and perpetual planned outages still continued.

In this regard, the development of Optical fiber sensing technology became prominent for the monitoring of temperature on the power line. The optical fiber sensor is apparently more reliable and accurate compared to convection methods because it is immune to electromagnetic interference, mechanical vibrations, electric noise and performs best under harsh conditions [1] [2]. It is understood that the higher the temperature on an ACSR (Aluminum Conductor Steel Reinforced) conductor, it causes annealing of the conductor. In this paper, the response of the Fiber Bragging Sensor to temperature is demonstrated by theoretical analysis and software simulation.

II. PRINCIPLE OF OPERATION

Most Bragg grating structures of a single mode fiber optics are formed by a periodic modulating of the core's index of refraction [3]. When light propagates along the core of the fiber optics it scatters at each grating plane, once the Bragg condition is not met the reflected light from each of the grating planes moves out of phase canceling out each other. When the Bragg condition is met, each of the grating plane add progressively to the backward reflection moving in the backward direction defined by the center wavelength forming a reflected peak [4] [5] [6] [7].

The simple understanding of Fiber Bragg Grating grafted in the core of the optic fiber is that it creates periodic modulation of the core's refractive index. When a light source or a laser beam serving as a spectral broadband source is incident on the core of the fiber, the Fiber Bragg Grating selectively reflects a narrow spectral region that satisfies the Bragg first order condition centered at the specific wavelength. The remaining light spectrum or signal is allowed to pass through [1], [2] [6]. It is important to note the parameter to which the fiber grating sensor is sensitive to is the Bragg wavelength ($\boldsymbol{\lambda}_B$).

Evidently, the Bragg wavelength is equal to $\boldsymbol{\lambda}_B = \boldsymbol{2neff\Lambda g}$, [3] [4] this means its variation is due to change on the index of refraction and grating period or grating pitch as the effect of temperature lingers [2], [5].

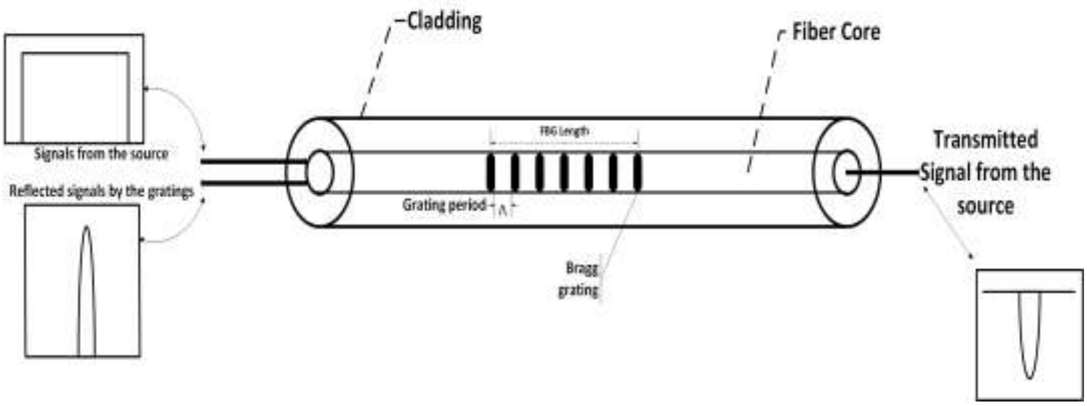

Figure 1 operational structure of Fiber Bragg Grating Sensor

III. FABRICATION TECHNIQUES

Different techniques are employed in the fabrication of Fiber Bragg Gratings, some of which includes [2]

- Point to point technique
- interferometric fabricating technique
- phase mask technique

3.1 Point to point technique

In this technique, grating planes are inscribed along the core of the fiber gradually at periodic intervals by using ultra violet pulse laser or femtosecond laser to individually inscribe them. Index change within the core of the fiber optics at one point is formed by focusing single light pulse through silt [1].

At the point at which irradiation takes place, the refractive index is changed corresponding to the grating period at a fixed distance "Λ", to achieve the desired grating length the procedure is repeated.

3.2 Interferometric fabricating technique

This technique utilizes interferometer such that single laser ultraviolet light or beam is split into two components or beams and then recombined to form an interference pattern [4] [10] [11]. This fringe pattern upon exposure to photosensitive fiber induces a modulated refractive index in the core. Wave-front splitting and amplitude splitting interferometers are occasionally used in the fabrication of Bragg gratings [1] , [2].

3.3 Phase Mask Technique

This technique is the most widely used being very simple and not very expensive in fabricating gratings of quality. It makes use of phase mask of silica glass flat slated [2] [6]. Holographically or by electron-beam lithography are ways phase masks are created.

IV. METHODOLOGY AND DESIGN

When the Fiber grating acts as a temperature sensor, as the temperature changes, the grating period as well as the grating refractive index changes too. Consequently, the response of the grating device of the grating device is changed when temperature change [7] [8].

4.1 Mathematical Expression relating Bragg wavelength with temperature given below:

$\boldsymbol{\lambda}_B = \boldsymbol{2neff\Lambda g}$ (1)

Where $\boldsymbol{\Lambda g}$= grating period, $\boldsymbol{neff}$= effective refractive index

Since the temperature affects the refractive index, the temperature-induced refractive index change is given as shown in equation (2):

$$\Delta neff = \xi . neff . \Delta T \quad (2)$$

Where ξ is the thermo-optic coefficient of the fiber and ΔT is, the temperature change

Therefore, temperature -induce grating period change is given as shown in equation (3):

$$\Delta\Lambda_g = \eta . \Lambda_g . \Delta T \quad (3)$$

Where η is thermal expansion coefficient

So, the change in Bragg wavelength with relationship with temperature is given as shown in equation (4)

$$\Delta\lambda_B = \lambda_B[\eta + \xi]\, \Delta T \quad (4)$$

Where λ_B is the wavelength of the reference temperature at 20 ˚C, η is the thermal expansion coefficient of fiber optics, its constant and given as $0.55\times10^{-6}C^{-1}$, ξ is the thermo-optic coefficient,ΔT is the temperature change.

Experimentally it has been discovered that the thermo-optic coefficient increases with temperature proportionally from 0˚C to 400˚C. Where the thermo-optic coefficient for a reference temperature of 20 ˚C and 100˚C is 8.089×10^{-6}/ ˚C and 9.14×10^{-6}/ ˚C respectively, the corresponding thermo-optic coefficient within the temperature range, this can be done by simply interpolating [9].

Thus, the thermo-optic coefficient is given as:

$$\frac{T_{100}-T_{20}}{\xi_{100}-\xi_{20}} = \frac{T_t-T_{20}}{\xi_t-\xi_{20}} \quad (5)$$

$$\xi_t = \frac{(\xi_{100}-\xi_{20})(T_t-T_{20})}{(T_{100}-T_{20})} + \xi_{20} \quad (6)$$

Where T_t = Any induced temperature above the reference temperature, ξ_t = Thermo-optic coefficient of the induced temperature

Result of the calculations above illustrating the change in temperature with corresponding change in grating period, thermo-optic coefficient and the reflected wavelength is shown in the table below for temperatures ranging from 20 ˚C to 160 ˚C.

Table 1 Temperature change with corresponding change in Bragg Wave length, grating period and Thermo-optic coefficient

Temperature(˚C)	Thermos-optic coefficient ($\times10^{-6}$/ ˚C)	Change in Bragg wavelength($\times10^{-9}$nm)	Bragg wavelength($\times10^{-9}$nm)	Grating Period ($\times10^{-6}$µm)
20	8.089	0.01339	1550	0.534483
40	8.352	0.275902	1550.275	0.534578
60	8.615	0.56823	1550.56823	0.534679
80	8,877	0.8767	1550.8767	0.534785
100	9.14	1.20156	1551.20156	0.534897
120	9.403	1.5427	1551.5427	0.535015
140	9.666	1.900176	1551.900176	0.535138
160	9.929	2.27335	1552.2735	0.535267

4.2 Software Simulation

In demonstrating the working operation of FBG sensor, it was modelled and simulated using an Optiwave software [8] called Optisystem. Fig 2 and fig 3 shows the flow chart for the software simulation and the modelling of the Fiber Bragg Grating Sensor respectively.

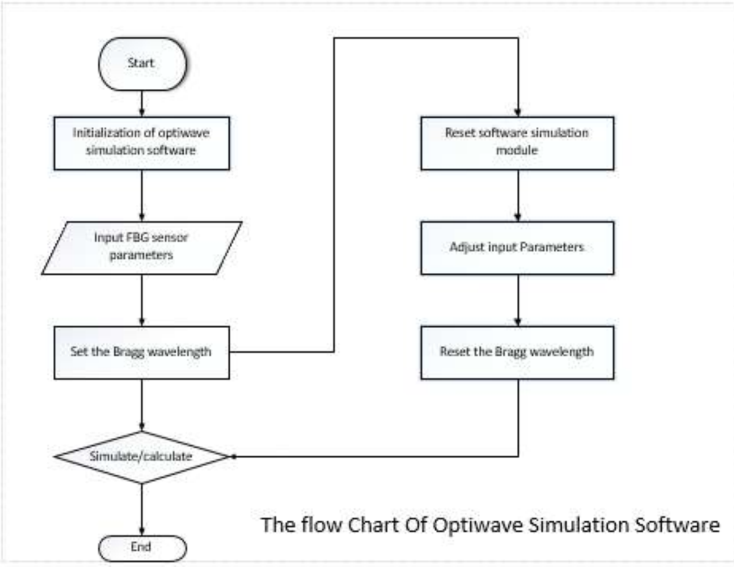

Figure 2 Software flow chart

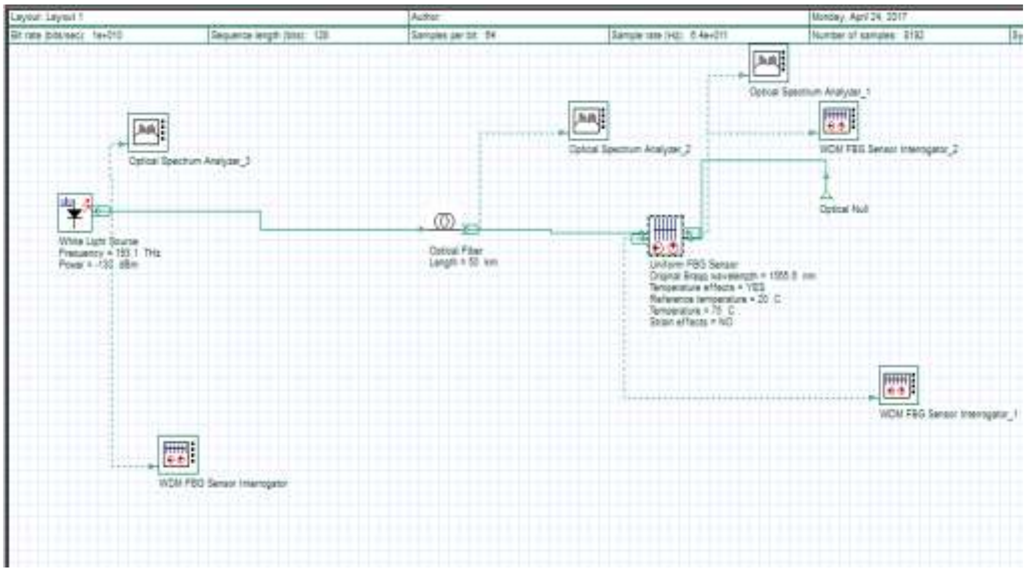

Figure 3 The designed model of simulated system with Optisystem

The layout parameters from Optisystem is as shown in Figure 3.4. The components used during the simulations are therefore described below.

1. Continuous Laser Diode (cw): it's used to generate optical signals, this supplied input signal are within the spectrum range of 1530nm to 1570nm and having a center wavelength of 1550nm. Its input power and operating frequency is -130dbm and 193.1 THz respectively.
2. Optical Fiber: the optical fiber used here is a single mode optical fiber due to its less dispersion, higher data rate and operate in a long-distance haul. The modelled design above used a length of 50km for its signal transmission. The fiber has an attenuation coefficient of 0.2db/km.
3. Fiber Bragg Grating (FBG): been used as a dispersion compensator to reflected specific signal spectrum resulting from either or both changes in its grating period or index of refraction. The length used for the proposed model above is 10mm.
4. Optical Spectrum Analyzer (OSA): the optical spectrum is used to analyze signal spectrum strength at end of every component.
5. WDM Sensor Interrogator: is used to display the output and reflected signal spectrum, and observe the working condition of the Fiber Bragg Sensor.

V. RESULTS AND DISCUSSION

This project was simulated using the Optisystem simulation software, on the interface of the software a transmission system is designed to illustrate the working operation of a Fiber Bragg Grating when used to monitor temperature on the power line. The fiber length used Is 50km which depicts the distance of a transmission exposed to increasing temperature from the outside due to atmospheric conditions or sun heating effect or the joule effect that occur as a result of current passing through the power line.

During the simulation, different parameters such as the thermal expansion coefficient, thermo-optic coefficient and induced temperature range were used to generate the reflected wavelength. This reflected wavelength of a particular light source spectrum is a result of induced temperature change affecting the grating period and index of refraction. It is the major output required for the monitoring of temperature on the power line. As the temperature increases, there happens to be a shift in the reflected Bragg wavelength from the center as illustrated from Fig 5 and Fig 6. In order words, the Bragg wavelength change is temperature reliant, making temperature the independent variable and the Bragg wavelength the dependent variable.

Fig 4 is a graph illustrating the change in Bragg wavelength against temperature. The graph shows the proportionality between Bragg wavelength and temperature. For every corresponding change in temperature induced on the power line there is a change in the reflected wavelength seen at the FBG sensor interrogator.

The Fiber Bragg Grating Sensor response to the effect of temperature is shown in the following diagrams Fig 5 and Fig 6. These figures show the narrow band which is reflected back when a wide-band of spectrum is injected at the input and these reflections is displayed by the FBG sensor. The peak of the wavelength is understood to be dependent on the index of refraction and the grating period and it displays the sensitivity of the fiber waveguide to environment temperature. Also, it is seen that the reflected spectrums shown in the diagrams are a measurement of the reflected power which is a function of the Bragg wavelength. This is as a result of the coupling of the optical power from the tunable laser into the fiber having the FBG sensors.

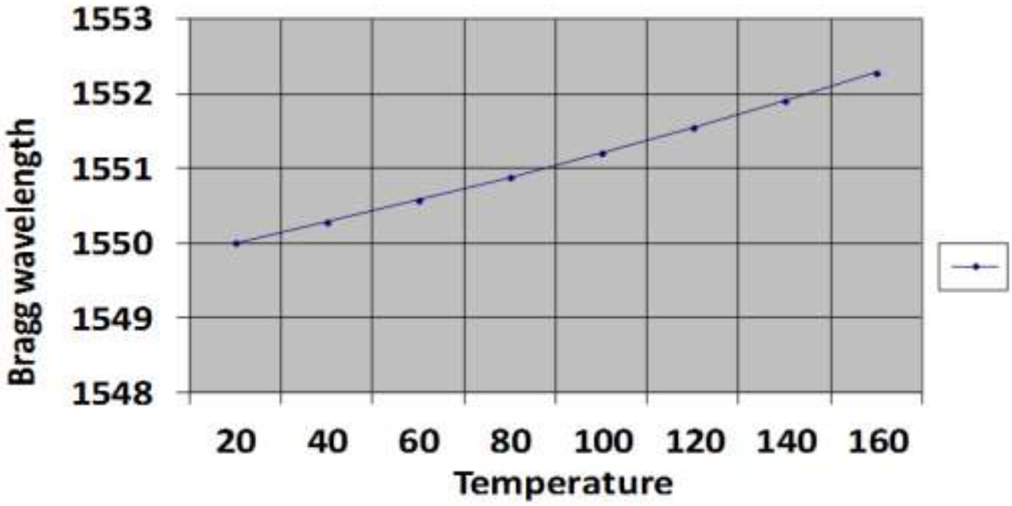

Figure 4 Bragg wavelength against Temperature

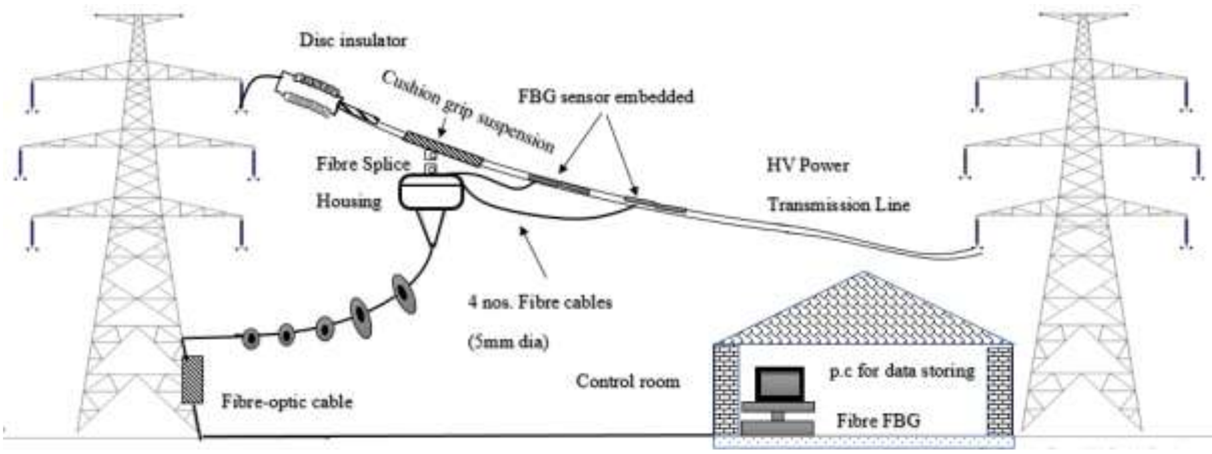

Figure 5 Practical implementation

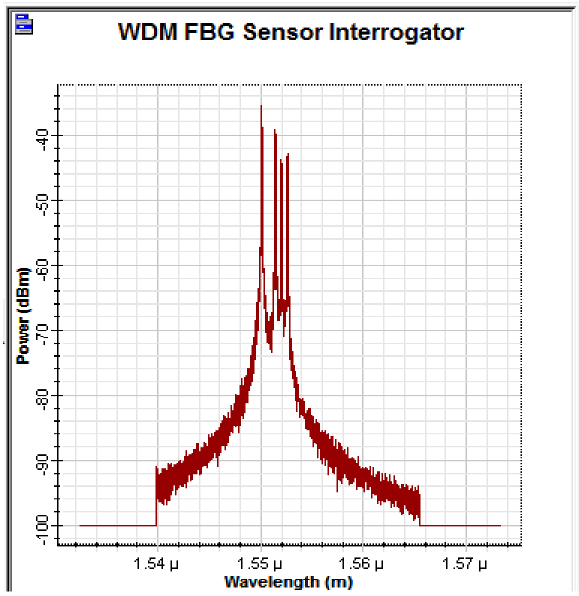

Figure 6 Shift in Bragg wavelength for temperatures from 20-80

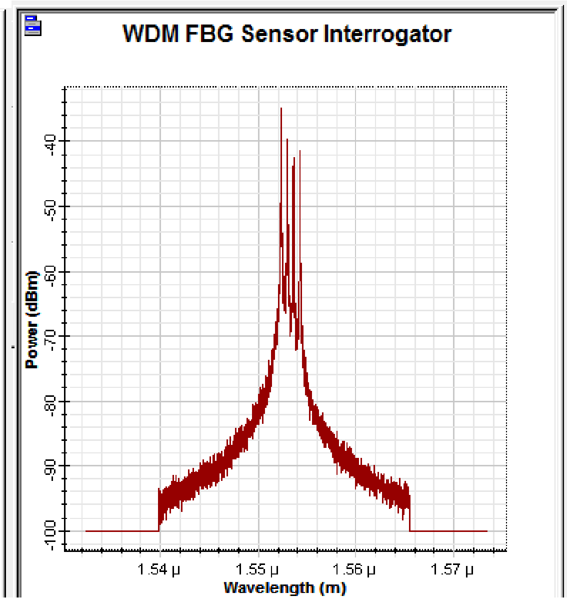

Figure 7 Shift in Bragg wavelength for temperatures from 100-160

Fig 7 and Fig 8 displays the transmitted light spectrum after the reflected light spectrum. The simulation results show several dips in the spectral analysis which indicates certain portion of the light spectrum have been reflected towards the source and this is as a result of the effect of the temperature on the Fiber Bragg Grating sensor.

Fig 7 is an output transmitted spectrum indicating by the dips the reflected wavelengths from 1550nm, 1550.275, 1550.5623nm and 1550.8767nm which is as a result of the effect of temperature change from the reference temperature. These temperatures therefore responsible for the shift in the change wavelength or Bragg wave length are 20˚C, 40˚C, 60˚C and 80˚C.

While for Fig 8 the temperatures 100˚C 120˚C, 140˚C and 160˚C are responsible for the corresponding Bragg wavelength changes 1551.20156, 1551.5427, 1551.900176 and 1552.2735 which are indicated by the dips in the output transmitted spectrum.

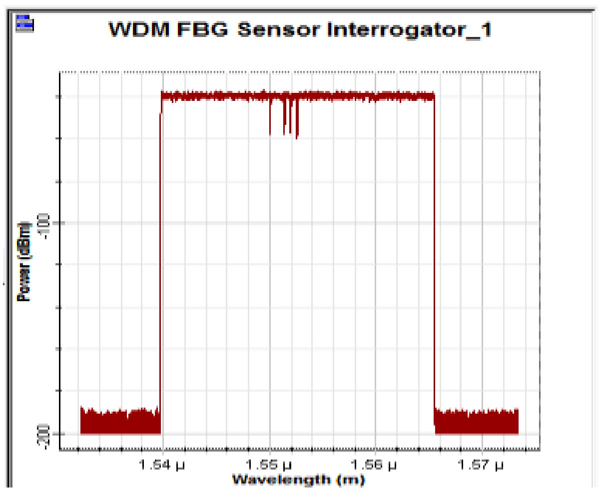

Figure 8 transmissivity for temperatures 20˚C -80˚C

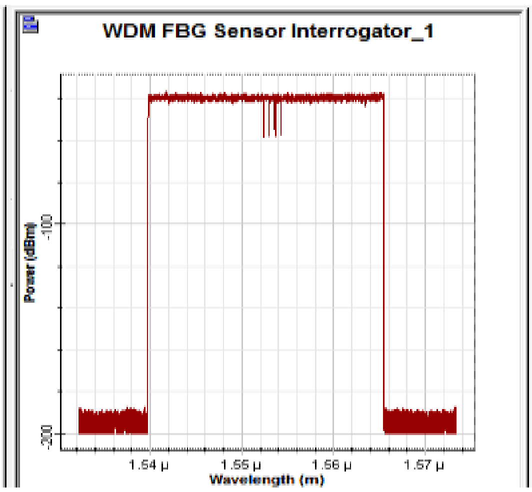

Figure 9 transmissivity for temperature 100˚C-160˚C

VI. Conclusion

In summary, Fiber Bragg Grating sensor are known as the Bragg reflector which are discrete spectrally reflective engraved in the core of a Fiber Optics under the intensity of a laser or light source with high intensity. In this paper was it designed to analyze the working operations of Fiber Bragg Grating sensor in monitoring the temperature on powerline. For the theoretical and simulation purposes, the temperature range was taken from 20˚C to 160˚C. The reference temperature is take as 20˚C while the maximum allowable temperature for ACSR overhead powerline is 80˚C

Theoretical calculations to determine the relationship between the increase in temperature, grating period, thermo-optic coefficient and wavelength was established to understand the correlation between these parameters. An optical transmission system was therefore simulated to show the peak reflectivity of every shift in Bragg wavelength and the transmitted spectrum. It was therefore shown in the dissertation the linearity between the change in temperature and shift in Bragg wavelength.

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