# Modeling and Checking the Power Quality of High Pressure Sodium Vapor Lamp

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*Abstract*— **High pressure sodium Vapor lamps due to long service life High Light, as the most comprehensive street lighting and industrial lighting Whose use is increasing day by day. One of the major drawbacks to these lamps is producing a lot of current harmonic. Therefore, check the Power Quality of these lamps becomes necessary. To check the quality of our lamps, it's necessary to express the exact model of these lamps. In this paper, we simulate a high-pressure lamp based on plasma physics equations. With this exact model, the power consumption of these lamps is considered by using THD and the results are compared with the standard values. In this paper, taking into account the magnetic ballast for a high-pressure sodium Vapor lamp, a precise simulation of these lamps was performed using the MATLAB / Simulink software.**

*Index Terms*— **High pressure sodium Vapor lamps, THD, magnetic ballast, MATLAB.**

## I. Introduction

Imagine the world without Electrical engineering can be difficult. The branches of electrical engineering can be divided into range of fields such as Power Electronics, Communication, Control, and Robotics [1].

Many researchers many works have been done in the field of Power electronics[2-5] , i.e. A power system state estimation for cyber security is investigated in [6]. A power system dynamic model reduction is introduced in [7]. A new algorithm for coherently partition the network based on the dynamic response of the system is proposed in [8]. Different aspects of system resilience with their corresponded metrics are proposed in [9] with the goal of enhancing the resilience of a disrupted system. For voltage source converter many works have been done, but some of them used the application of the control to control the voltage's out put of this system. i.e. a linear quadratic gaussian with loop transfer recovery (LQG/LTR) controller is proposed for a rectifier voltage source converter [10]. The robustness controller is shown under nonlinearities and measurement noise, also wind turbine attract a lot of attentions these years in power electronics [11].

Experimental and theoretical optimum tilt angles of a photovoltaic panels is considered in [12]. It is shown that produced energy of photovoltaic systems with experimental yearly tilt angle is 3% higher than fixed theoretical optimum tilt angle. Iran south east power system's static voltage stability is analyzed in [13] using extended continuation power flow method. Experimental and mathematical model predictions for tilt angle of photovoltaic panels is investigated in [14]. In [15], distributed generation(DG) modern technologies and benefits entice electric utility distribution planners to implement DG as a new approach in distribution system planning (DSP). Under all the testing cases, the PSO always converges very quickly towards the optimal positions but may slow its convergence speed when it is near a minimum is investigated in [16]. In [17], simultaneous employment of electrical vehicle-to-grid (V2G) and wind power generation in security constrained unit commitment (SCUC) problem are considered.

In the microgrid systems, some works have been presented [18, 19], as in [20], the impact of running Direct Load Control (DLC) program and different positions of installing storage units on microgrid are investigated.

a new method for application in communication circuit system is proposed that it causes increasing the efficiency, PAE, output power and gain. One of the paper discusses about switching class E-J and another one is about switching class AB-J [21, 22]. The power recovery problematic by nature, the bi-level mechanism has been used for the power system refurbishment [23, 24].

Control and robotics plays a main role in the engineering systems [25-30]. i.e. An adaptive neuro-fuzzy based correlation model is used in [31] for dynamic tumor motion tracking that employs several data clustering algorithms for antecedent parameters construction to achieve an appropriate performance. It also developed for feasibility study in [32].

Control of systems needs to be robust and reliable [33, 34]. In [35] used an adaptive robust control to tracking problem with the known and unknown parameters in the presence of torque disturbances are addressed. Taheri Andani used Sliding mode control for solving the desired trajectory tracking and stabilizing problem in the mobile robots, specifically in the spherical mobile robot, then by using Lyapunov theorem proved the stability of the system [36].

Imagine world of electronics without artificial light bulbs can be difficult... Artificial lights have important role in various aspects of human life and today, many devices are used to convert electric energy to light. About 20 percent of the world's electrical energy consumption is lighting. Lighting is one of the most important factors in the consumption of electrical energy. Which in USA alone accounts for about 33 percent of the peak load and the country's consumption of 3.1 percent the street lighting [37].

Gas lamps have long been used for street lighting. In recent years, the use of a series of these lamps, called high pressure sodium vapor lamps, has been rising relative to similar lamps due to long life and high yields [38].

Therefore, a precise model and simulation of these types of lamps should be considered and the side effects of

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high-pressure sodium hydrogen sulfide lamps such as the increase in current harmonics, voltage distortion, produced flicker and radio interference, etc.

Gas discharge lamps are one of the nonlinear devices in spite of the injection of network harmonics [39], because

high longevity, efficiency and high intensity of light, as well as the problem of energy efficiency, regional power companies recommend the use of these lamps to consumers.

Sodium lamps, electric arc furnaces have a similar function [40] harmonics are generated and the like.

These lamps affect the power quality of the network and capture the capacity of the lines due to harmonics, which should compare these standard harmonics with standard values, and, in the event of a violation of standard values, to modify and even replace these lamps. The most important problem with the quality of these lamps is the production of harmonic harmonics by the third Which is the most harmful harmonic level and increases the current flow of a system and should be considered in the design of industrial complexes including lamps [39-43].

Ballasts used in these types of lamps are two types of electrical and magnetic ballasts. Because magnetic ballast is more frequent this type of ballast is used for simulation.

When it is used in an electric discharge lamp, the gas in the bulb becomes plasma. Therefore, for a precise simulation of these types of lamps, the rules of plasma physics should be used.

In this paper, the laws governing plasma physics, a high-pressure sodium steam lamp, have been simulated by MATLAB / Simulink software.

## II. High pressure sodium vapor lamp

High intensity discharge lamps, which named HID lamps. From the most efficient to the lowest efficiency.

1) *Low pressure sodium bulbs (have low color matching ability)*
2) *High-pressure sodium lamps (color matching capabilities for moderate to good)*
3) *Metal halide or metal halide lamps (The color is good to excellent)*
4) *Mercury vapor lamps (Good matching color)*

Due to their power consumption and their optical flux, they have different meanings in public lighting and passageways [40].

The second group of gas discharge lamps, high pressure sodium vapor lamps, in addition to having a relatively good optical performance and brightness, they also have good color and for use in public places where color matching is important, and it does not find much to fit.

The high-pressure sodium bulbs are a handful of these bulbs. Structurally, due to the arc generated between two electrodes, a lamp is produced.

In these lamps, first, to discharge the electrical energy of the gas in the lamp-holder, a very high voltage of about 1222 to 5222 V at a time of about 1 microsecond should be applied to the pulse in two electrodes of the lamp, which is done by an Ignitor or a quick start.

This very high voltage causes an electric discharge from the inside of the vaporization lamp of this gas, and the venting between the two electrodes in the pipelines leads to a flow in the gas. The electrons gain energy from the potential difference, which involves stimulating and producing light from other atoms.

The radiation spectrum is a function of the gas type, pressure, temperature, and electrical conditions. The gases that have been used up until now are: Bauxhid, Wax, Cadmium, Neon and Carbon.

Lamps used to illuminate passages and streets and public places often use high-pressure strain reliefs due to long life and high optical gain. But the disadvantages of these bulbs as a nonlinear charge are due to the arcing of electrical arrester during electrical discharge and gas ionization. Harmonic and special harmonics produce the third harmonic that is harmful. Plus, despite the high optical gain by these lamps, the light produced by these lamps are not good quality and is a light-yellow orange light that is not suitable for use in homes.

## III. Ballast of sodium vapor lamps

Vapor lamps need to have an intermediate circuit and a lamp starter that is called a ballast. Solar-free light bulbs act like open circuit and for turning on requires a high voltage to ionize the gas inside the lamp. When the lamp is lit, the ionized gas enters the plasma and the lamp current increases.

Because of this, the resistance of the bulb is almost inversely proportional to its current, and therefore the lamp is one the negative dynamic resistance indicates that the ball is used to reduce this current.

So, the task of the ballast can be summarized in two parts

*1) Increase the voltage before discharge*

By disconnecting and connecting the starter that plays the role of the fast starter in the sodium regulator. A large amount of inductive voltage is applied at a voltage pulse of about 1222 to 5222 (volt) at a very short time, about 1-micron seconds in two bulbs. This very voltage causes the electric discharge in the gas and ionization and the lamp starts to work.

*2) Limiting Current After Discharge Gas*

After the ionization operation, the electrical resistivity of the lamp decreases, and due to fluctuation of current, an instability is created which causes the power loss in the ballast and the grid, in which case the Chuk is responsible for limiting and controlling the current.

Electronic ballasts have significant advantages over magnetic ballasts such as: Has a higher power and output coefficient, lower THD, output power despite constant input voltage variations, the melting of the bulb electrode is less and so the lamp life will last long.

But electric ballast is used less because of the cost of making more. In this paper, the magnetic ballast is also used.

In addition to the above components in the lamps, a power factor correction capacitor is also used that will improve the voltage profile. Because it is high due to the presence of a choke in the circuit of lamps and the harmonic contamination in the current consumption of the gas discharge lamp,

The power factor of this lamp is very low, so the capacitor is used to improve the power factor in the circuit of these lamps.

## IV. Simulation of high pressure sodium vapor lamp

The simulation of these lamps is an interdisciplinary problem involving electricity, plasma physics, and chemical engineering. In this paper, 422 watts of high-pressure sodium lamp are considered. And according to [40, 42-44]the simulation is presented. This model is based on the simplification of the power loss and energy accumulation mechanism in the arc columns. For the ballast, by considering a magnetic ballast, it resonates with a resistor and inductance to simulate the differential equation governing it and simulated.

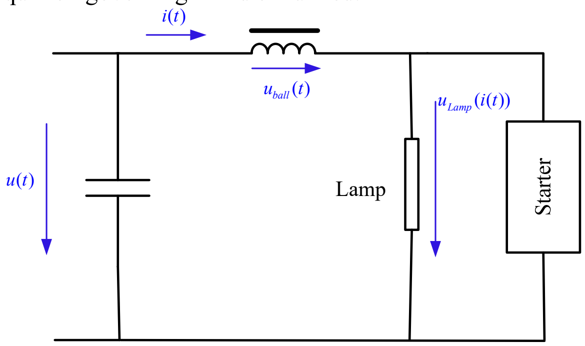


**Fig1:** The circuit of the Lamp

In regard to this paper, only the normal operation time of the lamp is considered, and the operation of the lamp at the time of lightning and the use of the starter or the ignitor was not considered, the simulation of the igniter model was neglected, and only the lamp and its ballast, which is a ballast Magnetic is modeled. Due to the circuit of the lamp in the form of a parallel with a capacitor and series with a high inductance and is located to a parallel to the orthogonal.

When the circuit operates in steady state, the current $i(t)$ causes a voltage drop in the $U_{ball}$ ballast and $U_{lamp}$. At that time, the open circuit does not enter the current circuit; therefore, the governing equations can be written as follows.

$$U_{lamp} = U - U_{ball} \quad (1)$$

$$U_{ball} = iR + L\frac{di}{dt} \quad (2)$$

Using these differential equations, a block diagram consisting of a ballast of a lamp is modeled in Fig. 4:

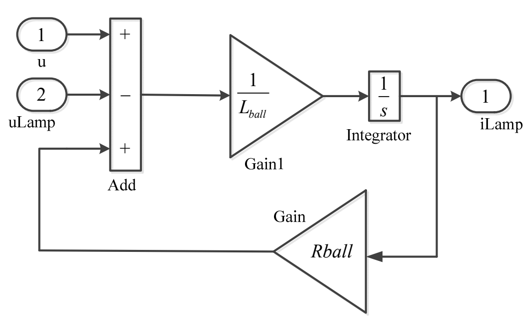


**Fig2:** Bulust magnetic of the Lamp

In the case of using any other circuit as an electric ballust, it can easily be substitute with the circuit.

To simulate high pressure sodium vapor lamps, there are various techniques including Zeiss and Anton models that act based on modeling the electrical conductivity of the lamp and using Ohm's law.

$$G(t) = \frac{i_{lamp}(t)}{V_{lamp}(t)} \quad (3)$$

The models presented for basically the electrical conductivity are basically the same and just for different situations, they have different uses, which are as follows

$$\frac{dG(t)}{dt} = a_2(i(t)+a_1)^2 - [b_3G^3(t)+b_2G^2(t) + b_1G(t)+b_0] \quad (4)$$

$$\frac{dG(t)}{dt} = \frac{a_2}{G(t)}(i(t)a_1)^2 - [b_2e^{b_3G(t)} + b_1G(t)+b_0] \quad (5)$$

$$\frac{dG(t)}{dt} = \frac{a_2}{G(t)}(i(t)+a_1)^2 - [b_3G^3(t)+b_2G^2(t) + b_1G(t)+b_0] \quad (6)$$

These models are called polynomial, exponential, and quadratic, respectively, in this paper, the lamp polynomial model is used.

To simulate the values of the parameters, they were simulated as follows [6]

$$a_2 = 21, a_1 = 0, b_3 = 0, b_2 = 100171, b_1 = 299, b_0 = 0$$

To simulate the ballast, the bulb has a resistive ballast of 7 ohms and a choke that is an inductor of 352 milligrams.

$$R_{ball} = 7(\Omega)\ L_{ball} = 350(mH)$$

To simulate a sodium vapor lamp, according to the plasma energy equilibrium equations contained in [7], the blocks and lamp equations were simulated in the Simulink software environment. And the lamp has simulated like the circuit of Figure (3).

This model can be used to determine the number of simulated lamps in which the number of lamps was chosen 1.

In the Fig. (3) model of high pressure sodium vapor lamp is simulated and in Fig. (4), the lamp is observed along the way to the magnetic ballast connected to it

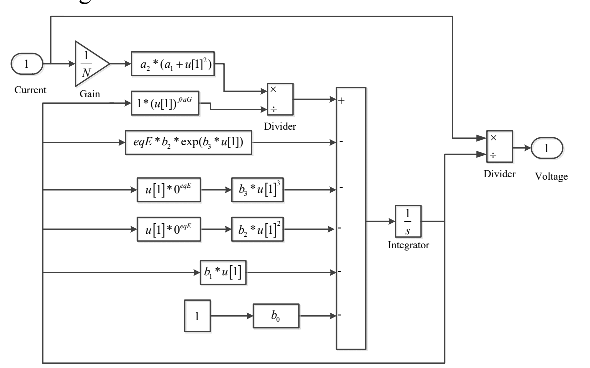


**Fig3:** Model simulated sodium vapor lamp

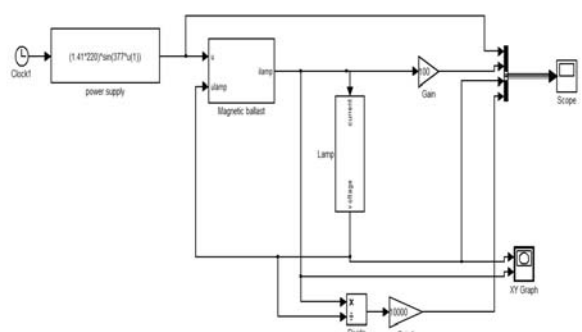


**Fig4:** Model simulated Bulust and sodium vapor lamp

## V. Simulation Results

In order to consider the source of voltage using a clock, and the following equation for a frequency of 62 Hz, we simulated a sine voltage source.

$$u(t) = \sqrt{2}U_{rms}\sin(\omega t) \quad (7)$$

Figure (4) sodium lamps with magnetic ballasts same way it is connected to a voltage source to a lamp is shown. Measurement of electrical quantities including current, voltage and current type as voltage and electrical conductivity after the flow of the circuit to a steady state has been taken. And are shown in Figures 5to9. The comparison of the voltage waveform and the two-bulb current flow with the [8-8],vertices confirms the simulations performed.

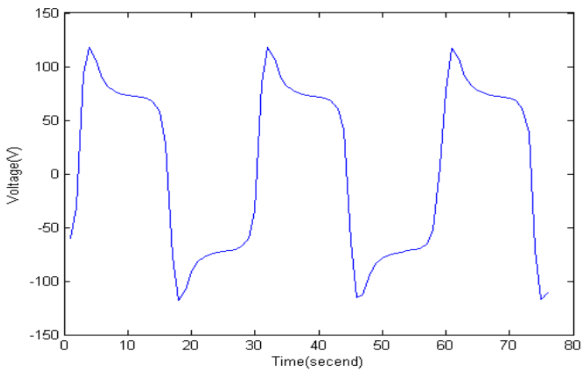


**Fig5:** Voltage of the Lamp

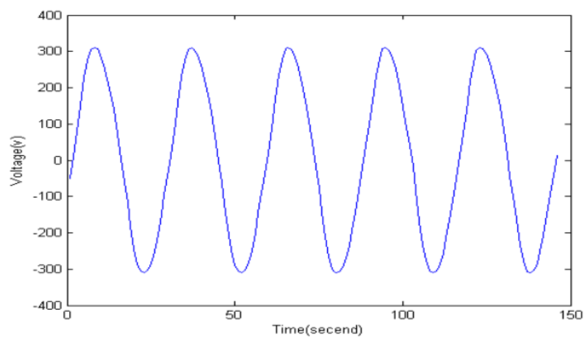


**Fig6:** Output voltage of lamp and Bulust

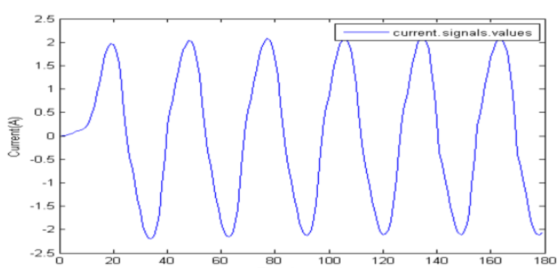


**Fig7:** Current of the Lamp

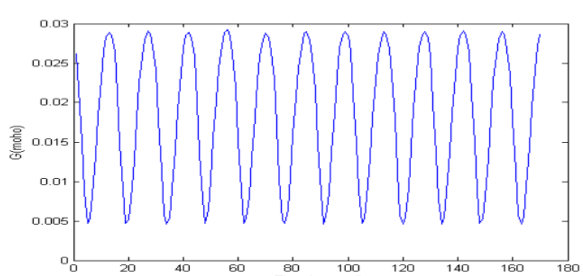


**Fig8:** Electric conductivity of the lamp

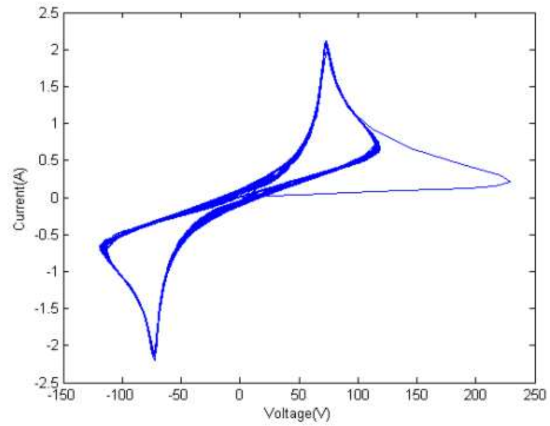


**Fig9:** Lamp current in light bulb voltage

As shown in Fig. 9, this diagram is similar to an electric arc furnace which is carried out in both the electrochemical discharge and the produced material is in the plasma.

## VI. Simulation Results

The voltage source was simulated using a clock pulse in sin waveform at 60 HZ as

$$u(t) = \sqrt{2}U_{rms}\sin(\omega t) \quad (8)$$

Where, u is the voltage, t is time, and ω is frequency. A Sodium-Vapor lamp with its magnetic ballast is shown in Fig. 4. Electrical quantities including current, voltage, current shape according to voltage, and electrical conductivity have been measured after the steady state of the current and have been shown in Fig.5 to Fig 9, respectively. The comparison (similarity) of the voltage and current of the lamp with [8-9] verifies the correctness of the simulations.

The graph in Fig. 11 looks like an electric arc furnace. In both, an electrical discharge is occurred, and the produced material is plasma.

## VII. Power Quality of High Pressure Sodium Vapor Lamp:

Due to electrical discharges, sodium vapor lamps have nonlinear structure and are a source of harmonic production. Given the growing trend of using these lamps in the street lighting, the harmonic effects of these lamps as other harmonic sources should be considered in the quality of the network power.

Our criterion to obtain the harmonics of high pressure sodium vapor lamps was THD as given by [8]:

$$THD = \sqrt{\frac{\sum_{h=2}^{h\max} M_h^2}{M_1}} \quad (9)$$

Table 1 and table 2 show the THD values for the voltage and current of the lamp after the steady state, respectively.

**Table I** : Total Voltage Distortion Percentage

| Frequency | Percentage (%) | Degree |
|---|---|---|
| 0 (DC) | 0.31 | 90.0 |
| 60 | 100.00 | -2.6 |
| 120 | 2.14 | 7.5 |
| 180 | 1.19 | 16.6 |
| 240 | 0.77 | 20.1 |
| 300 | 0.71 | 27.9 |

| | | |
|---|---|---|
| 360 | 0.58 | 49.3 |
| 420 | 0.46 | 38.5 |
| 480 | 0.48 | 45.8 |
| 540 | 0.47 | 58.4 |
| 600 | 0.38 | 67.9 |
| 660 | 0.37 | 71.1 |
| 720 | 0.38 | 73.1 |
| 780 | 0.34 | 88.3 |

**Table II:** Total Current Distortion Percentage

| Frequency | Percentage (%) | Degree |
|---|---|---|
| 0 (DC) | 16.48 | 90.0 |
| 60 | 100.00 | -62.7 |
| 120 | 30.73 | 37.2 |
| 180 | 17.01 | 9.1 |
| 240 | 12.92 | 16.1 |
| 300 | 9.83 | 34.0 |
| 360 | 7.84 | 40.7 |
| 420 | 6.87 | 42.8 |
| 480 | 6.41 | 49.6 |
| 540 | 6.01 | 58.1 |
| 600 | 5.43 | 65.1 |
| 660 | 5.23 | 70.1 |
| 720 | 5.12 | 77.0 |
| 780 | 4.99 | 84.3 |

The THD value for the voltage is equal to %2. 94 which is less than the standard value (5%) [8], and therefore is allowable.

## VIII. Conclusion

The purpose of this paper was to analyze the power quality of a high-pressure sodium vapor lamp. Therefore, the model of the lamp was simulated in SIMULINK and the results verified the correctness of the simulations.

Then, the produced harmonics were investigated with considering THD evaluation criterion. The results in table I and II confirm that harmonic values are standard. Therefore, high pressure sodium vapor lamps satisfy the power quality standards. Regarding high efficiency and high optical gain, and the obtained simulation results, it can be concluded that high pressure sodium vapor lamps are the best options for the Use in street lighting and industrial centers.

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