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Research Article

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The Effect of Harmonic Distortion in Capacitive and Inductive Loads on the Performance of Electrical Grids in Huge projects (Faden Spectrum Phenomenon – An Example)

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Abstract
This research presents the investigation, evaluation, and resolution of an enigmatic occurrence that surfaced following the installation of a massive screen owned by Faden Spectrum Company on one of the towering structures in the Saudi Arabian city of Khobar. The screen, which encompasses 2000 m^2, 2000 cabins, and 2000 feeding cells, each with an area of 1 m^2. This phenomenon includes two things: The first is the appearance of an annoying noise emanating from the main feeder MDB, and the noise increases exponentially with increasing illumination intensity, becoming a noise of 90 dB at 60% illumination and 155 dB at 100% illumination. The second most surprising thing is that the cables became hot only at the point of their exit from the ceiling of the panel, as the temperature then reached 83 degrees, noting that the cables before and after this point, it was not affected by this temperature at all. Its temperature was 28 degrees before the entry point, and the same temperature after the exit point, while the iron metal of the panel's ceiling was clearly affected, also recording 83 degrees.

Keywords: Faden Phenomenon, Capacitive Loads, Harmonics, Inductive Loads, Electrical Power Factor, Capacitor Bank and Power Improvement Factor

1. Introduction

In the past decades when capacitive loads were less common. As a result, electrical networks only experienced electrical wave distortions on inductive loads, such as industrial pumps, refrigeration units, injection compressors, and electric motors; phase angle issues in the power triangle accounted for the majority of these issues. The classic, adding power factor capacitors were seem to be capable of solving majority of such issues [1-3]. However, harmonic distortions on capacitive loads were later produced by excessive use of computers, energy-saving light bulbs, mobile chargers, and routers; These distortions had a direct influence on transformer stations and significantly affected electrical network performance. At present times, the public and private electric power generation and distribution companies around the world have recently become aware of these problems and have imposed heavy fines on this type of due to the fact that it reduces the efficiency of state-level distribution stations while simultaneously undermining the principle of equitable power distribution.

In 1940s and earlier than that the Electric current was defined as simply an ordered flow of surface electrons in the conductor metal, allowing Ohm's law to be used to direct electric current. All definitions were predicated on this rule: An alternating electric current can be applied when it flows through a sinusoidal resistance that is pure. It was the basis for Ohm's law in direct current, and things were straightforward because industrial magnets and electric motors were not as big and complicated, and the majority of the current was used for heating (in electric baths, boilers, and tungsten cookers) or lighting (in tungsten bulbs). All of these devices were semi-pure sinusoidal resistors in line with the previous definition [4].

The early issues began with the popularization of the neon bulb, as it became clear that the current is not simply the resultant of two always identical waves, but rather the resultant of two identical waves on the current intensity wave and the voltage wave under specific conditions. In the case of the neon bulb and mercury bulbs, the current intensity wave preceded the voltage wave. Making the sum of the two distorted waves in some way; frequency multipliers were directly related to the algebraic sum of these waves. At first, there were two distinct categories of electrical loads [5].

1. Linear Loads: These Loads may be used without additional parameters in Ohm's law with direct current since they are almost pure loads.
2. Non-Linear Loads: They create harmonic interference (it was

later shown that the third harmonic had the greatest impact on these loads).

The concept was then expanded to distinguish between nonlinear loads themselves, as it turned out that they are also of two types:

• Inductive loads in which the voltage wave precedes the ampere wave.

• Capacitive loads in which the ampere wave precedes the voltage wave.

However, electrical projects in the past contained both types of loads closely, which allowed the giant networks to repair themselves and physically match the resultant of the two waves without the need for any other solutions. Nevertheless, because modern factories rely solely on electrical current—primarily from inductive loads—the voltage wave, rather than the ampere wave, takes precedence. This led to noticeable distortions, also known as THDv, and the world's electricity companies mandated that these factories install power factor optimization devices to fix the problem for Reduction of phase angle and contrast (KVAr).

1.1 Research Significance and Objectives

The significance of this research lies first in shedding light on the emergence of the problem of distortion of capacitive loads THDi and the birth of active pulse filters as well as on electrical distribution systems of the family TN being the most widely used in the world. Moreover, the second significance defines grounding, its types, its importance for major projects, and how to use Marcionite and volcanic slag powder as effective alternatives to coal and rock salt in reducing the specific resistance of the soil. However, the research objectives present the importance to introduce the phenomenon of **Faden** Spectrum (FADEN Spectrum) and finding solutions for it. This name was given in reference to FADEN Spectrum, a giant company in the Gulf that supplies and installs giant road display screens on huge towers and bridges. This strange phenomenon occurred when they installed a giant screen on one of the huge towers in the city of Al-Khobar, Saudi Arabia.

2. Research Methodology

• The problem of distortion of capacitive loads appears THDi and the birth of active pulse filters:

Problems with capacitive loads are described in the standard IEEE-519, which is perhaps the most comprehensive specification for this type of problem, especially the amendments that have been made to it by specification number IEEE 519-14 [6].

Since the beginning of the third millennium, the use of savings bulbs, mobile chargers, and computers has expanded, causing major problems in shopping malls, major hotels, and palaces as a result of capacitive loads in which the amperage wave precedes the voltage wave. A large number of losses due to currents returning to the transformer stations could not be tolerated, and a solution had to be solved, and thus the principle of the active pulse generator arose [7]. It is a filter that generates a voltage wave that precedes the ampere wave, so that the two waves are matched and the total distortion is reduced to a minimum. It is commonly called (Active Power Filter, APF for short) and is also sometimes called (Active Harmonic Filter, AHF for short), and both have the same meaning. This type of filter is advanced version on inductive pulse generator static which is known as (Static VAR Generator (SVG for short).

2.1 Electrical Distribution Systems of the Family TN

There are many systems supported in Power supply and Electrical distribution, but what concerns us here is the distribution system TN is the most widely used in the world and has been precisely described in IEC 60364 and its amendments and in IEEE 80-13 and its amendments, in addition to BS, DIN and other specifications [8]. This system is divided into two types:

Distribution system TN-S: This system separates the neutral and the ground for the investor. Electricity companies may install zigzag-type transformers to completely separate the ground from the neutral in some cases that require this form of connection.

Distribution system TN-C: This system allows grounding the zero point of the transformer by connecting the neutral line directly to the ground. Usually the system followed is: TN-C at the transformer and TN-S at the investor's facility because it is an effective and cheap balancing system.

2.2 The Importance of Grounding In General and In Solving the Faden Spectrum Problem in Particular

Engineers may overlook the importance of a good ground, and the international standard specifications have been somewhat lenient in it to reduce the massive financial burdens resulting from a typical grounding in small establishments, and have sometimes allowed the grounding resistance to reach up to 16 ohms in some areas where it is difficult to reach typical values. It is the grounding of the contact that is important in these specifications in order to protect equipment and individuals from electrocution [9].

Additionally, many professional engineers have also suffered due to poor grounding in major projects, as they are treated with extreme indifference and neglect during the establishment of infrastructure, and then the owner of the facility pays the price later because the grounding was unable to keep up with the huge and sensitive loads in hospitals, for example, and an individual personally suffered from this. Moreover, in many hospitals, the highly advanced echo Doppler device in one hospital was unable to distinguish between a stool mass and a malignant tumor in the patient’s abdomen. Another device to test osteoporosis gave results for osteoporosis and severe calcium deficiency for all people, including those who were in good health.

The nominal value set on these devices required a resistance of less than 1 ohm to the ground, and a potential difference of less than half a volt between the ground and the neutral to give accurate results, and this was not achieved due to improvised grounding. These problems were easily solved by simply constructing a typical ground that met these conditions. Good and thoughtful grounding has allowed this research to solve a large part of the **Faden Spectrum** problem, as will be seen later.

2.3 Types of Grounding

There are kinds many for grounding [10] Among them few have been mentioned in this research such as:

• ***Grounding against Contact Current,*** which is grounding that purposes primarily to protect individuals and equipment from electrification.

• ***Grounding against Step Tension,*** which is the grounding that aims to protect tall individuals and large animals such as camels and cows from electrocution in/near transformer stations and at medium and high-tension lines and poles.

• ***Grounding against Static Currents,*** which is grounding that targets to protect valuable equipment such as medical devices from being affected by the static currents that arise between them and their users, especially in summer and fall.

• ***Linear Grounding against Capacitive Harmonics in Star Distribution*** systems aims to balance the zero point in transformers in a typical and cheap way, which is what we did as one of the most important procedures for solving the Faden Spectrum problem.

• ***Grounding and Shielding,*** which aims to isolate weak currents and data transmission networks from low, medium and high current lines.

•

2.4 Use the Marcionite and Volcanic Slag Instead of Salt and Coal When Building Grounding:

It is considered Marcionite (low electrical resistance cement) and volcanic slag powder (Slag)They are ideal for reducing the specific resistance of the soil. In contrast to ordinary salt, which quickly disappears with rain within a year or two, Marcionite and volcanic slag do not decompose, which makes them very good in typical ground construction. They also facilitate achieving a resistance of less than 2 ohms. Marcionite has been given to us by Type ABB-FURSE/25kg Very excellent results arrived in Land of the Faden Spectrum screen site for a resistance of less than 1 ohm after obtaining the specific resistance of the soil by H While it gave less than 5 ohms in rocky areas [11].

2.5 Definition of the Faden Phenomenon

Faden Spectrum Company (Faden Spectrum is a giant company in the Gulf [12] that supplies and installs giant road display screens on towers and huge bridges [12]. A very strange phenomenon occurred with it when it installed a giant screen on one of the huge towers in the city of Al-Khobar, Saudi Arabia. The screen area on the front of the tower is 22000 m and consists of 2000 cabins that feed 2000 cells, the area of each cell is m21. It is forced cooled by 63 2-ton split air conditioners.

In addition, for a 25-ton package air conditioner it is operated automatically in support of illumination (the cooling rate increases with increasing illumination). The screen is fed from a distribution box three-phase MDB with a capacity of 2250 amps and an air breaker ACB 2500A/3P 400V-60Hz.It is fed directly from a transformer allocated to it with a capacity of 1.5 Megavolt Ampere (1500 KVA) See Figure (1). It exits the transformer through a ground manhole towards the box MDB 11 single cables, each with a cross-sectional area 630mm2 in addition to the land line, and is distributed as follows:

• Three 630 mm2 cables for each active phase
• Kaplan 630mm2 for neutral
• 120 mm2 cable for ground

It emerges from the ceiling of the panel towards another distribution and control box of the same type MCC, 12 meters away from it, the same cables after the ceiling of the panel was drilled with 12 holes and 12 2-inch metal cables were installed so that the cables could pass through it to the top. The cables were then carried directly on a cable tray (tray) fixed to the ceiling. According to data shown in the following table (Table 1):

Distributing Type	ACB Ampacity	Voltage	Frequency	Number of Cables
TN-S	2500A	3P 400V	60 Hz	[11 x (1C 630mm2 XLPE/PVC)] + 1C 120mm2 Y/G for PE

Table 1. Measurements of cable (tray) fixed to the ceiling

Figure 1. The Faden Company screen is the focus of this study (Al-Khobar - Kingdom of Saudi Arabia)

3. Description of the Problem

This research has first explained, that the main feed Cables of the MDB on standard trays is located in the tower's electrical room. It is a typical room that is perfectly cooled by a 2-ton split air conditioner. However, as soon as the screen is turned on at 20% brightness, an annoying noise begins to emanate from the main MDB feeder, and the noise increases exponentially with increasing lighting intensity, becoming a noise of 90. dB at 50% illumination and 155 dB at 100% illumination (the noise level was measured using a Sound Meter LUTRON SL-4022). The engineers first thought that the noises coming from the feed box were just poor tightening of some of the mounting bolts, and for more than a week they tightened and replaced every bolt and nut to no avail.

It became clearer that the ceiling temperature of the distribution box exceeded 80 degrees Celsius, when one of the workers screamed in pain while tightening the screws of the cable tray, just by placing his hand on the ceiling of the panel. An infrared thermometer of the type (**Fluke HVAC Pro 561**) Hurry and here was the surprise: The temperature of the copper cables was very normal and close to the average temperature along the line (28.3 degrees Celsius), but at the point where the cables exited from the ceiling of the panel, the temperature of the cables became 83.4 degrees for less than one centimeter, and then the temperature returned to normal immediately (28.3 degrees) as soon as they moved away from the ceiling. The plate was contrary to the known laws of thermodynamics, where heat exchange was supposed to take place and thus raise the temperature of the cables along the line. This type of thermal entropy was difficult to understand as shown in figure 2 below.

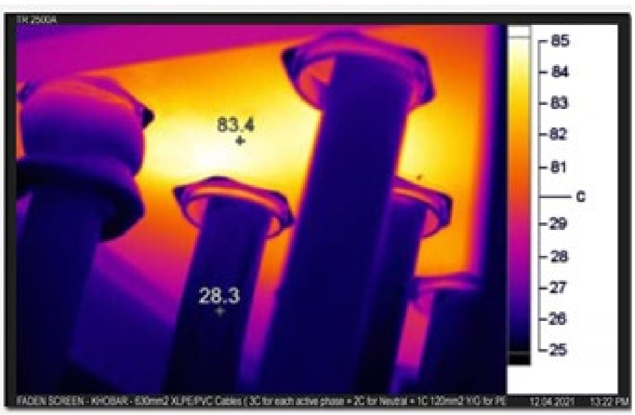

Figure 2. Thermal image of cable exits from the roof of a box MDB to understand the depth of the phenomenon.

Faden Spectrum sent all the results and data to the manufacturer to explain the phenomenon and solve the problem, however, unfortunately, the manufacturer was unable to provide any understanding of the phenomenon or assistance of any kind, so the company contacted international consulting offices in Germany and Belgium, to no avail as well. The company Fadden Spectrum then formed an international multinational working group under the supervision of Professor Dr. Hazar Shtat from Jordan to solve this dilemma.

Work Team

- Professor Dr. Hazar Shtat from Jordan - Head of the working group
- Engineer Abdullah Habra from Syria - Automation and Programming Responsible
- Engineer Ashraf Ali from Egypt - Data and Systems Analysis Officer
- Engineer Mohamed Haikal from Egypt - responsible for developing capacity improvement transactions
- Engineer Mohamed Ismail from Egypt - Supervisor
- Engineer Mohamed Saker from Egypt - Supervisor of inductive coil manufacturing

From Faden Spectrum Company

- Mr. Muhammad Al-Garawi from Saudi Arabia - Director
- Dr. Uzair Syed from India - General Supervisor
- Engineer Salim Al-Sheikh from India - Supervisor
- Engineer Younus Azheri from India - Supervisor

4. Proposed Theoretical Explanation

This study has assumed from the beginning that the noise was caused by distortions of the third harmonic frequency, and were successful in that. As for the strange thermal phenomenon associated with it, we explained it as being caused by the flow of electric current electrons, the wave being originally distorted due to harmonic problems, as they advance between the atoms of the iron metal (the ceiling of the plate) and collide with its atoms (Which does not move from one place to another, but it oscillates in place and therefore has kinetic energy) without stopping. During these collisions, the moving electrons lose almost all of their kinetic energy, and part of this kinetic energy is transferred to the atoms of the metal, and this leads to an increase in the speed of oscillation of the atoms, and thus the temperature of the metal rises, and the height, in turn, leads to a significant increase in oscillation, which forced them to collide with each other and produced higher degree of heat as a result. Once the electrons are freed from the influence of the iron metal, they return to their original thermal nature.

The model used was the quantum Drude model of Ohm's law for the study and was the best way to understand the phenomenon and work on it. In the same context, the researcher also developed an integrated action plan, which was in order as follows:

- Resorting to a professional electrical systems analysis company to provide a comprehensive report on the input and output currents and accurately determine the waveform to know the values and shape of the distortions occurring.
- Constructing a typical grounding as described above instead of the previous grounding that was adopted for contact grounding only for the following reasons:

1. The previous grounding resistance was about 5 ohms in no-load mode which is an acceptable value
2. Once the monitor was powered on the grounding resistance was 2 mega ohms
3. When the illumination is raised to 50%, the grounding resistance is 20 mega ohms
4. At 100% illumination, the grounding resistance becomes close to infinity
5. Ground the zero point of the transformer via the new grounding box the MDB itself was unable to ground and connect the transformer for purely technical reasons, and this was done after obtaining the approval of the General Electricity Company for this.
6. Caging and shielding the new ground when it passes through the walls towards the tower’s electrical room (Faraday cage) because the cable used is from the last peg towards the box the MDB is 240mm2 SDBC type
7. Replacement of ferrous metal for panel roof MDB with a 3 cm thick Teflon sheet with an area of 1 m2 to neutralize any emerging magnetic field.
8. Support the neutral line consisting of2x (1C 630mm2 XLPE/PVC) with a third line of the same type and size in accordance with Schneider’s recommendations and regulations No. ION7400 in accordance with the requirements of EN50160-10 and its amendments.
9. Install an active harmonic filter after performing the above procedures completely, if necessary.

These works took about 13 AD months

The general situation was at the moment when the work was started and according to the report of the Energy Systems Analysis Company as stated Table (2). However, as for the neutral (cold) line, the situation was as in (Table 3).

LED BRIGHTNESS (%)	15%	30%	50%	70%	100%
MEASURED CURRENT (A)	347	460	605	744	995
TRANSFORMER LOAD CURRENT (BASED ON 2160A)	16%	22%	28%	35%	46%
ACCEPTED THD-CURRENT AS PER IEEE 519-2014	31%	22%	17%	14%	11%
ACCEPTED THD-VOLTAGE AS PER IEEE 519-2014	5%	5%	5%	5%	5%
MEASURED THD-CURRENT	93%	97%	95%	80%	77%
MEASURED THD-VOLTAGE	5.70%	7.7%	9.90%	11%	13%
RESULT AS PER IEEE 519- 2014	**NOT ACCEPTED**	**NOT ACCEPTED**	**NOT ACCEPTED**	**NOT ACCEPTED**	**NOT ACCEPTED**

Table 2: The general situation at the moment we started work regarding the active phases, according to the report of the Energy Systems Analysis Company

LED BRIGHTNESS (%)	15%	30%	50%	70%	100%
MEASURED CURRENT (A)	347	460	605	744	995
MEASURED NEUTRAL (A)	**443**	**638**	**811**	**930**	**1134**

Table 3. The general situation at the moment we started work, according to the report of the Energy Systems Analysis Company for the *"neutral line"*.

The box diagram of the feeding assembly was from the transformer to the box MDB then as well the figure shows it (3). While the wave distortion of THDv and THDi are at 100% illumination at the moment of starting work, as he explains the shape (4):

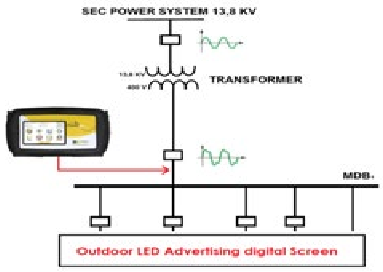

Figure 3. Box diagram of the feeding group from the transformer to the box MDB

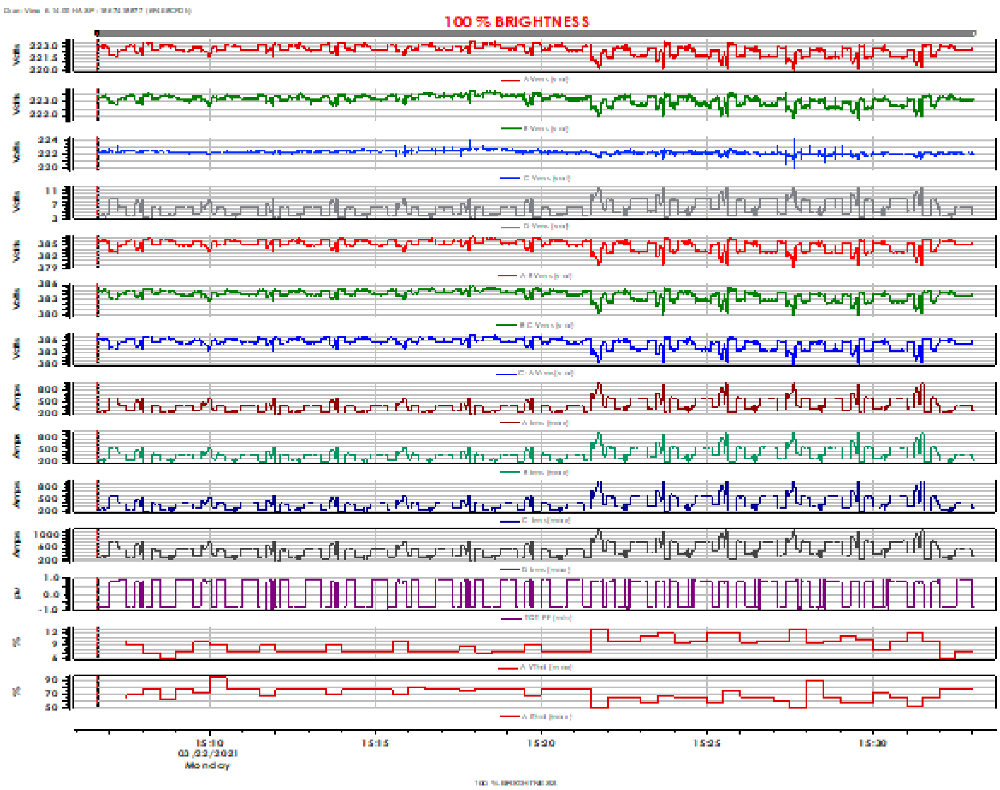

Figure 4. Wave distortion of THDv and THDi at 100% illumination at the moment of work start

After completing the work, which took 13 months, the researchers applied the above agenda in its entirety, and obtained acceptable results below.

• Physically reducing the harmonics on the neutral line to 47% instead of 95% at 50% illumination.
• Reduce the apparent amperage capacity on the neutral line to438 amps instead of 811 amps at the same illumination rate.
• Reduce the noise55 dB at the mentioned illumination rate.
• Complete absence of the thermal field, especially where the cables exit from the roof of the box MDB has been done make sure of that after using an advanced type of thermal imaging device Fluke TiS55, See Figure (5).
• The emergence of a large thermal field along the cold line feeding the control system and data in the control room, which is a line of small cross-section type (1C 35mm2 XLPE/PVC), This emergency problem was solved by completely disconnecting the line and its feed data from a plate MCC directly.
• Reducing the electricity bill by approximately 45% compared to the same month of the previous year, despite the same operating hours and increasing the lighting rate from 50% to 65%.
• Total absence of **VAr** is clear in the Saudi Electricity Company invoice-the attached,

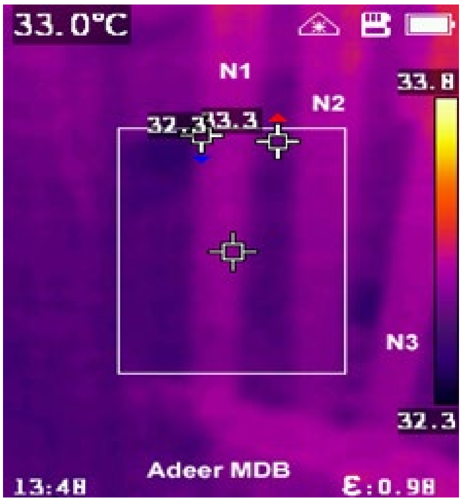

Figure 5. Thermal image After overcoming the enigmatic thermal field

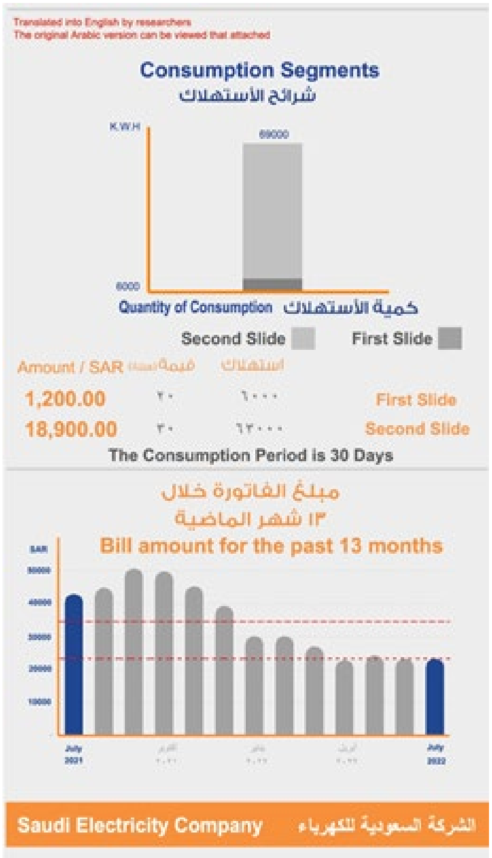

Figure 6. Consumption rate after implementing the solutions mentioned above

5. Results and Discussion

This research explained the results by describing that the harmonic fields tend to affect lines of lower and higher cross-section, and the thermal effect appears clearly on weaker lines. Capacitive harmonics can be reduced by doubling the neutral line cross-section, but it cannot be a magic solution that replaces active filters in large projects. The physical solution presented in this study was an acceptable solution, but it was not typical and does not replace active filters. However, this study has presented a creative solution that will reduce the volumetric and capacitive mass of the active filter will be reduced by at least half if Faden company decides to install it, which means saving more money, as the cost of a 400 amp filter is much lower than the cost of a 1200 amp filter, even if it is according to the 400 amp system X 3. Moreover, a good grounding can connect to the neutral (based on the system TN-C). Capacitive distortion is greatly improved provided that there is another independent grounding against the contact current to protect individuals from electrification for any reason. The problem of the thermal effect when cables meet ferrous metal under heavy loads (Fadden phenomenon) is a problem resulting from harmonics within specific requirements but it still needs more study to establish regulating mathematical laws based on Drude's quantum interpretation of Ohm's law.

6. Conclusion

The study concludes that well-studied physical solutions can solve a large portion of this type of problem with an acceptable (non-typical) removal of the risk. Despite this, active filters cannot be dispensed within this type of load, even though the solutions presented in this study can reduce the consumption rate effectively. As is clear from Figure 6, which shows the consumption rate at the moment the invoice is issued compared to the same month in the previous year, despite the increase in the lighting rate from 50 to 65%.

Recommendations

In this type of problem associated with this type of load, this study strongly recommends the following:

• Distributing the load among several small transformers (which was impossible in the Faden project due to technical considerations related to the electricity company itself)

• Use CTs on internal bus bars of MDB type distribution box anti-rubber to shake

• Use a static inductive pulse generator SVG, which is also not possible in Faden case for technical reasons related to available space.

• Use an active pulse generator APF After doing all the procedures we did above, the problem with this type of filter is that it is very expensive

• When it is not possible to carry out the above procedures, the physical solutions that this study have implemented can be sufficient according to strict conditions, the most important of which is that the damage to the current transformers is of the type5-9VDC is within the relatively controlled dimming rate, provided that the illumination rate in hot afternoon hours does not exceed 60-65% at an average temperature that does not exceed 45 degrees Celsius.

Aspirations

The researcher looks forward to benefiting from the Faden phenomenon by generalizing the solutions presented in this research paper - in other projects to improve THD at the lowest cost on the one hand, and achieving savings in the electricity bill on the other hand, exactly as happened with Faden. The solution can also be adapted to suit mixed projects that suffer from instability THDv too.

The researcher has noticed a state of instability in huge malls and major hospitals THDi and THDV between summer and winter, as these projects are characterized by instability in terms of THDv in the summer as a result of the excessive use of air conditioning devices, especially chillers. On the other hand, these projects suffer from phase imbalance and THDi problems in the winter as a result of the excessive use of saving lighting without any significant THDv due to the lack of need for air conditioners in this period of the year. Therefore, it is possible to reconcile the two situations through design PFCB (Power Factor Capacitor Bank) according to the following:

- The highest value of the is first calculated KVAr by using a reliable electrical systems analysis device, after running the entire project design is done PF is based on the maximum value of KVAr multiplied by the margin of safety 1.2.
- A reader tool is used the PF is a good and reliable type of quadruple type PPPN and can read every active phase in addition to the virtual load on the neutral and is equipped with an Ethernet network socket is used. The PLC is equipped with a powerful processor and a reliable data and communication exchange unit to obtain readings and process data, and then program it in accordance with the nature of the project to insert and output the group of capacitors, each separately and sequentially whenever necessary system is used TN-C in distribution after providing the project with a typical grounding while maintaining the existing grounding for Touch currents.
- Because large harmonics affect the performance of the controllers, forcing them to send wrong signals, and to prevent any signal interference that is not benign as well, it is used CT is specific to the neutral line, so that it prevents the entire PF bank from working when the apparent amperage on the neutral reaches the critical limit, because it definitely means a large flow of THDi and we do not need to enter any capacitors to increase it.
- Capacitors are connected KVAr with triple choke coils to safely discharge the capacitors when they stop working.
- Contactors are used Standard PF equipped with thermal coils to discharge excess charges to prevent damage.

This design works PFCB is reliable when there is any type of THDv, and it stops working forcibly if the THDi wave overcomes the THDv wave, even if the commands overlap, because the priority of opening and closing will be given to the reading results on the neutral line, and it is therefore valid for work in all circumstances.

As for dealing with the wave of the THDi is large, the project requires a strong grounding against harmonics according to the TN-C system, as previously explained in this research paper, and suitable for balancing the zero point in the transformer, which requires the use of a conductive cable of at least 120mm2 SDBC type, and it is necessary to maintain the basic grounding in the existing project. According to the TN-S system to protect against contact current only and not introducing it to the new ground network.

Initial Executive Model

The proposed form of the model ***PF.CB*** initial CB (Power Factor Capacitor Bank) will be suitable for connecting to the internal network of the project and working in all seasons of the year, and it will be 160 KVAr, which allows us to test it - after building it on projects whose capacity may reach up to 600 KW (however, careful systems analysis is what determines the validity of the model For experimentation in this or that project, and the size capacity of the model can be increased to be compatible with larger projects by increasing the stages. The prototype that we developed has begun implementation by the **Faden Spectrum** team, and will be ready within 4 months at the latest. The proposed box model can be seen in Figure 7, which is developed based on the results of Faden Spectrum Phenomenon.

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