DESIGN OF LIGHTING SYSTEM AND ITS POWER SUPPLY SCHEME FOR A TELEVISED SPORTS ARENA- A TYPICAL TENNIS COURT

A thesis submitted towards partial fulfilment of the requirements for the degree of

Master of Technology
in
Illumination Technology and Design

Submitted by
Sayan Chakraborty
Exam Roll No.- M6ILT22023
Registration No.- 150187 of 2019-20

Under the guidance of
Dr. Biswanath Roy

School of Illumination Science Engineering and Design

Jadavpur University

Course affiliated to

Faculty of Engineering and Technology
Jadavpur University
Kolkata-700032
India
2022

CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"DESIGN OF LIGHTING SYSTEM AND ITS POWER SUPPLY SCHEME FOR A TELEVISED SPORTS ARENA - A TYPICAL TENNIS COURT"** is a bonafide work carried out by **SAYAN CHAKRABORTY (Exam Roll No.- M6ILT22023, Registration No.- 150187 of 2019-20)**, under my supervision and guidance for partial fulfillment of the requirement of **Master of Technology (Illumination Technology and Design)** in School of Illumination Science, Engineering and Design during the academic session 2021-2022.

THESIS SUPERVISOR
Dr. Biswanth Roy
Professor
Electrical Engineering Department
Jadavpur University
Kolkata - 700 032

Prof. Subenoy Chakraborty
DEAN
Faculty of Interdisciplinary Studies,
Law and Management
Jadavpur University

Prof. Parthasarathi Satvaya
Director
School of Illumination Science,
Engineering and Design
Jadavpur University

M.Tech (Illumination Technology and Design)
Course affiliated to
Faculty of Engineering and Technology
Jadavpur University
Kolkata, India

CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

Committee of final examination for evaluation of Thesis

DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his Master of Technology (Illumination Technology and Design) studies during academic session 2021-2022.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

NAME: SAYAN CHAKRABORTY (Exam Roll No. - M6ILT22023, Registration No.- 150187 of 2019-20)

THESIS TITLE: DESIGN OF LIGHTING SYSTEM AND ITS POWER SUPPLY SCHEME FOR A TELEVISED SPORTS ARENA- A TYPICAL TENNIS COURT

DATE: SIGNATURE

ACKNOWLEDGEMENT

A lot of inputs from various sources have been utilized in completion of this entire thesis work, carry out necessary analysis and prepare this report. I wish to take this opportunity to thank them all.

First and foremost I want to thank Dr. Biswanath Roy, Professor, Electrical Engineering Department, Jadavpur University for providing me with the opportunity to carry out my thesis work under his constant guidance and supervision. I also would like to thank him for providing me his valuable time and helpful suggestions without which it would have been impossible to develop this thesis work.

I am highly indebted to Prof. Parthasarathi Satvaya, Director, School of Illumination Science, Engineering and Design, Jadavpur University, Dr. Kamalika Ghosh, Assistant Professor, School of Illumination Science, Engineering and Design, Jadavpur University and other faculty members of Electrical Engineering Department, Jadavpur University for their valuable suggestions and encouragements during this project work. I am indebted towards Dr. Prithwiraj Purkait, Professor, Power Engineering Department, Jadavpur University; Mr. Sarit Kumar Chakraborty, Advisor, Bharatpur Electricity Services Limited; Mr. Sudip Ghosh, Sr. Engineer, Bharatpur Electricity Services Limited for providing me with necessary concepts, data-sheets, suggestions and most importantly their valuable time to develop this thesis work.

I am also thankful to all non-teaching staffs of Electrical Engineering Department of Jadavpur University, all my classmates and many friends who directly or indirectly encouraged me in completing my thesis work successfully.

Last but not the least, I am indebted to my Parents for their constant love, support and motivation during the progress of my thesis as well as this degree.

DATE: SIGNATURE

THIS THESIS WORK IS DEDICATED TO MY MOTHER MRS. BASABI CHAKRABORTY, MY FATHER MR. SARIT KUMAR CHAKRABORTY, WHO HAS BEEN CARING, LOVING AND SUPPORTING ME THROUGH OUT MY LIFE ; TO ALL MY TEACHERS I CAME ACROSS DURING MY ACADEMIC CAREER WITHOUT WHOSE GUIDANCE I WOULD NOT HAVE BEEN HERE AND IS DEDICATED TO JADAVPUR UNIVERSITY

Contents

List of Figures

List of Tables

Introduction

Lighting Design is a segment of study that requires knowledge and idea of engineering, science and aesthetics altogether. A balanced possession of all three makes a lighting designer and design done by him perfect and his design becomes well sustainable than others'. Be it Indoor lighting design or Outdoor lighting design, the dynamic admissibility of it depends on the application of the above three possessions of the lighting designer into it.

Among all type of lighting designs, Sports lighting design is the most challenging task a lighting designer ever encounters. It desires utmost excellence from a lighting designer. Unlike other type of lighting designs, sports lighting is something beyond just satisfying a set of standardized design criteria. Sports lighting involves infinite number of viewing perspectives of different users of the sports facility involved - players, match referee and/or umpires, other gaming and non-gaming staffs, spectators present in the live game and the cameras for televised gaming events. Hence, the lighting design should be perfect enough that everybody's viewing experience is satisfactorily pleasing. Also, a smooth transition from daylight to artificial lights has to be ensured to maintain the quality of the game and the visual experience.

When the lighting designer overcomes his part of challenges, another set of challenges are faced by the electrical engineers involved with the power supply of those lights as well as other auxiliary electrical loads of the sports facility. Although, among all, the floodlights are considered to be the primary load of a sports facility. A sports arena consumes huge amount of energy from the electrical grid to feed these floodlights along with other secondary loads. Hence it is indispensable to appropriately and tactfully design the electrical power supply scheme of the corresponding floodlighting system with suitably rated cables, circuit breaker, transformers and other electrical equipment. There may be failure in the supply system during the game, hence to keep the game played uninterruptedly, arrangement and quick switching of backup power supply must necessarily be present in the facility.

In this thesis work, design of the lighting system using LED floodlighting luminaires and the corresponding power supply scheme for a typical outdoor tennis arena has been carried out considering all of the above discussed conditions. The lighting design has been done considering both the cases that the game-play will and will not be broadcast through television. The power supply scheme has been designed taking the condition into account that the game-play will be television broadcast only, since the power consumption of the non-televised event is very less and non-significant in comparison to the televised one. Also a Bill of Quantity for both Lighting system and power supply arrangement is prepared.

Literature Survey

Not only at present age of technological and engineering development, researches and experiments were conducted even before the advent of LED to achieve better quality illumination in sports lighting. In 1937, nature published a report which says, tennis court lighting design must include complete freedom from glare and that the light should have a high speed of discrimination. In Philips Technical Review (Eindhoven) of August 1936, it has been pointed out that sodium lights are well capable of fulfilling both these requirements exceptionally. It states that, experiences show the presence of these lamps even in the field of vision is much less disturbing than other lamps of same candela power. Experimental proofs are also present in the support of the quicker discrimination of objects under sodium lamps than others. According to this literature, good results were obtained in illumination of three open-air tennis courts in the Netherlands East Indies with 8 numbers of 150 watt sodium lamps, arranged in two rows, containing four each, on the sides of the court and situated 20 feet above the ground.

In 1953, M.W.Pierce addresses some issues with indoor and outdoor sports lighting together in order to find some satisfactory solutions. A tennis court lighting design using the tungsten filament lamp and other equipment and corresponding cost analysis has been depicted in the literature. It reports that artificial lighting design causes more comfort than that played in the sunshine. Some probable reasons of difficulty in judging the ball speed in artificial lighting has been explained also.

R.A. Hargroves et.al. in the year 1986, prepared a report describing the effectiveness of the formula given by International Commission on Illumination (CIE), which estimates the subjective impression of a floodlighting installation, evaluating for Tennis court lighting. Although the formula was based upon evaluation of glare in football training ground and stadium, it was well applicable for airport apron and railway marshalling yards illumination. Their report has been prepared using two test results conducted at two tennis clubs. In the preliminary tests at Redbridge five observers falling in the age group of 35 to 55 made two series of glare appraisals. The appraisals were made over too small range of glare quality and hence no significant correlation could be achieved. Further, On 19 March 1985, 23 working aged observers, each made two sets of 21 glare appraisals on the tennis courts at the Balfour-Beatty Sports Ground at Chislehurst, Kent. There were three courts lit by twelve metal halide floodlights each column having three at an height of 12 meters placed in the corners. The observers were given sheets having a particular format and corresponding numbering for making the appraisals. All observations were taken towards particular position due to uniform background. The ten-point scale was chosen for the ease of comparison with test results of football stadium and training grounds. The results showed well applicability of the proposed

formula for glare appraisals to tennis courts.
Ashwathi Suresh et. al. in their literature depicted an energy efficient lighting design for an indoor squash facility in the Manipal Institute of Technology. They followed the standards specified by World Squash Federation to validate their design. Energy efficient LED lights has been used in the same. The results show that their proposed design is 77% energy efficient than the system previously existed.
Jane Preema Salis et.al. has suggested a retrofitting design of an indoor table tennis facility in Manipal University. Their suggestion follows Philips Lighting Standards. The Lighting simulations have been performed in DIALux Evo software.

Problem Identification

- Design of illumination system for a typical outdoor tennis court for both televised and non-televised events following standards given in National Lighting Code (NLC) (SP 72: 2010) published by Bureau of Indian Standards (BIS).
- Design of the corresponding power supply scheme, i.e.- drawing of the single line diagram of the corresponding electrical system with ratings of different electrical components required for the illumination purpose and calculating voltage drop of the cable.

Objectives

- To illuminate a typical outdoor tennis court using 250W Energy efficient LED luminaire.
- To achieve different photometric parameters according to the standard values for both televised case and non-televised case separately as given in NLC 2010 (SP 72: 2010) published by BIS.
- To draw the single line diagram of the Electrical system required for the Lighting System of the televised court.
- To calculate ratings of different electrical components used in the system.
- To calculate the cable voltage drop at different segments of the power supply scheme.

Steps of Execution

- Doing necessary theoretical and background study to get idea about the DIALux

4.13 software, different photometric parameters and their values standardized in Indian National Lighting Code 2010.

- Studying previous literatures to get an idea about the process of executing the design.
- Executing the design in DIALux 4.13 software for both televised and non-televised tennis game-play.
- Comparing the obtained photometric parameters with that of NLC 2010.
- The number of luminaires is obtained from the design a with the help of which, drawing the single line diagram of the electrical system , calculating the ratings of different electrical components and cable voltage drop at different segments.

Conceptual Flow Diagram of the Project

The methodology followed to implement this thesis work from the beginning has been described in Figure 1-

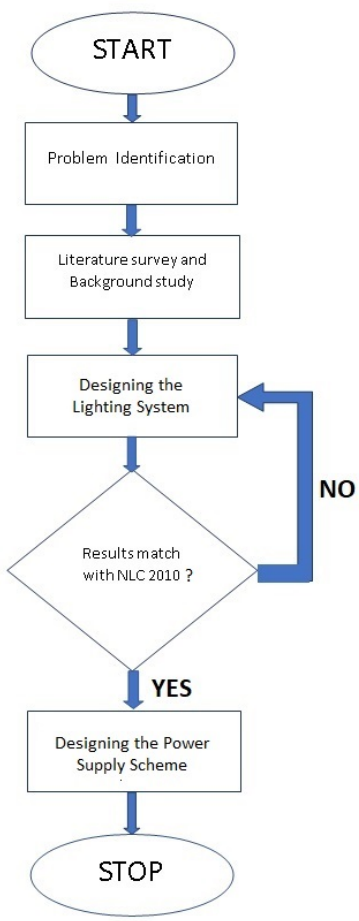


Figure 1: Conceptual Flow Diagram of the Project

Thesis Organization

This thesis work is organized in Five Chapters, Three Appendixes and One Acronym list at the end. In brief, the structure is as follows -
Chapter 1 deals with a general discussion on Sports Lighting. It highlights the uniqueness and challenges of sports lighting design from other type of outdoor area lighting designs.
Chapter 2 depicts different famous international tennis tournaments and various available standards, Indian and International, and corresponding values of parameters that are required to be achieved while performing a tennis court lighting design in software.
Chapter 3 deals with details of the lighting design performed in DIALux 4.13 software and analytical comparison of the parameter values with the NLC 2010.
Chapter 4 comprises of the design of power supply scheme and including calculations of the ratings of various electrical components.
Chapter 5 contains the Bill of Quantity of both the lighting system and power supply scheme designed in chapter 3 and chapter 4 respectively.

Chapter 1

Basics of Sports Lighting Design

1.1 Introduction

The first step in the design of a floodlighting scheme for sports lighting is to decide the appropriate lighting criteria.For the proper visibility of an object or scene to the human eye, proper lighting of the same is necessary. Without appropriate illumination, not only the object or scene is improperly visible, but sometimes a completely different perception of the same is perceived by the viewer. Some external physical factors are involved with the action of "seeing". Although external, but these factors are of paramount necessity to perform visual task by the viewer. The five major factors, namely size, contrast, time, luminance, colour [1]. These factors are equally necessary for both type of designs - Indoor and Outdoor.

1. Size- Increasing the visual size, increases the visibility of the object or the scene.
2. Time- The likelihood of seeing becomes more if longer time is given for seeing.
3. Contrast- Visibility is directly proportional to Contrast, such as increasing the contrast increases the visibility. A darker object is better visible in light background, similarly a light object is better visible in darker background.
4. Luminance- Increasing the luminance up to a certain level increases the visibility but beyond that visibility decreases sharply causing glare.
5. Colour- Colour not only effects seeing but also perception of objects and/or spaces are effected.

Here in this chapter, a brief discussion on sports lighting, its importance , challenges and other parametric aspects has been carried out.

1.2 Sports Lighting Criteria

Major sports lighting parameters are-

- Horizontal Illuminance

- Vertical Illuminance
- Illuminance Uniformity and Illuminance Gradient
- Glare Restriction
- Modelling and Shadows
- Colour Properties

Achievement of sports lighting criteria means satisfaction of the following parameter values as mentioned in recommended standards for different sports events.

1.2.1 Luminance

Luminance is defined as the ratio of luminous intensity to the area of the source. Supposing, ΔA is an elementary area of an extended source and ΔI_v is the luminous intensity of the source when viewed from a direction that makes an angle ϕ with the normal to the surface of the source as given in Figure 1.1 , then luminance is given as -

$$L = \frac{\Delta I_v}{\Delta A cos\phi} \tag{1.1}$$

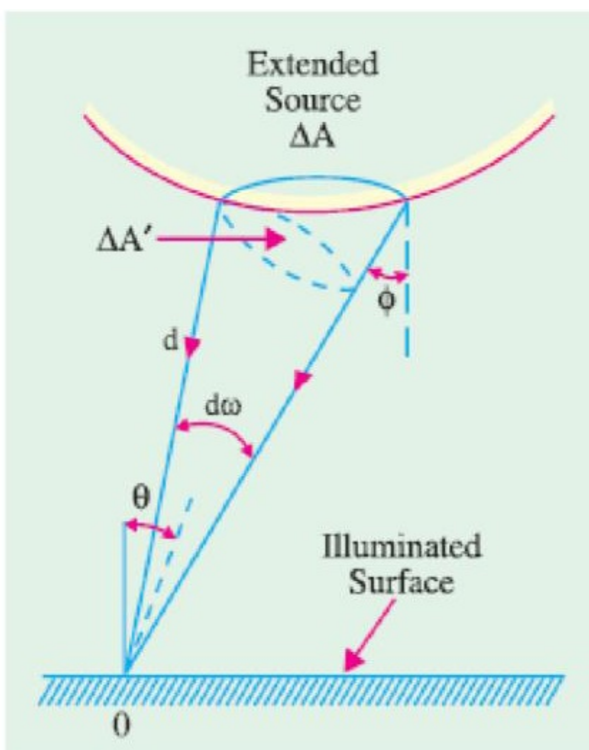


Figure 1.1: Luminance Explanation
[2]

1.2.2 Horizontal Illuminance

The area where game is played is horizontal surfaces in most of the sports events. The playing area covers maximum portion of the field of view of the players, spectators, officials and other staffs involved. The illuminance value measured on this surface is the horizontal illuminance involved in sports lighting. Proper horizontal illuminance on this surface creates a soothing and comfortable background to every human interaction of the sports.

It necessary that secured movement of people in the sports arena is to assured. Hence horizontal illumiances on several other surfaces like stands, gallery, sitting area, near doors and gates, staircases etc. equally necessary. However, as per NLC 2010, a value of 20% of the average playing field illuminance is sufficient for these auxiliary places.

1.2.3 Vertical Illuminance

Vertical illuminance is important in the sports where visibility in the vertical plane is important, i.e.- Cricket, Tennis, Football, Badminton etc. Also in some sports events, it is important for the players to see each other. Those sports events also require proper illuminance in the vertical field.

The average height of the human eye is taken at 1.5 meters [3]. Hence the calculation of vertical illuminance is done at the same height in order to ensure optimal visualization.Vertical illuminance is more important than horizontal illuminance in case of televised sports. To ensure that the television picture has a well-balanced brightness, the ratio between the average vertical and horizontal illuminance should match as closely as possible, but shouldn't exceed a 0.5 to 2 ratio.Also for televised sporting events, camera should be able capture close shots of players' faces, spectators, scoreboard and movement of bat, ball, shuttle etc. which will be possible iff proper vertical illuminance is achieved everywhere.

Apart from these two, a concept of Spherical Illuminance and Cylindrical Illuminance is also available theoretically.

Luminance Based Design or Illuminance Based Design

It is clear from figure 1.1 that, Luminance of a surface depends on the amount of light falling on it(known as Illuminance), angle from which it is viewed and its reflectance. In sports lighting, people involved encounter huge number of reflecting surfaces, such as bat, racket, ball, shuttle, other players, other spectators, score boards, playing area and many more. Needless to mention, all these have infinite number of viewing angles. Consequently, each surface results in infinitely different surface luminances [2].

Thus, calculation of and based on luminance is extremely difficult, if not impossible, in sports ligting. Hence, any designs and specifications in sports lighting are Illuminance based. The designer or the person drawing up the specifications should, however, always bear in mind that surfaces with high reflectance (light surfaces) will, for a given illuminance, result in a higher luminance than surfaces with lower reflectance (darker surfaces).

1.2.4 Illuminance Uniformity and Illuminance Gradient

Illuminance Uniformity is responsible for eradicating adaptation problems for both players and spectators and ensuring smooth transitional visibility of objects, players etc. from any direction of viewing [2]. If the proper uniformity is not achieved, players will find it difficult playing the game and the spectators will find it difficult to enjoy the game from some particular directions or positions. Illuminance Uniformity is expressed as -

i The ratio of the lowest to the highest Illuminance

$$U1 = \frac{E_{min}}{E_{max}} \tag{1.2}$$

ii The ratio of the lowest to the average Illuminance

$$U2 = \frac{E_{min}}{E_{average}} \tag{1.3}$$

Even though the defined uniformity ratios are acceptable [4], quick changes in the illuminance levels turns out to be disturbing. This problem comes into picture when a television camera pans. The illuminance uniformity for TV/film coverage at a certain grid point thus has to be expressed as a percentage change from the average adjacent grid points. This is called the uniformity gradient.

1.2.5 Glare Restriction

Glare is a major issue for every segment of lighting designer, be it Indoor or Outdoor [5]. Glare causes disturbing effect in the human eye and hinders the comfort in the action of 'seeing'. In sports lighting it troubles players, spectators and judges in their viewing action. Consequently, controlling of Glare has been a matter of concern in sports lighting design for a very long time. Control of Glare in sports lighting is done mostly with the help of software. Computer software calculates glare ratings in any number of desired directions and at any number of points from practical possibilities.
The International Commission on Illumination (CIE) has carried out extensive field research for developing CIE 112 Glare Evaluation System which is used within Outdoor sports application along with Area lighting. This is based on the work of van Bommel, Tekelenburg and Fischer but their formula has been modified so that the higher the

rating the more the glare sensation to bring it into harmony with other glare systems. It makes no distinction between discomfort and disability glare. The CIE formula is -

$$GR = 27 + 24log\frac{L_{vi}}{L_{ve}^{0.9}} \quad (1.4)$$

where, L_{vi} is the veiling luminance (cd/m^2) produced by the luminaires and L_{ve} is the veiling luminance (cd/m^2) produced by the environment or background.Interpretation GR values has been discussed in Table 2.10. For outdoor floodlighting installations including sports lighting, where GR has validity, a maximum GR value of 50 is required. At earlier times, study, measurement and control of glare in sports lighting was confined within the players and spectators who are present on or very close to the lit area. But further research showed that stray lights coming out from the sports facility disturbs people using the vicinity area of the enlighten space, such as drivers and pedestrians of the nearby road, residents of the localities etc. Hence now a days glare limiting is done by proper luminaire aiming, considering these factors also.

1.2.6 Modelling and Shadows

The ability of lighting to reveal form and texture, is known as its "modelling" capability. Better Modelling ability provides a overall pleasant impression of the athletes and objects in the field of play, not to mention of the spectators in the gallery and stand as well. An installation where light comes from only one direction will result in harsh shadows and poor modelling.

1.2.7 Colour Properties

Colour properties of luminaires can be assessed by two important aspects-

i The Colour appearance of the light, it is responsible for creating the overall colour appearance of the game environment.

ii Colour rendering Index – It is defined as the ability how good the light sources can reproduce the true colours.

While some of the color distortions that artificial lighting causes are acceptable for non-televised activities but TV broadcasting requires highly accurate color rendition. The European Broadcasting Union (EBU) has developed the Television Lighting Consistency Index (TLCI), which is based on camera response. TLCI is gaining popularity among broadcasters as a color metric specifically designed for their needs. Discussion of this topic is ongoing, but there's a general consideration that it should be easy to get colors right with a TLCI>80. [3]

1.3 Importance of Sports Lighting

Sports lighting is a category of Area Floodlighting design, having both Indoor and Outdoor aspects of it. Although, in the NLC 2010 Sports lighting has been discussed as a part of Exterior Illumination, this too contains recommended values for Indoor Sports.

Optimized lighting of a sports facility covers several aspects. It is beyond just placing some lights and making the venue available for a gameplay. A sports involves three types of human interaction. First and foremost are the Players, second are the referees or umpires or both depending on the game and the third are the spectators of the game. Now if the gameplay is being broadcast in television, then the people watching the game in the television are also involved with the sports lighting. The lighting designer must keep in mind the viewing perspective of all these human categories.

According to the dimension of the sports area, it is divided in to parts Principal Playing Area (PPA) and Total Playing Area (TPA). PPA is the boundary area Within which the game is being played. TPA includes some extra space outside the PPA. A proper sports lighting design must enable the players to clearly see what all is going on the PPA so that they can deliver their best performance. Eventually, this will enhance the efficiency of the players and in turn quality of the game.

The jurisdiction persons of the game must be able to view the game properly so that proper judgement can be done and the gameplay results to be fair one consequently. If optimum illumination is not available the referee or umpire may overlook some movements of the players, ball, shuttle or any equipment that involves scoring and that could lead an undesirable result of the game.

The spectators who are present in the stadium must be able to follow the performances of the players and the continuation of the game in an enjoyable and comfortable environment.

Again, if the game is being broadcast in television or streamed over the internet, proper illumination is highly required for good picture quality, accurate visibility of the game, the scores and every other part the camera captures. Also some sports involve continuous playing in the daylight as well as artificial light. For those cases, the transition between daylight and artificial light must be as smooth as possible so that the players' performance and the spectators' experiences are not disturbed.

1.4 Challenges in Sports Lighting Design

In Section 1.2 it has been discussed that Lighting of a sports venue is a very crucial consideration which is overlooked many a times. Good illumination of a sports venue not only enables the players to perform well and improve the standard of the game

but gives the spectators a comfortable and enjoyable environment and also ensures a good television broadcast.
Unlike lighting design of other areas, while design a sports facility lighting there are so many factors which stand as the odds.
There are specified standard values of different photo-metric parameters for different sports. The simultaneous achievement of those values in the simulation of the design as well as in practical worksite is of utmost necessity.
Along with offering proper and comfortable visual environment of the game, a sports facility must enable the spectators to see their surroundings and other nearby spectators also. Along with these, safe entry, exit and movement of the every person in the sports arena is also important. Along with these, there must be provision for safety lighting and power backup when the main illumination and supply system fails.
Availability of power supply back up is a major consideration in sports lighting. There might be scenarios where part of or main power supply fails and consequently, a transient disruption in illumination level is encountered [6]. In such cases, proper switching should be present which would isolate the failed system from the healthy system and trigger automatically the back up power supply to drive the lights considering the re-striking time of the floodlights. This scheme has to ensure that broadcasting of televised events are not hampered.
Another challenging task in sports lighting design is the control of spill light and reducing light pollution as much as possible. In sports lighting design, to attend vertical illumination, there is a possibility that a huge amount of light goes above horizontal plane passing through the luminaire centre. This incident often disturbs the environment and people around the vicinity of the stadium. Also, there might be designs where the standard values of the parameters have been achieved but utilizing unnecessary amount of lights [7]. These unoptimized designs not only consume undesirable amount of energy but create light pollution as well. Thus it is the duty of the designer to ensure an optimized design which will neither create spill light nor cause light pollution.

1.5 Level of Activities in a Sports Facility

Any type of game-play can be divided into three classes- Class I, Class II, Class III according to the level of game-play.
Class I – Top level international and national level game-plays which consists of huge number of spectators, fall under this class. Top level training games often are also considered under this category. Viewing distance of this class of sports is also very large.
Class II- Mid level competition such as regional or local club level competition falls

under this class of sports. Generally, in this class, the spectator capacity is also medium and not very large. In Class II category of sports the viewing distance is also medium. Class III – Sports which does not involve any spectator and are played at local or small club level falls under this category. General training, physical education (school sports) and recreational activities will also come into this category.
The amount and distribution of lights in the sports arena is a function of these classes. According to these classes of game-play, or the level of activity, standard values of different photometric parameters has been suggested. Apart from these three classes some international sporting events and countries formulate some extra classes as per requirement, which has been discussed in chapter 2.

1.6 Prerequisite Data of Sports Lighting Design

In previous sections of this chapter a clear discussion has been done on the complexity of sports lighting design. Hence it is quite crucial to gather some field data before actually starting the design in software. Such as-

- In detail drawing of the sports facility with all dimensions clearly mentioned.
- Type of pole arrangement and available space for it according to standards.
- For indoor sports facilities, structural rigidity for accommodating luminaires and other gears, cables etc.
- If the event is televised, it is required to check the camera positions, their height and maximum shooting distance.

1.7 Sports Lighting Design and Installation Aspects

Sports facilities can be divided according to the following characteristics-

- Outdoor or Indoor Stadiums
- Type of Sports being played
- Level of Sports being played
- Televised or Non-televised event

The issues which are related to sports lighting design and installation aspects-

- Type of Luminaire arrangement
- Lighting parameter calculation
- Switching Arrangements

- Aiming and Commissioning

In case of indoor lighting design, scenarios may arise where architectural details needs to be highlighted or shadowed. Again, indoor stadiums, even in some cases outdoor stadium galleries are designed by roof structure mounted luminaires. Before starting such designs , it is essential to verify that whether it is feasible to do so. If such possibilities are not there then masts are needed to be installed. Lighting adds such many other elements, like switchgears, cables, catwalks, distribution boards for power supply, lifts and hoists etc. All these require additional spaces within the province of the stadium. Position of the masts are important factors in terms of installation aspect. There can be Corner Mounted or Side Mounted mast arrangements. Even sometimes mixed arrangements of masts and roof mounted luminaires are incorporated depending on the lighting needs and architectural perspectives.

1.8 Conclusion

Floodlighting means lighting a huge area by one or more number of luminaires. In floodlighting, individual luminaires have to be aimed individually to achieve required design criteria and a smooth, even distribution of lights through out the concerned area. Sports lighting is a special and probably the most byzantine segment of area floodlighting. Designing a Sports facility is always a challenging task to both lighting designer and electrical engineer. Lighting designer has to ensure all lighting design criteria are achieved in the field and electrical engineer has to keep arrangement of proper power supply and ensure that those design criteria, achieved by lighting designer is available in the field through out the gameplay.
So far this chapter has been developed with the brief discussion of the Sports lighting design criteria, their relevance and importance in sports lighting, probable challenges that might be encountered by lighting designer and electrical engineer in developing a sports facility with lights and powering them and different design and installation aspects of sports lighting.

Chapter 2

Tennis Sports Arena - A Brief Discussion

2.1 Introduction

After originating in the 19th century England, Tennis started gaining popularity 20th century onwards. With increasing popularity around the globe, setting up of an uniform rule for the game became inevitable. In 1876, representatives of different famous Tennis clubs met together and set up a protocol for deciding the venue, equipment, play style, competition and rule for playing the game and that was accepted and followed most of the tennis matches played in England as well as outside of it. [8]
Proper lighting is indispensable for every sports including tennis. It is essential to make the players able to play the game well, make the referees and umpires judge properly, to make the game visible to the audience of the stadium as well as for those watching via television. Overall, proper lighting enhances the quality of the game itself.

2.2 Size of Tennis Court

The tennis court is a rectangular field. There are two standard sizes of tennis courts-

i Singles' tennis court- Its standard size is 23.77 meters in length and 8.23 meters in width [9].

ii Doubles' tennis court- Its standard size is 23.77 meters in length and 10.97 meters in width [9].

There is a leave room behind each end line and side line. The end line free space is not less than 6.40 meters and the side line free space is not less than 3.66 meters. The middle is separated by a ball net. [9] Figure 2.1 shows-

2.3 Types of Tennis Court

The design of mainstream tennis court ground focuses mostly on the safety and prevention of injuries of the players, regardless of the material of the floor.
Tennis courts can be divided into two categories-

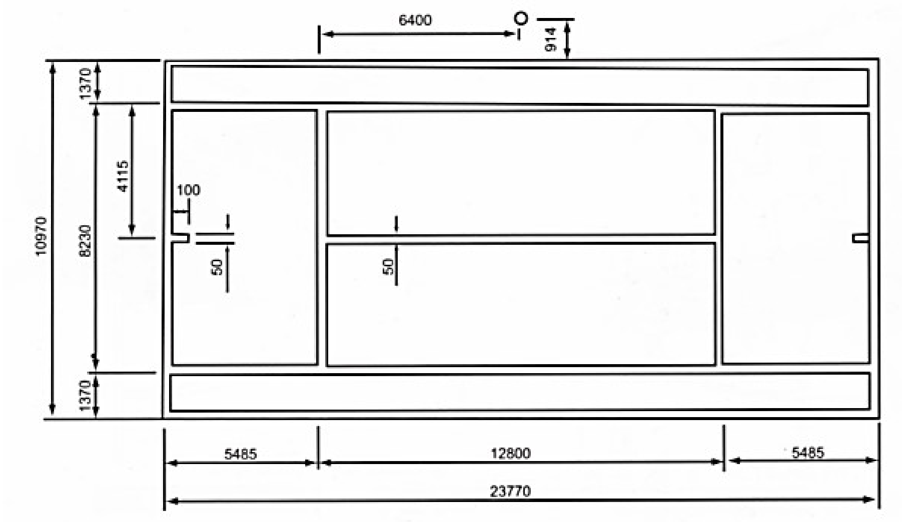


Figure 2.1: Dimension of Tennis Court
[9]

i Outdoor—The nets around the outdoor tennis court are placed generally between 4 meters to 6 meters. Although, depending on the building height and environment it is adjusted appropriately. [10]

ii Indoor–For indoor tennis courts, the clear height above the end line is not less than 6.40 meters, and the clear height of the indoor roof above the net is not less than 11.50 meters. Beyond the end line, a standard tennis court covers an area of not less than 36.6 meters x 18.3 meters. Steel structures are used for constructing most of the domestic indoor tennis stadiums. The height ranging from 7-12 meters [10]. Most of which are 8 meters and 9 meters.

There are various types of court surfaces. Economy is the key factor which determines the selection of courts. For instance, lawn tennis is the most basic outdoor court, but it is too expensive in terms of establishment and maintenance costs. Artificial courts have come into the picture as a replacement which are cheaper and easier to maintain.

2.3.1 Grass field

The characteristic of the oldest and the most traditional tennis court is that the friction between the ball and the ground is less when the ball lands. The ball rebounds fast which requires a faster reaction and agility of the player [10] [9].
Therefore, grass is often regarded as the world of "offensive tennis." It is said the playing and winning tennis in grass court is the toughest. The players have to adopt various tactics for winning game on Grass Court.

2.3.2 Clay Field

Clay field is also known as the "soft court". It is the most traditional and the most typical representative the French Open tournament. In addition, all kinds of common sand, mud, etc. can be called soft grounds [9].
Unlike Grass court, the characteristic of this kind of court is that there is greater friction between the ball and the ground when it lands, and the ball speed is slow. Players get a lot of room for sliding when running, especially when they stop and return. It is essential to have better physical fitness and agility to succeed in clay field.

2.3.3 Hard Court

Hard courts are the most common venues of modern games. This type of tennis courts are generally pavement made of cement and asphalt and are coated with red and green plastic surfaces. Bounce of the ball is regular but rebound is very quick [9].

2.3.4 Carpet Field

As the name suggests, this is a "portable" roll-up tennis court. Its surface is a plastic surface layer, nylon woven surface layer, etc. It is usually bonded to a certain strength and hardness of asphalt, cement, and concrete bases with special glue. On the ground. The speed of the ball is dependent on the flatness of the field surface and the roughness of the carpet surface. The maintenance of this kind of site is also very simple, as long as the ground is kept clean, free from damage and no accumulation of water.

2.4 Famous International Tournaments

There are many famous tennis tournaments happening all over the world in different countries. These tennis tournaments attract good numbers of spectators every time and provide them with a cherish able experience. Among the many international tennis tournaments four famous grand-slams are-

- Wimbledon
- US Open
- Australian Open
- French Open

2.4.1 Wimbledon

Starting in 1877, Wimbledon is the most famous tennis tournaments. It was first played in the All-England Club, situated at the outskirts of London [11]. Maintaining its tradition, it is still played in grass courts. The exquisite presence of the Royal British Family [11], fresh strawberry and cream and all white dresses are some of the traditions of Wimbledon which make the game more attractive too. Great tennis players from the world participate in the game which is played for a duration of two weeks during the late June or early July. This game has hosted most of the iconic and memorable matches of the game-play.

2.4.2 US Open

The US National Championship was first played in 1881 [11], presently which is known as US Open and also is one of the famous grand slam tennis tournaments. It is generally the last grand slam of the season.What makes it one of the best tennis tournaments to attend? Well for starters, it offers a different and unique atmosphere than the other majors. It's lively, fun, and exuberant, just like its host city, New York.This tournament is played at the US National Tennis Centre in Flushing Meadows , New York. Many celebrities make their graceful presence at the game and make it more attractive and prestigious.The US Open plays out each year in late August/early September and probably it's the perfect way to wrap up the summer.

2.4.3 Australian Open

Australian Open comes first in the calendar among the four major tennis grand slams. It is said to be the largest and one of the most popular Sports event in the entire Southern Hemisphere.Melbourne Park is the traditional venue of this tournament since the year 1988. Although the game was possibly first played in 1905 [11]. The Australian Open is played on a hard-court surface and has been dominated by Novak Djokovic in recent years. As the first grand slam of the year, the excitement about this game is always high among the players as well as to the fans.This famous Melbourne tennis event is one of the highest attended.

2.4.4 French Open

It is the only grand slam event which is played in clay court. Clay is known to be a difficult surface to play on, due to the slower moving ball. Some players seem to excel on the clay, most notably Rafael Nadal [11], who won has an incredible thirteen French Open Championships. One of the best parts about the French Open is the amazing city of Paris. There's a reason it is regarded as one of the most beautiful cities in the world. With its charming cafes, amazing food, great hotels, and stunning architecture, it makes an ideal backdrop for one of the best tennis tournaments in the world.

2.5 Tennis Court Lighting

Two most common types of lamps used in tennis court illumination are Metal Halide Lamps and LED lamps. Previously when LEDs were not so very into picture, metal halide lamps were considered for the purpose. But after LEDs' invention, it attracted people's sight quickly. The energy saving and emission reducing characteristics is the foremost reason behind this. LED lamps can produce same lumen with a very less wattage in comparison to Metal Halide lamps. Thus, most of the countries and tournament organisers want the courts to be illuminated by LED lamps. Irrespective of the scenario, whether the illumination is to be done for the first time or for maintenance purpose, LED lamps are getting priority. In some cases, well operational metal halide lamps are being retrofitted for the purpose of energy savings and cost reduction due to extra wattage consumption.

2.5.1 Outdoor Tennis court Lighting

For stadiums that need to be installed with lighting, except for the distribution of indoor roof lamps, there should be no lamps on the outdoor court and on both sides of the end line. Outdoor court lamps should be set on the sides of the nets above 6 meters above the ground, and the lights are evenly illuminated from the scene on both sides of the court [9].

i Corner Arrangement: In this arrangement the light poles are placed at the four corners of the playing area.

ii Side Arrangement: Here in this arrangement the lamps and poles are placed at the sides of the playing field.

iii Mixed Arrangement: Here in this arrangement the facility is lit up by a combination of both Side arrangement and Corner Arrangement of poles with luminaires.

2.5.2 Indoor Tennis Court Lighting

Indoor tennis court can be illuminated in the following three ways-

i Arrangement at the top- in this arrangement, the light beams fall perpendicular to the field, as the lamps are arranged above the site.

ii Arranged on both sides- the lamps are arranged on both sides of the field of play.In this case, light beam is not arranged perpendicular to the plane of the site.

iii Mixed arrangement- the combination of the top arrangement and the two arrangements.

Tennis is a game where fast movement is associated, be it the players or the ball, within a very short distance, and it is very necessary for the players to judge the movement and speed of the ball accurately.
The indoor tennis court lighting layout should not be above the principal playing area. If that is done so, then the players will experience serious glare to their eyes. Therefore, tennis lighting should be placed in a space outside the principal playing area. Additionally, the installation of the lamp outside the net is should not be done at a height less than 9.144m; at the bottom line, the height of the lamp should not be less than 9.096m. If the ceiling cloth light method is used, the ceiling is a diffuse reflection ceiling or a grid ceiling, and the light is illuminated on the ceiling. Then through the ceiling light transmission to achieve the lighting effect. There are few points which are needed to be considered-

i Lamps having Symmetrical light distribution should be used on the top layout, which is suitable for spaces have higher requirements on ground level illumination uniformity, and do not have television broadcasting requirements.

ii Places where high vertical illuminance and television broadcast is required Asymmetrical light distribution lamps should [3] [9]be used for the lighting on both sides, when lights are arranged on both sides, the aiming angle of the lamp should not be greater than 65 degrees.

iii The mixed arrangement includes a variety of light distribution lamps, which are suitable for large comprehensive stadiums.

iv The indoor tennis court lighting cloth lights should be parallel to both sides of the court, the total length of the arrangement should not be below 36 meters, the aiming of the lamps should be perpendicular to the longitudinal centre line of the court, and the accuracy of the lamps should not be greater than 65 degrees.

Lighting Designers follow existing standards for Tennis Court Illumination, given by different regulatory authorities. A standard proposed by International Tennis Federation (ITF) for both indoor and outdoor tennis courts is followed in mostly all tennis games. But there are many international tournaments which has their own standard of illumination as per location, audience preference, energy savings, cost reduction etc. Although most of them are manipulated form of the one given by International Tennis Federation. In the following sections, standards of ITF, four prestigious international tennis tournaments, and the Indian standard of Tennis court illumination has been comprehended.

2.6 Lighting Requirements as Suggested by International Tennis Federation

The ITF recommends the necessary amount of lighting and other relevant parameters required in a tennis match. Although, the values of the parameters are slightly varied in different tennis tournaments. The recommendations of ITF are shown in Table 2.1 and Table 2.2.

	Horizontal Illuminance (Lux)	Uniformity of Illuminance	Glare(GR)	Lamp Color Temperature (K)	Lamp Color Rendering
Class I	>500	>0.7	<50	>4000	>80
Class II	>300	>0.7	<50	>4000	>65
Class III	>200	>0.6	<55	>2000	>20

Table 2.1: Lighting Criteria for Outdoor Tennis Courts by ITF

	Horizontal Illuminance (Lux)	Uniformity of Illuminance	Glare(GR)	Lamp Color Temperature (K)	Lamp Color Rendering
Class I	>750	>0.7	<50	>4000	>80
Class II	>500	>0.7	<50	>4000	>65
Class III	>300	>0.5	<55	>2000	>20

Table 2.2: Lighting Criteria for Indoor Tennis Courts by ITF

2.7 Lighting Requirements of Different Tennis Grand Slams

2.7.1 Wimbledon

Happening in the UK, Wimbledon follows the British sports lighting standard "British Standards European Norm (BS EN) 12193 Light and Lighting – Sports Lighting" [12]. According to this standard shown in T able 2.3 and Table 2.4, there are specific recommendations for indoor tennis match and outdoor tennis match.

Indoor			Reference Area		Number of Grid Points	
			Length(m)	Width(m)	Length	Width
Tennis PA			36	18	15	7
Class	Horizontal Illuminance					Ra
	Em (lx)	Emin/Em				
I	750	0.7				60
II	500	0.7				60
III	300	0.5				20

Table 2.3: Lighting Recommendations for Wimbledon Indoor Tennis Match

Outdoor			Reference Area		Number of Grid Points	
			Length(m)	Width(m)	Length	Width
Tennis PA			36	18	15	7
Class	Horizontal Illuminance				GR	Ra
	Em (lx)	Emin/Em				
I	500	0.7			50	60
II	300	0.7			50	60
III	200	0.5			55	20

Table 2.4: Lighting Recommendations for Wimbledon Outdoor Tennis Match

2.7.2 US Open

The lighting requirements for a tennis court for separate level of game-play is recommended by Illuminating Engineering Society (IES) and United States Tennis Association (USTA). The Same standard is followed in the US Open [13]. According to this standard tennis tournaments are categorized into four classes-

- Class I- Professional Level Play
- Class II- College Level/ Challenger Sport
- Class III- School Level/ Private Clubs
- Class IV- Recreational

and the corresponding lighting levels are shown in Table 2.5

Class	Horizontal Illuminance (lx)	Vertical Illuminance (lx)	Uniformity	Glare	Color Rendering Index
I	1000-1250	500	1.5 rated at 700-1000	50	80
II	600-750	300	1.5 rated at 700-1000	50	65
III	400-500	200	2 rated at 200-400	55	60
IV	200-300	N/A	N/A	N/A	Not Specified

Table 2.5: Lighting Recommendations for US Open

2.7.3 Australian Open

The Australian open is managed by Tennis Australia. The requirement of lighting in the games is also suggested by them. The Lighting requirements of Australian Open are shown in Table 2.6 [14]-

2.7.4 French Open

Lighting of French Open is done following the standards of EN 12193, i.e.- European standard for Outdoor Sports Lighting Levels [15]. The Following lighting levels shown

Standard of Play	Average Initial Lux Level	Average Maintained Lux Level	Minimum Average Uniformity
Social Play	310	250	0.6
Club Competition	435	350	0.6
International	1250	1000	0.7

Table 2.6: Lighting Recommendations for Australian Open

in table 2.7 are recommended for the tournament-

Sport	Horizontal (Non CTV)						Glare Rating			Vertical Illuminance Level in Lux (CTV Broadcast)		
	Class I		Class II		Class III		I	II	III	Maximum Camera Shooting Distance (m)		
	Illuminance (Lux)	U0 (min/avg)	Illuminance (Lux)	U0 (min/avg)	Illuminance (Lux)	U0 (min/avg)				50	100	150
Tennis	500	0.7	300	0.7	200	0.6	50	50	55	680	920	1150

Table 2.7: Lighting Recommendation for French Open

2.8 Indian Standard

The NLC 2010 (SP 72: 2010) published by BIS, recommends the standard values of horizontal lluminance, vertical lluminance, uniformity and other parameters which are required to be achieved.
According to the classes of game-play, or the level of activity, standard values of different photometric parameters has been suggested mainly for Non-televised events. Table 2.8 and Table 2.9 depicts the same for Outdoor tennis games and Indoor tennis games respectively-

Class	Horizontal Illuminance(Lux)	U0(min/avg)	Ra	Glare Rating
I	500	0.7	>60	<50
II	300	0.7	>60	<50
III	200	0.6	>20	<55

Table 2.8: Indian Standard for Lighting of Outdoor Tennis Court

For televised game-plays, along with the horizontal illuminance, the camera vertical illuminance is also required to achieve with other parameters mentioned in the non-televised case. According to Figure 2.2, the horizontal axis shows maximum shoot-

Class	Horizontal Illuminance(Lux)	U0(min/avg)	Ra
I	750	0.7	>60
II	500	0.7	>60
III	300	0.5	>20

Table 2.9: Indian Standard for Lighting of Indoor Tennis Court

ing distances and the vertical axis shows the corresponding illuminance values to be achieved. According to NLC 2010, sports can be classified into three groups A, B and

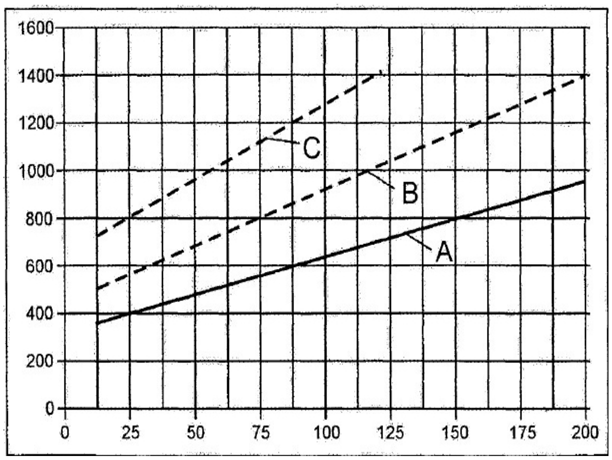


Figure 2.2: Recommended Vertical Illuminaces Related to Camera Shooting Distances

C characterized mainly by speed of action occurring during camera shots. This is an important parameter in determining vertical illuminance. Tennis falls under Group B of sports.

Apart from satisfying the recommendations of vertical illuminance given in NLC for televised events of game-play, other parametric recommendations must also be achieved by the designer. Such as- on planes facing a sideline bordering a main camera area or facing a fixed main camera position this should be:

$$\frac{E_{vmin}}{E_{vmax}} > 0.4 \tag{2.1}$$

$$\frac{E_{hmin}}{E_{hav}} \geq 0.6 \tag{2.2}$$

The uniformity of vertical illuminance at a single grid point over the four planes facing the sides of the playing area shall be:

$$\frac{E_{vmin}}{E_{vmax}} > 0.3 \tag{2.3}$$

As the illuminated field forms a major part of the field of view of the camera, an adequate horizontal illuminance is important. A sufficiently good balance between the horizontal and vertical lighting levels is obtained when the average horizontal to the average vertical illuminance (relative to each of the main camera areas or main camera positions) is such that-

$$0.5 \leq \frac{E_h}{E_v} \leq 2 \tag{2.4}$$

On the playing field shall be:

$$\frac{E_{hmin}}{E_{hmax}} \geq 0.5 \tag{2.5}$$

Glare Interpretation-The assessment scale given in table 2.10 corresponds with the values of the glare rating GR.

According to NLC 2010, the cases where Glare is significant, a GR value of 50 is

90	Unbearable
80	
70	Disturbing
60	
50	Just Admissible
40	
30	Noticeable
20	
10	Unnoticeable

Table 2.10: GR Interpretation

required. Although glare has been considered mostly for the players and spectators on or very close to the lighted area. But in practical cases, for outdoor sports lighting, the lighting installations can cause disturbances for people outside the stadium, may be nearby residents or traffics of adjacent roads. Hence aiming of the luminaires must be done very carefully.

For events which are being broadcast in colour television,desires keeping away from colour matching and balance problems. If the lamps which are being used does not differ in colour temperature greatly, then in order to avoid these issues it is recommended to keep the Correlated Colour Temperature within the range of 2000K and 6000K. Also if the game is being played in a combination of daylight and artificial lights, then NLC suggests to keep the colour temperature of the lamps greater than 4000K again to avoid adaptation problems.

The images of the lighting requirements given by ITF, for different tournaments mentioned above and of Indian National Lighting Code (NLC) 2010 has been shown in Appendix A.

2.9 Conclusion

As the popularity of tennis increases, tennis court illumination has become very necessary for tennis players, spectators, referee and other staffs involved with the game.

The required illumination standards for lighting a tennis courts changes based on the level of play ranging from recreational to professional. Tennis facilities must ensure an even distribution of light to provide a well-lit playing area for everybody involved with the game-play. In this chapter so far, an idea on tennis gameplay and its lighting arrangements has been presented. Different tennis grand-slams and their corresponding lighting parameter requirements has been briefly discussed. Different parameters and their required values for sports lighting mentioned in NLC 2010 has also been presented.

Chapter 3

Design of The Lighting System

3.1 Introduction

This thesis work is entirely simulation based, and hence this does not involve any physical site visit, data collection such as measurement of dimension, lux audit etc. The design has been performed in DIALux 4.13 software. DIALux 4.13 is a very popular and widely used lighting design software. Performance of both Indoor and Outdoor type of designs is very feasible in this software. In this chapter, the methodology for designing a lighting system of a tennis court, both for non-televised and televised event using this software has been performed. In the later part, the analytical comparison of the results achieved through simulating the design with the values prescribed inNLC 2010 has been carried out.

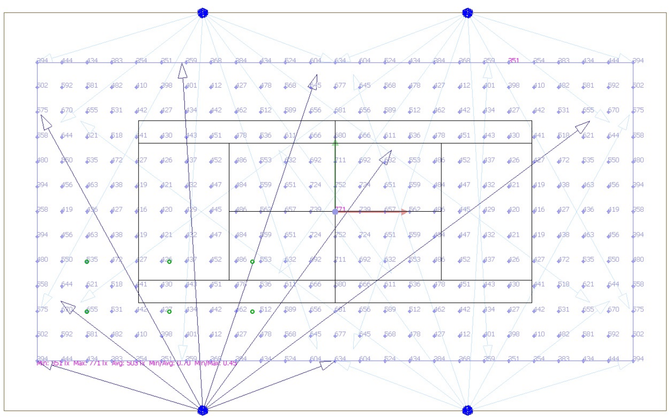
3.2 Methodology

To perform the design of an outdoor tennis court, a "New Exterior Project" has been incorporated at the very beginning. A typical model of tennis court is taken from available sports sites. As per the NLC 2010 any sports site is divided into two parts Total Playing Area (TPA) and Principal Playing Area (PPA) [16]. PPA is the amount of area where the game-play happens. In most of the sports sites, this area is separately marked. TPA includes an additional safety area along with the playing area.

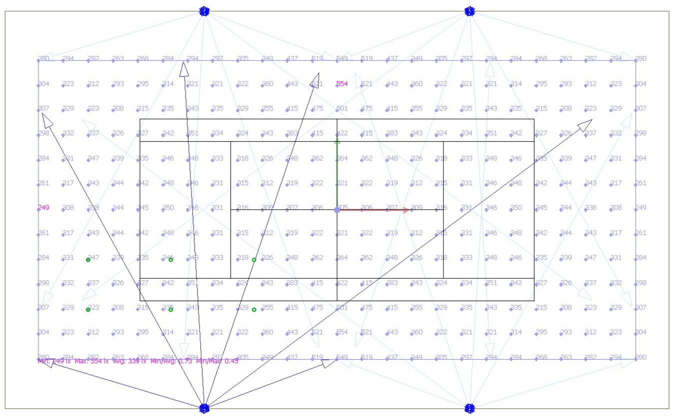
In DIALux 4.13 this TPA is named as PA, where the PPA is by default 23.77 m. in length and 10.97 m. in breadth for a tennis court. In this design, the PA is taken 36.00 m. and 18.00 m. in length and breadth respectively. The ground element has been adjusted accordingly. To keep a similarity with grass court of tennis, the colour of the court is taken green. Since the design has been simulated using LED luminaires the light loss factor has been taken 0.8. The luminaires are placed at two frames of the four high masts of heights 16m. and 15m.

3.2.1 Design for Non-Televised Event

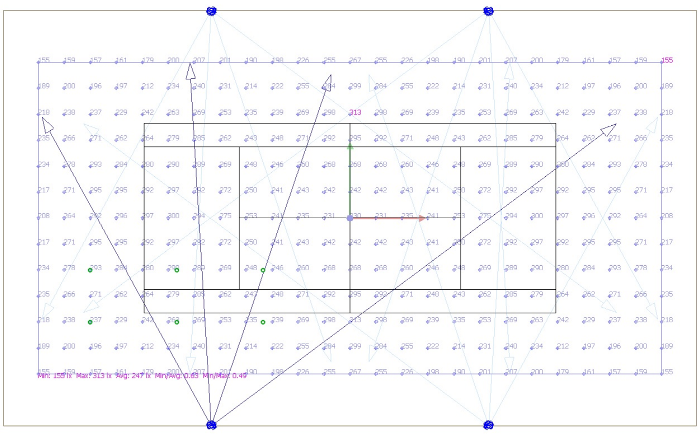
While performing the non-televised event court design, switching phenomena has been used with the help of Control Group option in DIALux 4.13. The design of class III has been done at first with minimum number of luminaires, aimed at particular points. This is followed by class II and class I. Extra luminaires are added to the previous class but the aiming angles of previous class's luminaires are kept unaltered. The idea behind that is, in practical cases, changing of luminaire aiming angles for every class of game-play is actually impossible. The design should be and is made keeping in mind such that only the required number of luminaires are switched on and off according to the level of game-play.The luminaire aimings of the three classes has been shown in Figure 3.1a, 3.1b, 3.1c.



(a) Luminaire Aiming of Class I



(b) Luminaire Aiming of Class II



(c) Luminaire Aiming of Class III

Figure 3.1: Luminaire Aiming of Tennis Facility Design for Different Classes of Gameplay

3.2.2 Design for Televised Event

For the Televised case of design two cameras has been utilized for the simulation of camera vertical illuminance. The primary camera is placed at a height of 8.00 m. and the secondary camera has been placed at a height of 2.00 m. The vertical illuminance

is measured at a height of 1.00 m. by both the cameras.
The luminaire aiming for the televised design is shown in Figure 3.2. The flow chart

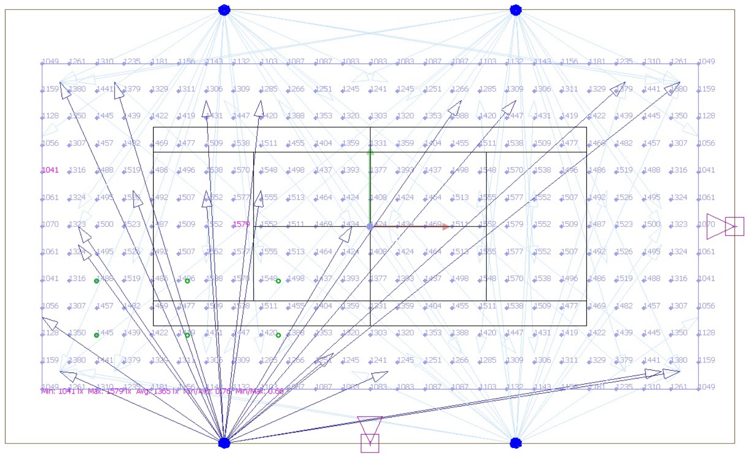


Figure 3.2: Luminaire Aiming of Televised Tennis Court

of the adopted methodology has been given in Figure 3.3.

3.2.3 Switching between Both Designs

It is often hard to arrange separate sporting arenas for televised and non-televised games, due to unavailability of spaces, funds , manpower etc. So There might be cases where a single venue is used for both televised and non-televised events. For example, before happening of a televised game, the players play practice matches or warm up games in the same venue. Quite necessarily and obviously those sessions will not be broadcast by TV camera but requirement of artificial lights may still be there. Although the amount of light required will obviously be lesser compared to that of Televised event but it must comply with the values in NLC 2010. Hence proper control scheme must be there to illuminate the field as per requirement.
Similar idea has been incorporated here in this design too. With the use of dimming method in the televised event court design, the horizontal average illuminance value has been reduced to match with the Non-televised event standard of NLC 2010. This method has been applied to achieve the Class I values of Illumination for Non-televised events from the televised one. Table 3.1 shows the results of this conversion process.

Type	Average Illuminance (E_{av})(lx)	Minimum Illuminance (E_{min})(lx)	Maximum Illuminance (E_{max})(lx)	E_{min} / E_{max}	Uniformity (U_0) (E_{min} / E_{av})	GR (Maximum)
Horizontal	682	521	790	0.66	0.76	35

Table 3.1: Results of Class I Achieved Through Switching from Televised Court Design

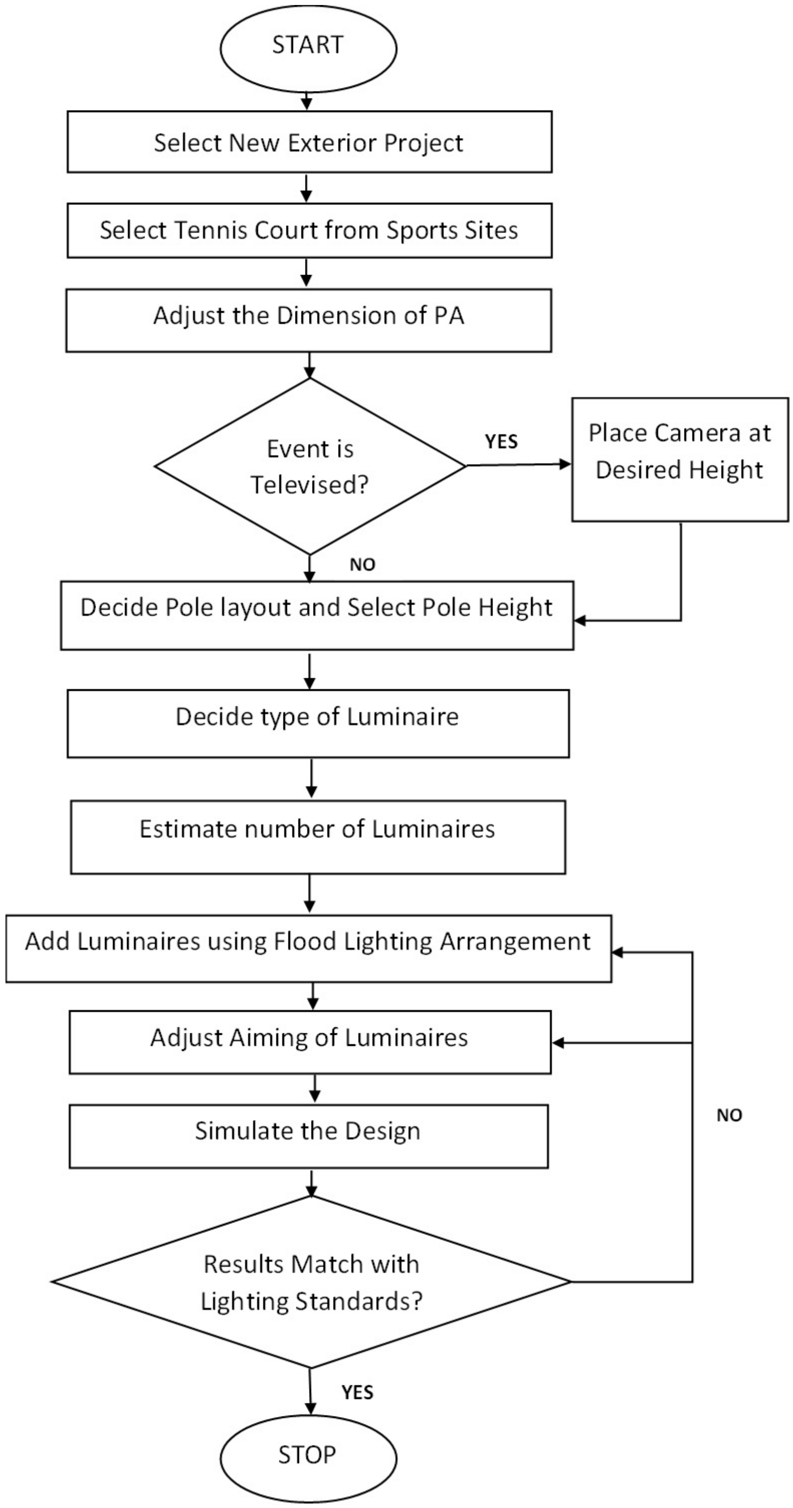


Figure 3.3: Flow Chart of the Design Methdology

3.3 Technical Data of Selected Luminaires

The lighting design has been performed here using Side Arrangement of Poles or luminaires instead of Corner Arrangement. Both the televised and non-televised designs have been performed using a combination of LED luminaires having two different beam angles- Medium Beam and Narrow Beam. The type of game-play and corresponding luminaires used has been tabulated in Table 3.2.

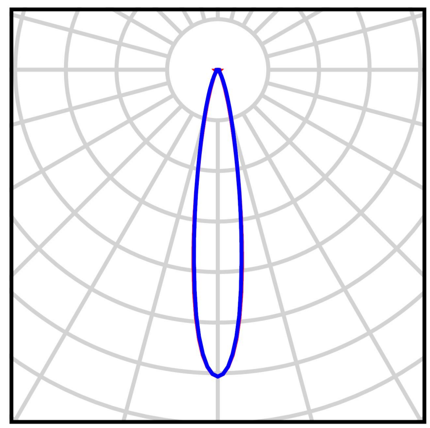
Type of game-play		Combination of luminaires used
Non-televised	Class I	24 NB + 8 MB
	Class II	16 NB+ 8 MB
	Class III	16 NB
Televised		48 NB + 32 MB

Table 3.2: Luminaire Configuration at a Glance

The luminaires that have been used here are of two different beam angles. The Narrow Beam (NB) has a beam angle of 10 degrees and Medium Beam (MB) has 30 degrees beam angle. Apart from these two, another type of flood lighting luminaire with Wide Beam Angle is used in many sports lighting applications. But here only luminaire with Narrow Beam and Medium Beam has been utilized for the concerned design purpose. The details of the luminaire is depicted in Figure 3.4.

Numbers Used	Details
48 Pieces	XXX 01 LED_FL_Sym_200_10 Article No.: 01 Luminous flux (Luminaire): 31207 lm Luminous flux (Lamps): 31250 lm Luminaire Wattage: 250.0 W Luminaire classification according to CIE: 100 CIE flux code: 90 96 99 100 100 Fitting: 1 x LED_FL_Sym_200_10 (Correction Factor 1.000).

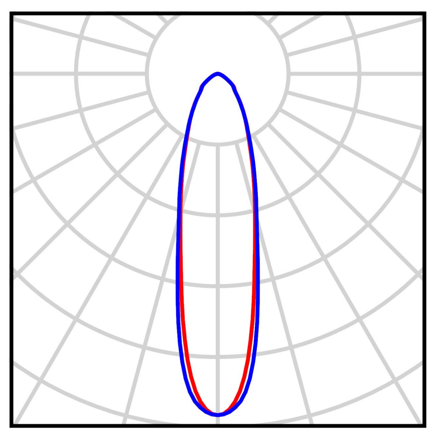
(a) Deatils of Narrow Beam Luminaire



(b) Polar Curve of Narrow Beam Luminaire

Numbers Used	Details
32 Pieces	XXX 01 LED_FL_Sym_200_30 Article No.: 01 Luminous flux (Luminaire): 31236 lm Luminous flux (Lamps): 31250 lm Luminaire Wattage: 250.0 W Luminaire classification according to CIE: 100 CIE flux code: 77 94 99 100 100 Fitting: 1 x LED_FL_Sym_200_30 (Correction Factor 1.000).

(c) Deatils of Medium Beam Luminaire



(d) Polar Curve of Medium Beam Luminaire

Figure 3.4: Luminaire Technical Details

3.4 Result Analysis

In both the designs, televised and non-televised, a grid size of 1.5 m * 1.5 m has been taken to simulate the design. After performing the design in DIALux 4.13 software, the values of Average Illuminance, Uniformity ratio and Glare were analysed to see whether it complies with the values given in NLC 2010. The illuminance values have been measured at z=0 of DIALux 4.13. The simulation results of design of Non televised game-play tennis court is shown in Table 3.3 and the same for televised game-play is shown in Table 3.4 the designs have been shown below-

Class Type	Average Horizontal Illuminance (E_{av})	Minimum Horizontal Illuminance (E_{min})	Maximum Horizontal Illuminance (E_{max})	U0 (E_{min}/E_{av})	E_{min}/E_{max}	GR (Maximum)
Class I	503	351	772	0.70	0.45	33
Class II	339	249	553	0.74	0.45	36
Class III	247	155	312	0.63	0.50	39

Table 3.3: Non-televised Tennis Court Lighting Design Results

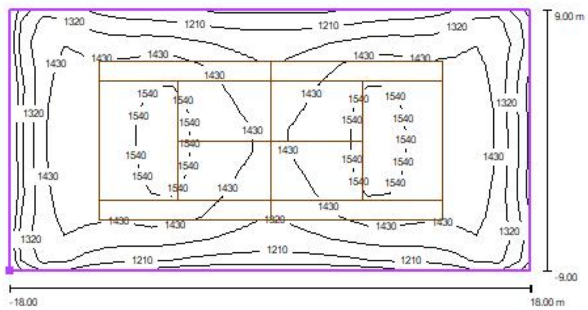
Type	Average Illuminance (E_{av})(lx)	Minimum Illuminance (E_{min})(lx)	Maximum Illuminance (E_{max})(lx)	E_{min} / E_{max}	Uniformity (U_0) E_{min} / E_{av}	GR (Maximum)
Horizontal	1364	1041	1579	0.66	0.76	35
Camera1	1007	690	1689	0.41	0.69	
Camera2	1045	498	1464	0.34	0.48	

Table 3.4: Televised Tennis Court Lighting Design Results

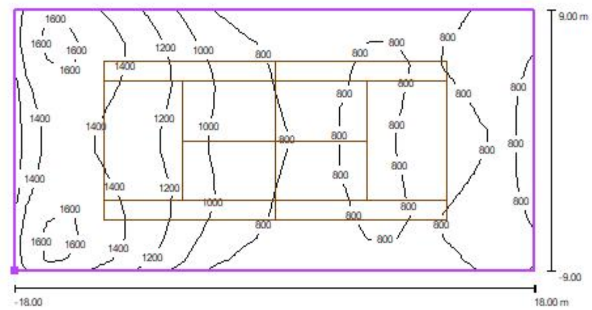
Figure 3.5a and 3.5b shows the Illuminance Isolines in horizontal work plane and as measured by the primary camera due to the lighting design of televised events respectively. Figure 3.6a, 3.6b, 3.6c respectively shows the Illuminance Isolines formed due to the lighting design for different classes of non-televised tennis game-play. Significant percentage of Upward Light Ratio (ULR) or Upward Light Output Ratio (ULOR) is evident in all the performed designs. Table 3.5 shows the corresponding ULR values achieved in each design. Looking at the values it is quite evident that very negligible amount of Light goes upward and hence the design does not create considerable amount of light pollution. The images of the simulation results has been given in Appendix B.

Type of game-play		Perecentage of ULR
Non-televised	Class I	3.0
	Class II	3.5
	Class III	4.0
Televised		3.5

Table 3.5: Percentage of Upward Light Ratio

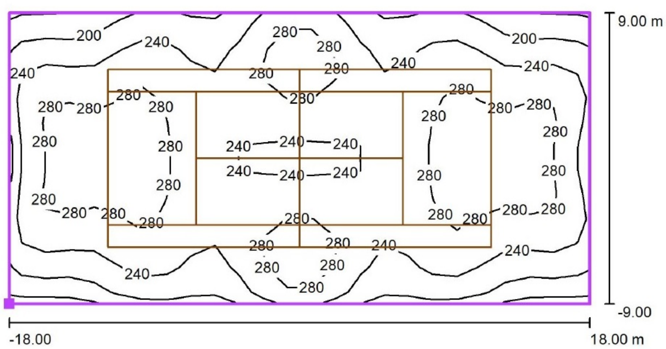


(a) Isoline Diagram of Horizontal Illuminance of Televised Design

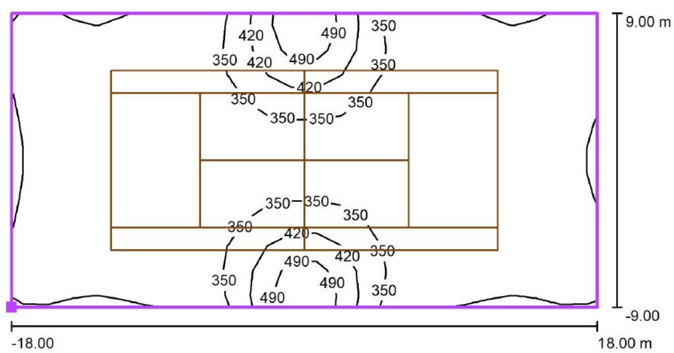


(b) Isoline Diagram of Vertical Illuminance as Measured by Primary Camera of Televised Design

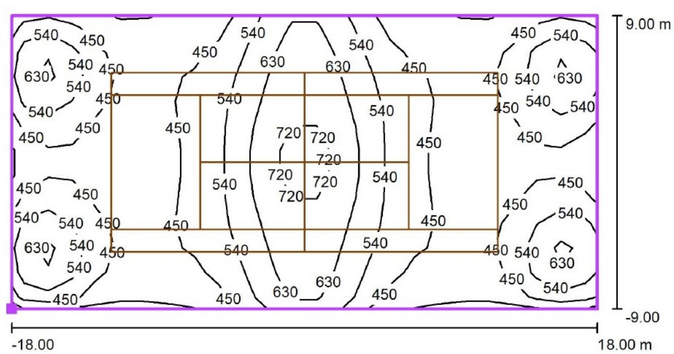
Figure 3.5: Illuminance Isoline Diagram : Design for Televised Event



(a) Isoline Diagram of Horizontal Illuminance a for Class III



(b) Isoline Diagram of Horizontal Illuminance a for Class II



(c) Isoline Diagram of Horizontal Illuminance a for Class I

Figure 3.6: Illuminance Isoline Diagram : Design for Non-Televised Events

3.4.1 Power and Energy Consumption

The total installed power for televised design is 250 W * 80=20 kW.
If the average burning hour of the lamps is 10, then total energy consumption of the lamps in a year is approximately 20000*10*365=73000kWh or .
The total installed power for class I, which has the maximum no of luminaires in the non-televised design is 250W * 32= 8kW.
If the average burning hour of the lamps is 10, then total energy consumption of the lamps in a year is approximately 8000*10*365= 29,200 kWh.

3.5 Conclusion

It is quite clear from Table 2.8 and 2.10 and Figure 2.2 which states the standard values given in NLC 2010 and Table 3.3 and 3.4 which shows the simulation results, that the simulation results comply with the standard values very well. Most importantly the design results a maximum GR value of 35 for televised case and 39 for non-televised case, both of which are far below 50, the recommended value. Hence it can be said the design is efficient in terms of quality game-play and smooth visibility of players, other gaming staffs and audiences.

In this design, for the Televised game-play, the Camera 1 is considered as the Primary Camera and Camera 2 is considered as the secondary camera. Among the parameters measured by these two cameras, it is necessary that all parameters measured by the Primary camera satisfies the values of NLC 2010 and Table 3.4 shows that it does in this design also. Moreover, it is to be noted that most of the values measured by the secondary camera matches with the required ones.

Chapter 4

Design of Power Supply Scheme

4.1 Introduction

In the previous chapters it has been explained and shown that Lighting design of a tennis court or any sports facility is not an easy task, especially when the case is for Televised game-play. The lighting designer of the facility is mostly concerned with the achievement of the photometric parameters as per the standard value. But another complex yet indispensable system runs behind for the achievement of these parameters is the Electrical Power Distribution system. The primary electrical load for any sports facility is the lighting load . Generally, for both outdoor and indoor sports, towers are involved consisting the lamps, but now a days indoor facilities are often designed with downlighters also.
Generally, lighting designers are not concerned with this electrical system. It is the job of the Electrical Engineers to take care of this. Starting from installation to schedule and proper maintenance of the electrical system is highly important and is done very carefully by the Maintenance Management Team. In this chapter, a brief discussion on the electrical power distribution system of a generic sports facility has been done and a probable design of the same for the lighting design of the tennis court of Chapter 3 has been proposed.

4.2 Maintenance Work of a System

Maintenance work of building, electrical installation or machines is a function of availability of funds. Hence shortage of funds often causes curtail of proper maintenance. But such limitations are not involved in Sports Lighting, since the facilities are mostly used for National and International level of gameplay, which is why sufficient funds is always available.
The role of a maintenance engineer or team mainly comprises of three folds of responsibilities. The first is to get the job done within and utilizing the existing system. The second is to try to make the existing system better or improve. The third being

Energy management. Among these the second one is no doubt the toughest one. This requires great knowledge, leadership and hardwork.
Basically Maintenance Management is an IMM which may be depicted as a system to ensure the optimum service availability and stability of the installation at the lowest possible cost maintaining good relation among the different wings of the service providing and different service utilizing departments.
Figure 4.1 shows a brief overview of how entire maintenance work of any facility is performed.

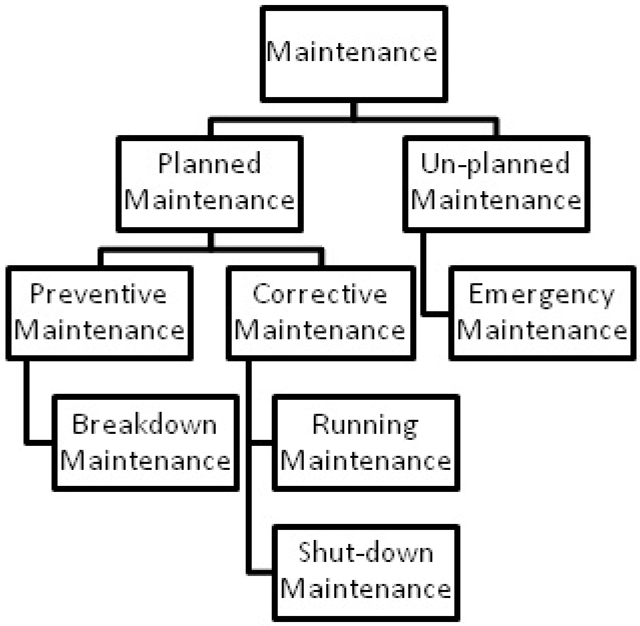


Figure 4.1: Division of Maintenance Work
[17]

4.3 Electrical Power Supply System of Sports Lighting

The importance of proper electrical system and its maintenance in sports lighting has already been stated [18]. To properly install and maintain the system, control the lamps during operation or failure it is of high necessity to understand the entire system, the connections, the equipment used very clearly. Now due to the complexity and hugeness of the system, it is impossible for anyone to physically catch on it. Hence help of diagrams are taken. Single Line Diagram (SLD) and Wiring Diagram are the two primary diagrams which are referred for the understanding of the electrical system and to do further operational and maintenance activity on the same.
In power engineering, an SLD, also sometimes called one-line diagram, is a simplest

form to symbolically represent an electric power system [19]. A single line in the diagram typically represents more than one physical conductor. Such as, in a direct current system the line includes the go and return paths, and in a three-phase system the line represents all three phases, sometimes including the neutral too.
On the other hand, Wiring Diagram is a simplified traditional pictorial representation of an electrical circuit [20]. It shows the components of the circuit as simple shapes, and the power and signal connections between the devices.
A wiring diagram mainly provides information about the relative position and arrangement of devices and terminals on the devices, to help in building or servicing the device. This is unlike a schematic diagram, where the arrangement of the components' interconnections on the diagram usually does not correspond to the components' physical locations in the finished system. It has been drawn and discussed in the following section, SLD and wiring diagram of the electrical system required for illumination of the tennis court used for televised events which has been worked on in the previous chapter.

4.4 Design of Power Supply Scheme of a Televised Tennis Court : a typical example

4.4.1 Components Required

The illumination of any sports facility, tennis court to be precise for this thesis work, comprises of a number of equipment. This does not include only the lamp and the electrical system, but few other auxiliary things as well. A list of items involved in the illumination process directly and indirectly has been prepared [17] below-

- High mast with fixed head frame
- Detachable man rider unit for accessing the flood light
- 250W LED lamps and Luminaires
- Main Lighting Distribution Board (MLDB)
- Sub-Lighting Distribution Board (SLDB)
- Distribution Board (DB)
- Cables
- Distribution Transformer
- Control Gear Racks
- Earthing Equipment
- Anti Panic Lighting System and Power Sources(UPS)

- Mimic cum Local Control Panels- Part of Control Scheme.

For the sake of relevance and compactness of this thesis, the discussion has been kept limited within the Lamps and Electrical Equipment only.

4.4.2 Methodology

Since this thesis work does not include any physical sports site visit, the design procedure is based upon some assumptions, which might vary slightly from the actual scenario. Here design of the power supply scheme refers to drawing of an SLD and wiring diagram consisting some typical components, listed above, that are necessary to power mostly all Tennis facility lighting design and installation.
As per the power and energy calculation in Section 3.4, the power consumption of the non-televised case is not much and less significant in comparison to the televised case. Hence, the electrical system has been designed for the purpose to supply power to the lighting arrangement of a Televised Tennis game-play only. The following discussion is moved forward with the explanation of the Single Line Diagram [21], shown in Figure 4.2, of the designed system. Although the ratings of the equipment are mentioned here but the related calculations has been shown in further section.

- Incomer - Incomer is the Electrical Transmission Line of 11kV, 50 Hz AC. The Distribution Transformer is connected to this through a 630A Circuit Breaker.

- Three Phase Distribution Transformer - The Distribution Transformer is required to step down the 11 kV transmission line voltage to distribution voltage of 415 V. The primary winding of the transformer is connected as Delta and the secondary side is connected as Star with Neutral. The neutral wire is required since Single phase LED floodlight lamps are to supplied at rated voltage of 240 V.
  The transformer is connected to the transmission line with a circuit breaker of rating 630A CB because there may be cases where the transformer or the supply system needs to be isolated from the transmission line, for example - during the maintenance work of the system or the transformer itself. The transformer power rating is decided as per the power consumption of the system. Here a rating of 63kVA has been taken.

- Main Lighting Distribution Board (MLDB) - The Main Lighting Distribution Boards are indoor floor mounted, metal enclosed, single front, vermin proof, IP52 protected as per IS-247. The bus bars are air insulated and made up of electrolytic graded Aluminium. Bus bars shall be Polyvinyl chloride (PVC) sleeved having red, yellow, blue and black coloured strips arranged according to IS-375.
  Incomer to the busbar includes Four Pole Molded Case Circuit Breaker (FPM-CCB) with a current rating of 63A. Rating of this decided as per the connected

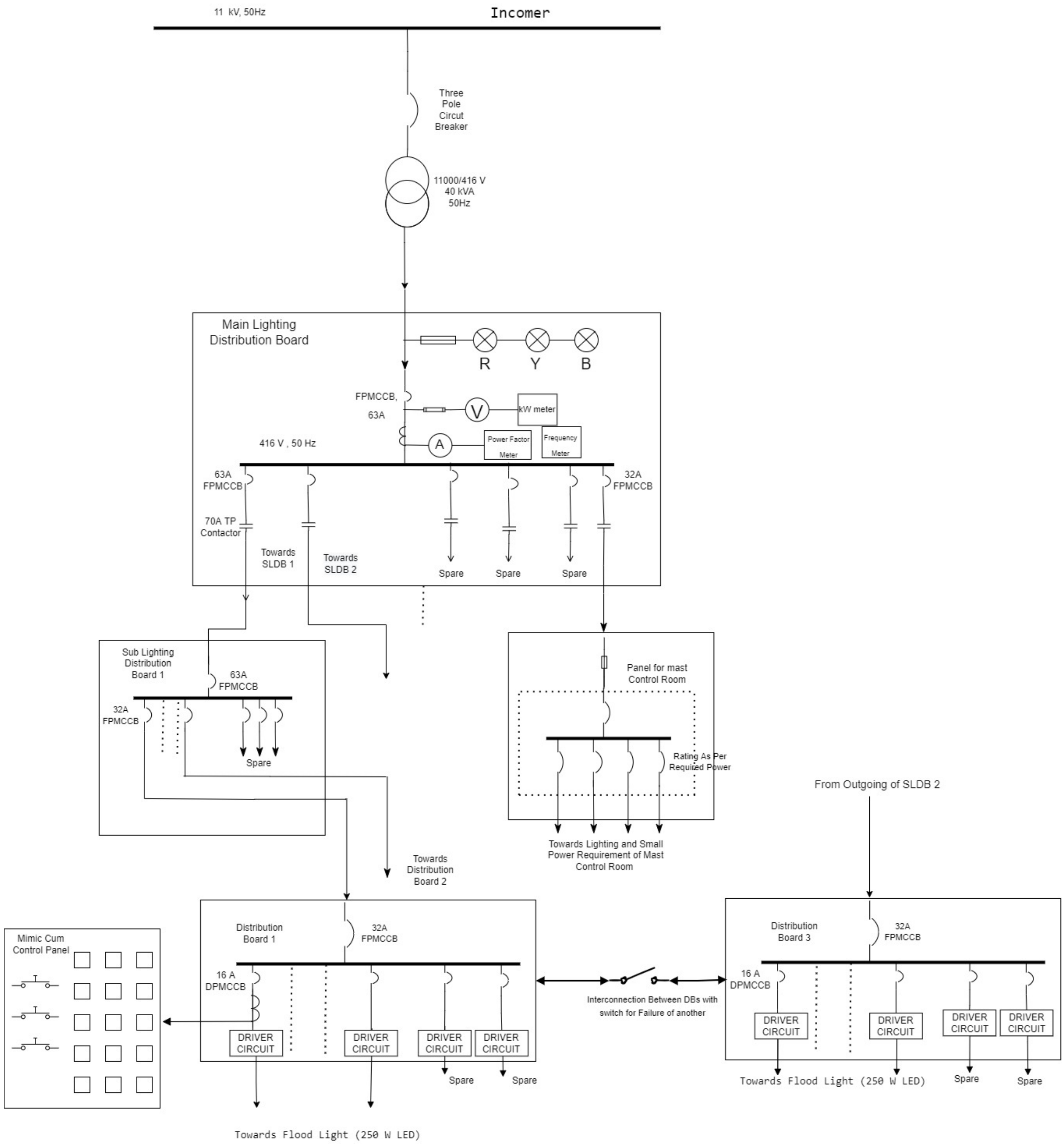


Figure 4.2: Simplest Single Line Diagram of the Designed Power Supply Scheme

load due to the floodlighting system. Incomer MCCB also contains overlaod and short citcuit releases along with ammeter and voltmeter with selector switch, kW meter, Power factor meter and frequency meter. The incomer also have one set of red, yellow and blue phase indicating lamps with control fuses and ON/OFF/Trip indicating lamps.

Outgoings of the busbar of MLDB consists of 63A FPMCCB. The number of feeders will be decided as per the illumination design and load distribution. Each outgoing MCCB is provided with 70A Three Pole contactor, and ON delay timer with. Switching arrangement is made to keep required number of lamps "ON" according to the level of match-"Practice", "National", "International". Apart from these, there is one outgoing feeder with 32A FPMCCB to feed panel for small power requirement of the mast control room.

- Sub-Lighting Distribution Board (SLDB) These are metal enclosed wall mounted type. The incomer to SLDB are 63A FPMCCB. Outgoings contain 32A FPMCCB. Each outgoing feeders supply power to DB and the number depends on the load distribution.

- Distribution Board (DB) - Distribution Boards have 32A FPMCCB as incoming and the outgoings with 16A Four Pole Molded Case Circuit Breaker (FPMCCB). The outgoings go directly to the Flood light luminaire through the driver circuit. Each floodlight circuit is connected with Current Transformer for sensing current and decide the ON/OFF status of the lamp and the output status is fed to the LED display of the Mimic Cum Control Panel.

- Mimic Cum Control Panel - One Mimic cum local control panel is provided with distribution boards so that the ON/OFF status of the lamps can be monitored and controlled stage-wise basis. Each floodlight circuit is provided with CT to sense the current for the indication purpose.

  Mimic cum control panel is equiped with a set of push buttons for switching control. The number of push buttons indicates the corresponding number of level of game-play- International, National, Practice or any other level if required .

  The system works in the following way- if a push button of corresponding level is pressed, it actuates required numbers of contactors of the outgoing feeders of the Main Lighting Distribution Board (MLDB). This in turn will switch on corresponding lighting panels in stages depending on the time delay set. Tine delay set is given to restrict the heavy inrush of current due to switching on of floodlights together.

- LED Floodlights- For the design of the lighting system of the typical televised tennis court, LED floodlights has been chosen with power rating of 250 W. Previously, Metal Halide lamps were used predominantly for sports lighting purpose. But the energy consumption of metal halide lamps were very alarming. Hence, now a days LEDs are mostly replacing all kind of other lamps and being used extensively for the purpose.

- Cables- There are two types of cables used in the power supply schems- Power Cables, Control Cables. The cable distribution is as follows -

  i From Transmission Line Supply to Transformer Primary Side.

  ii From Transformer secondary side to Main Lighting Distribution Board (MLDB).

  iii From Main Lighting Distribution Board (MLDB) to Sub-Lighting Distribution Board (SLDB).

  iv From Sub-Lighting Distribution Board (SLDB) to Distribution Board (DB).

  v From Distribution Board (DB) to control gear racks where driver circuits are kept and interconnection between Distribution Board (DB)s.

  vi From Control gear racks to flood lights.

  vii Interconnected control cables form mimic cum control panel to MLDB for actuating the contactors and from control gear racks to mimic cum control panel for LED diaplay.

  Among these, except (vii) all other cables are power cables and (vii) is control cable. Among the power cables, (i) is High Tension power cable and the others are Low Tension power cable. The ratings of the all the cables has been calculated and discussed later.

- Anti-Panic Lighting system - It is necessary to provide some backup flood lights at the top of the masts so that minimum visibility can be achieved in case of complete power failure. These lights can be powered through suitably rated Uninterrupted Power Supply.

- Earthing - High mast towers is to be earthed at two separate point by means of two numbers of earth pits with 600*600*6mm Gl earth plate with required accessories and connected by 50*6 mm Gl flat. Equipment in the control room shall be earthed using suitable Gl flat connected to the existing earth grid of the control room.

The equipment discussed above has been mentioned with their ratings. Now in the following discussion the calculation of those ratings has been catered. Also, the total cable length required approximately will also be shown. To do so, help of the wiring diagram, given in Figure 4.3 been taken. To move forward with the calculation, the following assumptions has been made in the diagram.

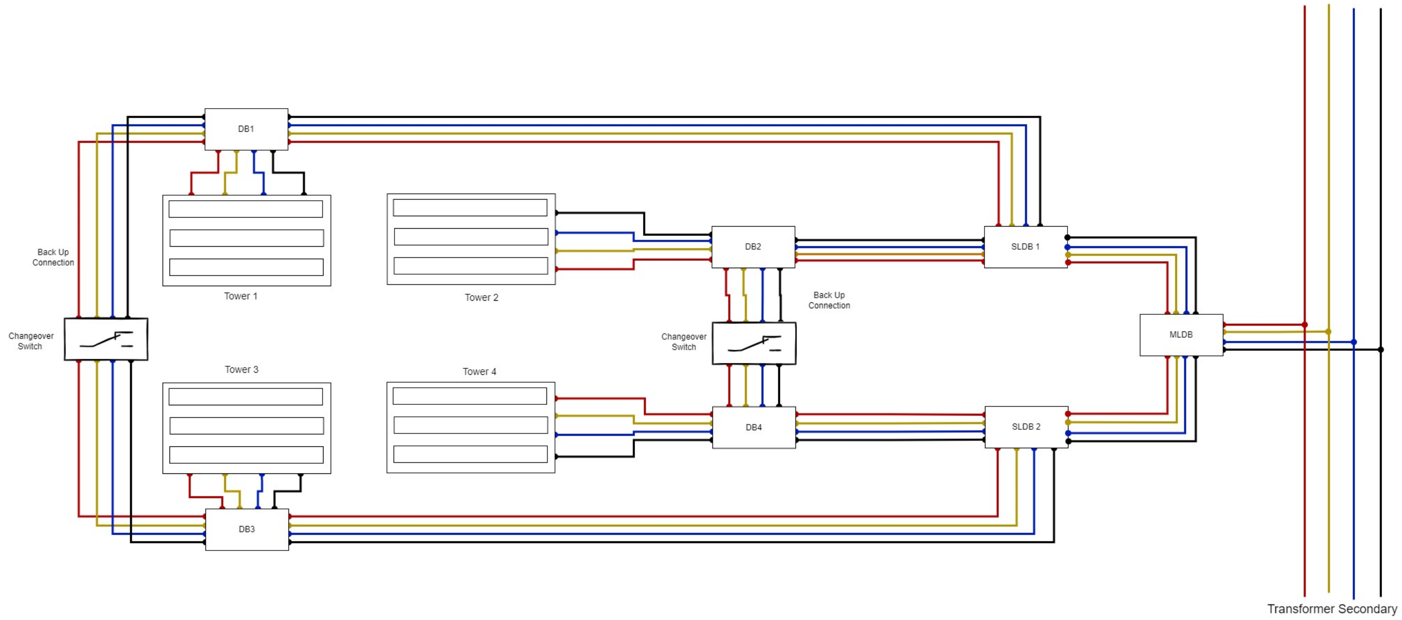


Figure 4.3: Wiring Diagram of The Power Supply scheme

Assumptions

As per Figure 4.3, approximate distance between –

- Distribution transformer to MLDB = 70m.
- MLDB to each SLDB = 20m.
- SLDB1 to Tower2 and SLDB2 to Tower4 = 50m.
- SLDB1 to Tower1 and SLDB2 to Tower3 = 70m.
- DB1 and DB3 = 40m.
- DB2 and DB4 = 20m.
- DB to Corresponding Tower = 10 m.

Apart from these, let us assume the distance between Transformer and Transmission line supply (11kV)=100m.

Cable Length Calculation

The above distances are approximated as point by point distance. But when the cable will be installed either through ground or through air, it will require extra length due to bending and exact distance. Hence, while designing, it is safe to keep some extra length in the cables of all segment. Here an additional length of 15m. plus extra 10% of total length is kept as spare cable length. Due to that, the following cable lengths are required.

i From 11kV supply grid to Transformer = (100+15)*1.10 = 126.6 ≈ 130m.

ii Distribution transformer to MLDB = (70+15)*1.10 = 93.5 ≈ 95m.

iii MLDB to each SLDB = (20+15)*1.10 ≈ 40m.

iv SLDB1 to DB2 and SLDB2 to DB4 = (50-10+15)*1.10 = 60.5 ≈ 60m.

v SLDB1 to DB1 and SLDB2 to DB3 = (70-10+15)*1.10=83.5 ≈ 85m.

vi DB1 to DB3 = (40+15)*1.10 = 60.5 ≈ 60m.

vii DB2 to DB4= (20+15)*1.10=38.5 ≈ 40m.

viii From DB to corresponding tower = (10+15+16)*1.10 ≈ 45m.

Current Calculation

LT Side:

As per the televised tennis facility lighting design data from Chapter 3,
Total number of luminaire per pole is 20, each of wattage 250W.
Thus, active power consumed by each pole = 5000W or 5kW
Current consumption by each tower due to floodlighting loads is calculated by following equation [19] [22]-

$$\sqrt{3} * V_{line} * I_{line} * powerfactor = ActivePowerConsumption \tag{4.1}$$

from this, putting V_{line} = 415 V and power factor=0.9,

$$I_{line}=7.73A \approx 8A$$

The 20 lamps in each tower is distributed in 7+7+6 in each phase respectively. This 8A current is drawn by each phase also, since the Distribution secondary is Star Connected with Neutral wire, hence I_{phase}=I_{Line}.
Therefore, this 8A current flows through-

i Distribution Board to Each phase of Tower

ii Each Sub-Lighting Distribution Board to Distribution Board

Therefore, the current flowing between, Main Lighting Distribution Board and each Sub-Lighting Distribution Board = 8+8=16A.
Similarly, the current flowing between Transformer secondary to Main Lighting Distribution Board = 16+16 = 32A.
Now, case of failure occurrence has been assumed in the following three possibilities-

i Cable between Main Lighting Distribution Board to any one of the Sub-Lighting Distribution Boards.

ii At any one of the Sub-Lighting Distribution Boards.

iii Cable between Sub-Lighting Distribution Board to connected Distribution Boards.

As per Figure 4.3 backup connections are arranged and because of occurrence of the failure, there will be changes in current flow than the healthy system. Thus the rating of the equipment must be calculated on the basis of situation of failure.
Assuming, the above discussed failure happens in the upper portion of the system according to Figure 4.3, i.e.- between MLDB and either DB1 or DB2. Thus the total current drawn by the system will follow the following path-

MLDB → SLDB2 → DB3 → i. Tower3 and ii. Tower1 through Changeover Switch and DB1.

and

MLDB → SLDB2 → DB4 → i. Tower4 and ii. Tower2 through Changeover Switch and DB2.

It is quite clear from the above current flow path, at the time of power failure, any electrical equipment connected between the MLDB and the DBs of healthy part of the system, i.e.- the bottom part of the system, will encounter double the current flow in normal condition of the system. Similar thing will happen when the failure occurs at the bottom part of the system.
Now, to calculate the ratings of different electrical equipment, a Safety Factor of 1.25 has been considered.
Thus, the current Rating of the equipment like cables, MCCB, switches etc. will be as follows, if connected between-

i Main Lighting Distribution Board to Each Sub-Lighting Distribution Board = 32 * 1.25 = 40A.

ii Sub-Lighting Distribution Board to Distribution Board = 16 * 1.25 = 20A.

iii Distribution Board to Tower or Each phase of lamp = 8 * 1.25 = 10A.

Now, the backup connection for the above cases of failure, as shown in Figure 4.3 connects the DBs through a Changeover Switch. The amount of current coming from SLDB to respective DBs during failure, will be distributed with the normal value (8A) to its respective Tower and to one of the towers which is from the faulty part of the system through changeover switch.
Hence, current rating of the cable and the changeover switch used for the backup connection = 8 * 1.25 = 10A.

HT Side:
Transformer secondary current I_2=40A (considering safety factor)
Transformer secondary voltage V_2=415V
Transformer primary voltage V_1=11kV

Therefore Transformer primary current I_1 is given by the equation-

$$\frac{V_1}{V_2} = \frac{I_2}{I_1} \tag{4.2}$$

Now, putting values, $I_1 = 1.51\text{A}$

Selection Of Cables

LT Side:

Power Cables

Among all the segments discussed before where cables are required, it is assumed that, cables at all the segments, except DB to Lamps are laid underground and cable between DB to Lamp are laid in air.
In order to select cables that can tolerate the currents, discussed above, the standard IS-7098(Part-1) and for market availability of required cables, a catalogue from Havells India Limited has been consulted. Consulting both, the following specification of the power cables has been selected-

- 1.1kV, Four Core, Aluminium Conductor, XLPE insulated, Armoured Cable.

The Figure 4.4 shows the different physical and electrical parameters and 4.5 shows the Cross-sectional view of the selected cable from Havells India Limited catalogue.

Size (Cross Sectional Area)	Minimum No. of Strand in Conductor		Nominal Insulation Thickness	Minimum Inner Sheath Thickness	Flat Strip Armoured					Round Wire Armoured				
					Nominal Armour Strip Dimension	Minimum Outer Sheath Thickness	Approx. Overall Dia of Cable	Approx. Weight of Cable		Nominal Dia of Armor Wire	Minimum Outer Sheath Thickness	Approx. Overall Dia of Cable	Approx. Weight of Cable	
	Aluminium	Copper						With Al'm Cond.	With Cu Cond.				With Al'm Cond.	With Cu Cond.
Sqmm	No's	No's	mm	mm	mm	mm	mm	Kg/Km	Kg/Km	mm	mm	mm	Kg/Km	Kg/Km
4	1/3	1/3	0.70	0.30	N/A	N/A	N/A	N/A	N/A	1.40	1.24	16	440	560
6	1/3	1/3	0.70	0.30	N/A	N/A	N/A	N/A	N/A	1.40	1.24	17	520	670
10	1/7	6	0.70	0.30	N/A	N/A	N/A	N/A	N/A	1.40	1.40	19	620	900

(a) Physical Parameters of Selected LT Cable

Size (Cross Sectional Area)	Max. Conductor D.C.Resistance at 20 °C		Approx. Conductor A.C.Resistance at 90 °C		Reactance of Cable at 50 Hz (Approx.)	Capacitance of Cable (Approx.)	Normal Current Rating						Short Circuit Current Rating for 1 Second Duration	
							For Aluminium Conductor			For Copper Conductor				
	Aluminium	Copper	Aluminium	Copper			Ground	Duct	Air	Ground	Duct	Air	Aluminium	Copper
Sqmm	Ohm/Km	Ohm/Km	Ohm/Km	Ohm/Km	Ohm/Km	µF/Km	Amps	Amps	Amps	Amps	Amps	Amps	K.amps	K.amps
4	7.41	4.61	9.48	5.90	0.098	0.11	34	28	30	44	37	39	0.376	0.572
6	4.61	3.08	5.90	3.94	0.090	0.13	43	37	40	55	47	50	0.564	0.858
10	3.08	1.83	3.94	2.34	0.084	0.16	57	48	53	74	61	67	0.940	1.43

(b) Electrical Parameters of Selected LT Cable

Figure 4.4: Parameters of Selected LT Cable

The cross sections of the power cable required at different parts of LT side of the designed system is 10sq.mm.

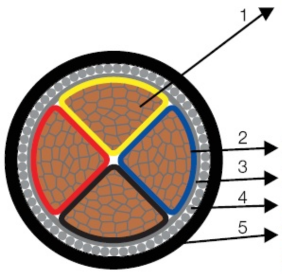


Figure 4.5: Cross Sectional View of Selected LT Cable

Control Cables

Apart from the above specification of the power cables, control cables complying the standard IS-1554(Part-1) with following specification can be used -

- Four core, 1.5sq.mm., Copper Conductor PVC/XLPE insulated flexible cables.

HT Side:

For cable selection of HT side also, the catalogue from Havells India Limited has been referred along with standard IS-7098 (Part-2). The cable chosen for the purpose is-

- 11kV, Three core, Aluminium Conductor, XLPE insulated, Armoured Cable.

Figure 4.6 shows the different physical and electrial parameter of the selected cable. Figure 4.7 shows the Cross-sectional view of the selected HT cable from Havells India Limited catalogue.

Size (Cross Sectional Area)	Nominal insulation thickness	Minimum Inner Sheath Thickness	Flat Strip Armoured (A2XFY/2XFY)					Round Wire Armoured (A2XWaY/2XWaY)				
			Nominal Armour Strip Dimension	Minimum Outer Sheath Thickness	Approx. Overall Dia of Cable	Approx. Weight of Cable		Nominal dia of armor wire	Minimum Outer Sheath Thickness	Approx. Overall Dia of Cable	Approx. Weight of Cable	
						With Al'm Cond.	With Cu Cond.				With Al'm Cond.	With Cu Cond.
						A2XFY	2XFY				A2XWY	2XWY
Sqmm	mm	mm	mm	mm	mm	Kg/Km	Kg/Km	mm	mm	mm	Kg/Km	Kg/Km
25	5.50	0.50	4 X 0.80	1.88	48	2700	3050	2.50	2.04	51	3900	4200
35	5.50	0.50	4 X 0.80	2.04	50	3000	3500	2.50	2.20	54	4250	4700

(a) Physical Parameters of Selected HT Cable

Size (Cross Sectional Area)	Max. Conductor D.C.Resistance at 20 °C		Approx. Conductor A.C.Resistance at 90 °C		Reactance of Cable at 50 Hz (Approx.)	Capacitance of Cable (Approx.)	Normal Current Rating						Short Circuit Current Rating for 1 Second Duration	
	Aluminium	Copper	Aluminium	Copper			For Aluminium Conductor			For Copper Conductor				
							Ground	Duct	Air	Ground	Duct	Air	Aluminium	Copper
Sqmm	Ohm/Km	Ohm/Km	Ohm/Km	Ohm/Km	Ohm/Km	µF/Km	Amps	Amps	Amps	Amps	Amps	Amps	K.amps	K.amps
25	1.20	0.727	1.54	0.931	0.145	0.14	95	82	105	120	105	135	2.35	3.58
35	0.868	0.524	1.11	0.671	0.138	0.16	115	97	125	145	125	165	3.29	5.01

(b) Electrical Parameters of Selected HT Cable

Figure 4.6: Parameters of Selected HT Cable

The cross section of the power cable at HT side is taken 25sq.mm. Control cables are not applicable for HT side.

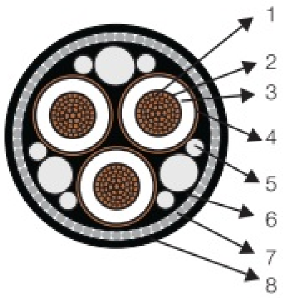


Figure 4.7: Cross Sectional View of Selected HT Cable

Selection Of Distribution Transformer

For the purpose of selecting the distribution transformer required to give supply to the entire system, a standard IS-2026/1977 and catalogue of Marsons Limited has been consulted for market availability checking.
The selected Distribution Transformer is of following specification-

- 3 phase, 11/0.415kv, 63kVA, 50Hz, Aluminium Wound, Dyn-11, without OCTC
- The transformer should be suitable for working with following power supply variations - i. Voltage : -12% to +12%, ii. Frequency : ± 3% (48.5 Hz to 51.5 Hz), iii. Power Factor - Zero (Lag) – Unity – Zero (Lead)
- Percentage Impedance - 4%
- ONAN cooling
- Length - 1140mm, Breadth- 900mm , Height- 1320mm.
- Maximum Ambient Air Temperature - 50 ° Centigrade
- Minimum Ambient Air Temperature - 8 ° Centigrade
- Average Daily Ambient Air Temperature - 38 ° Centigrade
- Relative Humidity - 15% to 85%

Selection Of Circuit Breakers

For the selection of MCCBs at different parts of the supply system, IS/IEC-60898-1 : 2002 standard and a catalogue of Schneider Electric India has been referred, to check market available ratings of the same. The circuit breakers connected at different parts of the system are as following-

- Between Transmission Line and Transformer Primary : 12kV, 630A, 3 Pole Circuit Breaker
- Between Transformer Secondary and MLDB Busbar : 415V, 63A, 4 Pole, MCCB

- At outgoing of MLDB and incoming of SLDB : 415V, 63A, 4 Pole, MCCB
- Between outgoing of MLDB and incoming of panel for mast control room : 415V, 32A, 4 Pole, MCCB
- At outgoing of SLDB and incoming of DB : 415V, 32A, 4 Pole, MCCB
- At outgoing of DB, i.e.- feeder of each lamp : 415V, 16A, 2 Pole, MCCB

4.5 Percentage Voltage Drop Calculation

Percentage voltage drop calculation is required to check voltage drops at different sections of the power supply system. Basically, the resistance and reactance of the cable used, causes some drop in supply voltage at the load terminal. As a result, the rated voltage is often not reached at the load terminal. But this is to be ensured there is not a voltage drop of <5% at the load terminal than its rated voltage.
In this section, a the calculation of % voltage drop has been shown. The detailed calculation is as follows-

System Details

Total electrical load of the system = 20kW. But at different DBs, the loads are distributed in following manner-

- At MLDB = 20kW or 23kVA.
- At each SLDB = 10kW or 11.11kVA.
- At each DB(Tower)= 5kW or 5.55kVA.

Distance between different DBs and Current flow through different sections have already been mentioned previously in this chapter.
Rated Line voltage = 415V, Power factor = 0.9 , Demand Factor = 1.
The Permissible voltage drop at Load Terminal= 5%.

Cable Lying Details

- All the cables except Distribution Boards to its corresponding tower is directly buried under a depth of 1m. at ground.
- Ground Temperature = 35° Centigrade.
- Atmospheric Air temperature = 35° Centigrade.
- Number of cable per trench = 1.
- Number of run of cable between each type of Distribution Boards = 1.

Soil Details

- Thermal Resistivity of soil is not known.
- Nature of soil = Damp.

Some Important Factors

- Temperature Correction Factor when cable is in Air = K1
- Ground Temperature Correction Factor = K2
- Thermal Resistance Correction Factor for Soil(when thermal resistance for soil is not known = K4
- Cable Depth Correction Factor = K5
- Cable Distance Correction Factor = K6
- Cable Grouping Factor(No. of Tray Factor)= K7

Now, Total Derating Factor is defined as K1*K2*K4*K5*K6*K7.
Now, according to values shown in Appendix C, for the chosen cable,
When it is laid underground-
K1=1, K2=0.89, K4=1.05, K5=1, K6=1, K7=1
Therefore, Derating factor = 0.93.
When it is in air-
K1=0.96, K2=1, K4=1, K5=1, K6=1, K7=1
Therefore, Derating factor = 0.96.

Calculation

As per the design is concerned, type of cable used is 10sq.mm. The cable laid between Distribution Boards and corresponding towers is through air, and rest everywhere it is laid under ground. To get the value of cable reactance and resistance, Figure 4.4 has been referred. The percentage Voltage Drop of the cable is calculated using the following equation-

$$\%VoltageDrop = \frac{\sqrt{3} * RatedCurrent * (R * cos\phi + X * sin\phi) * CableLength * 100}{LineVoltage * NumberofCableRun * 1000} \tag{4.3}$$

where, R=Resistance in ohm/km., X=Reactance in ohm/km., ϕ=angle between voltage and current Using equation 4.3 and putting corresponding values in it, the following voltage drops are resulted-

- At each SLDB terminal = 0.96%
- At DB1 and DB3 terminal = 1.13%

- At DB2 and DB4 terminal = 0.71%
- At Each Lamp Input = 0.54%

Now the Net Percentage Voltage Drop at load terminal is the cumulative sum of all four Percentage drops at different terminals.
Hence, Net Percentage Voltage Drop = (0.96+1.13+0.71+0.54)% =3.34%
Now, it is seen that the voltage drop at the load terminal is very much less that 5%. But there are some other conditions too, which are required to be satisfied to conclude that the used cable is suitable for the purpose.These are-

i Cable derating ampere should be higher than full load current of loads.

ii Cable voltage drop should be less than defined voltage drop.

iii No. of cable runs $\geq$ (Full load Current/Cable derating current)

Now the satisfaction of these conditions by the used cable and system is checked below.

i Total derating current of 10sq.mm.(at ground) = 57*0.93=53.01A > 32A
Total derating current of 10sq.mm.(at air)=53*0.96=50.88A > 8A

ii It is already shown, cable voltage drops are less than defined voltage drop(5%).

iii The ratio (Full load current/Cable derating current) is clearly less than corresponding cable run(=1).

Thus, since all the conditions are satisfied, it can be said that the used cable is apt for the purpose, and the design and cable selection is justified.

4.6 Conclusion

The above designed power supply scheme for televised tennis court, is totally a typical one and includes many assumptions and simplicity. The actual scenario may very from the designed one. Some limitations of the designed system has been figured out as -

- In the system only one distribution transformer has been considered. There should be a backup transformer to substitute that as and when need arises.
- The condition of failure considered here is anywhere at downstream of MLDB towards the towers, but the condition of the same at upstream of MLDB, and itself at MLDB has not been considered. Hence, the backup connection will not work in that case.
- This design does not include any calculation or discussion regarding the specification of the driver circuit of the LED lamps.

The system can be redesigned addressing these limitations and a better and more realistic design can be made.

Chapter 5

Bill of Quantity

After the designs of Lighting system and Power Supply scheme has been finalized, it is important to tabulate the details of different components required. A document prepared to calculate the exact or sometimes approximate costing of project work by multiplying number of item by corresponding rate, is known as Bill of Quantity (BOQ).
In this chapter, the BOQ for the components required for both lighting and power supply design, has been prpepared separately.

5.1 BOQ for Lighting System Design

Sl. No.	**ITEM**	**SPECIFICATION**	**QUANTITY**	**PRICE PER UNIT QUANTITY (Rupees)**
1	High Mast for Sports Lighting	16m. , Hot Rolled Structured Steel	4	1,35,000.00
2	LED luminaire for Sports Lighting	250w, 4000K, Beam Angle -10 degree, 31250 lm.	48	16500.00
		250w, 4000K, Beam Angle -30 degree, 31250 lm.	32	15500.00

5.2 BOQ for Power Supply Scheme Design

Sl. No.	ITEM	SPECIFICATION	QUANTITY	PRICE PER UNIT QUANTITY (Rupees)
1	Distribution Transformer	11/0.415kV,63kVA,50Hz,3-phase	1	1,18,000.00
2	Cables	1.1kV, Four Core, Al Conductor, XLPE insulated, Armoured Cables(10sq.mm.)	800m.	262.00
		Four-core, Cu Conductor , XLPE insulated flexible cables(1.5sq.mm.)	100m.	182.00
		11kV,Three-core, Al Conductor , XLPE insulated Armoured cables(35sq.mm.)	150m.	1051.00
3	MCCB	415V, 4-Pole(63A)	5	7300.00
		415V, 4-Pole(32A)	9	7300.00
		415V, 2-Pole(16A)	80	2700.00
4	Distribution Boards excluding MCCB	20*16*8in(l*b*w)	7	5000.00
5	Contactor	415V, 3-Pole(70A)	3	2500.00
6	Changeover Switch	415V, 4-Pole(32A)	2	1000.00
7	Circuit Breaker	12kV, 3-Pole(630A)	1	7,00,000.00

It is to be noted that, the pricing indicated in above tables, are approximate prices only. Actual prices may vary depending upon year to year market variation and several other factors.

Conclusion and Future Scope of Work

By the time, it can be fairly concluded that, the thesis work is divided grossly in two set of works - the first is the design of the Lighting System of a typical televised tennis court while the second being the corresponding electrical power supply system design. So, the future scope of work can also be discussed for both the designs separately.
The lighting design performed here is for a typical outdoor tennis court without any site inspection and physical measurement, using LED sports lighting luminaire. In future this work is extendable in following manner-

- The design can be performed using Metal Halide sports lighting luminaires.
- Further a comparative analysis between this design with LED and new design with Metal Halide can be performed.
- Also, the comparative analysis can be carried out in two ways,
    - i Keeping the lumen output of LED and Metal Halide sports lighting luminaire same and varying their wattage.
    - ii Keeping the wattage of both type of luminaires same and varying their lumen output.

The electrical power supply scheme designed above, for televised tennis court, is totally a typical one and is based upon many presumptions and includes less complexity. The actual scenario may very from the designed one. Since, this design is the simplest form of its, this has many scope of extendable future works, such as-

- The system can be redesigned with backup connection considering failure at the upstream of MLDB.
- Design and discussion on the control scenario of the lamps and the entire system includes a good amount of work to be done in future. Technology like SCADA can be included in the control process.
- A study and improvement on the driver circuit of the lamps is also a future scope of work this design.

Bibliography

[1] M. W. Peirce, “Sports lighting,” *Transactions of the Illuminating Engineering Society*, vol. 18, no. 7_IEStrans, pp. 177–198, 1953.

[2] R. H. Simons and A. R. Bean, *Lighting Engineering Applied calculations*, 1st ed. Architectural Press, 2001.

[3] PhilipsLighting, “Sports lighting: Key considerations for illuminating the field of play and the spectator zones,” 2018.

[4] K. W. Houser, M. Wei, and M. P. Royer, “Illuminance uniformity of outdoor sports lighting,” *LEUKOS*, vol. 7, no. 4, pp. 221–235, 2011.

[5] R. Hargroves, I. Henry, and M. Trezzi, “Glare evaluation of tennis court floodlighting,” *Lighting Research & Technology*, vol. 18, no. 4, pp. 157–160, 1986.

[6] A. Suresh, J. P. Salis, and K. Shailesh, “Lighting optimization to save energy in an indoor sports facility,” in *2019 Second International Conference on Advanced Computational and Communication Paradigms (ICACCP)*, 2019, pp. 1–5.

[7] K. Houser, M. Royer, and R. Mistrick, “Light loss factors for sports lighting,” *LEUKOS*, vol. 6, no. 3, pp. 183–201, 2010.

[8] Wikipedia, “Tennis,” https://en.wikipedia.org/wiki/Tennis.

[9] R. Haynes, “Tennis court lighting layout and lighting design,” https://tachyonlight.com/tennis-court-lighting-layout-and-design/.

[10] R.Haynes, “Lighting standards for tennis court,” https://tachyonlight.com/lighting-standards-for-tennis-courts/.

[11] A. Baker, https://www.roadtrips.com/blog/9-best-major-tennis-tournaments/.

[12] BritishStandardsInstitution, *BS EN 12193:Light and lighting — Sports lighting*, Std., 2018.

[13] IlluminatingEngineeringSociety, *NSI/IES RP-6-20, Recommended Practice: Lighting Sports and Recreational Areas*, Std., 2020.

[14] TennisAustraliaLimited, *AS2560.2.1: Outdoor Court Lighting Information Sheet*, Std.

[15] EurpeanCommitteeForStandardization, *CEN EN 12193:Light and lighting — Sports lighting*, Std., 2017.

[16] J. P. Salis, A. Suresh, and K. Shailesh, “Lighting design of an indoor sports facility-a case study,” in *2019 Second International Conference on Advanced Computational and Communication Paradigms (ICACCP)*, 2019, pp. 1–5.

[17] S. U. K. Basu, “Operation and maintenance of sports lighting - power distribution,” *35th Annual Number*, pp. SF39–SF48.

[18] R. Dugan, S. Santoso, M. McGranaghan, and H. Beaty, *Electrical Power Systems Quality*, ser. McGraw-Hill professional engineering. McGraw-Hill Education, 2002.

[19] P. Purkait and I. Bandyopadhyay, *Electrical Machines*, 1st ed. Oxford University Press, 2017.

[20] J. Arrillaga and N. R. Watson, *Power System Harmonics*, 2nd ed. John Wiley and Sons, 2003.

[21] M. Nagraj, “Sports lighting - associated system design and commissioning,” *35th Annual Number*, pp. SF23–SF31.

[22] P. S. Bhimbra, *Generalized Theory of Electrical Machines*, 5th ed. Khanna Publishers, 2007.

Appendix A

Different Standards of Tennis Court Lighting

Spectator area lighting

For the visual comfort of spectators rather than safety or emergency reasons, the lighting level should be at least 10 lux.

5.2 Lighting recommendations for outdoor courts

5.2.1 Lighting requirements

	Horizontal illuminance	Uniformity of illuminance	Glare	Lamp colour temperature	Lamp colour rendering
	E_h average (lux)	E_{min}/E_h ave.	GR	(K)	Ra
Class I	> 500*	> 0.7	< 50	> 4000	> 80
Class II	> 300*	> 0.7	< 50	> 4000	> 65
Class III	> 200*	> 0.6	< 55	> 2000	> 20

Table 4. Summary of the lighting criteria for outdoor courts. The above average horizontal illuminances are maintained values.

5.2.2 Installation recommendations

In order to get the appropriate horizontal illuminance on the ground (average level and uniformity) and also a sufficient illuminance level to reveal the ball in flight within the playing volume above the court, while ensuring that players do not suffer from disability glare, positioning and height of luminaires should be carefully considered as well as the choice of luminaire.

It is recommended to use sharp cut off luminaires, with accurate light output control, mounted on columns; for a single court, mounting height between 8 and 12 m is generally appropriate to achieve the above conditions.

Columns are set up on either side of the TPA, using two to four column positions on both of the longitudinal sides, depending on the required quality of the lighting system (*see Fig. 4*).

FACILITIES GUIDE | JUNE 2020

55

5.3 Lighting recommendations for indoor courts

5.3.1 Lighting requirements

	Horizontal illuminance	Uniformity of illuminance	Glare	Lamp colour temperature	Lamp colour rendering
	E_h average (lux)	E_{min}/E_h ave.	GR	(K)	Ra
Class I	> 750*	> 0.7	< 50	> 4000	> 80
Class II	> 500*	> 0.7	< 50	> 4000	> 65
Class III	> 300*	> 0.5	< 55	> 2000	> 20

Table 7. Summary of the lighting criteria for indoor courts. The above average horizontal illuminances are maintained values.

5.3.2 Installation

Recommended systems of lighting use luminaires that are mounted parallel to the sidelines and outside the PPA. No luminaires should be positioned in the part of the ceiling which is directly above the area limited by the rectangle of the marked area extended to the full depth of the run back behind the base lines.

The interior surfaces of indoor courts can help to make the ball more visible against them however, the right choice of colour and reflectance can also assist with perceived quality of the lighting installation. Background colours of blue or green are preferable and should be as uniform as possible.

Glare from windows – positioning windows at low level alongside the court and not behind the server reduces this possibility.

FACILITIES GUIDE | JUNE 2020

58

Figure A.1: Lighting Recommendations by International Tennis Federation (ITF)

EN 12193:2007 (E)

Table A.3

	Reference Area Length m	Reference Area Width m	Number of grid points Length	Number of grid points Width
Aerobics	–	–	–	–
Athletics (see NOTE) Track 200 m PA:	50	4,9 to 9,8	17	3
Field PA:	85 to 93	30 to 42	19	7 to 9
Dancing	–	–	–	–
Equestrian Jumping PA:	60	40	17	11
Dressage PA:	70	30	19	9
Gymnastics PA:	32 to 50	22,5 to 25	15 to 17	9
Roller skating PA:	40	20	15	9
Rhythmic gymnastics PA:	14	14	11	11
Speed skating Short Track PA:	50	6	17	3
400 m PA:	100	8	21	3
Wall climb	–	–	–	–

Class	Horizontal illuminance		Vertical illuminance (Wall climb)			R_a
	$\bar{E}_m$ lx	$E_{min}/\bar{E}_m$	$\bar{E}_m$ lx	$E_{min}/\bar{E}_m$		
I	500	0,7	500	0,7		60
II	300	0,6	300	0,6		60
III	200	0,5	200	0,5		20

NOTE Glare cannot be quantified. It can however be controlled by careful positioning of luminaires e. g. over pole vault area. The vertical illuminance at the finishing line should be 1 000 lx for photo-finish equipment and officials.

Table A.4

Indoor (see NOTE)	Reference Area Length m	Reference Area Width m	Number of grid points Length	Number of grid points Width
Tennis PA:	36	18	15	7

Class	Horizontal illuminance					R_a
	$\bar{E}_m$ lx	$E_{min}/\bar{E}_m$				
I	750	0,7				60
II	500	0,7				60
III	300	0,5				20

NOTE No luminaires should be positioned in that part of the ceiling which is directly above the area limited by the rectangle of the marked area extended to 3 m behind the base lines.

26

EN 12193:2007 (E)

Table A.15

Outdoor		Reference Area Length m	Reference Area Width m	Number of grid points Length	Number of grid points Width
Archery	Shooting lane	–	–	–	–
	Target	–	–	–	–
Shooting	Shooting lane	–	–	–	–
	Target	–	–	–	–

Class	Horizontal illuminance Shooting		Vertical illuminance Target			R_a
	$\bar{E}_m$ lx	$E_{min}/\bar{E}_m$	$\bar{E}_m$ lx	$E_{min}/\bar{E}_m$		
I	200	0,5	750	0,8		60
II	200	0,5	750	0,8		60
III	200	0,5	750	0,8		60

Table A.16

Outdoor		Reference Area Length m	Reference Area Width m	Number of grid points Length	Number of grid points Width
Tennis	PA:	36	18	15	7

Class	Horizontal illuminance				GR	R_a
	$\bar{E}_m$ lx	$E_{min}/\bar{E}_m$				
I	500	0,7			50	60
II	300	0,7			50	60
III	200	0,6			55	20

32

EN 12193:2007 (E)

On the rare occasions when only one fixed main camera position is defined, it is possible to take the vertical planes on which the requirements shall be fulfilled as those facing the main camera position.

In the case of an unrestricted choice of camera position, the illuminances on vertical planes facing all four sides of the pitch shall be taken into account.

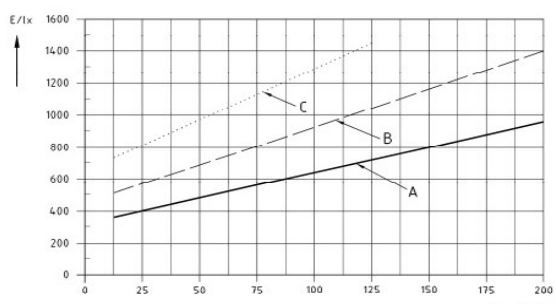
NOTE Where the reference area is not a simple shape like a rectangular football pitch, (e. g. tracks) the orientation of the vertical plane(s) facing the camera position(s) should be decided according to the general principles described in CIE Publication 67.

6.3.2 Level of vertical illuminance

The levels of vertical illuminance depend mainly upon the speed of action, the shooting distance and the lens angle.

Sports can be divided into three groups, A, B and C characterized mainly by the speed of the action occurring during camera shots and the dimension of the object. These CTV groups are defined in the list of 6.2 (see Table 4).

The knowledge of the maximum shooting distance and the CTV group, for the sport envisaged, allows the corresponding maintained vertical illuminance given in Figure 3 to be determined. This graph is not suitable for situations where slow motion recordings are regularly made. In such situation higher lighting levels are needed.



Key
A, B, C CTV groups defined in Table 4.

Figure 3 – Maintained vertical illuminance level as a function of maximum shooting distance

20

Licensed copy:PONTYPRIDD COLLEGE, 14/02/2008, Uncontrolled Copy, © BSI

Figure A.2: Lighting Recommendations for Wimbledon and French Open

Outdoor Court Lighting Information Sheet

tennis
Australia's Favourite

Introduction

Statistics show that night tennis is a major growth area in the sport, therefore a club with good lighting becomes more vibrant with increased use and revenue. Illuminated outdoor courts provide additional available hours for play for those people working during the day who have limited time available to play tennis.

The aim of a tennis court lighting installation is to control the brightness of the ball and the background against which it is viewed, so that the ball is visible, regardless of its location and speed. At the same time minimising any potential adverse effects of obtrusive and spill lighting.

With any lighting installation there are a number of considerations and conflicting interests that need to be taken into account. Interested parties range from the club, its members, local municipality, electricity supplier and neighbours. The intended standard of play is also a major consideration.

Planning permission

Many local government authorities have introduced stringent requirements in respect to obtrusive and spill lighting for sports lighting installations. Before commencing, find out what are the planning permission obligations and address these as early as possible. Special aviation and traffic spill lighting restrictions may also apply to your area.

Court lighting levels

The lighting level to be provided by the floodlighting depends on the intended standard of play.

Standard of play	Average Initial Lux level	Average Maintained Lux level *	Minimum average uniformity
Social Play	310 Lux	250 Lux	0.6
Club Competition	435 Lux	350 Lux	0.6
International	1250 Lux	1000 Lux	0.7

* after lamp burn-in and allowance for lamp depreciation and dust build-up.

Figure A.3: Lighting Recommendations for Australian Open

SP 72 : 2010

Table 3A Recommendations for Non Televised Events: Outdoor Sports
(*Clause* 6.2)

Class	Horizontal Illuminance(Lux)	Uniformity (E_{min}/E_{av})	Ra	Glare Rating
American Football , Athletics, Basketball, Cycle Racing, Equestrian Sports, Fistball, Football, Handball, Netball, Rugby and Volleyball				
I	500	0.7	>60	<50
II	200	0.6	>60	<50
III	75	0.5	>20	<55
NOTE — For Class III athletics and equestrian sports the minimum illuminance is 100 lux.				
Swimming				
I	500	0.7	>60	<50
II	300	0.7	>60	<50
III	200	0.5	>20	<55
NOTE — For diving, vertical uniformity should also be considered. Class I: 0.8 Eh/Ev. Class II: 0.5 Eh/Ev. Class III: 0.5 Eh/Ev.				
Tennis				
I	500	0.7	>60	<50
II	300	0.7	>60	<50
III	200	0.6	>20	<55
NOTE — Values refer to 'Total Playing Area' as defined by ITF.				
Baseball, Bandy, Cricket, Hockey, Ice Hockey, Ice Skating, Motorcycling and Softball				
I	750	0.7	>60	<50
II	500	0.7	>60	<50
III	300	0.7	>20	<55
Outfield for Baseball, Cricket and Softball				
I	500	0.5	>60	<50
II	300	0.5	>60	<50
III	200	0.3	>20	<55
Bobsleigh and Luge				
I	300	0.7	>60	<50
II	200	0.7	>60	<50
III	50	0.5	>20	<50
Bowls sport (Lawn, Raff and Petanque)				
I	200	0.7	>60	<50
II	100	0.7	>60	<50
III	50	0.5	>20	<55
Archery				
I,II,III	200	0.5	>60	<50
Vertical Illuminance in luxI,II,III on target	750	0.8	>60	<50
Alpine and Freestyle Skiing				
I	150	0.5	>60	<50
II	100	0.4	>20	<50
III	50	0.3	>20	<55

PART 6 EXTERIOR ILLUMINATION — SECTION 6 SPORTS LIGHTING 203

SP 72 : 2010

Table 3A (*Concluded*)

Class	Horizontal Illuminance(Lux)	Uniformity (E_{min}/E_{av})	Ra	Glare Rating
Ski Jump Landing Area				
I	300	0.7	>60	<50
II	200	0.6	>60	<50
III	200	0.6	>20	<55
NOTE — Run Down, Class I 50 lux (0.5), Class II 50 lux (0.3), Class III 20 lux (0.3)				

Table 3 B Recommendations for Non Televised Event: Indoor Sports
(*Clause* 6.2)

Class	Horizontal Illuminance(Lux)	Uniformity (E_{min}/E_{av})	Ra	Glare Rating
Aikido, Basketball, Bodybuilding, Cycle Racing, Fistball, Floorball, Football, Handball, Jujutsu, Judo, Karate, Korfball, Netball, Powerlifting, School Sports, Sumo, Taekwondo, Volleyball, Weightlifting, Wrestling, Wushu				
I	750	0.7	>60	–
II	500	0.7	>60	–
III	200	0.5	>20	–
Boxing				
I	2000	0.8	>80	–
II	1000	0.8	>80	–
III	500	0.5	>80	–
NOTE — Vertical illuminance at 1.5 m should be >50 percent of Eh.				
Athletics, Dancing, Equestrian Sports, Gymnastics, Roller Sports and Wall Climbing				
I	500	0.7	>60	–
II	300	0.6	>60	–
III	200	0.5	>20	–
NOTE — For wall climbing Class I: 500 lux vertical. Class II: 300 lux vertical. Class III: 200 lux vertical				
Swimming (Aquatic Sports)				
I	500	0.7	>60	–
II	300	0.7	>60	–
III	200	0.5	>20	–
NOTE — For diving, vertical uniformity should also be considered. Class I: 0.8 Eh/Ev. Class II: 0.5 Eh/Ev. Class III: 0.5 Eh/Ev.				
Tennis				
I	750	0.7	>60	–
II	500	0.7	>60	–
III	300	0.5	>20	–
NOTE — Values refer to 'Total Playing Area' as defined by ITF.				
Badminton, Basque Pelota, Cricket, Cricket Nets, Curling, Fencing, Hockey, Ice Hockey, Ice Skating, Racquetball, Squash and Table Tennis				
I	750	0.7	>60	–
II	500	0.7	>60	–
III	200	0.7	>20	–
NOTE — For fencing, Class I: 500 lux vertical. Class II: 300 lux vertical. Class III: 200 lux vertical. Cricket nets, Class I: 1500 lux (0.8). Class II: 1000 lux (0.8). Class III: 750 lux (0.8)				

204 NATIONAL LIGHTING CODE

Figure A.4: Lighting Recommendations of National Lighting Code,India

For televising or filming with fixed camera positions, it is sufficient to ensure that the illuminance on vertical planes at right angles to the camera position(s) are adequate in order to obtain an acceptable picture.

The orientation of the vertical planes can be indicated as the direction at right angles toward a reference point. In the case of a single camera position, the reference point is the camera position itself [*see* Fig. 1a)]. In the case of an unrestricted choice of camera positions, the vertical illuminance on planes facing all four sides of the pitch should be taken [*see* Fig 1b)].

4.3 Illuminance Uniformity

Good illuminance uniformity in the horizontal and vertical planes is important in order to avoid adaptation problems for players and spectators, and adjustment problems for cameras, respectively, for different directions of view. Moreover, if the uniformity is not good enough, there is a certain risk (especially with television cameras) that the ball or a player will not be seen clearly at certain positions on the field.

Uniformity can either be expressed as the ratio minimum-to-maximum illuminance or as the ratio minimum-to-average illuminance. For colour television lighting the ratio minimum-to-maximum is more critical, whereas the minimum-to-average ratio is usually considered for non-televised activity and lower levels of play.

4.3.1 *Vertical Illuminance Uniformity*

On planes facing a sideline bordering a main camera area or facing a fixed main camera position this should be:

$$Ev_{min}/Ev_{max} > 0.4\ ,\ Eh_{min}/Eh_{av} \geq 0.6$$

where

Ev_{min} = the minimum vertical illuminance, in lux;

Ev_{max} = the maximum vertical illuminance, in lux; and

Ev_{av} = the average vertical illuminance, in lux.

The uniformity of vertical illuminance at a single grid point over the four planes facing the sides of the playing area shall be:

$$Ev_{min}/Ev_{max} > 0.3$$

where

Ev_{min} = the minimum vertical illuminance, in lux; and

Ev_{max} = the maximum vertical illuminance, in lux.

4.3.2 *Relation between Horizontal and Vertical Illuminance*

As the illuminated field forms a major part of the field of view of the camera, an adequate horizontal illuminance is important. A sufficiently good balance between the horizontal and vertical lighting levels is obtained when the average horizontal to the average vertical illuminance (relative to each of the main camera areas or main camera positions) is such that:

$$0.5 \leq Eh_{av} / Ev_{av} \leq 2$$

where

Eh_{av} = the horizontal average illuminance, in lux; and

Ev_{av} = the vertical average illuminance, in lux.

4.3.3 *The Uniformity of the Horizontal Illuminance*

On the playing field shall be:

$$Eh_{min}/Eh_{max} \geq 0.5,\ Eh_{min}/Eh_{av} \geq 0.7$$

where

Eh_{min} = the minimum horizontal illuminance, in lux;

Eh_{max} = the maximum horizontal illuminance, in lux; and

Eh_{av} = the average horizontal illuminance, in lux.

4.3.4 *Gradient*

It is also important that there is not too great a change in horizontal illuminance over a given distance. For example, on large playing fields such as football pitches the maximum gradient of horizontal illuminance shall be not greater than 25 percent change per 5 m.

4.4 Glare Rating

Needless to say, glare has a disturbing effect on the visual comfort of both players and spectators. Glare can be minimised by paying careful attention to the aiming of the floodlights relative to the main direction of view for the sport or sports considered.

Some measures for limiting glare may be taken from CIE Publication 117-1995.

The glare rating shall be calculated for agreed observer positions and angles of view.

For viewing directions not directly toward the floodlights, study has led to a measure for the degree of glare restriction for outdoor sports floodlighting installations. The measure is dependent upon two lighting parameters:

a) the veiling luminance produced by the luminaires: L_{vl}; and

b) the veiling luminance produced by the environment: L_{ve}.

L_{ve} can be approximated from the average horizontal field illuminance Eh_{av}

L_{ve} (veiling luminance produced by the environment) $= 0{,}035 \times Eh_{av} \times \rho/\pi$, where ρ = the field reflectance.

L_{vl} (veiling luminance, produced by the luminaires)

$$= \sum_{i=1}^{n} \frac{E_{eye,i}}{\theta_i^2}$$

capacities with medium viewing distances. High level training can also be included in this class; and

c) Lighting Class III: Low level competition such as local or small club competition which generally do not involve spectators. General training, physical education (school sports) and recreational activities will also come into this category.

Table 1 Level of Competition and the Lighting Class
(*Clause* 5.2)

Sl. No.	Level of Competition	Class I	Class II	Class III
(1)	(2)	(3)	(4)	(5)
i)	International and National	x	-	-
ii)	Regional	x	x	-
iii)	Local	x	x	x
iv)	Training	-	x	x
v)	Recreational	-	-	x

5.3 Sports can be classified into three groups A, B and C characterized mainly by speed of action occurring during camera shots as stated below. This is an important parameter in determining vertical illuminances.

a) Group A : Archery, athletics, billiards, bowling, curling, darts, diving, horse jumping, shooting, snooker and swimming;

b) Group B: Badminton, baseball, basketball, bob sleigh, luge, football (soccer, American, rugby), gymnastics, handball, hockey, ice skating, judo, karate, lawn tennis, racing (motorcar, cycle, dog and horse), roller skating, ski jumping, ski racing, softball, speed skating, volleyball and wrestling; and

c) Group C: Boxing, cricket, fencing, ice hockey, lacrosse, racquetball, squash and table tennis.

5.4 Each of these groups is then subdivided into three subsections according to maximum shooting distance and vertical illuminances (in lux) recommended as given in Table 2.

Table 2 Maximum Shooting Distance
(*Clause* 5.4)

Sl. No.	Maximum Shooting Distance		25 m	75 m	150 m
(1)	(2)		(3)	(4)	(5)
i)	Group of Sport	A	500	700	1 000
ii)		B	700	1 000	1 400
iii)		C	1 000	1 400	—

5.5 Recommended vertical illuminances for various groups of play and camera shooting distance are given in Fig. 2.

6 LIGHTING RECOMENDATIONS

6.1 For non televised events, any event can be classified into the following:

a) t/r = Training and Recreational;

b) ca = Amateur Competition; and

c) cp = Professional Competition.

6.2 Recommended Average (Maintained) Minimum Illuminance for Non Televised Activity

Recommended horizontal illuminance for different level of sports activity for non televised events for outdoor and indoor sports events are given in Table 3A and Table 3B. All recommended horizontal and vertical illuminances are the average values.

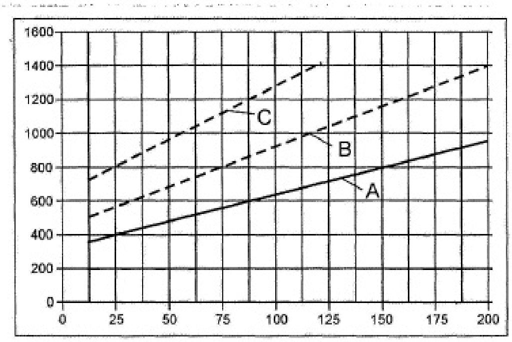


Fig. 2 Recommended Vertical Illuminances Related to Camera Shooting Distance

Figure A.5: Lighting Recommendations of National Lighting Code,India

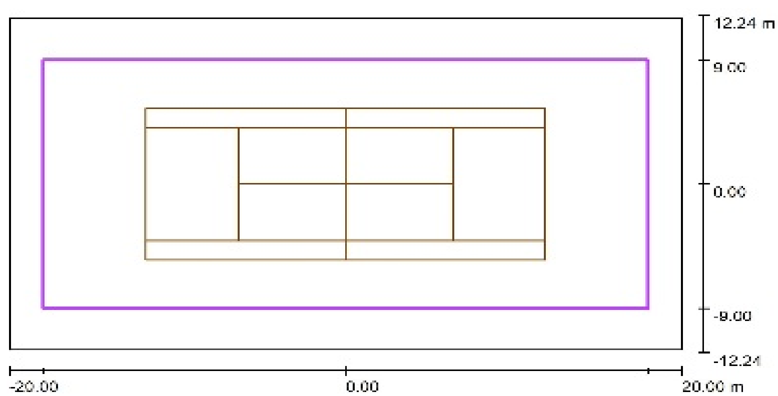
Appendix B

DIALux Simulation Results

Project 1 DIALux
25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_Class III / Tennis 1 Calculation Grid (PA) / Summary



Scale 1 : 323

Position: (0.000 m, 0.000 m, 0.000 m)
Size: (36.000 m, 18.000 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 25 x 13 Points
Belongs to the following sport arena: Tennis 1

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	247	155	312	0.63	0.50	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

Page 1

Figure B.1: Summary of Class III

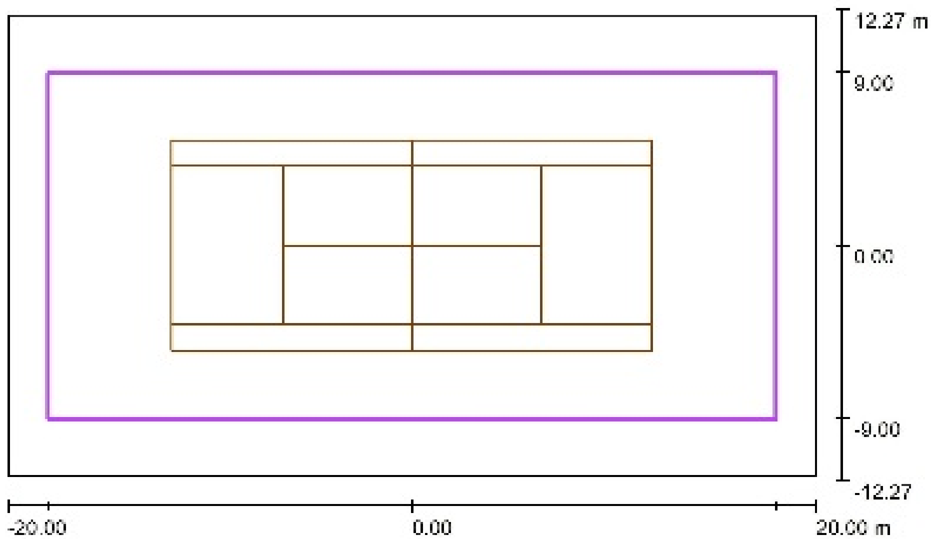
Project 1

DIALux

25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_Class II / Tennis 1 Calculation Grid (PA) / Summary



Scale 1 : 323

Position: (0.000 m, 0.000 m, 0.000 m)
Size: (36.000 m, 18.000 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 25 x 13 Points
Belongs to the following sport arena: Tennis 1

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\ m}/E_{m}$	H [m]	Camera
1	horizontal	339	249	553	0.74	0.45	/	0.000	/

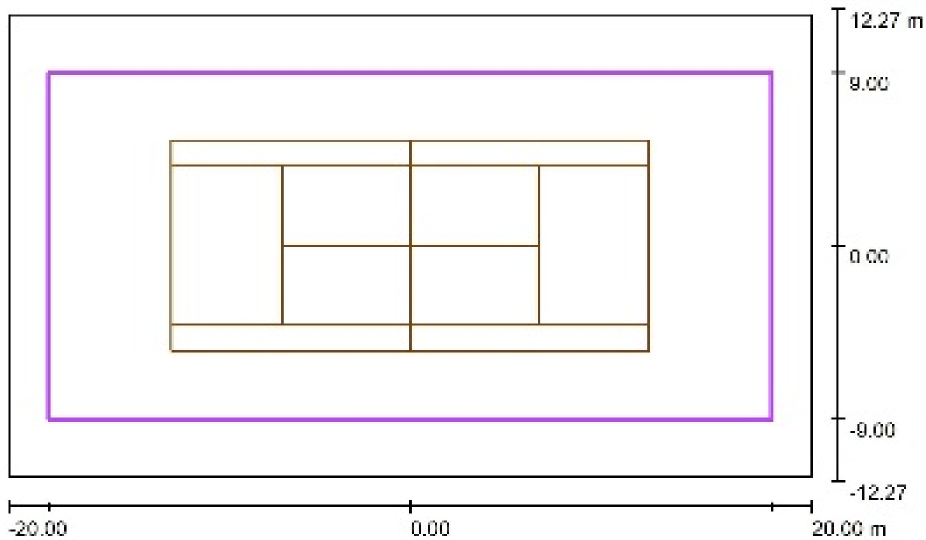
$E_{h\ m}/E_{m}$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

Page 1

Figure B.2: Summary of Class II

Operator
Telephone
Fax
e-Mail

Exterior Scene_Class I / Tennis 1 Calculation Grid (PA) / **Summary**



Scale 1 : 323

Position: (0.000 m, 0.000 m, 0.000 m)
Size: (36.000 m, 18.000 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 25 x 13 Points
Belongs to the following sport arena: Tennis 1

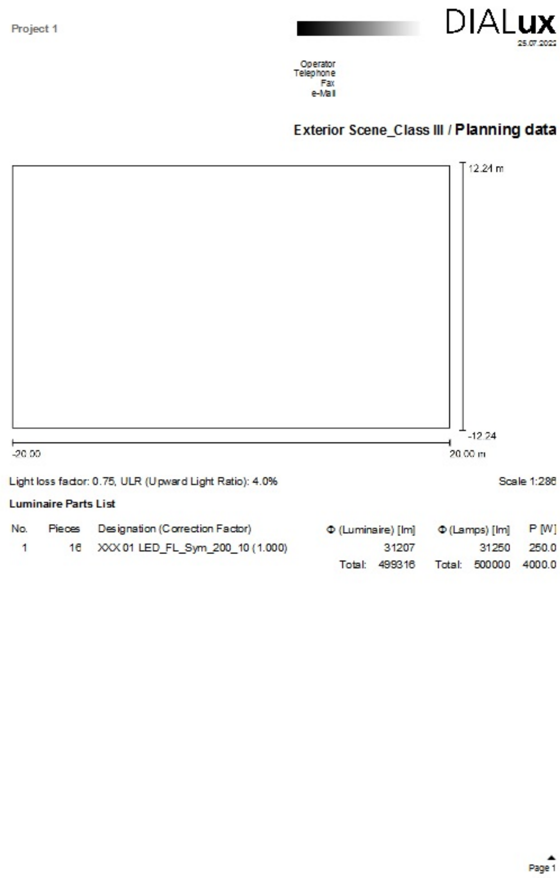
Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	503	351	772	0.70	0.45	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

Page 1

Figure B.3: Summary of Class I



Project 1

DIALux
25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_Class III / Planning data

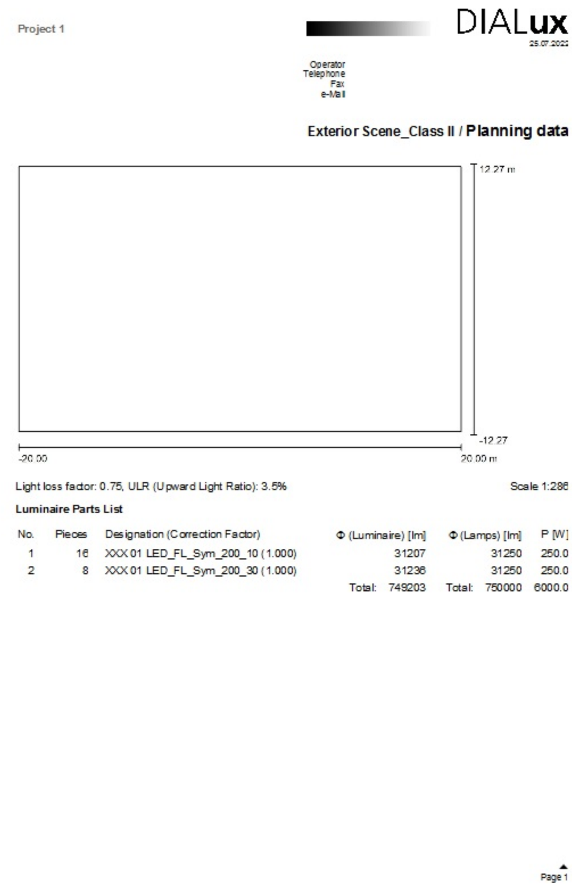
Light loss factor: 0.75, ULR (Upward Light Ratio): 4.0% Scale 1:286

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	16	XXX 01 LED_FL_Sym_200_10 (1.000)	31207	31250	250.0
			Total: 499316	Total: 500000	4000.0

Page 1

(a) Planning Data for Class III



Project 1

DIALux
25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_Class II / Planning data

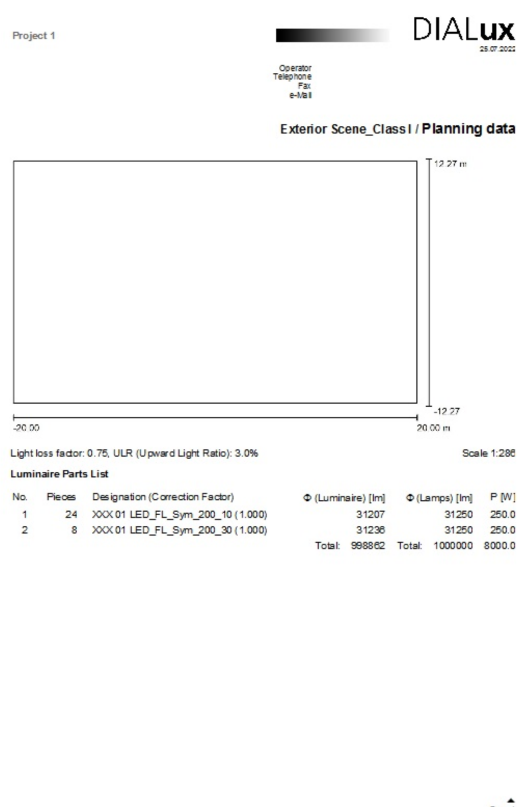
Light loss factor: 0.75, ULR (Upward Light Ratio): 3.5% Scale 1:286

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	16	XXX 01 LED_FL_Sym_200_10 (1.000)	31207	31250	250.0
2	8	XXX 01 LED_FL_Sym_200_30 (1.000)	31236	31250	250.0
			Total: 749203	Total: 750000	6000.0

Page 1

(b) Planning Data for Class II



Project 1

DIALux
25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_Class I / Planning data

Light loss factor: 0.75, ULR (Upward Light Ratio): 3.0% Scale 1:286

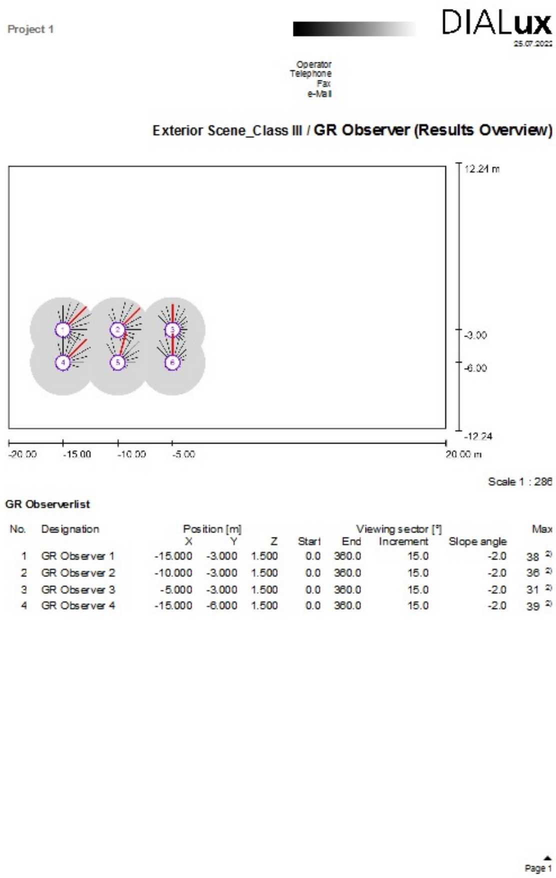
Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	24	XXX 01 LED_FL_Sym_200_10 (1.000)	31207	31250	250.0
2	8	XXX 01 LED_FL_Sym_200_30 (1.000)	31236	31250	250.0
			Total: 998862	Total: 1000000	8000.0

Page 1

(c) Planning Data for Class I

Figure B.4: Planning Data for Non-televised Events


Project 1

DIALux 25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_Class III / **GR Observer (Results Overview)**

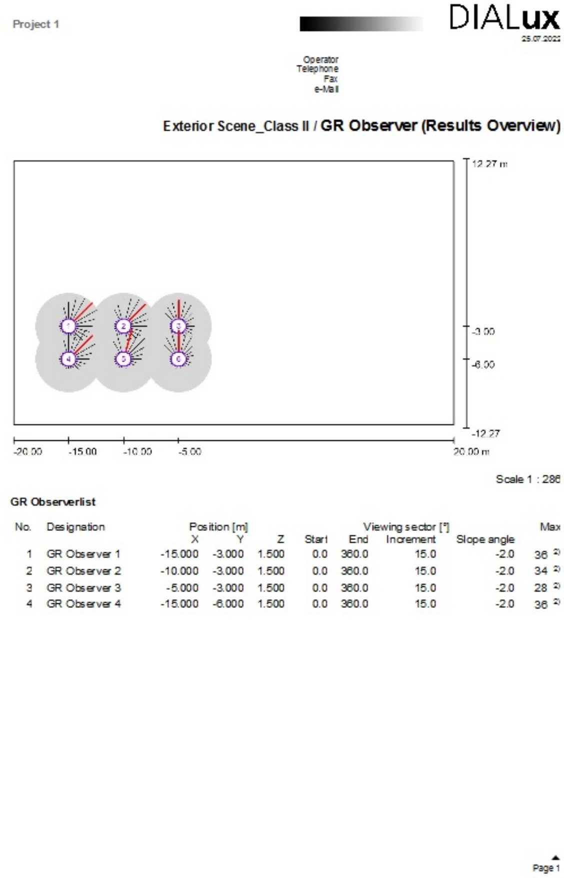
Scale 1 : 286

GR Observerlist

No.	Designation	Position [m] X	Y	Z	Viewing sector [°] Start	End	Increment	Slope angle	Max
1	GR Observer 1	-15.000	-3.000	1.500	0.0	360.0	15.0	-2.0	38 [2)]
2	GR Observer 2	-10.000	-3.000	1.500	0.0	360.0	15.0	-2.0	36 [2)]
3	GR Observer 3	-5.000	-3.000	1.500	0.0	360.0	15.0	-2.0	31 [2)]
4	GR Observer 4	-15.000	-6.000	1.500	0.0	360.0	15.0	-2.0	39 [2)]

Page 1

(a) GR Summary for Class III


Project 1

DIALux 25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_Class II / **GR Observer (Results Overview)**

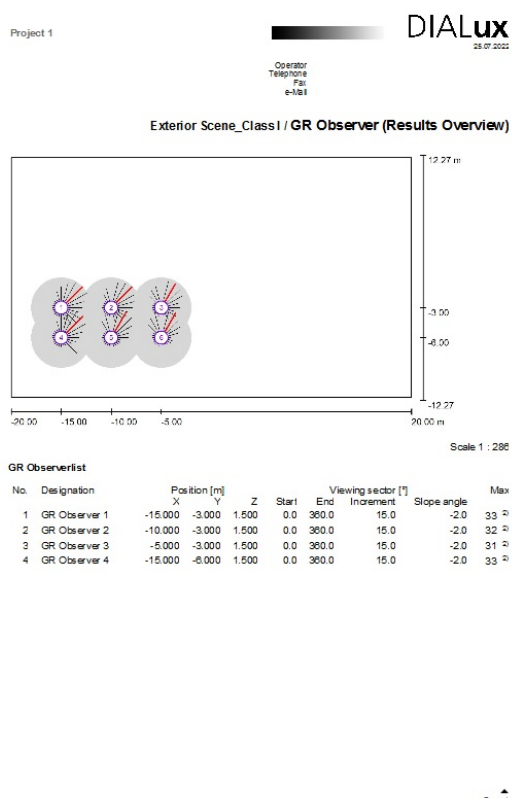
Scale 1 : 286

GR Observerlist

No.	Designation	Position [m] X	Y	Z	Viewing sector [°] Start	End	Increment	Slope angle	Max
1	GR Observer 1	-15.000	-3.000	1.500	0.0	360.0	15.0	-2.0	36 [2)]
2	GR Observer 2	-10.000	-3.000	1.500	0.0	360.0	15.0	-2.0	34 [2)]
3	GR Observer 3	-5.000	-3.000	1.500	0.0	360.0	15.0	-2.0	28 [2)]
4	GR Observer 4	-15.000	-6.000	1.500	0.0	360.0	15.0	-2.0	36 [2)]

Page 1

(b) GR Summary for Class II


Project 1

DIALux 25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_Class I / **GR Observer (Results Overview)**

Scale 1 : 286

GR Observerlist

No.	Designation	Position [m] X	Y	Z	Viewing sector [°] Start	End	Increment	Slope angle	Max
1	GR Observer 1	-15.000	-3.000	1.500	0.0	360.0	15.0	-2.0	33 [2)]
2	GR Observer 2	-10.000	-3.000	1.500	0.0	360.0	15.0	-2.0	32 [2)]
3	GR Observer 3	-5.000	-3.000	1.500	0.0	360.0	15.0	-2.0	31 [2)]
4	GR Observer 4	-15.000	-6.000	1.500	0.0	360.0	15.0	-2.0	33 [2)]

Page 1

(c) GR Summary for Class I

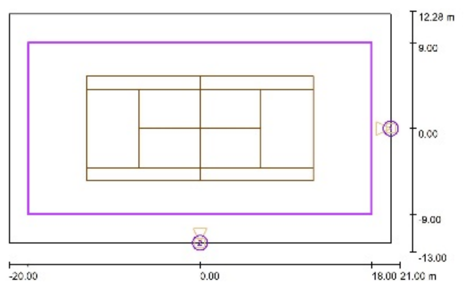
Figure B.5: GR Summary for Non-televised Events

Project 1

DIALux
25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_TELEVISED / Tennis 1 Calculation Grid (PA) / Summary



Scale 1 : 331

Position: (0.000 m, 0.000 m, 0.000 m)
Size: (36.000 m, 18.000 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 25 x 13 Points
Belongs to the following sport arena: Tennis 1

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	1364	1041	1579	0.76	0.66	/	0.000	/
2	Camera	1007	690	1689	0.69	0.41	1.35	1.000	1
3	Camera	1045	498	1464	0.48	0.34	1.31	1.000	2

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

Page 1

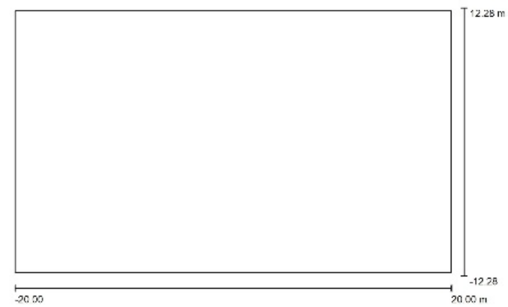
(a) Summary for Televised Events

Project 1

DIALux
25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_TELEVISED / Planning data



Light loss factor: 0.80, ULR (Upward Light Ratio): 3.5%

Scale 1:286

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)		Φ (Luminaire) [lm]		Φ (Lamps) [lm]	P [W]
1	48	XXX 01 LED_FL_Sym_200_10 (1.000)		31207		31250	250.0
2	32	XXX 01 LED_FL_Sym_200_30 (1.000)		31236		31250	250.0
			Total:	2497497	Total:	2500000	20000.0

Page 1

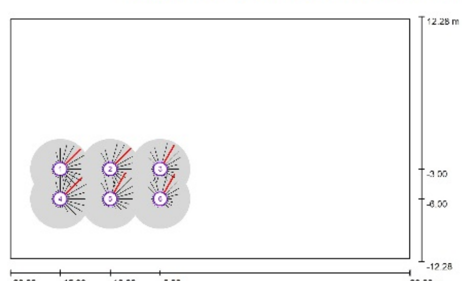
(b) Planning Data for Televised Events

Project 1

DIALux
25.07.2022

Operator
Telephone
Fax
e-Mail

Exterior Scene_TELEVISED / GR Observer (Results Overview)



Scale 1 : 286

GR Observerlist

No.	Designation	Position [m]			Viewing sector [°]				Max
		X	Y	Z	Start	End	Increment	Slope angle	
1	GR Observer 1	-15.000	-3.000	1.500	0.0	360.0	15.0	-2.0	33 [2)]
2	GR Observer 2	-10.000	-3.000	1.500	0.0	360.0	15.0	-2.0	34 [2)]
3	GR Observer 3	-5.000	-3.000	1.500	0.0	360.0	15.0	-2.0	32 [2)]
4	GR Observer 4	-15.000	-6.000	1.500	0.0	360.0	15.0	-2.0	35 [2)]

Page 1

(c) GR Summary for Televised Events

Figure B.6: Simulation Results for Televised Events

Appendix C

Factors Related to Cable Voltage Drop Calculation

EEP | ELECTRICAL ENGINEERING PORTAL   Home   Premium Membership

Temperature Correction Factor (K1) When Cable is in the Air

Temperature Correction Factor in Air: K1		
Ambient Temperature	Insulation	
	PVC	XLPE/EPR
10	1.22	1.15
15	1.17	1.12
20	1.12	1.08
25	1.06	1.04
35	0.94	0.96
40	0.87	0.91
45	0.79	0.87
50	0.71	0.82
55	0.61	0.76
60	0.5	0.71
65	0	0.65
70	0	0.58
75	0	0.5
80	0	0.41

Figure C.1: Temperature Correction Factor(Air)

Ground Temperature Correction Factor (K2)

Ground Temperature Correction Factor: K2		
Ground Temperature	Insulation	
	PVC	XLPE/EPR
10	1.1	1.07
15	1.05	1.04
20	0.95	0.96
25	0.89	0.93
35	0.77	0.89
40	0.71	0.85
45	0.63	0.8
50	0.55	0.76
55	0.45	0.71
60	0	0.65
65	0	0.6
70	0	0.53
75	0	0.46
80	0	0.38

Figure C.2: Temperature Correction Factor(Ground)

Thermal Resistance Correction Factor (K4) for Soil (When Thermal Resistance of Soil is known)

Soil Thermal Resistivity: 2.5 KM/W	
Resistivity	K3
1	1.18
1.5	1.1
2	1.05
2.5	1
3	0.96

Soil Correction Factor (K4) of Soil (When Thermal Resistance of Soil is not known)

Nature of Soil	K3
Very Wet Soil	1.21
Wet Soil	1.13
Damp Soil	1.05
Dry Soil	1
Very Dry Soil	0.86

Cable Depth Correction Factor (K5)

Laying Depth (Meter)	Rating Factor
0.5	1.1
0.7	1.05
0.9	1.01
1	1
1.2	0.98
1.5	0.96

Figure C.3: Thermal Resistance Correction Factor, Soil Correction Factor, Cable Depth Correction Factor

Cable Distance correction Factor (K6)

No of Circuit	Nil	Cable diameter	0.125m	0.25m	0.5m
1	1	1	1	1	1
2	0.75	0.8	0.85	0.9	0.9
3	0.65	0.7	0.75	0.8	0.85
4	0.6	0.6	0.7	0.75	0.8
5	0.55	0.55	0.65	0.7	0.8
6	0.5	0.55	0.6	0.7	0.8

Cable Grouping Factor (No of Tray Factor) (K7)

No of Cable/Tray	1	2	3	4	6	8
1	1	1	1	1	1	1
2	0.84	0.8	0.78	0.77	0.76	0.75
3	0.8	0.76	0.74	0.73	0.72	0.71
4	0.78	0.74	0.72	0.71	0.7	0.69
5	0.77	0.73	0.7	0.69	0.68	0.67
6	0.75	0.71	0.7	0.68	0.68	0.66
7	0.74	0.69	0.675	0.66	0.66	0.64
8	0.73	0.69	0.68	0.67	0.66	0.64

Figure C.4: Cable Distance Correction Factor, Cable Grouping Factor

Acronyms

BIS Bureau of Indian Standards. 9, 29

BOQ Bill of Quantity. 57

BS EN British Standards European Norm. 27

CB Circuit Breaker. 53

CCT Correlated Colour Temperature. 31

CIE International Commission on Illumination. 8, 15, 16

CT Current Transformer. 46

DB Distribution Board. 43, 46, 47, 49, 50, 54, 55

EBU European Broadcasting Union. 16

FPMCCB Four Pole Molded Case Circuit Breaker. 44, 46

HT High Tension. 47, 52

IEC International Electrotechnical Commission. 53

IES Illuminating Engineering Society. 28

IMM Integrated Maintenance Management. 42

ITF International Tennis Federation. 2, 4, 26, 27, 31, 61

LED Light Emitting Diode. 9, 25, 33, 36, 44

LT Low Tension. 47

MB Medium Beam. 37

MCCB Molded Case Circuit Breaker. 50, 53, 54

MLDB Main Lighting Distribution Board. 43, 44, 46, 47, 49, 50

NB Narrow Beam. 37

NLC National Lighting Code. 4, 9–11, 14, 17, 29–33, 35, 38, 40, 64, 65

OCTC Off Circuit Tap Changer. 53

ONAN Oil Natural Air Natural. 53

PA Playing Area. 33

PPA Principal Playing Area. 17, 33

PVC Polyvinyl chloride. 44, 52

SCADA Supervisory Control and Data Acquisition. 59

SLD Single Line Diagram. 4, 42–45

SLDB Sub-Lighting Distribution Board. 43, 46, 47, 49, 50, 54

TLCI Television Lighting Consistency Index. 16

TPA Total Playing Area. 17, 33

ULOR Upward Light Output Ratio. 38

ULR Upward Light Ratio. 6, 38

UPS Uninterrupted Power Supply. 43, 47

USTA United States Tennis Association. 28

WB Wide Beam. 37

XLPE Cross Linked Polyethylene. 51, 52