UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUTE OF SCIENCE AND TECHNOLOGY

ON THE UTILIZATION OF SOLAR ENERGY IN TRAINS

MASTER THESIS

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Electrical and Electronics Engineering Department

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Supervisor: Assist. Prof. Dr. Ibrahim MAHARIQ

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University of Turkish Aeronautical Association Institute of Science and Technology's No.1406030052 Master Degree student, ZELİHA KIRILMIŞ ÖZTÜRKTEN as required by the relevant regulations after having met all the conditions prepared ON THE UTILIZATION OF SOLAR ENERGY IN TRAINS thesis, was presented with the success to the jury of the signatures below.

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April 2018 ZELİHA KIRILMIŞ ÖZTÜRKTEN

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

P_{MAX}	:	Nominal Power
V_{oc}	:	Open-Circuit Voltage
I_{sc}	:	Short-Circuit Current
W_p		Peak Power

Abbreviations

AC	:	Alternating Current
AM	:	Air Mass
AU	:	Astronomical Unit
CPV	:	Concentrator PV
c-Si	:	Crystalline Silicon
DC	:	Direct Current
ECP	:	Electric Collection Panel
GaAs	:	Gallium Arsenide
IMPPT	:	MPPT Current
MJ	:	Multi Junction
MPP	:	Maximum Power Point
MPPT	:	Maximum Power Point Tracking
NOCT	:	Nominal Operating Cell Temperature
PID	:	Potential Induced Degradation
PV	:	Photovoltaic
STC	:	Standard Test Conditions
TSI	:	Total Solar Irradiance

ABSTRACT

ON THE UTILIZATION OF SOLAR ENERGY IN TRAINS

KIRILMIŞ ÖZTÜRKTEN Zeliha
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It is an undeniable fact that the solar energy has many advantages. Some of them are non-polluting, low maintenance, easy installation and long lasting. Therefore, it provides huge benefits to use them on the trains. Also its price-cost margin would be high and the cost of consumed electrical energy is reduced. This research will create a model that is possible useful formation. The model to be presented in this thesis will decrease the electricity absorbed from grid in the electrically excited trains, decrease the carbon dioxide emission thanks to the renewable energy usage. The results of this thesis will present promising results in terms of economy and environment.

Key words: Solar Energy, Photovoltaic Systems, Electric Train, Renewable Energy

ÖZET

TRENLERDE GÜNEŞ ENERJİSİ KULLANIMI

KIRILMIŞ ÖZTÜRKTEN, Zeliha
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Güneş enerjisinin pek çok avantajı olduğu yadsınamaz bir gerçektir. Bunlardan bazıları kirliliğe sebep olmaması, azbakım, kolay kurulum ve uzun ömürlü olmasıdır. Bu nedenle, trenlerde bunları kullanmak büyük bir avantaj sağlar. Ayrıca fiyat- maliyet marjı yüksek olması ve tüketilen elektrik enerjisi maliyetinin az olmasıdır. Bu araştırma olası yararlı bir model oluşturacaktır. Bu tez ile sunulan model ile elektrikli trenlerin şebekeden çekeceği güç azaltılacak, böylece yenilebilir enerji kullanımı sayesinde karbon dioksit salınımı azaltılacaktır. Bu tezin sonuçları ekonomik ve çevresel açıdan ümit verici sonuçlar ortaya koyacaktır.

Anahtar Kelimeler: Güneş Enerjisi, Fotovoltaik Sistemler, Elektrikli Trenler, Yenilenebilir Enerji

CHAPTER ONE

INTRODUCTION

Energy is the foundation of our civilization. The need for energy has been one of the main problems of mankind since centuries. In the last period when the fossil fuels are running out, the world of science has searched for new energy sources. Among these sources, solar energy is one of the most important renewable energy sources [1]. Because the power of the solar world is $8x10^{11}$ MW is an enormous amount of energy, which is now a few thousands of the current energy consumed worldwide [2]. Recent advances in semiconductor technology and power electronics have increased photovoltaic (PV) photovoltaic energies in electric power applications [3].

One other advantage of the renewable sources is that it generates power without any fuel cost. In other words, the solar radiation or wind are free of charge. It results in cheaper energy generation compared to conventional generation sources such as thermal power plants. Therefore, renewable energy systems are primarily preferred in the economical dispatch. This is why renewable energy systems are supported by both governments and the investors. The return of the investment in the renewable energy systems is quite remarkable. As a result, huge percentage of the newly installed energy sources are renewable energy systems.

The most common type of solar energy is photovoltaic systems. Solar PV systems has constituted 47% of the newly installed renewable capacity in 2016 [1]. Solar PV systems is one of the most promising renewable type and its increase is expected to increase more and more in the upcoming future.

Nonetheless, only an infinitesimal portion of the available solar energy is being utilized today. Utilizing this solar potential would definitely bring financial benefits.

On the global front, creating the use of solar energy seems to be one of the best options available. The change in the climate world over is a serious threat to our planet which is causing much of the problems. The emission levels of carbon dioxide that we generate by the constant use of fossil fuel are literally killing our planet.

The usage of solar energy will not only provide people a clean environment, but also a life where there is no need to worry about the earth due to reduction in resources.

Therefore, the main purpose of this thesis is supplying the train electricity from solar systems such that the cost is reduced, the electricity of the train is yielded from renewable energy. In this way, the carbon dioxide emission is decreased, trains are supplied from environmental friendly source. Of course, it is not possible to supply all of the train power from the solar panels that is mounted on the train, but the implementation will definitely decrease the cost and the emission.

This thesis is organized as follows. In Chapter 2, the literature review is given. The previous studies in this subject is listed and example implementations are presented. In Chapter 3, the materials and methods of this thesis is given. The Solar PV System materials are given as well as the railway equipment. The methods used in The Solar PV system is also presented. In Chapter 4, Applications is located. The Electrical Project Drawings and Electrical Equıpment's Calculatıons of this project used in The Solar PV System. In Chapter 5, Results and Discussion of the Solar PV panel placement on top of a suburban railway train is presented.

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CHAPTER TWO

LITERATURE REVIEW

Photovoltaic technology which transforms the solar energy to a usable type of electrical energy has not been widely applied to railway carriages yet. Utilizing PV systems on railways can significantly reduce the carbon dioxide emissions. Note that for each kWh of energy produced by supercritical coal fired plant, 750-800 g carbon dioxide is emitted meanwhile this value can be reduced to 98-167g if the energy is obtained from PV systems [2]. Another advantage of such utilization is related to the accumulator lifespan. Suspension of the energy supply sets off the accumulators which continually recharge when run down. In a photovoltaic system, however, accumulators are kept continually charged by solar energy and, as a result, are subject to less damage. Hence, applying photovoltaic modules to rolling-stock also has huge potential to extend the life of the accumulators existing in the electrical trains. Therefore, it can be concluded that the dangerous wastes are decreased by increasing the lifespan of the accumulators.

According to the Paris Agreement on climate change, India has been forced to reduce emissions by 33-35% by 2030 from the 2005 levels. Therefore, India has set a target of 40% non fossil-based energy generation for 2030. In order to achieve such decarbonization and meeting 2030 goals, India has decided to utilize photovoltaic systems on top of the trains since the Indian Railways is the largest electricity consumer in the India. Therefore, such utilization can result in more practical results in the decarbonization process. Note that in this plan, the trains will still be pulled by diesel engines meanwhile the generated electricity will be used inside the train is order to supply power for lighting and fans. Moreover, India having huge solar power makes this utilization as more feasible and cost-effective. In this way, Indian Railways can decrease the fuel bill of the trains which is the second largest component of the expenses after the salaries of employees. Solar Photovoltaic system sample application is given in Fig. 2.1.

Figure 2.1: Solar photovoltaic system sample application of Indian railways [Singh, K. (2017].

Kebede (2015) made by the “Design of Hybrid Solar Energy System for The Application of Train Locomotive Power Source for The AALRT and Ethio-Djibouti Routs”, the use of hybrid solar energy as a power source for train locomotives has been investigated. The use of diesel or electric energy to get the thrust of the trains affects the pollution outside the fuel price. Solar energy is important in terms of being environmentally friendly and sustainable energy. The aim of the study is to examine the transfer of electric energy to the power transmission system of locomotives with photovoltaic solar panels. In the study, the application of solar energy to railway locomotive powertrain system, a system for the storage of energy from solar panels is analysed. Focusing on a supplementary energy source to a newly established railway system in Ethiopia, 5-year-old daily energy and radiation data of the route to be studied are examined to maximize the use of solar resources. YZ25G, DFN7G and AALRT models were chosen for the solar panels to be placed in the upper roof surface areas of the locomotives. It is estimated that the energy produced covers the range of 4.455% - 356.9% of the required energy depending on the sundial time, vehicle type and configuration. The excess energy is sent to the main network. According to the cost calculation based on the minimum energy production and the maximum configuration, the average return of the cost has reached the result that can be around 12 years [4].

Kameya, Suzuki and Katsuma (2012), “The Solar Light Rail” a solar power system is installed on the roof of the locomotives to provide a suitable electricity supply system for public transportation. The researchers built wind turbines and waterwheels around the stations. Electric double layer capacitors (EDLCs) were installed on wagons and stations with renewable energy. When the EDLC of the wagons in the train stations, the stations of the EDLC is charged quickly. Researchers estimated that 2.5 kg per kilometer of light rail vehicles kWh electricity consumption. 500 m between stations. It is necessary for the train to reach the next station 1.3 kWh energy requirement is calculated as the train arrives every 10 minutes and the energy production capacity of 99,000 kWh per station is calculated over the data that the trains run for 18 hours per day [5].

Karthikeyan, Nandhagopal, Rajakumar that, Sowndhari and Vimalraj (2017) made "Operation and Control of Hybrid Train Using Renewable Energy" a vital measure of renewable energy, indicating that the combination of wind and solar energy without harming the environment can be used sustainable energy sources are emphasized. The researchers worked on a system involving the integration of wind and solar energy. Solar panels and wind turbines are used in the system. The produced energy is running the train. With this method, the power consumption of electric trains can be reduced, resulting in higher efficiency than ordinary electric trains due to the use of renewable energy. It is important that the initial cost is high, but it does not lead to environmental pollution and it amasses the investment cost over time. It is stated that the use of this method will reduce the passenger ticket fees and save electricity for the future [6].

Vasisht, Vishal, Srinivasan and Ramasesha (2014) structured by "Solar Photovoltaic Assistance for LHB Rail Coaches" made from Vasisht, Vishal, Srinivasan and Ramasesha (2014) on the train wagons on the work solar photovoltaic feasibility of installing modules is assessed. The supportability of diesel generator sets powered by solar panel modules mounted on roofs of cars is reported in the study. The study results show that this method leads to a significant reduction in carbon dioxide emissions as well as fuel savings. A standard route was used as a reference in calculations. The price per liter of diesel fuel is assumed to be 66 Rupees and it is calculated that the annual saving will be 5,900,000 Rupees. As a result of the calculations made on the installation costs, the installation costs of the solar panel modules have reached the result that they will be amortized between 2 and 3 years. In addition, if solar panels are used in trains, annual emission of 239 tons of carbon dioxide will be reduced [7].

Vasisht, Vashista, Srinivasan and Ramasesha (2017) structured by “Rail coaches with rooftop solar photovoltaic systems: A feasibility study” is made by Vasisht, Vashista , Srinivasan and Ramasesha (2017) the solar photovoltaic mounted on the roof of the wagons of the Indian Railways the performance of the modules has been examined. The focus of the study was to measure the reduction of diesel consumption by using solar panels in the latest generation systems that power the electric charge in the new generation of wagons. Two flexible solar photovoltaics for research module, operated at a speed of 120 km / h, predicted the benefits of using solar panels on the basis of experimental results. Solar system with at least 18 kWh of electricity to be produced, it has been calculated, resulting in a 1700 liters diesel savings. Based on the total number of trains in India, the annual diesel fuel savings under ideal conditions were found to be 108.5 million liters. Researchers suggest that these results will be an important contribution to controlling environmental pollution and that annual carbon dioxide emissions will decline by 2.9 million tonnes [8].

Patel and Thu (2017) made the “Design of Solar-Powered Tram No.86 and I reliable to Solar Power Supply Line FR Its Operation in Victoria”, the advantages of the existing electric tram system between Bundoora and Waterfront City in Australia were investigated in case of conversion to solar-powered system. As a result of the research, it was determined that if the solar energy system is installed, enough electric power will be supplied, the system will have zero effect on greenhouse gas emissions and will reduce travel costs [9].

Jaffery et al. (2014) “The potential of solar powered the transportation and the casa for solar powered railway in Pakistan” was aimed at developing a solar-powered railway transportation system in Pakistan. For this purpose, the solar energy of the country has been evaluated. In the study, the solar panels mounted on the trains and the station equipment storing the solar energy and allowing the incoming train to be charged were researched. In the proposed system, a regenerative braking system based on gravity is to be used, for which stations are supposed to be built on a platform with commercial centers underneath [10].

Kameya et al. (2014) “Demonstration Experiment for Energy Storage and Rapid Charge System for the Solar Light Rail”, a rechargeable system is proposed. In the system, which can be used as a sustainable model in railway transportation, the stations are loaded with 17.6 V - 171.4 F electric double layer capacitor (EDLC) unit with solar panels. There are also EDLC units of 15.9 V - 100 F mounted on wagons. This is a fast charge [11].

Feria, M. and Sequeira, J. (2012) “Decision and Control System of a Solar Powered Train”, a control system designed and simulated for a solar powered train. An intelligent control approach aimed at managing energy consumption in the workplace has been followed. The researchers suggest that trains always reach their target with the proposed control system, so that energy stress will cease to exist. In the proposed system, all the energy production (solar panels, batteries) and consuming devices (sensors, calculation tools, etc.) are controlled in the proposed system and the topology, length, slope, location of intermediate stations, train dynamics, current solar radiation, weather forecast, train speed profile information such as passenger weight is used as an input to determine the boundaries on it [12].

CHAPTER THREE

MATERIALS AND METHODS

In this thesis study, it is expected to use information about solar cells, PV panels which are already owned in laboratory. In order to accomplish to the aim of pilot device, its procedure should be theoretically explained and results for PV panel usage for trains should be simulated and then the capacity of the offered photovoltaic energy to specify the most favourable energy supply-consumption should be evaluated. In this way, it is possible to diminish the costs of electrical energy used up by electrically excited trains from the electric system.

3.1. Solar Cell

The electrical device that transforms the energy captured from solar radiation into direct electricity with photovoltaic effect, a physical and chemical phenomenon, is called solar cell, or photovoltaic cell. A photoelectric cell can be defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when it is exposed to light. The smallest portion that can generate electricity is called as solar cell meanwhile the combining some defined numbers of cells constitutes solar panels. A monocrystalline solar cell is given in Fig. 3.1.

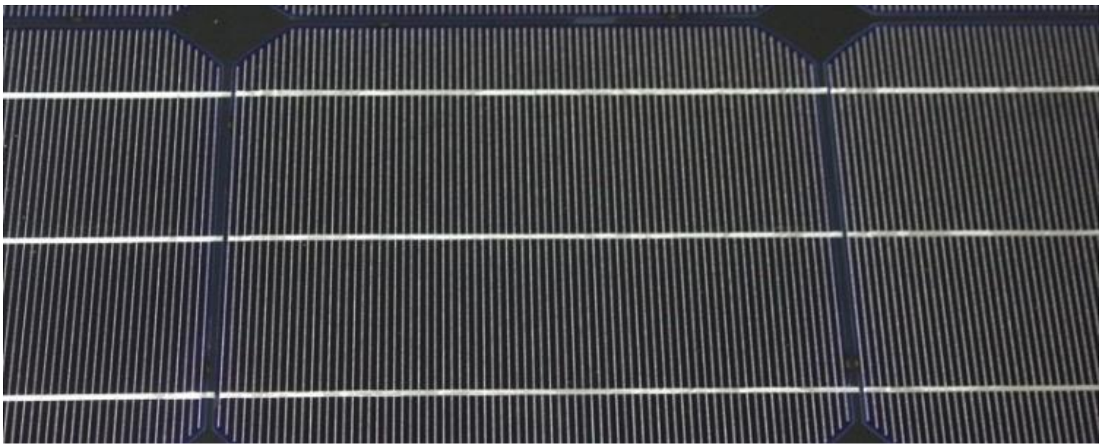


Figure 3.1: Monocrystalline solar cell (3 Bus) [13].

Due to the fact that they operate under bare sun shine or artificial light, they are called as 'photovoltaic'. It is possible to use them as photo detector in order to detect the light or any other radiation in a near area or to measure the light intensity.

The successful operation of a solar cell starts with the absorption of the light. There is a thin wafer layer inside the solar cells whose main goal is to produce an electric field inside the cell. Inside the electric field, electrons can be captured from the atoms of the semiconductor and swept inside the electrical field. These electrons form an electric current by circulating the current path.

In the other form of solar power generation, solar energy heat collector is used in order to produce heat from the solar power. That heat is then used to generate electricity similar to the steam turbines.

3.2. Photovoltaic Panel

Solar panels are devices that can generate power by absorbing the sun light. They are generally made of combination of the solar cells. They consist of either 60 (6*10) or 72 (6*12) solar cells. There are three main types of solar photovoltaic panels namely Monocrystalline, Polycrystalline and Thin Film. Monocrystalline type solar panels high efficiency due to the fact that its material is mainly highest-grade silicon. However, its operation is highly dependent on the temperature. Polycrystalline photovoltaic panels, on the other hand, are cost easy to produce and their cost is less than that of monocrystalline. Moreover, temperature changes do not affect the operation of polycrystalline panels compared to monocrystalline panels. A monocrystalline PV panel is shown in Fig. 3.2.

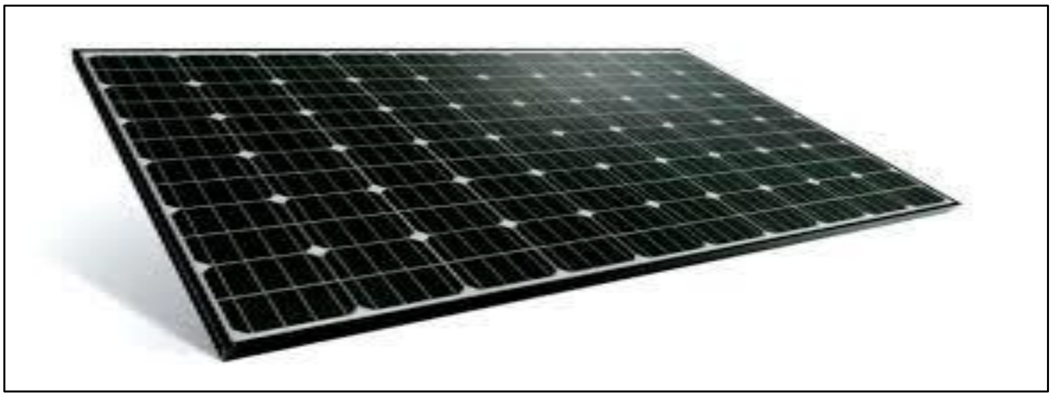


Figure 3.2: 60 cell monocrystalline solar photovoltaic panel [14].

A PV module is generally composed of 60 solar cells. A solar array is composed of the series connection of these PV modules. They are used in commercial and residential applications. The power of the module is determined by its DC output power according to the test conditions. These power range is between 100-320 Watts. For the same power output, efficiency of the module will determine the area of the module. In other words, 230 W module with efficiency of 8% would cover twice area that of the module with 16% efficiency. Now, commercial panel efficiencies have exceeded 20% efficiency.

A sample datasheet is given for a monocrystalline panel in Fig. 3.2.

Photovoltaic panels with our cutting-edge PANDA technology wake up earlier than regular PV modules and go to sleep later, thereby working harder to generate more energy, especially during mornings, evenings and winter months.

- Low Light Performance: PANDA technology is highly sensitive to photons (light energy), hence it continues to produce energy even at low light levels. The result is a higher yield from your system.
- High Power Density: PANDA technology has a higher efficiency than other technologies, so PANDA modules make the best out of each m^2
- Durable: Durable PV modules, independently tested for harsh environmental conditions such as exposure to salt mist, ammonia or known PID risk factors.
- PID Resistant: Tested in accordance to the draft standard IEC 62804, our PV modules have demonstrated resistance against PID (Potential Induced Degradation), which translates to security for your investment.
- Properties:
  - Cell Efficiency: 19.8%.
  - Product Warranty: 10 years.
  - Power Tolerance: 0 / +5 W
  - Linear Performance Warranty: 25 years.

The Electrical Performance values of 60 Cell Monocrystalline Solar PV Panel are given in Table 3.1.

Table 3.1: Electrical performance [14].

Electrical parameters at Standard Test Conditions (STC)							
Module type			YLxxxCG2530L-1 (xxx=P_{max})				
Power output	P_{max}	W	280	275	270	265	260
Power output tolerance	ΔP_{max}	W	0 / + 5				
Module efficiency	η_m	%	17.2	16.9	16.6	16.3	16.0
Voltage at P_{max}	V_{mpp}	V	31.3	30.9	30.5	30.1	29.7
Current at P_{max}	I_{mpp}	A	8.96	8.91	8.85	8.79	8.74
Open-circuit voltage	V_{oc}	V	39.1	38.8	38.6	38.3	38.1
Short-circuit current	I_{sc}	A	9.50	9.47	9.43	9.37	9.35
Electrical parameters at Nominal Operating Cell Temperature (NOCT)							
Power output	P_{max}	W	204.2	200.6	196.9	193.3	189.7
Voltage at P_{max}	V_{mpp}	V	28.5	28.1	27.8	27.5	27.1
Current at P_{max}	I_{mpp}	A	7.17	7.13	7.08	7.03	6.99
Open-circuit voltage	V_{oc}	V	36.2	35.9	35.7	35.4	35.3
Short-circuit current	I_{sc}	A	7.66	7.64	7.61	7.56	7.54

STC: 1000W/m^2 irradiance, 25°C cell temperature, AM1.5 spectrum according to EN 60904-3. Average relative efficiency reduction of 1.9% at 200W/^{m2} according to EN 60904-1.
NOCT: Open-circuit module operation temperature at 800W/m^2 irradiance, 20°C ambient temperature, 1m/s wind speed

The Thermal Characteristics values of 60 Cell Monocrystalline Solar PV Panel are given in Table 3.2

Table 3.2: Thermal characteristics [14].

Thermal Characteristics			
Nominal operating cell temperature	**NOCT**	**°C**	**46 + / - 2**
Temperature coefficient of P_{max}	γ	%/°C	-0.42
Temperature coefficient of V_{oc}	β_{Voc}	%/°C	-0.30
Temperature coefficient of I_{sc}	α_{Isc}	%/°C	0.04
Temperature coefficient of V_{mpp}	β_{Vmpp}	%/°C	-0.40

The Operating Conditions values of 60 Cell Monocrystalline Solar PV Panel are given in Table 3.3.

Table 3.3: Operating conditions [14].

Operating Conditions	
Max. system voltage	$1000V_{DC}$
Max. series fuse rating	15A
Limiting reverse current	15A
Operating temperature range	-40°C to 85°C
Max. static load, front (e.g., snow)	5400 Pa
Max. static load, back (e.g., wind)	2400 Pa
Max. hailstone impact (diameter / velocity)	25mm / 23m/s

The General Characteristics values of 60 Cell Monocrystalline Solar PV Panel in Table 3.4.

Table 3.4: General characteristics [14].

General Characteristics	
Dimensions (L / W / H)	1640 mm / 990 mm / 40 mm
Weight	18.5 kg

The Packaging Specifications for 60 Cell Monocrystalline Solar PV Panel are given in Table 3.5.

Table 3.5: Packaging specifications [14].

Packaging Specifications	
Number of modules per pallet	26
Number of pallets per 40' container	28
Packaging pallets dimensions (L / W / H)	1700 mm / 1160mm / 1165 mm
Box weight	514 kg

60 Cell Monocrystalline Solar PV Panel diagram is given in Fig. 3.3.

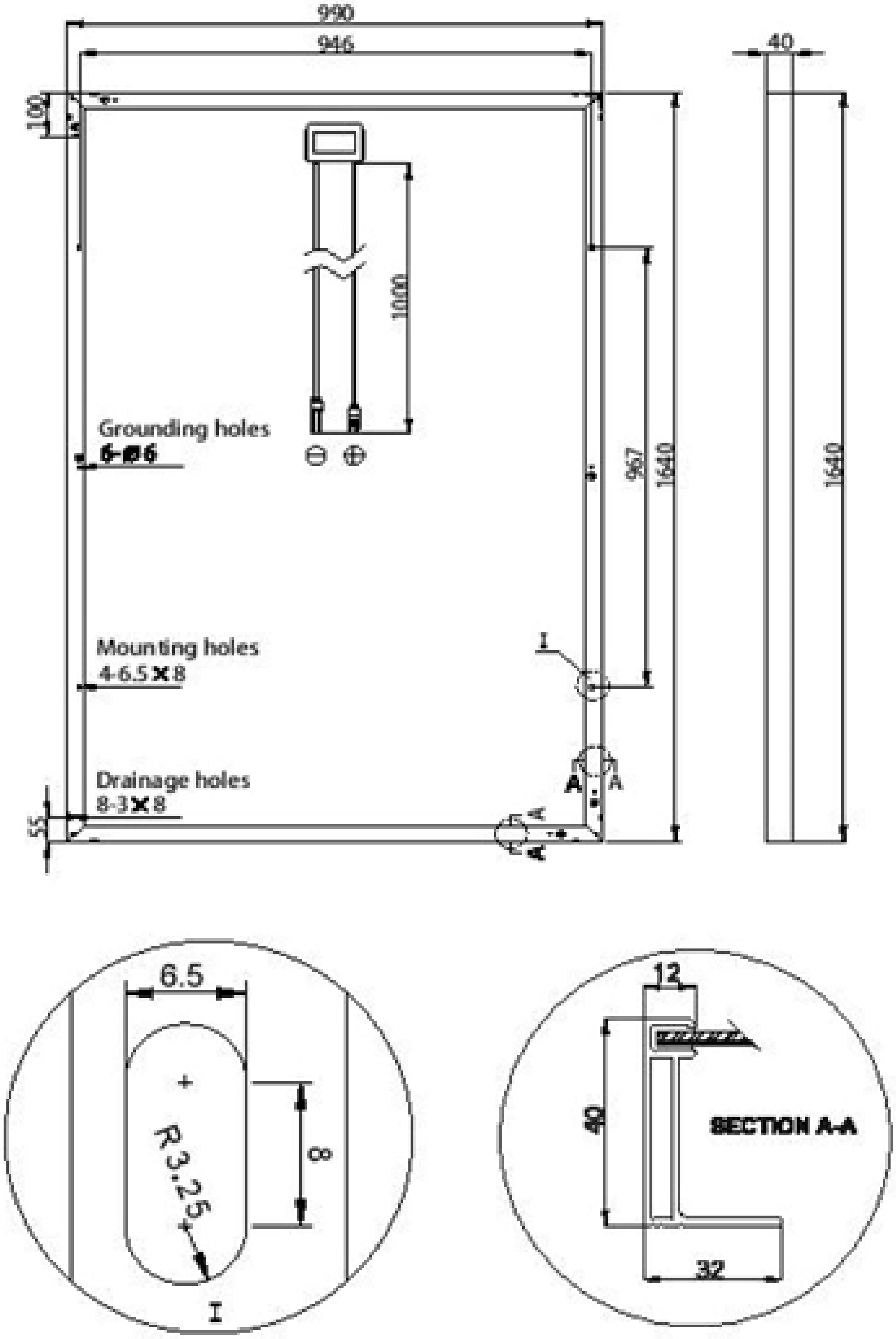


Figure 3.3: 60 Cell monocrystalline solar PV panel specifications [3].

Besides monocrystalline and polycrystalline panels, thin film panels are also common in the market. However, their efficiency is almost half of the efficiencies of other two types. Therefore, they are not preferred for roof-top applications due to the limited space.

A photovoltaic system is composed of panels, an inverter, interconnection wires may also include battery and solar tracker.

3.3. Solar Photovoltaic (SPV) Module

The power generated by a single cell is small and therefore several cells are interconnected in series/parallel combination to get the required voltage and current. When several solar cells are connected in series to get a specific voltage the unit so formed is called as Solar Module. Charging batteries is the primary use of SPV module. Therefore normally 36 cells are joined in series to form a standard module, which is capable of charging 12 volts battery. A terminal box is provided on the backside of the module for external connections. A Bypass diode is connected across + ve and – ve in the terminal box. Cathode of the diode will be at + ve terminal and Anode will be at – ve terminal of the module. This diode protects the module cells from overheating due to shadowing of the module or any cell breakage. Generally the rating of bypass diode is 1.52 times of the maximum current of module. The Repetitive Reverse Peak Voltage Vrrm of the diode should be double the string open voltage. For Indian Railways Solar Photovoltaic Module is manufactured as per RDSO Specification No. IRS: S 84/92 with latest amendment. A typical solar module is shown in Fig. 3.4 [15].

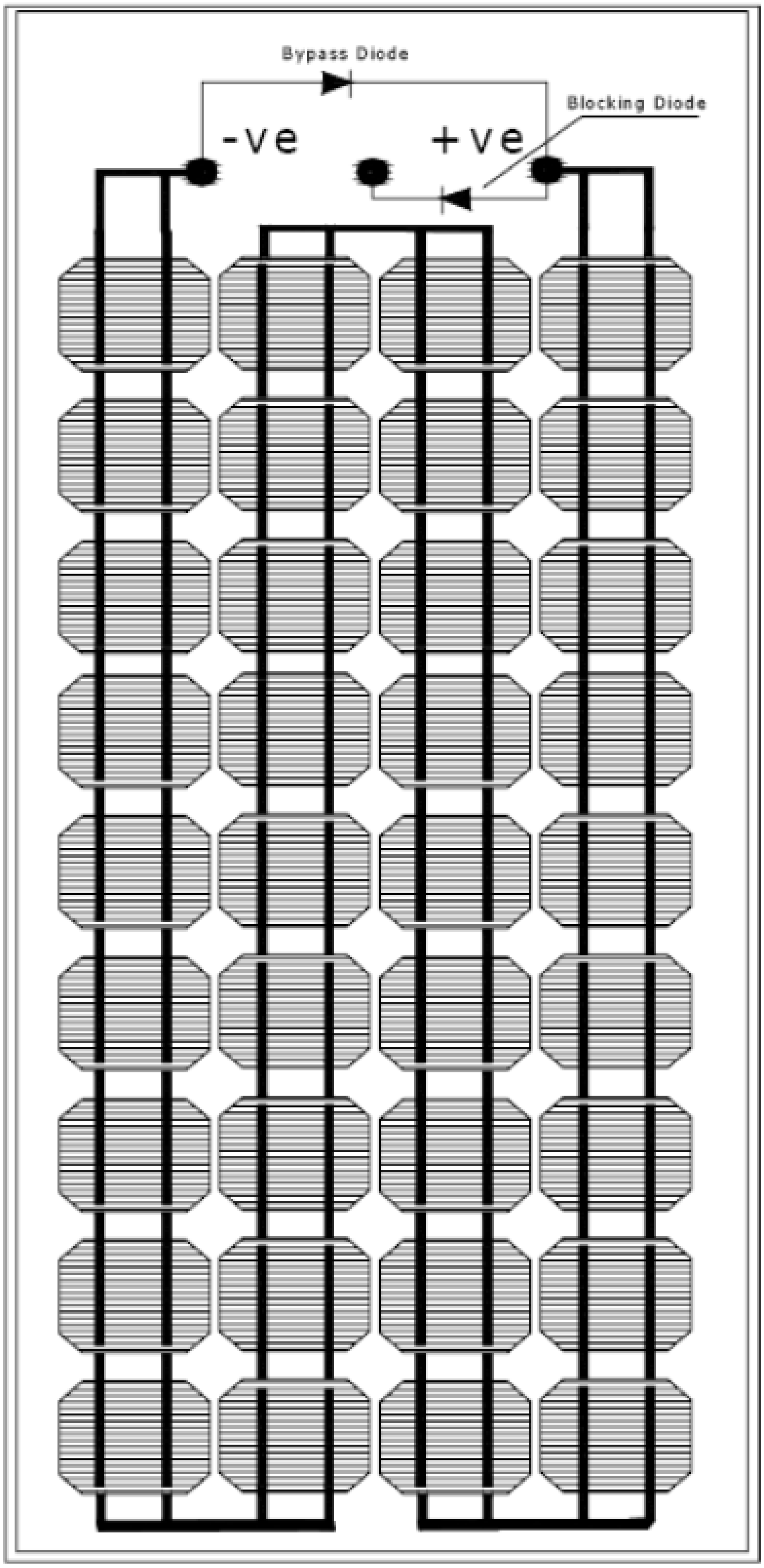


Figure 3.4: Solar module [15].

3.3.1. Construction

Solar modules use the energy captured from sun in order to produce electricity with the photovoltaic effect. Wafer-based crystalline silicon cells or thin-film cells based on cadmium telluride or silicon are used in the most of the modules. The structural (load carrying) part of a module can either be the top layer or the back layer.

Figure 3.5: PV solar panel construction [16].

Due to the fact that panels will be exposed to harsh conditions in the outside, they must be protected against physical damage and moisture. Some of the thin film cells can be used to produce semi-flexible panels. Note that very first usage of panels occurred in the space in 1958. Most of the space crafts are utilized with PV systems for its electrical device electrification.

Electrical connection of the PV system depends on the electrical requirements. Panels can be connected in series to combine their voltage and/or can be paralleled in order to stay in the allowed current bandwidth. The current carrying conductors can be silver, copper or non-magnetic conductive metals. The panels should be connected to each other and the rest of the system electrically. The connection between cells and conductors is made by connectors MC3 and MC4 to obtain a weatherproof operation. Bypass diodes should also be equipped to maximize the output power in case some of the panels are shaded. In this way, rest of the system can operate in a better operating condition and maximum output power. In the recent solar module designs, concentrators are equipped in which the light is focused by either lenses or mirrors.

3.3.2. Efficiency

PV cells can generate power from a range of frequencies depending on the construction. However, they cannot make use of entire solar range which also includes ultraviolet, infrared, low and diffused light. Therefore, most of the available energy captured from sun light is wasted. The efficiency might be much higher if they are illuminated with monochromatic light. Therefore, another design depends on the division of the light into different wavelengths and directing these wavelengths onto different frequency tuned cells. Spectrolab which design this type of photovoltaic cells, has achieved 36.9% efficiency and passed the previous efficiency of 35.2% that also belongs to themselves. The maximum efficiency according to Spectrolab is believed to be over 40% [17].

Highest efficiency for the new commercial products is around 21.5% which is generally lower than their efficiencies of the cells in isolation. The mass-produced solar panels have 175 W/m^2 power densities. According to a research made by Imperial College London has revealed that using aluminium nano cylinders increases the efficiency of the cells. Current of the solar cell can be increased by scattering the light in a longer path since longer path would absorb more protons. Even though this nano cylinders have already been used before, the light scattering is occurred in near infrared region. Therefore, the visible light is absorbed in a stronger way. The ultraviolet part of the spectrum has been absorbed by aluminium while the visible and near infrared spectrum is scattered by the surface of the aluminium. It is concluded that this can decrease the cost significantly since aluminium is cheaper and plentiful. Moreover, due to the increase in the current, thinner film cells are possible which would reduce the material consumption and cost. It should also be noted that these efficiencies are calculated by Maximum Power Point (MPP).

3.3.3. Technology

Biggest portion of solar modules are made from crystalline silicon (c-Si) solar cells which consists of multicrystalline and monocrystalline silicon. More than 90% of the worldwide cell production was made of crystalline silicon, in 2001, meanwhile the rest of the market was built of thin-film technologies which using cadmium telluride, CIGS and amorphous silicon. Improving third generation solar technologies use advanced thin-film cells. In this way high-efficiency conversion for the low cost compared to other solar technologies is achieved.

PV modules are also used in spacecraft to generate electricity. However, space applications require high power mass ratio. Therefore, high efficiency and close-packed rectangular multi-junction (MJ) cells are used in such application even though their cost is quite high. They consist of gallium arsenide (GaAs) and other semiconductors. Another improved PV technology using MJ-cells is concentrator photovoltaics (CPV).

3.3.4. Smart Solar Modules

Nowadays, PV modules are started to be embedded with power electronics. In this way, each module can be managed to follow the MPP and it is possible to observe the performance and the fault detection in the module level. A DC-DC converter is utilized to maximize power output with MPPT algorithm. Moreover, using power electronics can overcome the effect of shading of some PV modules and avoid the current of the strings to drop zero.

A DC-DC converter can be used either in panel output or the array output. Using a DC-DC converter on the panel output is more efficient due to the fact that it is possible find MPP voltages of each panel individually. However, if all panels in an array is operated at the same voltage, some panels would be operating away from their maximum power point. Hence, the efficiency of such system would be lower than the first case.

3.3.5. Performance

The performance of the module is tested under standard test conditions (STC) which is the irradiance of 1000W/m^2, solar spectrum of AM 1.5 and module temperature at 25°C. Nominal power (P_{MAX}, W), open circuit voltage (V_{OC}), maximum power current (I_{MPPT}), peak power (watt-peak, W_p) and module efficiency (%) are included in the electrical characteristics.

In the very early times, modules are used for battery charging. Therefore, the nominal voltage was referring the best suited voltage for charging. However, the output voltage of the module changes with irradiance, temperature and loading.

Therefore, there is no specific nominal voltage definition for these modules. Now, nominal voltage is used for checking the compatibility of the module to the system. V_{OC} is the open circuit voltage and it can be measured when the module is not connected to electrical system. It can be measured by directly on the module or the disconnected cables.

The peak power rating, W_p, is the maximum output power under STC. This value will not necessarily be the maximum possible output. Typical modules which are around 2 m^2 (1*2) have the power ratings from 75 to 350 W depending on the efficiency. After the test results, manufacturers bin its modules according to test results, typically modules are rated with 5W increments +/- 3%, +/-5%, +3/-0% or +5/-0%.

Modules should resist the harsh operating conditions as rain, snow, cold and heat for long time. Therefore, panel rated output should be well known for the upcoming years. Many crystalline panel manufacturers give a warrant of 90% production compared to the rated power for 10 years, 80% production for 25 years. Potential Induced Degradation (PID) is one cause of the power reduction with years due to the stray currents. The effect of PID might cause a 30% reduction in power output.

3.3.6. Maintenance

The main decrease in the solar panel efficiency is due to the dust, pollen and other particles that is layered on the panel surface. This decrease might increase up to 30% in the dusty or desert places. According to a study that is completed in the California, 145 days without any cleaning or raining, solar system have lost 7.4% of the efficiency. The study concluded that a typical residential solar system can increase its generation and gain 20$ by washing the panels during 2.5 months. However, for commercial rooftop systems, it would create higher financial losses. On average, panels lost almost 0.05% of the efficiency per day and this is why washing the panels is not necessary for panel maintenance.

3.3.7. Solar Irradiation

Solar irradiance can be defined as the power per area which is received from the sun in an electromagnetic radiation form in the measurement wavelength range. One can measure the irradiance in the space or at the surface of the Earth after scattering and atmospheric absorption. It should be measured perpendicular to the sunlight. One other parameter is Total Solar Irradiance (TSI) which is a measure of the solar power over all wavelengths per unit area incident on the upper atmosphere Earth. The solar constant is a conventional measure of mean TSI at a distance of one Astronomical Unit (AU). Irradiance, which is a function of distance from the sun, the solar cycle, and cross-cycle changes, on Earth is also measured perpendicular to the incoming sunlight. Insolation is the power received on Earth per unit area on a horizontal surface. It depends on the height of the sun above the horizon.

Photovoltaic panels are rated under standard conditions to determine the Wp rating which can then be used with insolation to determine the expected output,

As stated before, the peak power is determined under standard conditions. However, by using the insolation, it is possible to estimate the output of the solar system according to adjusted by factors like tilt angle, tracking and shading. Insolation is between 800 and 950 kWh/(kWp·y) in Norway to up to 2,900 in Australia.

PV systems convert the energy they get from the sun into electricity energy to the extent of their productivity. Therefore, PV systems are more efficient and useful in the fields that are highly radiation violent and when insolation time is high. Because of our country's geographical location, it has more sun energy than many other countries and is more convenient.

Turkey's yearly radiation level per meter-square is given in the map in Fig. 3.6 [15]._It can be seen in especially south, southwest and southeast zone PV systems convenient.

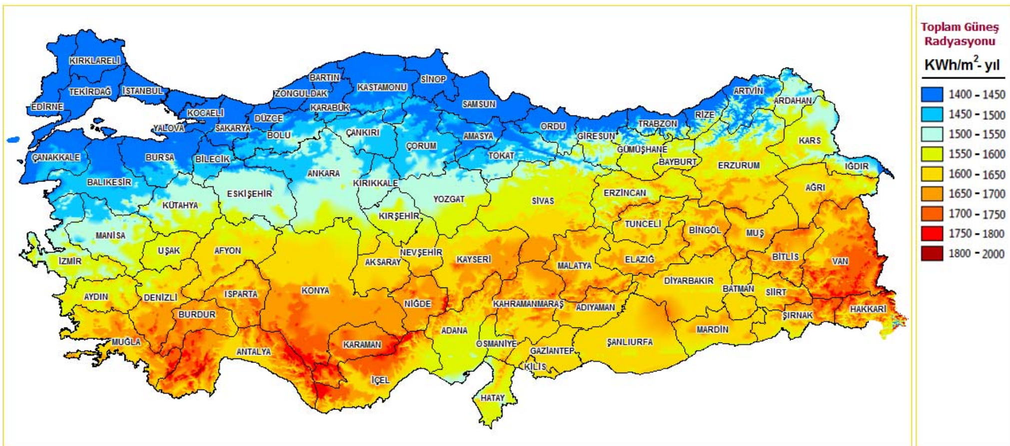


Figure 3.6: Solar irradiation in Turkey [18, 19].

According to a study of EIE utilizing DMU's work on insolation time and radiation violence during years1966-1982, Turkey's average yearly total insolation time is 2640 hours (7.2 hours in total per day), average total radiation is 1311 kWh / m^2-year (daily total 3.6 kWh / m^2).

Turkey's monthly sun energy potential and insolation time values are given in Table 3.6 [19].

Table 3.6: Turkey's monthly average sun energy potential [19].

Months	Monthly Total Sun Duration		Daylight Duration
	Kcal/cm^2-Month	kWh/m$_2$-Month	(Hours/Months)
January	4.45	51.75	103.0
February	5.44	63.27	115.0
March	8.31	96.65	165.0
April	10.51	122.23	197.0
May	13.23	153.86	273.0
June	14.51	168.75	325.0
July	15.08	175.38	365.0
August	13.62	158.40	343.0
September	10.60	123.28	280.0
October	7.73	89.90	214.0
November	5.23	60.82	157.0
December	4.03	46.87	103.0
Total	112.74	1311	2640
Average	308 cal / cm^2-day	3.6 kWh / m^2-day	7.2 hours / day

Turkey's top sun energy regions are South East Anatolia Area and Mediterranean Area respectively. Sun energy potential and insolation time value of regions are in Table 3.7. However, these values are below Turkey's real potential, as understood by following works. Since 1992, EIE and DMU receive the sun energy value for healthier measurement of sun energy. In the results of Turkey's continuing measurements, Turkey's sun energy potential is 20-25% more than the older measurements, as expected [19].

Table 3.7: Turkey sun energy potential regions by distribution [19].

Area	Total Sun Energy (kWh/m^2-year)	Insolation Time (Hour/year)
SE Anatolia	1460	2993
Mediterranean	1390	2956
East Anatolia	1365	2664
Inner Anatolia	1314	2628
Aegean	1304	2738
Marmara	1168	2409
Black Sea	1120	1971

With the help of measurement data from the new 8 EIE station and DMU calculations, sun energy and daylight duration are calculated and published in a booklet. [19].

3.4. Photovoltaic Panel and Modelling

Photovoltaic (PV) system basically makes electricity production from solar rays. This system may consist of PV cells, known as the most basic unit of PV systems -solar battery-, or PV panel (solar panel) which is acquired by serially or parallelly connecting PV cells to each other. A PV cell is the most basic and simple unit that provides electricity from the sun ray. Its structure is like a semiconducting electronic diode. Another words, a PV cell is a diode producing electricity. [20]

In practice of a PV system is cells or panels are connected to each other on exit terminals and voltage or current is obtained. This current and voltage may be directly used by connecting the load in illumination or DC engine applications; but in complicated systems requiring bigger loads, electronic converters are required between PV systems and loads.

PV systems are a non-linear current-voltage (I-V) in exits. Therefore, it is important to design of the PV system with a right modelling. The (I-V) characteristic of a PV system is seen in Fig. 3.7.

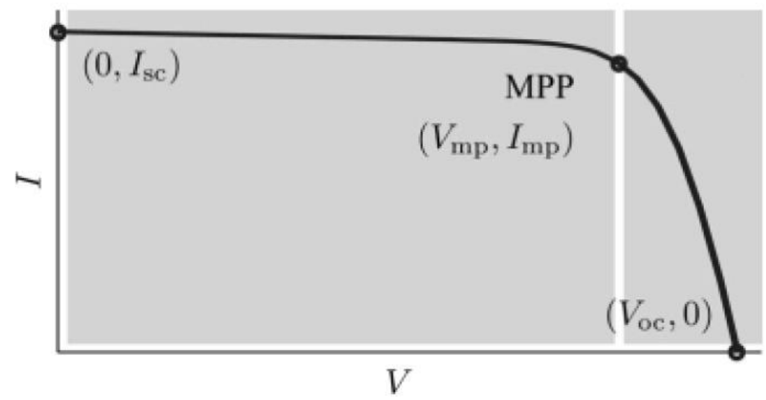


Figure 3.7: The (I-V) characteristic of a practical PV system [20].

Right modelling of photovoltaic systems is also important in MPPT applications which are useful for transferring maximum power to load. Because of PV systems' costs and production limitations of solar energy as mentioned in section one, loading energy without transfer loss is required. And this will be possible by appropriate inverter designs on right modelled PV systems.

3.4.1. Photovoltaic Cell's Physical Structure

PV cell structure can be defined as a diode constructed from a semiconductor material consisting of a p-n joint that is sensitive to light. In dark environment, a PV cell's I-V characteristic is very similar to a diode. Also, when PV cells are exposed to sunlight, electron-hole pairs start to occur. After that, pairs depart with the help of electricity area in the environment and each PV cell compose power at the exit [21]. Simply, PV work system can be defined as; solar radiation absorption creating freely moving structures on p-n junction and gathering of these structures at the exit of the PV system.

PV cells are made of a couple of different semiconductor materials that use different production methods. But monocrystalline and polycrystalline structures are the most commons given their cost and production prevalence. A PV cell physical structure is seen in Fig.3.8.

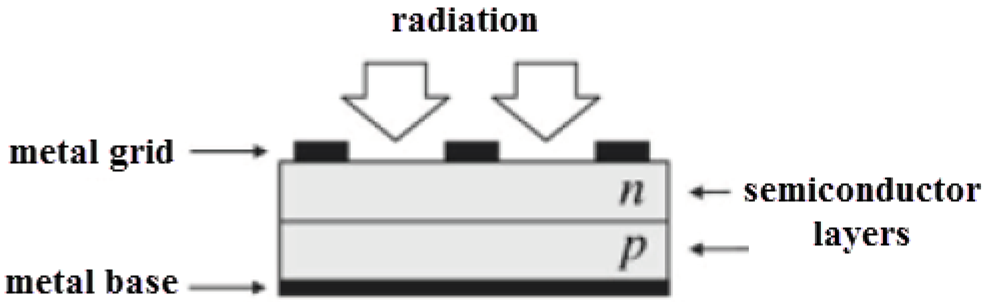


Figure 3.8: Physical structure of photovoltaic cell [20].

Electricity carrier's ratio in a PV cell is dependent on semiconductor's sorption capacity that is used in PV cell's production and the power of light. Sorption capacity is basically dependent on semiconductor band range, reflection on cell surface, inner structures of semiconductors, temperature and a few different factors.

In systems that are based on PV production, it is important to know characteristic of electricity in electronic converters. PV system (cell, panel) producers provides their users with data sets based on experimental data. Then, these data sets can be used to obtain PV system's mathematical modelling of I-V curve. Besides, some producers give the users I-V curves for different work conditions. [22].

3.4.2. Photovoltaic System Modelling

More than one model has been put forward in studies related to PV systems. The most important of these are the one-diode model shown in Fig. 3.9 and the two-diode model shown in Fig. 3.10 [23]. In the researches on these models some methods have been developed to determine the electrical properties of the models. In cases where the solar radiation is uniformly distributed, the electrical parameters of the PV systems can be obtained from these models [24]. The diode model is more preferred because it is simpler. In this thesis study, one-diode model is preferred in the modelling of PV systems.

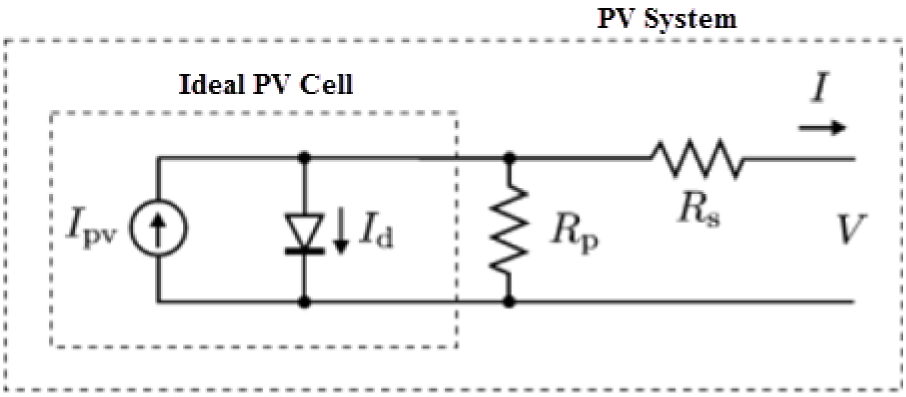


Figure 3.9: Equivalent circuit of PV: 1 diode model [23].

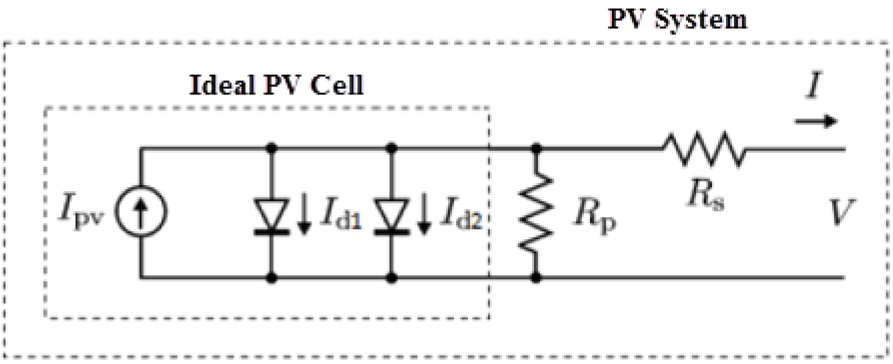


Figure 3.10: Equivalent circuit of PV: 2 diode model [23].

3.4.3. Mathematical Expression of Ideal PV Cell

The most basic mathematical expression of an ideal PV cell [20]:

$$I = I_{pv,hucre} - \underbrace{I_{o,\ hucre}\left[exp\left(\frac{qV}{akT}\right) - 1\right]}_{I_d} \quad (3.18)$$

Can be written as,

The description of the parameters in equation 3.18 is given in Table 3.8.

Table 3.8: Parameters of Ideal PV Cell Equation [20].

SYMBOL	EXPLANATION
$I_{pv,hucre}$	Curret generated by sunlight or radation
I_d	Shockley diode equation
$I_{o,\ cell}$	Diode reverse saturation current
q	Electron charge. (1.60217646x10^{-19} C)
k	Boltzmann constant (1.3806503x10^{-23} J / K)
T	$p - n$ zone temperature in Kelvin
a	Diode ideality factor.

3.4.4. Modelling of PV Panels

PV panels are structures that are formed with a couple of PV cells coming together. So, expecting the equation (3.19) to determine a PV panel's I-V characteristic would be a mistake. However, a PV panel's I-V characteristic can be observed by adding a couple of parameters to equation (3.19). As a result, the PV panel's mathematical expression:

$$I = I_{pv} - I_o \left[exp\left(\frac{V+R_s I}{V_t a}\right) - 1\right] - \frac{V+R_s I}{R_p} \quad (3.19)$$

is obtained in this way. Here, V_t is given by Equation (3.20) as the thermal stress of the panel.

$$V_t = \frac{N_s kT}{q} \quad (3.20)$$

R_s equivalent series resistance given in Equation (3.20), R_p is the equivalent parallel resistance, and N_s is the number of cells connected in series. Equation 3.19 is the exit point of the I-V curve.

One of the difficulties encountered when using Equation (3.20) for PV panel modelling is that not all the parameters in the equation are provided by the PV panel manufacturers.

Generally panel manufacturers produce panel data pages; ($V_{(oc, n)}$), the rated short circuit current ($I_{(sc, n)}$), the maximum power point voltage $V_{(mp)}$ and the current $I_{(mp)}$, the open circuit voltage / ($K_{(V)}$), the short circuit current / temperature coefficient ($K_{(1)}$) and the maximum experimental peak power ($P_{(max, e)}$). These parameters are given for nominal values of solar radiation and temperature values.

The amount of light intensity directly affects the production of charge-loaded blocks in the p-n junction, and therefore the current generated by the system. The current I_{pv} produced by the light of the PV cell exhibits a linear change due to the solar radiation change and is also affected by the temperature according to equation (3.21) [25].

$$I_{pv} = \left(I_{pv,n} + K_1 \Delta T\right) \frac{G}{G_n} \quad (3.21)$$

Descriptions of the parameters in this equation are given in Table 3.9.

Table 3.9: Explanations of the parameters given in Equation (3.21) [20].

Sembol	Açıklama
$I_{pv,n}$	Current produced by the light in nominal conditions (25°, 1000W / m^2)
ΔT	$T - T_n$ (Actual and nominal temperatures in Kelvin
G	Radiation on the system sueface (power per square meter)
G_n	Nominak radiation

The relationship between the diode saturation current, I 0, and the temperature of this current can be described as in Equation (3.22):

$$I_o = I_{o,n}\left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \tag{3.22}$$

In this equation E_g is the band gap energy of the semiconductor (E_g = 1.12eV for silicon at 25 ° C). In addition, the nominal saturation current I*o*:

$$I_{o,n} = \frac{I_{sc,n}}{\exp\left(V_{oc,n}/aV_{t,n}\right) - 1} \quad (3.23).$$

can also be defined as: In this equation $V_{(t,\,n)}$ is the thermal stress of the series-connected cells at the nominal temperature $T_{(n)}$.

In addition to all these given PV system equations, I_o given in Eq. (3.24) can be defined as follows [22] so that for a much wider range of temperature values the open-circuit voltage of the model can better match the experimental data [22].

$$I_o = \frac{I_{sc,n} + K_I \Delta_T}{\exp((V_{oc,n} + K_V \Delta_T)/aV_t) - 1} \tag{3.24}$$

This equilibrium model eliminates model errors in the vicinity of the open circuit voltage and in the other regions of the I-V curve with simplification.

3.5. Inverter

Inverters are devices that convert the panel output power to a proper form for electricity grid. The output of the solar panel is Direct Current (DC). Inverters are converters that can convert DC to Alternating Current (AC). Inverters are designed according to the power capacity of the solar system, input-output voltages and also the frequency of the grid. Inverters make use of the electronic switches such as MOSFETs, IGBTs which can close and open very fast. Thanks to these devices, inverters are able to dictate the panel output current and voltage. This is a useful property which enables the system to track MPP.

3.6. Maximum Power Point Tracking

MPPT is a technique which enable wind turbines and photovoltaic system to operate the system in the most efficient way. In a sample photovoltaic cell, the I-V curve is given with Fig. 3.11. As seen from the figure, as the current is increased starting from the V_{oc}, panel voltage decreases. As the voltage decreases with increasing current, the current goes to I_{sc} with zero panel voltage. However, when the power curve is observed the maximum power is obtained in a point in which the voltage is between zero and V_{oc} and the current is between zero and I_{sc}. MPPT algorithm is responsible for finding this MPP point. Note that this curve is dependent on the solar irradiance. Therefore, as the irradiance changes, MPP also changes. Therefore, algorithm tracks this point continuously.

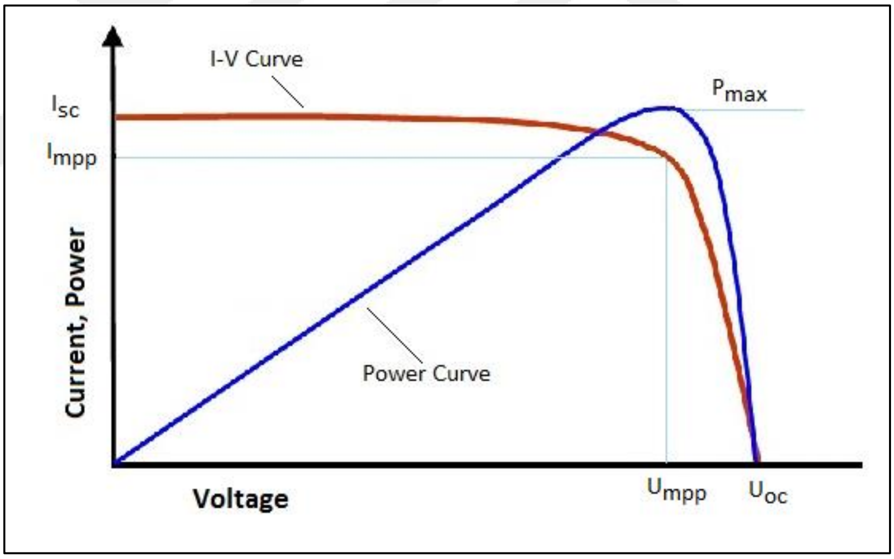


Figure 3.11: Solar Photovoltaic Panel MPPT Graphic of I-V Curve [26].

PV cell by provided power, voltage (V) and stream (I) product. Both open and closed-circuit conditions, given power is zero. One at the point (knee point around) given power. It is the maximum. A PV cell provides maximum current to the amount of short circuit current. When a voltage range's current linearity until maximum power voltage is considered, the cable and system size for short circuit current is reasonable [26].

PV solar systems exists in different configurations. The most basic and common configuration is that all generated power is injected to grid with inverter. Another PV solar system would have a battery and it inject some power to grid meanwhile the battery is being charged. The amount of power that will injected to grid and the battery is regulated according to micro grid operation [17]. Another configuration might be unconnected to grid at all meanwhile all the generated power goes to the battery with a dedicated MPPT algorithm.

Another variation of these configuration is the employment of micro inverter on each panel instead of a single inverter [27]. In this case, each panel would be operating on its MPP resulting in a higher efficiency. However, this case would increase the investment cost even though the solar efficiency is increased by 20%.

There are different MPPT algorithms in the literature. The first one is perturb and observe method. This method is one of the basic methods. The controller perturbs the operating point i.e. changes the voltages a little and observes the power output. If the new operating point yields more power than the previous operating point, then the algorithm understands that it is away from the MPP and perturbs further. This perturbation continues until MPP is exceeded. As the MPP is exceeded, then the perturbation is reversed in direction. The only disadvantage of this method is the oscillation around the MPP since the perturbation and observation continuously go on. This type of MPP point is most common due to its easy implementation and its efficiency can be increased with proper predictive and adaptive hill climbing method [28].

Another MPPT algorithm is the incremental conductance method. In this method, controller observes the small changes in the current so that it predicts the voltage change effect. The method utilizes the incremental conductance (dI/dV) of the PV array to compute the sign change in power with respect to the voltage (dP/dV). In this way, it can track the changes faster than the perturb and observe method. However, the controller requires more computation in order to move the operating point. Furthermore, the controller may end up with the oscillation in the MPPT point just as the perturb and observe method.

One other MPPT method is the current sweep. This method obtains the I-V characteristic of the PV array by sweeping the current at fixed time intervals. The MPP is found from the characteristic curve.

In the traditional inverters, all PV panels are operated under one MPPT resulting in a MPP. Therefore, the same current is dictated for all panels. However, there will be some difference between modules which leads different I-V curves between panels. The difference of I-V curves might be related to the partial shading or the manufacturing issue. However, a single MPP would result in a situation that some of the panels will be operating under the MPP leading an energy loss [27]. Therefore, MPPT followers are used for singular modules to allow each panel to perform at highest efficiency point even though the shading is uneven or electrical mismatch exists.

In the off-grid operation, PV system can supply the loads in the night by using batteries. Even though the battery voltage might be very close to the PV panel MPP voltage, this situation is no longer true at the sunrise since the batteries will be partially discharged. Charging operation may start with a voltage significantly below the PV module MPP voltage and a MPPT algorithm can solve this problem. When the PV generation is above the load demand and batteries are fully charged, then the MPPT cannot operate in MPP since there is no load to absorb the surplus power. In this time, the MPPT should change the operating point and until the generation and consumption are equal to each other. This problem also occurs in the space applications. In that case, MPPT algorithm is not distorted but the excess power is dissipated on a resistive load.

Table 3.10: MPPT systems table [36].

MPPT Techniques	PV Sequence Dependency	Right MPPT	Analogue Digital	Periodic Adjustment	Convergence Speed	Adaptation complexity	Parameters
P&O	-	+	D/A	-	Variable	low	Voltage, current
IncCond	-	+	Digital	-	Variable	medium	Voltage, current
Fractional Voc	+	-	D/A	+	medium	low	Voltage
Fractional Isc	+	-	D/A	+	medium	medium	current
Fuzzy Logic	+	+	Digital	+	fast	fast	Variable
Neural Network	+	+	Digital	+	fast	fast	Variable
RCC	-	+	Analog	-	fast	low	Voltage, current
Current Sweep	+	+	Digital	+	low	fast	Voltage, current
DC Link Capasitor Droop Control	-	-	D/A	-	medium	low	Voltage,
Load I or V Maximization	-	-	Analog	-	fast	low	Voltage, current
dP/dV or dP/dI Feedback Control	-	+	Digital	-	fast	medium	Voltage, current
Array Reconfiguration	+	-	Digital	+	low	fast	Voltage, current
Linear current Control	+	-	Digital	+	fast	medium	light
IMPP & VMPP Computation	+	+	Digital	+	N/A	medium	light, temperature
State-based MPPT	+	+	D/A	+	fast	fast	Voltage, current
OCC MPPT	+	-	D/A	+	Fast	medium	current
BFV	+	-	D/A	+	N/A	low	-
LRCM	+	-	Digital	+	N/A	fast	Voltage, current
Slide Control	-	+	Digital	-	fast	medium	Voltage, current

The MPPT Explanation and Graphic

MPPT is simply “adjusting inverters’ DC input power to the speed of solar panels’ changeable power production abiding by radiation.

Radiation value on solar panels may change due to many reasons. Among them, the most commons are:

- Geographical location (North, South, East, West directions)
- Shading (objects like tree, building, chimney etc. create shade according to sun’s movement)

- We can list the different number of panel groups as depending on the surface areas.

In high DC voltage, currents are shared by multiplying inputs of inverters in order not to work with high voltages.

Incoming DC are collected in one mutual bar to be transformed into AC current after crossing in energy protection circuit. Unless the parallely connected power supplies (string voltages coming from solar panels) are equal, current flow direction may be towards unwanted directions. To prevent so, voltage and currents of the strings that are connected to the mutual bar are required to be same. If the strings that are connected to the mutual bar are different due to reasons mentioned above (different directions or shading), these different voltage and current values are best to be on different switching circuits. If the strings that are connected in the same inverters need to have different quantities of solar panels (like in there aren't equal panels or the surface area not being homogenic), if all the panels do not see the same direction, if montage area has little shadow on it, maximum 1 MPPT inverters are more appropriate to be used in these kinds of fields.

Gain using MPPT is shown in Fig. 3.12.

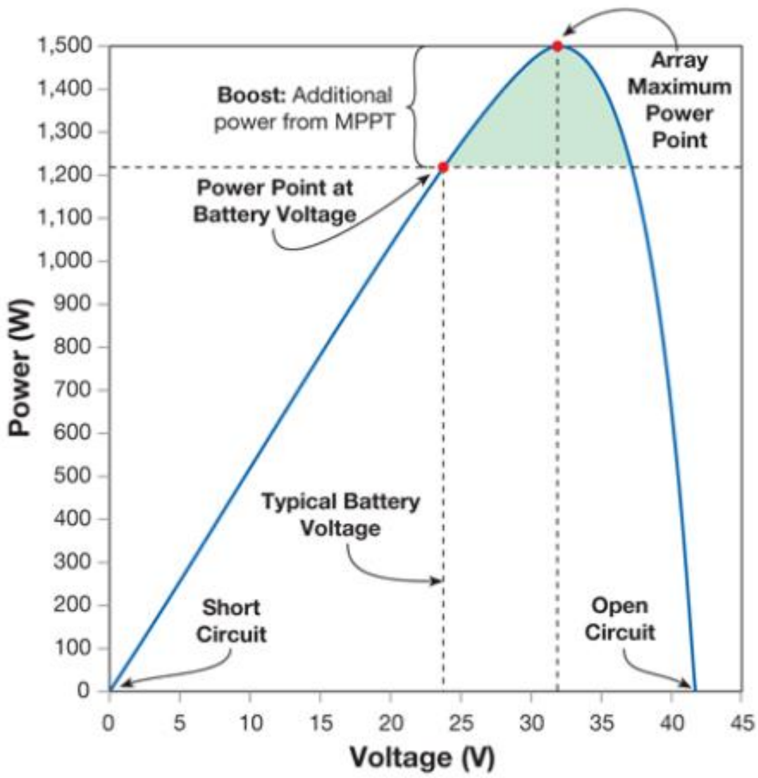


Figure 3.12: MPPT vs. Non-MPPT [29].

3.7. Electric Train

An electric train is a train that is powered by electricity instead of fuel. This electricity can be supplied from overhead lines, a third rail or the power can be extracted from any energy storage device such as battery fuel cell. If the power is supplied from on-board fuelled main movers, like diesel engines or gas turbines, these types of trains are called as diesel-electric or gas turbine-electric locomotives. Electricity is used to take advantage of the high efficiency of electric motors [30]. Electric train with catenary line is shown in Fig. 3.13 [31].

Figure 3.13: Electrical train with catenary line [31].

An example of a train with solar system implementation in India is given in Fig. 3.14 [32].

Figure 3.14: Train with solar panel on rooftop [32].

3.8. Power Transmission

Electrical circuits require two separate connections. If the three phase AC is used, then three connections are required. From the starting, the track was used for one side of the circuit. Distinct model railroads the track ordinarily supplies just one side, the other sides of the circuit being supplied separately.

The original Baltimore and Ohio Railroad electrification used a sliding shoe in an overhead channel, a system rapidly found to be insufficient. It is changed by a third rail that is a pickup rode, i.e. shoe, either below or on top of a smaller rail parallel to the main track, over level of ground. There were various pickups on both sides of the locomotive in order to accommodate the breaks in the third rail needed by track work. This system has been used in subways due to the close clearances it affords [28].

Overhead lines are often used in railways, generally called "catenaries" after the support system operated to hold the wire parallel to the ground. Three collection methods are possible. The first method is using trolley pole which is a long flexible pole, engaging the line with a shoe or wheel. The second method is bow collector. It is a frame that holds a long collecting rod against the wire. The last method is using a pantograph which is a hinged frame that holds the collecting shoes against the wire in a constant geometry.

3.9. Traction Motor

Electric motors are also used for traction applications in electric locomotive and electric roadway vehicles. Traction motors are very common in different applications such as electric vehicles such as trolleybuses, milk floats trains and also in hybrid electric vehicles. A typical traction motor is shown in Fig. 3.15.

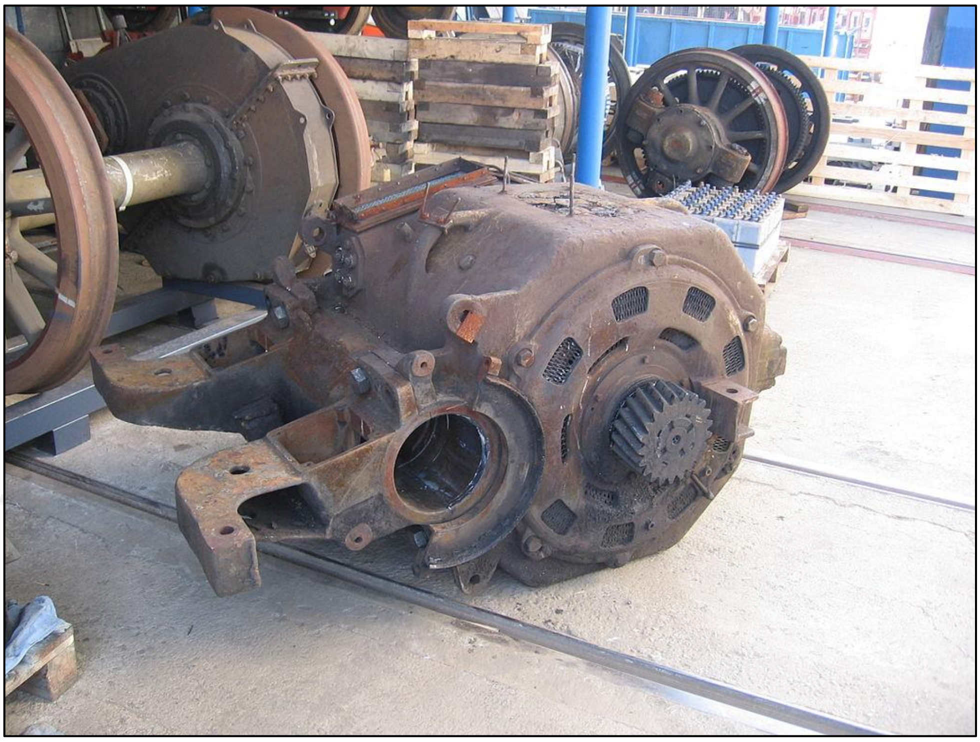


Figure 3.15: Traction motor [33].

The maintenance of AC induction motors and synchronous motors are easy and cheap meanwhile their fixed speed characteristic makes them unpromising candidates for these applications. In the grid frequency, AC induction motors has very narrow speed range. However, with the advances in the technology enable AC induction motors to operate in a very wide speed range. Therefore, they become very popular in the electrical vehicles applications. Moreover, due to the fact that there is no brushes or commutator, they became very promising candidate for these applications.

The advances on the high-powered semiconductors such as thyristors and the IGBTs has made practical the use of much simpler, higher-reliability AC induction motors known as asynchronous traction motors. French TGV which is a company of the France which serves high speed railway transportation between cities has also used asynchronous AC motors time to time. If the series-wound DC motors are used in traction applications, they cannot provide some advantages of electric motors. For instance, if the train starts to go down from a hill, the speed rises. If the speed is increased, back-EMF voltage also increases, reducing the torque until net torque becomes zero to have a constant speed. Since the field current is decreased by the back-EMF in a series-wound DC motor, there will not be a speed in which the back-EMF will be higher than the supply voltage, and hence these motors cannot provide dynamic or regenerative braking.

One of the biggest advantage of traction motors are regenerative braking. It is basically reversing the power flow direction when the train slows down. In other words, some amount of energy is generated in braking duration. In the regenerative braking duration, the energy generated can be injected to the supply. Moreover, the energy can also be dissipated on the resistors which is called dynamic braking. Dynamic or regenerative braking can bring the train to a lower speed or to a standstill, requiring relatively little friction.

3.10. APU (Auxiliary Power Unit)

The properties of the auxiliary power unit and the capacity calculations are given in the Appendix A and B. Note that an auxiliary power unit has the capacity of 120 kVA. Corresponding AC load power is given as 105 kVA. The properties of the auxiliary power unit and the capacity calculations are given in the Appendix A and B.

3.11. Other Equipment

Other equipment such as, main transformer of the train that transforms 27 kV/ 1 Phase to 3 kV and 0.4 kV /1.

There is main converter after transformer that converts single phase to three phase.

This suburban train moving between Kayaş and Sincan shows Republic of Turkey’s General Directorate of State Railways. It is shown in Fig. 3.16.

Figure 3.16: Republic of Turkey general directorate of state railways [34].

Technical details is located in Appendix B TCDD EMU (Multiple Electric Railway Series) Rotem Company R& D Center.

Overhead Connection Probe provides connection of the overhead line by 27 kV single phase to the train. This connection is shown in Fig. 3.17.

Figure 3.17: Overhead connection probe

(This photo was taken by the researcher)

There is main transformer of the train that transforms 27 kV /1 Phase to 3 kV and 0.4 kV /1 Phase. It is shown in Fig. 3.18.

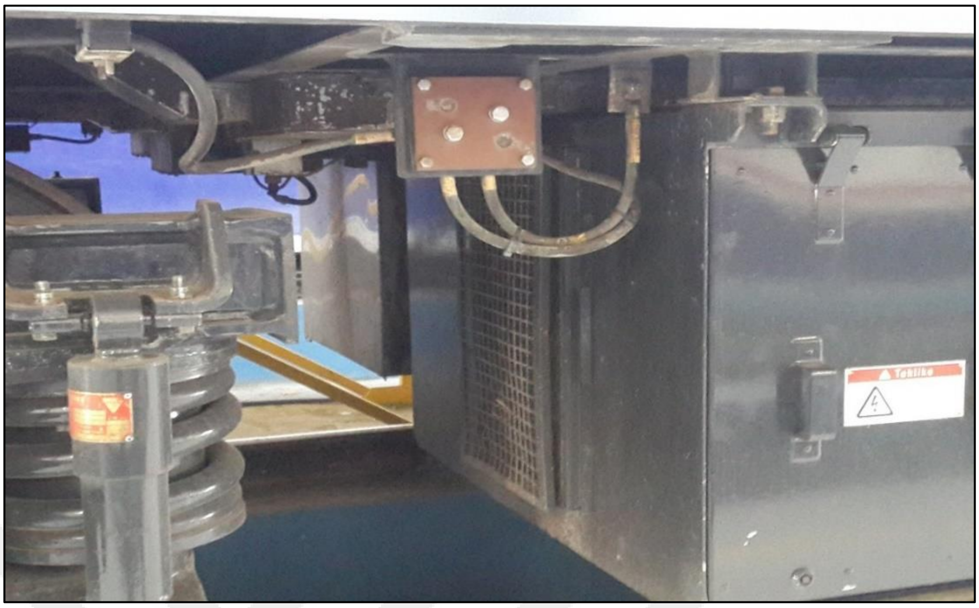


Figure 3.18: Main transformer.

(This photo was taken by the researcher)

There is main converter after transformer that converts single phase to three phase. It is shown in Fig. 3.19.

Figure 3.19: Main converter.

(This photo was taken by the researcher)

There is APU (auxiliary power unit) system using 400 V which supplies all other needs of train. It is shown in Fig. 3.20.

Figure 3.20: APU (auxiliary power unit).
(This photo was taken by the researcher)

Auxiliary Power Unit System General Description is given in Appendix B TOSHIBA.

There is no way to apply solar PV panels on 2. wagon ceiling because of the high voltage connection's equipment. It is not possible to construct panels on top of the wagon 2. It is shown in Fig. 3.21.

Figure 3.21: 2. Wagon ceiling.
(This photo was taken by the researcher)

As it seen in Fig. 3.22, It is possible to set up solar panels on 1st and 3rd wagon ceiling. Therefore, panels should be constructed on top of the wagon 1 and wagon 3.

Figure 3.22: 1st – 3rd Wagon ceiling.

(This photo was taken by the researcher)

3.12. Application Route

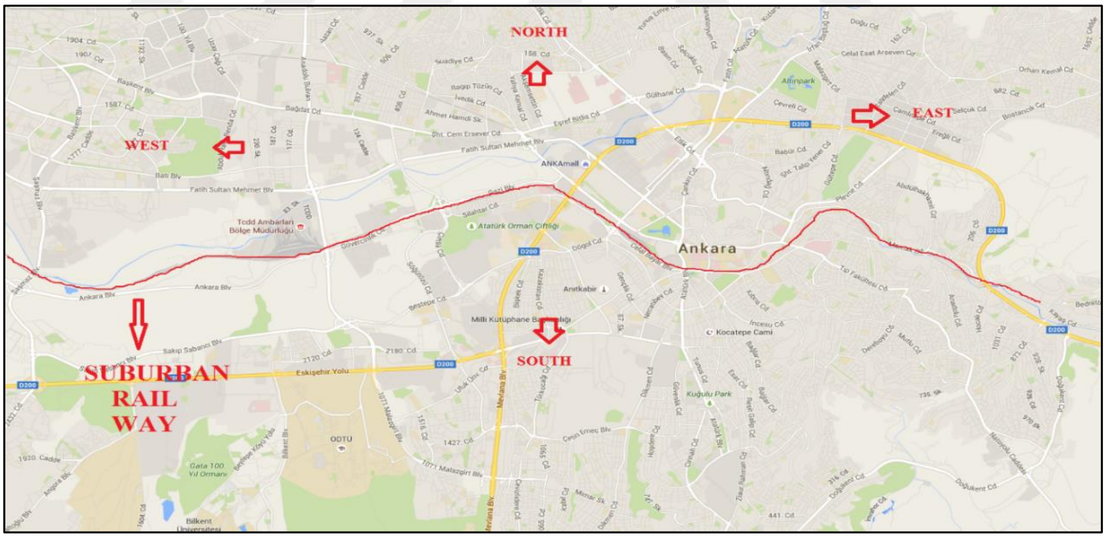


Figure 3.23: The railway of the train on the map.

The railway of Suburban Rail Way is shown on the Fig. 3.23. It shows that the train goes approximately the line on west to east or east to west.

Daily, monthly and annual average productions in kWh in the direction of the data taken from the PvGis program are as follows. They are given in Table 3.11.

Location: Ankara/Turkey

Latitude : 39°56'0" North,

Longitude: 32°51'35" East

Nominal power of the PV system 24.64kWp

Table 3.11: Application route [35].

Month	Development Ed	Em	Hd	Hm
1	38.2	1190	1.74	53.8
2	57.3	1600	2.6	72.7
3	88.4	2740	4.1	127
4	106	3170	5.05	152
5	128	3980	6.38	198
6	144	4330	7.25	217
7	149	4610	7.63	237
8	136	4200	6.93	215
9	109	3280	5.44	163
10	77	2390	3.66	113
11	52.3	1570	2.44	73.2
12	35.3	1100	1.63	50.4
Year	93.6	2850	4.58	139

- Ed: Average daily electricity production from the given system (kWh)
- Em: Average monthly electricity production from the given system (kWh)
- Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)
- Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

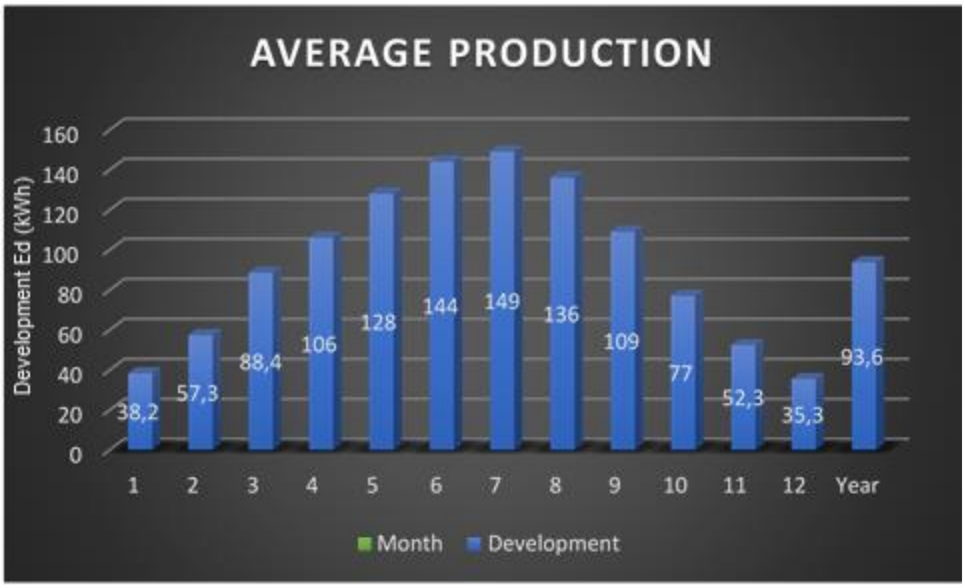


Figure 3.24: Average production.

Average production graphic is shown in Fig. 3.24.

CHAPTER FOUR

APPLICATIONS

4.1. Electrical Connection Design

Republic of Turkey General Directorate of State Railways 3 Wagon Electrical Suburban Train Set. It is the train of the subject of our work.

We have 3 Wagon Electrical Suburban Train Set.

We will talk about our existing system and then, firstly we will work by adding solar energy panels to appropriate wagons and secondly we will work by adding same solar energy panels to stationary system. Finally, we will compare 2 systems in terms of price and energy production.

4.1.1. Existing System Single Line Project

Train moves approximately the line on west to east or east to west. This route is between Kayaş and Sincan.

The working principle of Existing System Single Line Project in Fig. 4.1. is as follows;

27 000 volts comes through the overhead line from the transformer center. It enters to the main transformer of the train that transforms 27 kV 1-Phase to 3 kV and 0.4 kV 1-Phase. There is main converter that converts single phase to three phase.

This voltage is reduced 3 kV by 27 kV / 3 kV transformer. And then this 3 kV comes to main bar. So it feeds traction motors. We can’t supply energy for traction motors in our PV system. Traction motors are kept separate from the feeding cabin and internal feeding.

On the other hand 27 000 volts comes through the overhead line from the transformer center. This voltage is reduced 380 V by 27 kV / 380 V transformer. And then it comes to main bar. So it feeds APU1 and APU2.

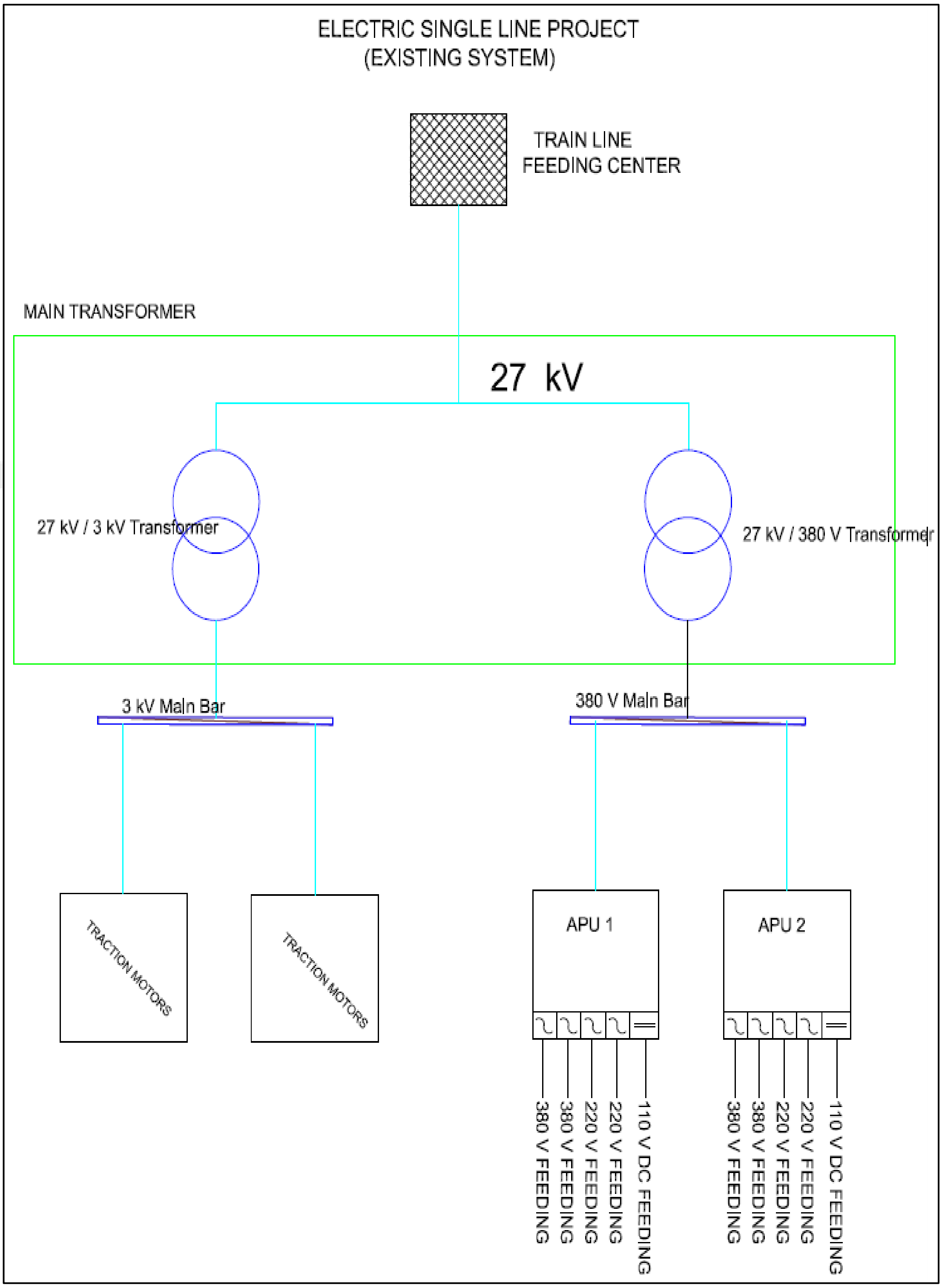


Figure 4.1: Existing system single line project.

Table 4.1: Load distribution of APU1.

APU1 TECHNICAL PROPERTIES						
1	FEEDING	USAGE PLACE	VOLTAGE	PIECE	POWER (W)	TOTAL POWER W
2	ILLUMINATION	PASSENGER CABIN	AC 220	22	36	792
3	ILLUMINATION RESERVE	PASSENGER CABIN	DC 110	4	36	114
4	CEILING HEATER	PASSENGER CABIN	AC 380	1	24000	24.000
5	FLOOR HEATER	PASSENGER CABIN	AC 380	1	12000	12.000
6	TECHICAL ARTICLES (DOOR MOTOR – HOM MECHANISM)	PASSENGER CABIN	DC 110	1	4700	4.700
					TOTAL	41.606

Table 4.2: Load distribution of APU2.

APU2 TECHNICAL PROPERTIES						
1	FEEDING	USAGE PLACE	VOLTAGE	PIECE	POWER (W)	TOTAL POWER W
2	ILLUMINATION	PASSENGER CABIN	AC 220	22	36	792
3	ILLUMINATION RESERVE	PASSENGER CABIN	DC 110	4	36	114
4	CEILING HEATER	PASSENGER CABIN	AC 380	1	24000	24.000
5	FLOOR HEATER	PASSENGER CABIN	AC 380	1	12000	12.000
6	TECHICAL ARTICLES (DOOR MOTOR – HOM MECHANISM)	PASSENGER CABIN	DC 110	1	4700	4.700
					TOTAL	41.606

Notes:
Traction motors are kept separate from the feeding cabin and internal feeding.
Technical drawing of APU feeding units are included in Appendix A.

The load distribution of APU1 is shown in Table 4.1. And the load distribution of APU is also shown in Table 4.2.

Existing System Single Line Project is shown in Fig. 4.1.

4.1.2. Suburban Train System With PV

In this system, we added 44 panels on 1st wagon and 44 panels on 3rd wagon to Our Existing Suburban Train System. We couldn't use the top of 2nd wagon because of that has equipment of the high voltage.

Electrical Connection Design or Electric Single Line Project of Suburban Train System with PV is shown in Fig. 4.2

And also

The whole project that is a more readable size is located in Appendix G.

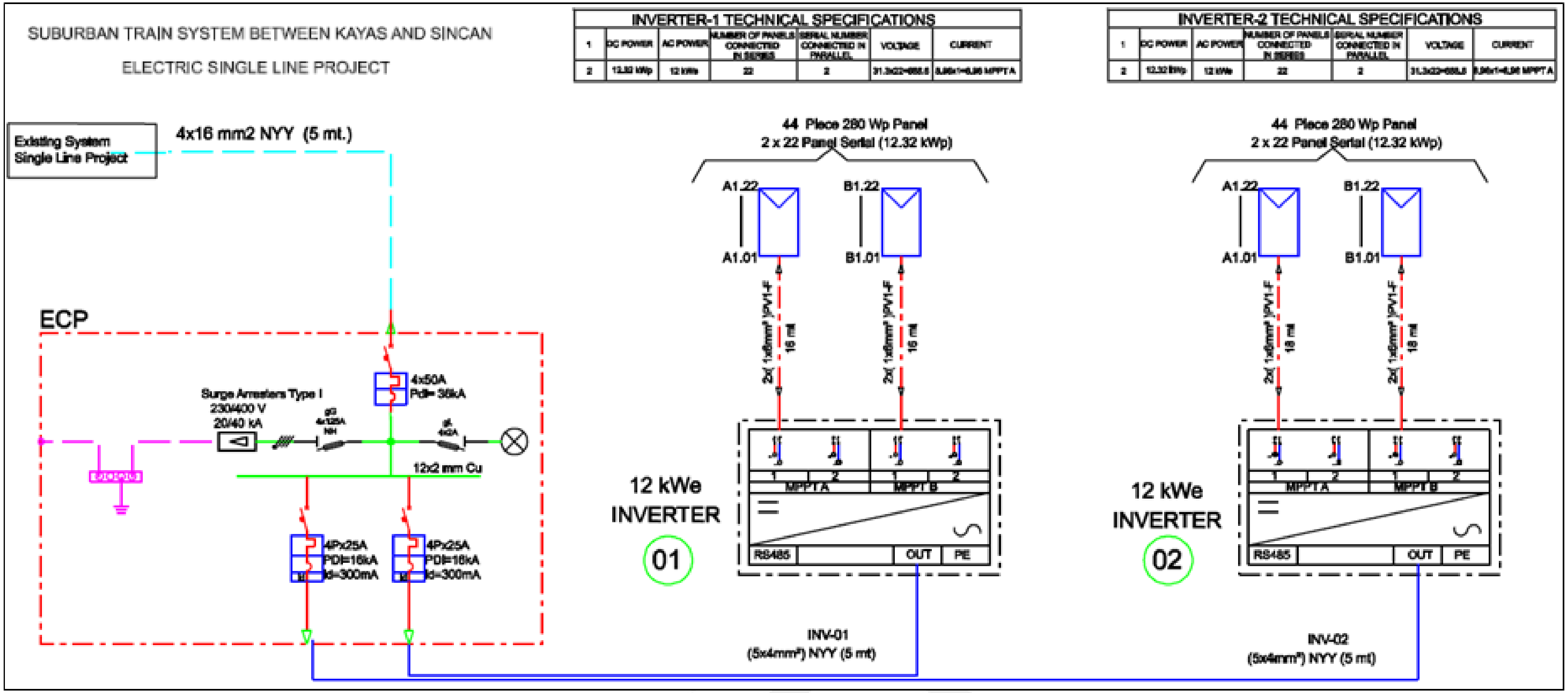


Figure 4.2: Suburban train system SES principle single line project.

The working principle of Electric Single Line Project of Suburban Train System with PV in Fig.4.2 is as follows;

For our system, we have 2 inverters in 2nd wagon. We have also 44 panels on 1st wagon and 44 panels on 3rd wagon.

The solar panels on 1st wagon are connected in parallel with 2 arrays and at each row as 22 serial solar panel is connected to 1st inverter that located at 2nd wagon

The solar panels on 3rd wagon are connected in parallel with 2 arrays and at each row as 22 serial solar panel is connected to 2nd inverter that located at 2nd wagon.

Since each panel has a nominal voltage of 31.3V, the DC voltage transmitted from the arrays to the inverters are 22 x 31.3 V = 688.6 V.

This DC voltage will be converted to 380V AC voltage by the inverters and transmitted to the main bar in 2nd wagon after passing through ECP Board.

380V AC voltage will be transmitted to the APU1 and APU2 Units from the main bus.

The energy that

APU1 + APU2 need 2 x 41.606 W = 83.212 W.

However,

Since the total power of our 2 ınverters is 2 x 12.000 = 24.000 W,

Our Solar Energy System (SES) will not be able to supply all these loads. Therefore, our Solar Energy System (SES) is a network-connected system.

Now let us explain step by step this system;

STS-01 The Electrical Connection Project of Solar Panels and Inverter 1 (Fig. 4.3).

The solar panels on 1st wagon are connected in parallel with 2 arrays and each row as 22 serial solar panels are connected to 1st inverter that located at 2nd wagon. Since each panel has a nominal voltage of 31.3 V. The DC voltage transmitted from the arrays to the inverter is 22 x 31.3 V = 688.6 V. This DC voltage will be converted to 380 V AC voltage by the inverters.

INVERTER-1 TECHNICAL SPECIFICATIONS

1	DC POWER	AC POWER	NUMBER OF PANELS CONNECTED IN SERIES	SERIAL NUMBER CONNECTED IN PARALLEL	VOLTAGE	CURRENT
2	12.32 kWp	12 kWe	22	2	31.3x22=688.6	8.96x1=8.96 MPPT A

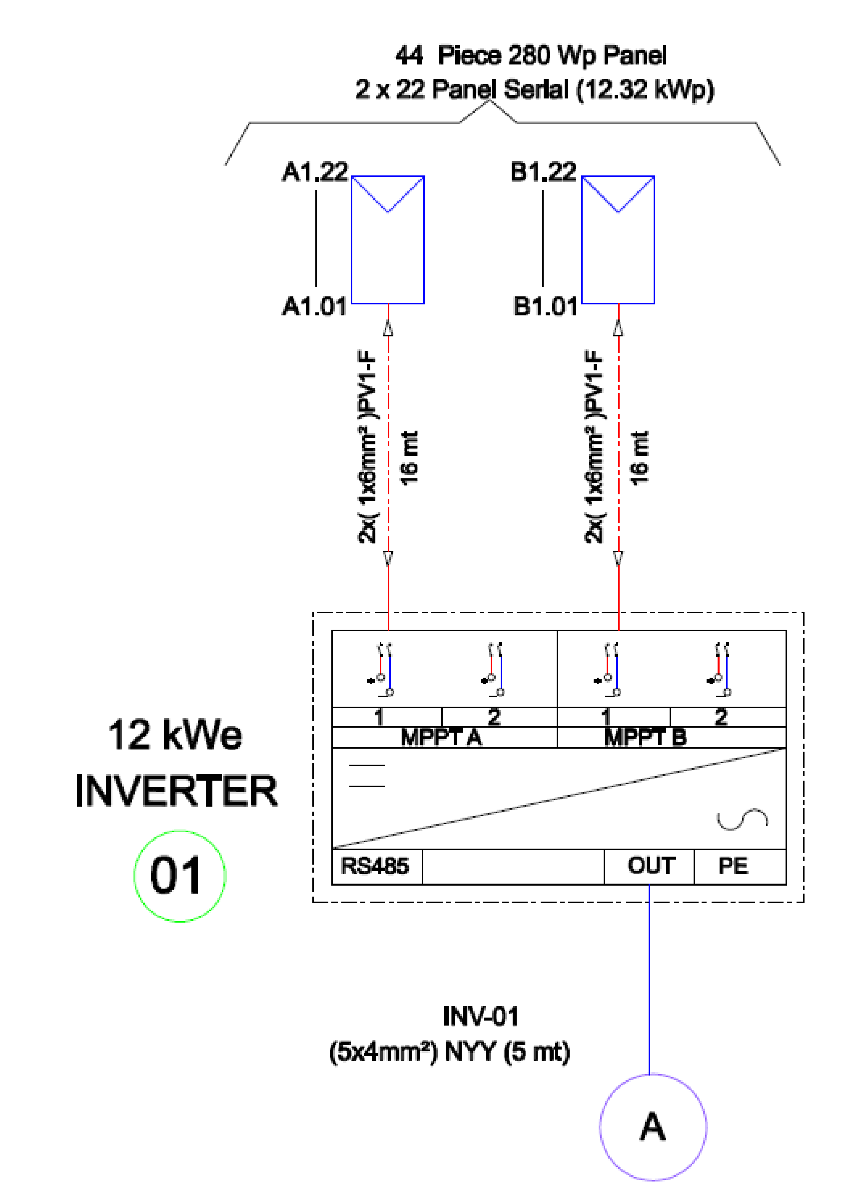


Figure 4.3: STS-01: Suburban train system SES principle single line project – inverter 1.

STS- 02 The Electrical Connection Project of Solar Panels and Inverter 2 (Fig. 4.4).

The solar panels on 3rd wagon are connected in parallel with 2 arrays and each row as 22 serial solar panels are connected to 2nd inverter that located at 2nd wagon. Since each panel has a nominal voltage of 31.3 V. The DC voltage transmitted from the arrays to the inverter is 22 x 31.3 V = 688.6 V. This DC voltage will be converted to 380 V AC voltage by the inverters.

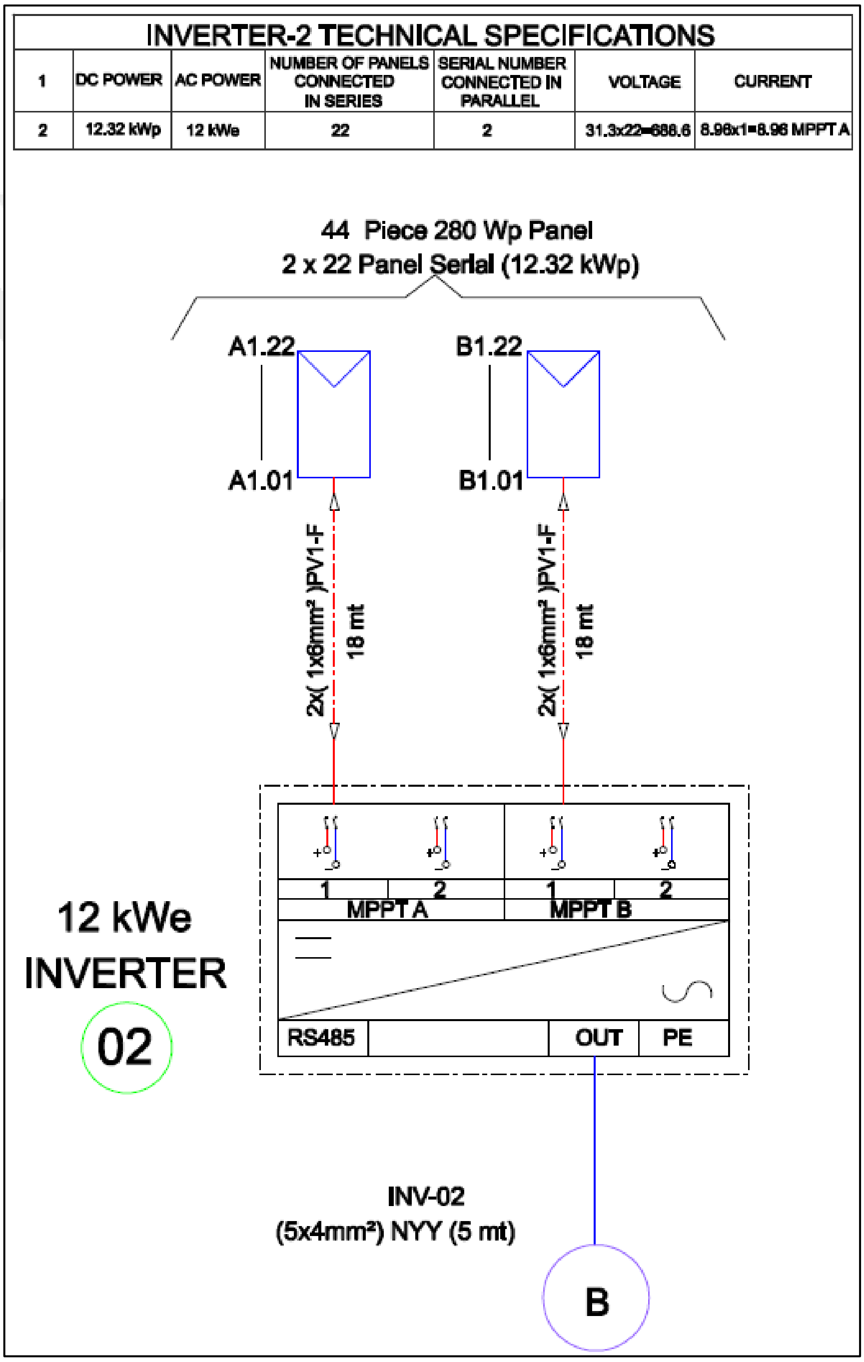


Figure 4.4: STS-02: Suburban train system SES principle single line project – inverter 2.

STS-03 Electric Collection Panel (Fig. 4.5).

It controls the operation of 2 inverters. It contains thermal magnetic switches that has the appropriate values which is found in the calculations.

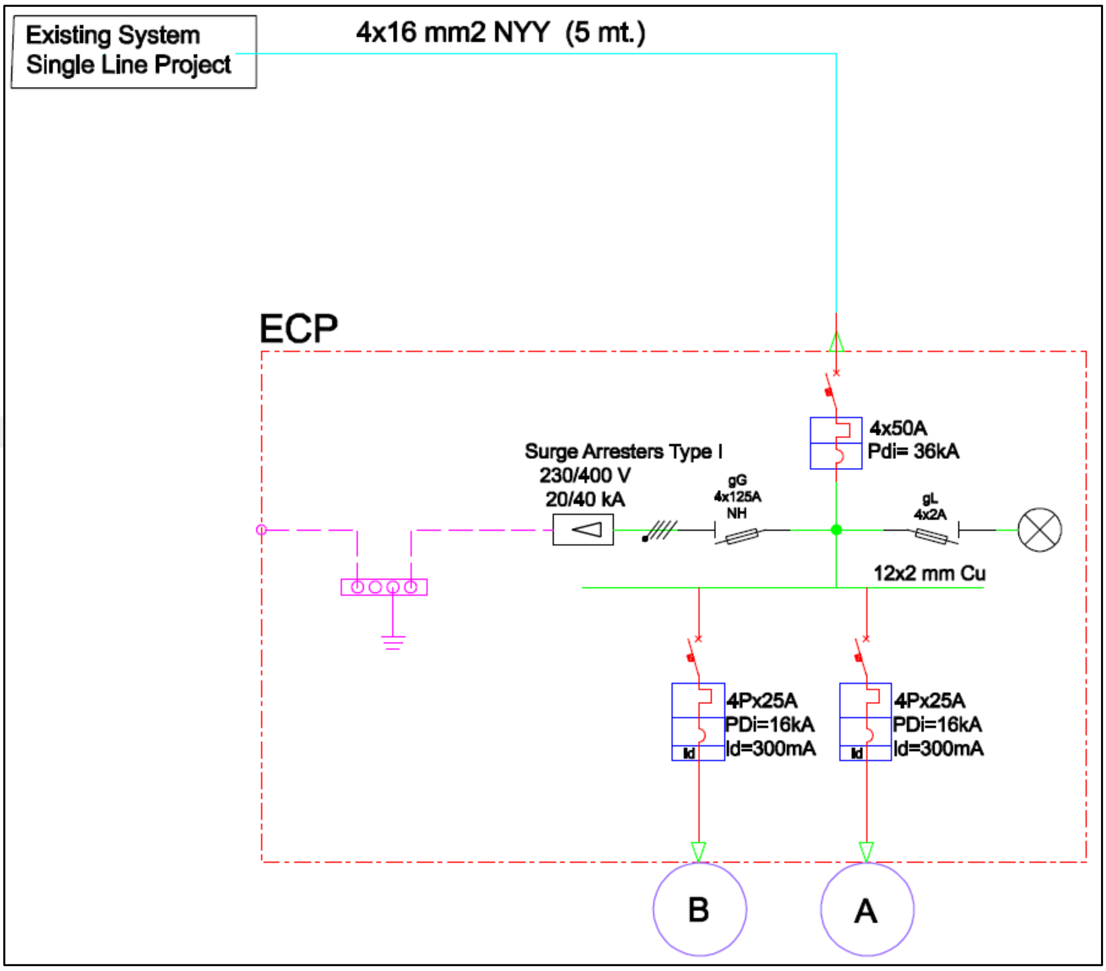


Figure 4.5: STS-03: Suburban train system SES principle single line project – ECP.

4.1.3. Stationary System With PV

In this part, we will work analysis of the situation when we put the same solar panels which is located on the suburban trains in the fixed station

Electrical Connection Design or Electric Single Line Project of Stationary System with PV is shown in Fig. 4.6.

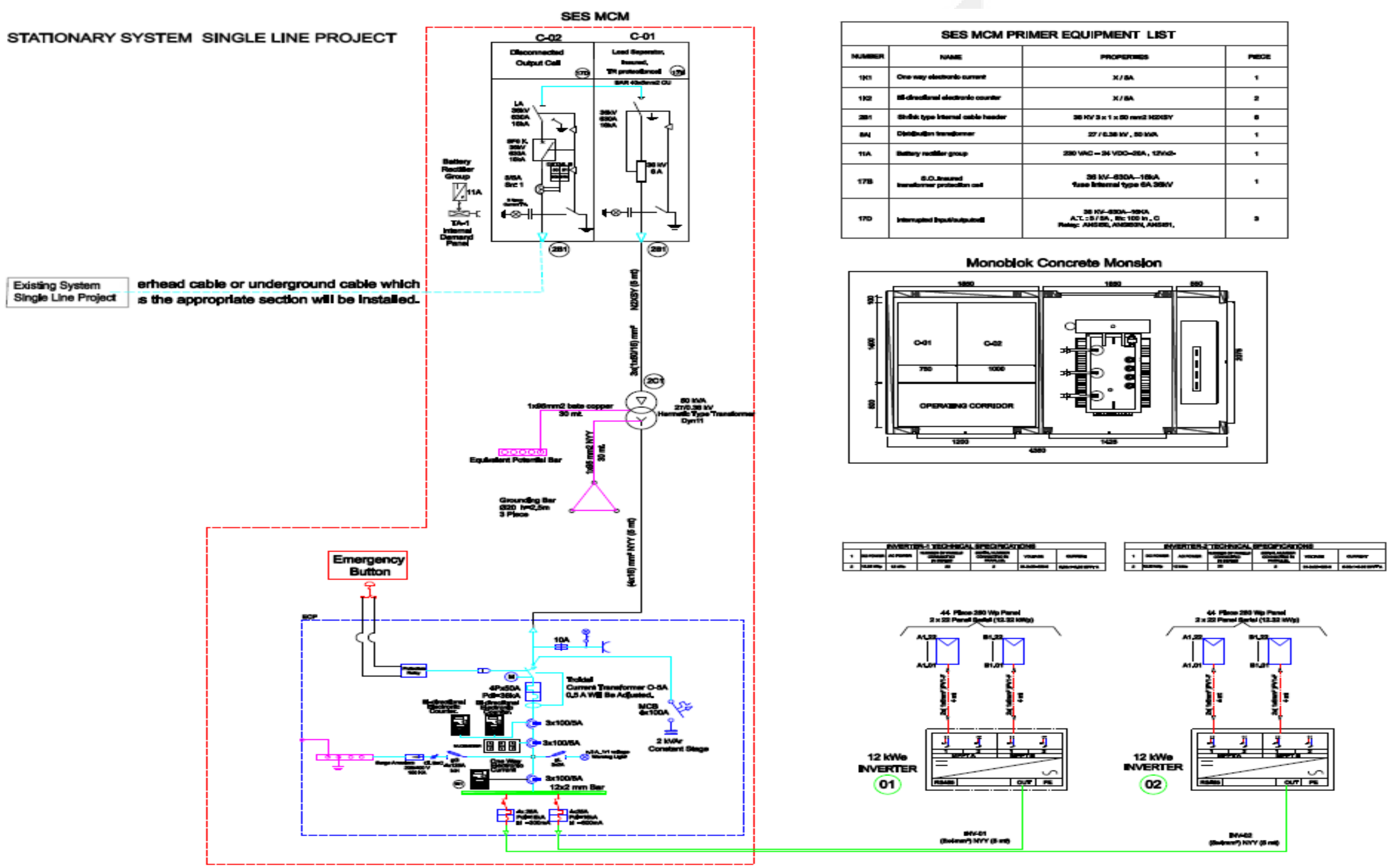


Figure 4.6: Stationary system SES principle single line project.

The working principle of Electric Single Line Project of Stationary System with PV is as follows:

We have 2 units of inverter and 2 arrays connected in parallel to each inverters, each array has 22 solar panels connected to each other in series.

Since each panel has a nominal voltage of 31.3 V,

The DC voltage of the inverter is 22 x 31.3 V = 688.6 V.

This DC voltage is converted to 380 V AC voltage by inverters

And

Transmitted to the LV (0.38 kV AC) side of Hermetic Transformer with 50 kVA, 27 / 0.38 kV after passing through ECP Board,

So,

The 27 kV AC voltage will be obtained by the transformer MV.

The obtained 27 kV AC voltage will be transmitted load disconnecting fuse transformer protection cell, from the output of disconnected output cell with overhead conductors or underground cables to The Train Line Feeding Center.

27 kV AC voltage from The Train Line Feeding Center will be transmitted to the MV side the transformer which has 27 kV / 380 V in the train

380 V AC voltage will be obtained by LV side of this transformer.

380 V AC voltage will be transmitted to the APU1 and APU2 Units from the main bar.

The energy that APU1 + APU2 need 2 x 41.606 W = 83.212 W

However, since the total power of our 2 inverters are 24.000 W,

Our Solar Energy System (SES) will not be able to supply all these loads. Therefore, Our Solar Energy System (SES) is a network-connected system.

Now let us explain step by step this system;

SS-01 The Electrical Connection Project of Solar Panels and Inverter 1 (Fig. 4.7)

We have 2 units of inverter and 2 arrays connected in parallel to each inverters, each array has 22 solar panels connected to each other in series. Since each panel has a nominal voltage of 31.3 V. The DC voltage transmitted from the arrays to the inverter is 22 x 31.3 V = 688.6 V. This DC voltage will be converted to 380 V AC voltage by the inverters.

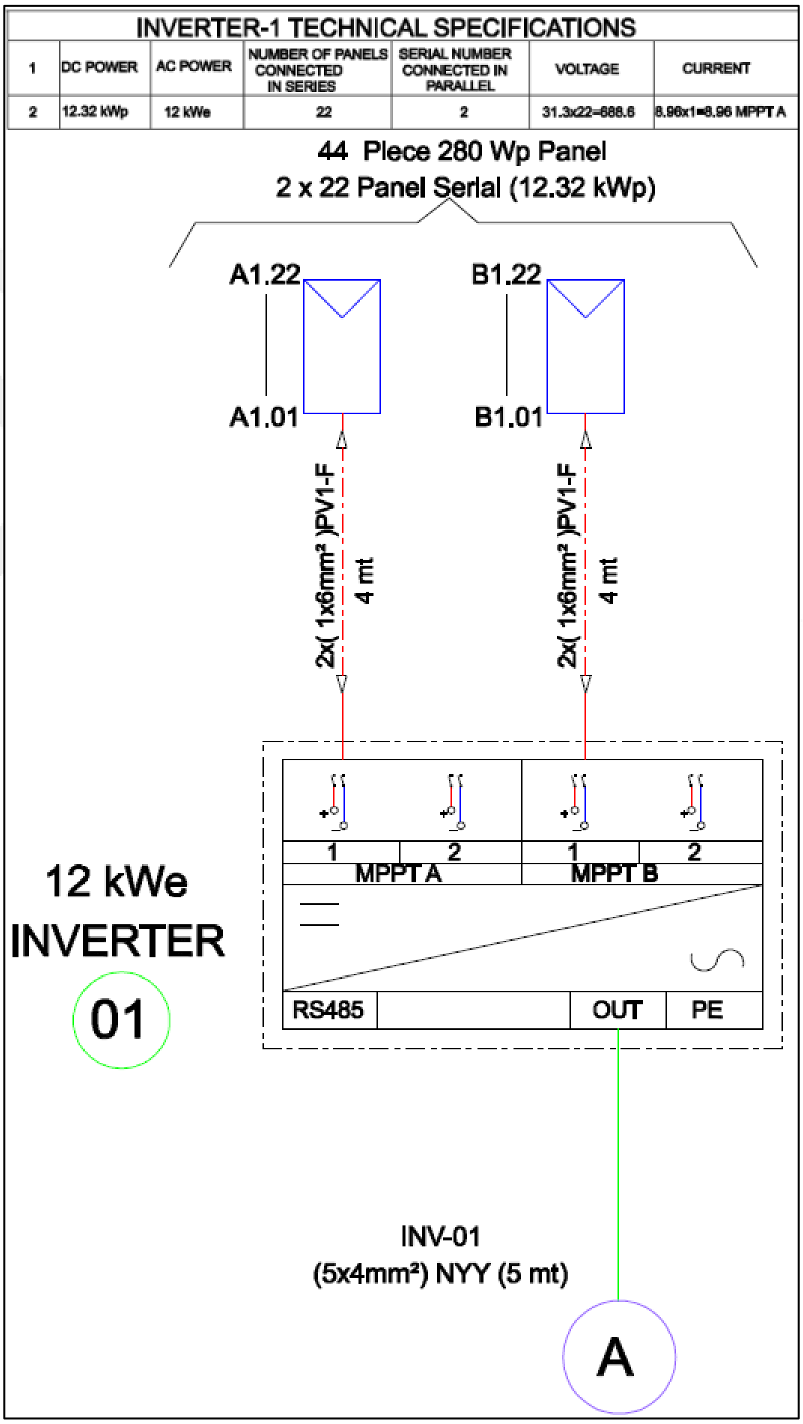


Figure 4.7: SS-01: Stationary system SES principle single line project – inverter 1.

SS-02 The Electrical Connection Project of Solar Panels and Inverter 2 (Fig 4.8).

We have 2 units of inverter and 2 arrays connected in parallel to each inverters, each array has 22 solar panels connected to each other in series. Since each panel has a nominal voltage of 31.3 V. The DC voltage transmitted from the arrays to the inverter is 22 x 31.3 V = 688.6 V. This DC voltage will be converted to 380 V AC voltage by the inverters.

INVERTER-2 TECHNICAL SPECIFICATIONS

1	DC POWER	AC POWER	NUMBER OF PANELS CONNECTED IN SERIES	SERIAL NUMBER CONNECTED IN PARALLEL	VOLTAGE	CURRENT
2	12.32 kWp	12 kWe	22	2	31.3x22=688.6	8.96x1=8.96 MPPT A

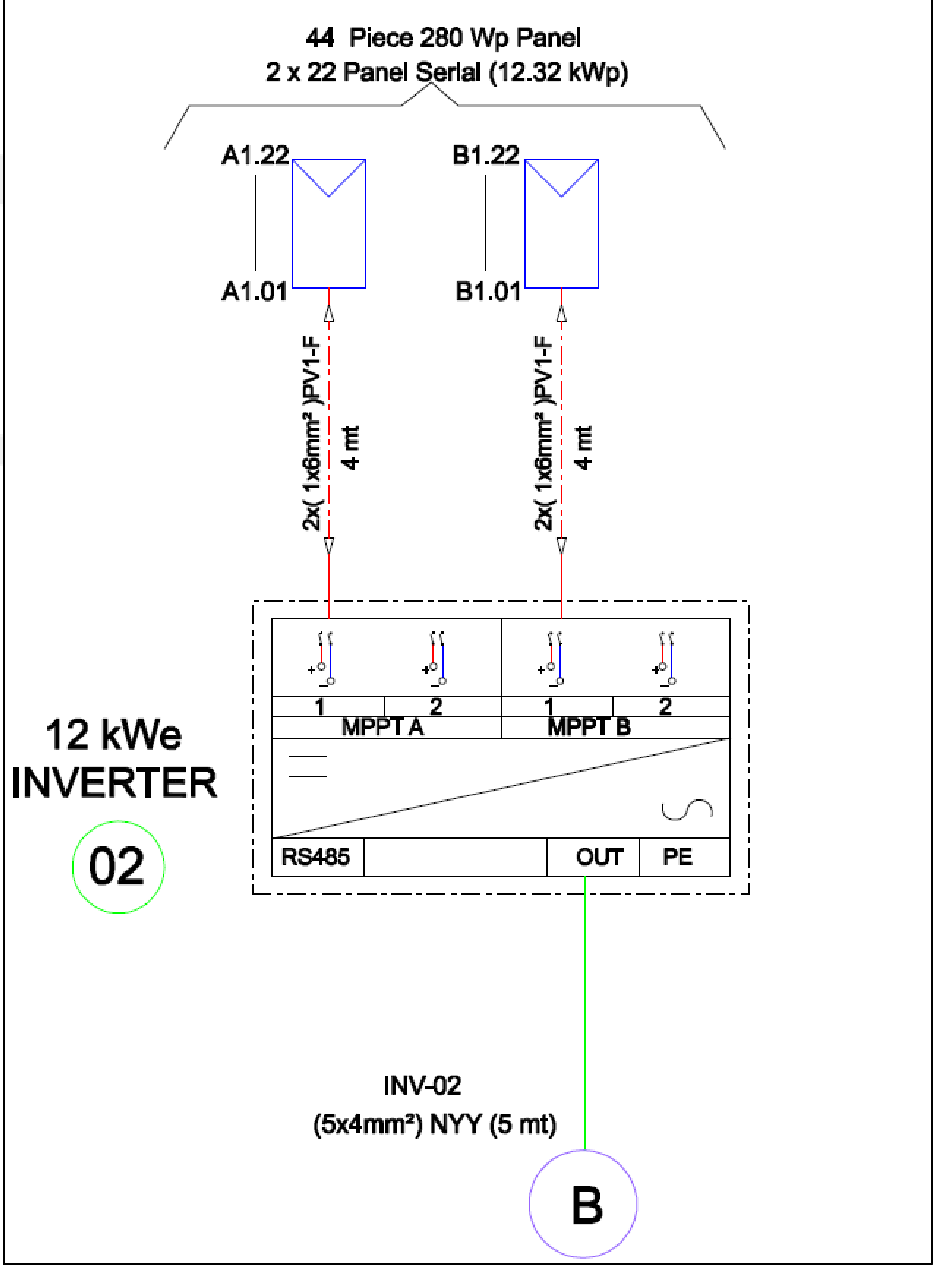


Figure 4.8: SS-02: Stationary system SES principle single line project – inverter 2.

SS-03 Electric Collection Panel (Fig. 4.9)

This AC voltage comes to Electric Collection Panel that controls the operation of 2 inverters. ECP Board contains current transformer, protection relay, thermal magnetic switches that has the appropriate values which is found in the calculations. It has 2 pieces bidirectional counter. Each of them is real and the other one is back up. We can follow the power which is produced and consumed for the system with these counters.

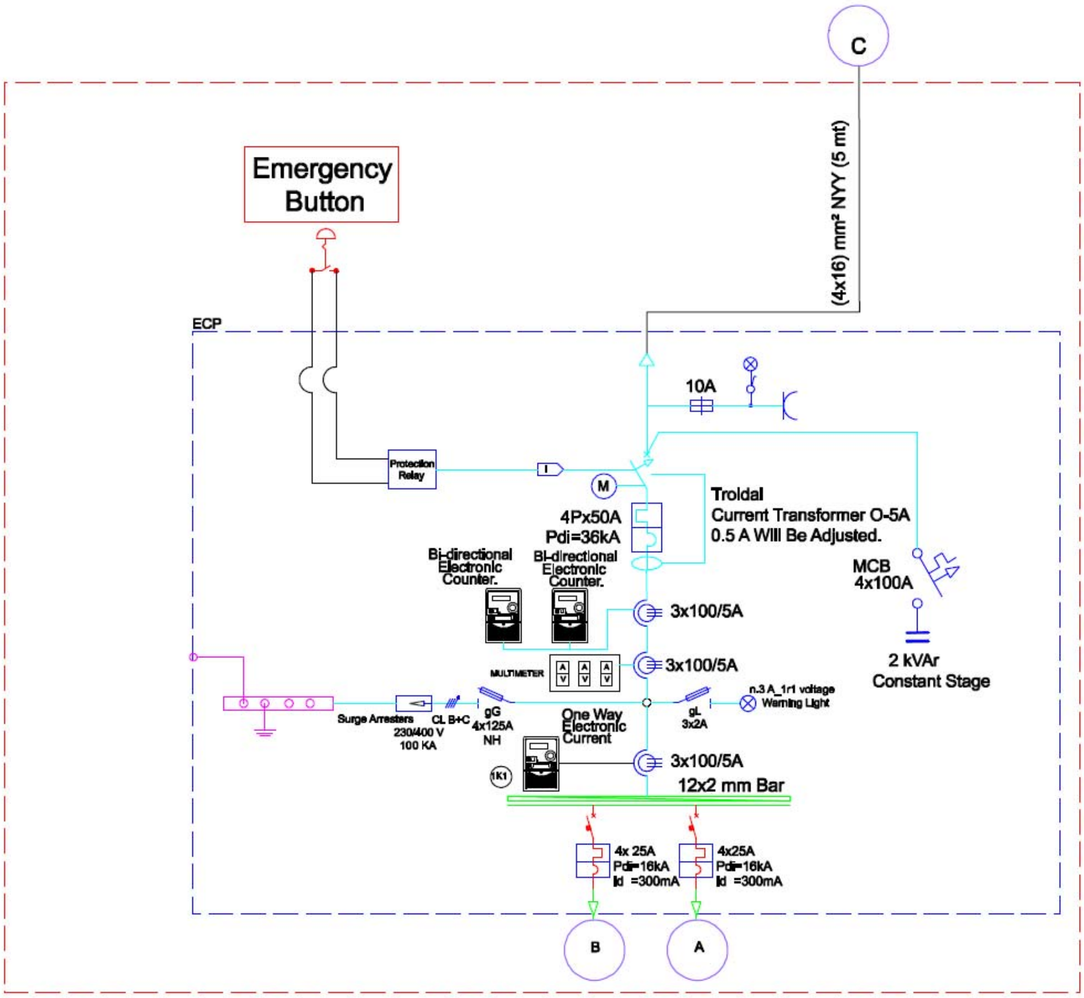


Figure 4.9: SS-03: Stationary system SES principle single line project – ECP.

SS-04 Hermetic Transformer (Fig. 4.10)

After passing through Measurement Electric Collection Panel, It is transmitted to the LV (0.38 kV AC) side of Hermetic with 50 kVA, 27 / 0.38 kV so the 27 kV AC voltage will be obtained by the transformer MV.

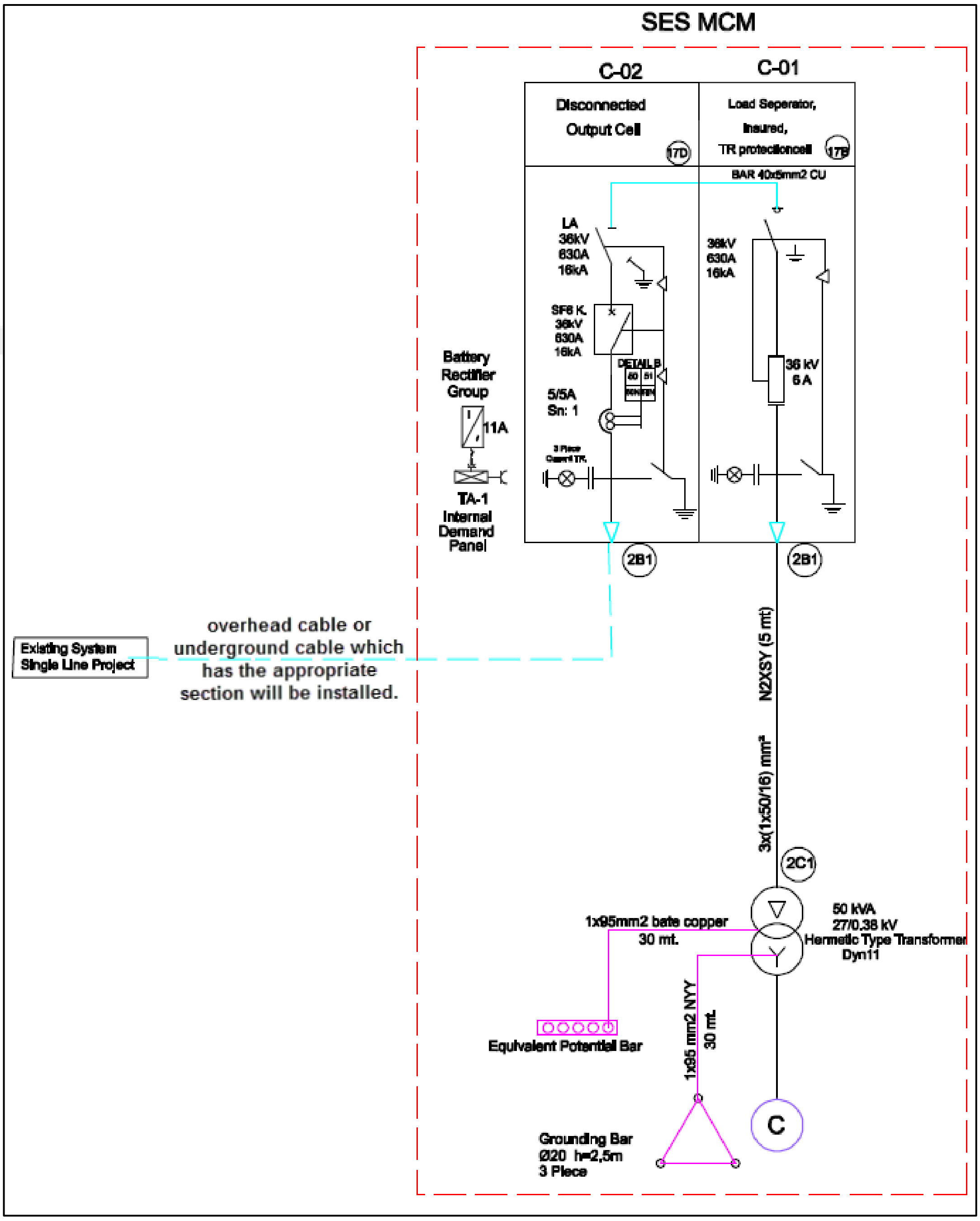


Figure 4.10: SS-04: Stationary system SES principle single line project – Hermetic transformer.

The obtained 27 kV AC voltage will be transmitted load disconnecting fuse, transformer protection cell, from the output of disconnected output cell with overhead conductors or underground cables to The Train Line Feeding Center.

SS-MCM Monoblock Concrete Mansion (Fig. 4.11)

It has transformer protection cell and disconnected output cell. The following table and drawing have primer equipment list and dimensions of MCM

SES MCM PRIMER EQUIPMENT LIST

NUMBER	NAME	PROPERTIES	PIECE
1K1	One way electronic current	X / 5A	1
1K2	Bi-directional electronic counter	X / 5A	2
2B1	Shrink type internal cable header	36 KV 3 x 1 x 50 mm2 N2XSY	6
8AI	Distribution transformer	27 / 0.38 kV , 50 kVA	1
11A	Battery rectifier group	230 VAC – 24 VDC–20A , 12Vx2-	1
17B	S.O.Insured transformer protection cell	36 kV–630A–16kA fuse internal type 6A 36kV	1
17D	Interrupted input/outputcell	36 KV–630A–16KA A.T. : 5 / 5A , Ith: 100 In , C Relay: ANSI50, ANSI50N, ANSI51,	3

Monoblok Concrete Monsion

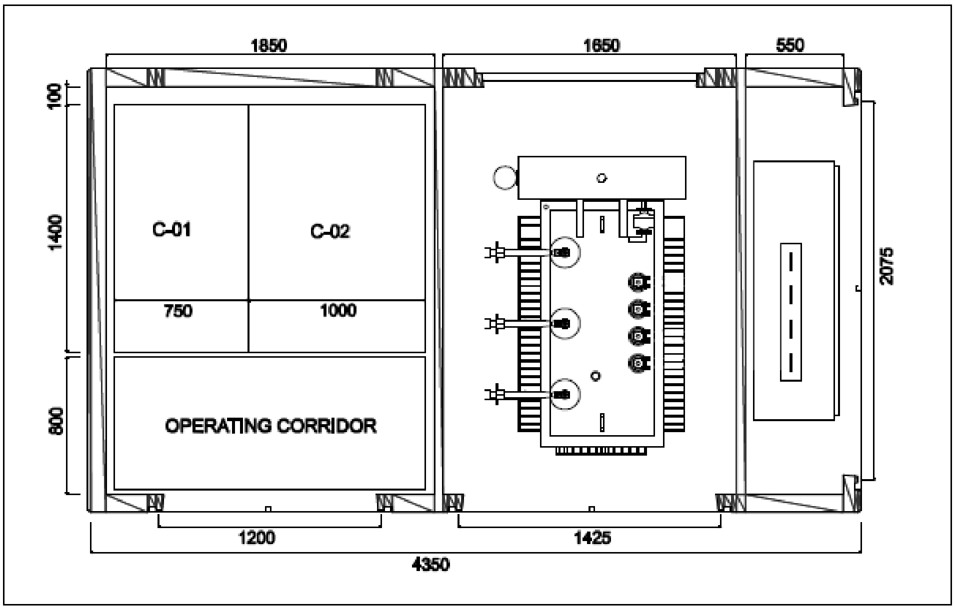


Figure 4.11: SS-MCM: Stationary system SES principle single line project – MCM.

4.2. Electrical Connection System Calculations

In this section, we will talk about panel inverter compatibility, PV module, PV inverter and system information, PV module insulator control, determination of maximum and minimum module dimensions in a serial, efficiency graphic which is related with temperature, maximum minimum module quantity in a serial panel - inverter confidence control, the calculations of high voltage - low voltage cable sections, control by nominal current, control by voltage drop, cable control between transformer and main panels, IEC 601364-5-52 Standard Tables, cable control between panel and inverter, current carrying control for number 01- 1A array, power loss, voltage drop, current capacity, thermal magnetic switch and fuse selection account, bar section calculations, primer equipment calculations.

4.2.1. Panel Invertor Compliance Calculations

In this section, we will talk about The Compatibility of Panel and Inverter Calculations, System Design Fundamentals in Fig. 4.12. Maximum-Minimum Module Quantity In A Serial in Fig. 4.14, Panel-Inverter Conformity Control in Fig. 4.15.

4.2.1.1. The Compatibility of Panel and Inverter Calculations

System Design Fundamentals

PV Module Information

Producer	:	Yingli Green Energy	
PV Module Type	:	YL280C-30b	
Number of cells	:	60	adet
Cell Type	:	Poli-Kristal	
Cell Dimension	:	60 (156 x 156)	
Weight	:	18,5	Kg.
Connection Type	:	MC4	

Nom. Power	Pmax.	:	280	Wp
Nom. Power Voltage	Vmpp	:	31,3	V
Nom. Power Current	Impp	:	8,96	A
Short Circuit Current	Isc	:	9,5	A
Open Circuit Voltage	Voc	:	39,1	V
Max. System Voltage		:	1000	V
Diode Current Voltage		:	15	A

NOCT		:	46	°C
Temperature Coefficient	Isc	:	0,04	%/°C
Temperature Coefficient	Voc	:	-0,30	%/°C
Temperature Coefficient	Vmpp	:	-0,380	%/°C
Temperature Coefficient	Pmax	:	-0,380	%/°C

From Panel Cataloque

Inverter Information

Producer	:	SMA	
Inverter Type	:	SUNNY TRİPOWER 12000TL	
1/3 phase	:	3 phase	
Inverter Dimensions	:	690 x 665 x 265	(HxWxD)
Array/Central Inverters	:	Array Inverter	
Protection Class	:	IP65	
Weight	:	38	Kg.

DC-Side

Max .DC Input Voltage	Vmax,abs	:	1000	V
	Vstart	:	188	V
	Vdc min	:	150	V
	Vdc max	:	800	V
MPPT number		:	2	adet
Max MPPT DC Input Power	Pmppt max	:	18000	KW
Max. DC Input Current	Idc maks.	:	28	A
Max. DC Input Current MPPT	Idc-mppt maks.		18	A
Max. DC Input Current MPPT	Idc-mppt maks.		10	A

AC-Side

Nominal AC Power	Pacr	:	12000	Kw
Max. AC Power	Pac max.	:	12000	kWe
Nominal AC Voltage	Vacr	:	380	V
AC Voltage Range	Vmin	:	160	V
	Vmaks.	:	280	V
Maks. AC Akımı	Iac,maks		34,8	A
Nominal frequency	facr	:	50	Hz
Frequency Range	fmim..fmaks.	:	50..60	Hz
Nom. Power Factor	Cosphiacr	:	>0,9	

From Inverter Cataloque

System Information

Total Number of PV Module	:	88	piece
Total Number of Inverter	:	2	piece
Installed Power (DC)	:	24,64	kWp
Installed Power (AC)	:	24,00	kWe

Figure 4.12: System design fundamentals.

Determination of Maximum and Minimum Module Dimensions In an Array

In inverter designs, temperatures and radiation commitments of the modules should be considered. Generator voltage extremely depends on temperature. Inverter's working range should be adjusted considering PV generator is affected by the temperature is shown in Fig. 4.13.

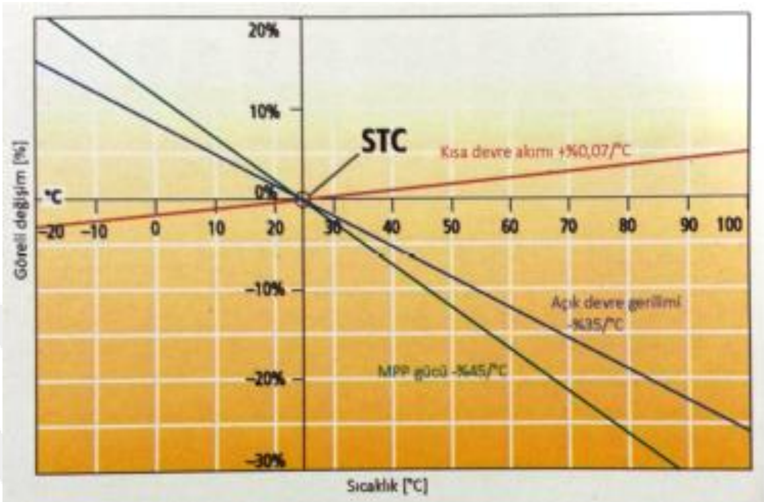


Figure 4.13: Efficiency graphic which is related with temperature.

In medium levelled climate regions, first border value is obtained in winter at 10 °C temperature. At low temperature, voltage of modules increases. Highest voltage in a working condition is open circuit current at low temperature. If the inverter shuts down due to any network errors, high open circuit voltage can occur when inverter is back online. This voltage should be lower than maximum DC input voltage in inverter. Or else, inverter can be damaged. So, maximum module numbers in series circuit can be obtained with the way of multiplying inverters' maximum input voltage by open circuit voltage of the module at -10 °C.

$$\eta_{max}=(U_{\text{inverter } max.})/(U_{L(module\ Tmin°C)})$$

In % L of information per °C:

$$U_{(module\ Tmin.°C)}=(1-\Delta T°C x\ ß_{L/(}\%100))\ x\ U_{L(STC)}$$

In % L of information per °C:

$$U_{(module\ Tmin\ °C)}=U_{L(STC)}\ -\Delta T°C\ x\ ß_{L}$$

In summer, modules may warm up to 70 °C on ceilings. Generally, minimum module number in a series can be detected with the help of this temperature. When radiation occurs in summer, FV facility has lower voltage than mentioned due to high temperature. Working voltage of the facility is under inverter's MPP voltage, maximum voltage possible is not obtained and even cause inappropriate shut down. Therefore, size is chosen with the way of obtaining minimum number of serially connected modules in a series by multiplication of inverter's minimum input voltage and module's voltage at 70 °C MPP. To identify module quantity in series circuit lower bound value is obtained.

$$\eta_{min} = (U_{MPP(\text{inverter } min)}) / (U_{MPP(module\ Tmax\ °C)})$$

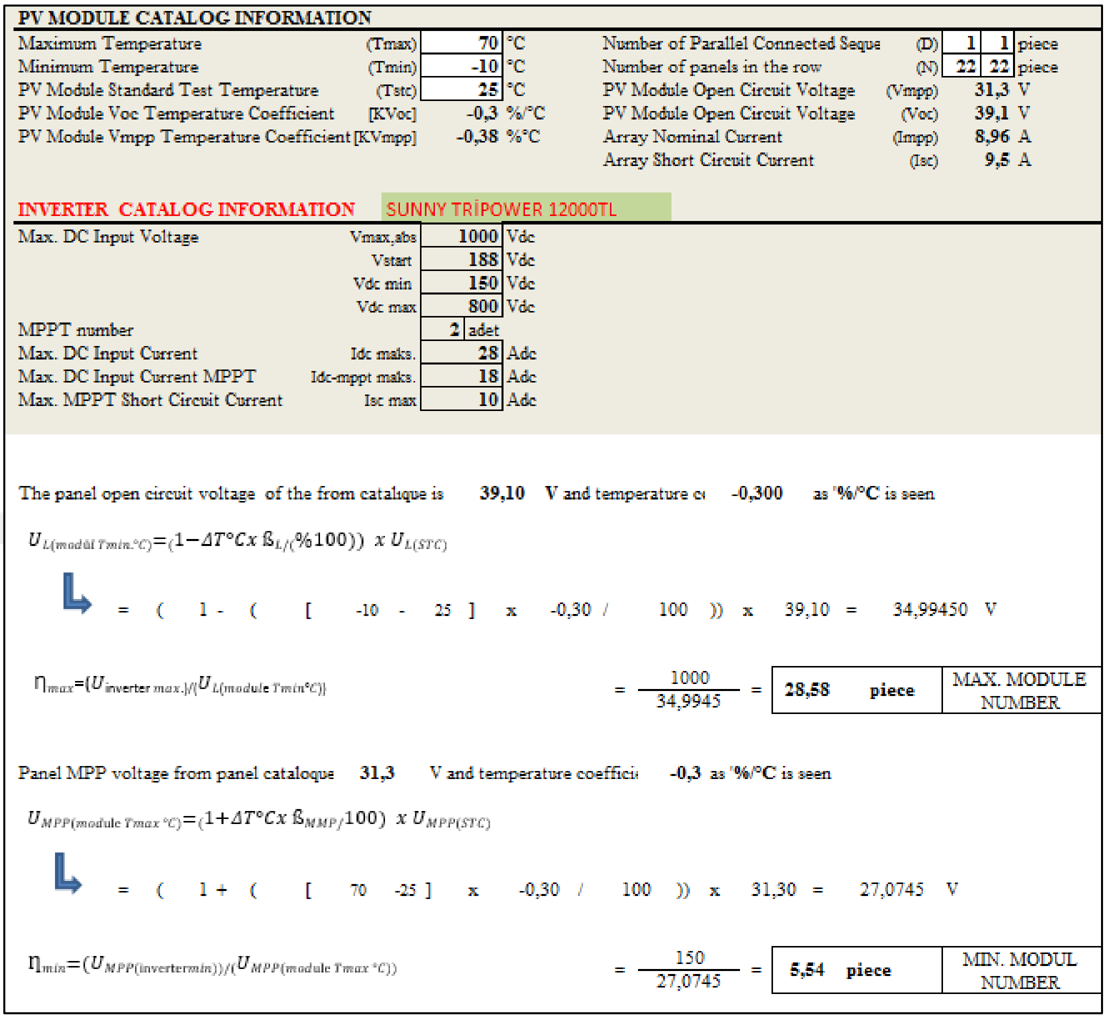
In % L of information per °C:

$$U_{MP(module\ Tmax\ °C)} = (1 + \Delta T°C x\ ß_{MMP/}100)\ x\ U_{MPP(STC)}$$

In % L of information per °C:

$$U_{MP(moduleTmax\ °C)} = U_{L(STC)} - \Delta T°C\ x\ ß_{L}$$

4.2.1.2. Max-Minimum Module Quantity In A Serial



PV MODULE CATALOG INFORMATION

Maximum Temperature	(Tmax)	70	°C	Number of Parallel Connected Seque	(D)	1 1	piece
Minimum Temperature	(Tmin)	-10	°C	Number of panels in the row	(N)	22 22	piece
PV Module Standard Test Temperature	(Tstc)	25	°C	PV Module Open Circuit Voltage	(Vmpp)	31,3	V
PV Module Voc Temperature Coefficient	[KVoc]	-0,3	%/°C	PV Module Open Circuit Voltage	(Voc)	39,1	V
PV Module Vmpp Temperature Coefficient	[KVmpp]	-0,38	%°C	Array Nominal Current	(Impp)	8,96	A
				Array Short Circuit Current	(Isc)	9,5	A

INVERTER CATALOG INFORMATION SUNNY TRİPOWER 12000TL

Max. DC Input Voltage	Vmax,abs	1000	Vdc
	Vstart	188	Vdc
	Vdc min	150	Vdc
	Vdc max	800	Vdc
MPPT number		2	adet
Max. DC Input Current	Idc maks.	28	Adc
Max. DC Input Current MPPT	Idc-mppt maks.	18	Adc
Max. MPPT Short Circuit Current	Isc max	10	Adc

The panel open circuit voltage of the from catalıque is **39,10** **V** and temperature co **-0,300** as '**%/°C** is seen

$U_{L(modül\ Tmin.°C)} = (1 - \Delta T°C x\ ß_{L/}(\%100))\ x\ U_{L(STC)}$

= (1 - ([-10 - 25] x -0,30 / 100)) x 39,10 = 34,99450 V

$\eta_{max} = (U_{inverter\ max.})/(U_{L(module\ Tmin°C)})$ = 1000 / 34,9945 = **28,58** **piece** MAX. MODULE NUMBER

Panel MPP voltage from panel cataloque **31,3** V and temperature coeffici **-0,3** as '**%/°C** is seen

$U_{MPP(module\ Tmax\ °C)} = (1 + \Delta T°C x\ ß_{MMP/}100)\ x\ U_{MPP(STC)}$

= (1 + ([70 -25] x -0,30 / 100)) x 31,30 = 27,0745 V

$\eta_{min} = (U_{MPP(invertermin)})/(U_{MPP(module\ Tmax\ °C)})$ = 150 / 27,0745 = **5,54** **piece** MIN. MODUL NUMBER

Figure 4.14: Max-min module quantity in a serial.

4.2.1.3. Panel - Inverter Conformity Control

PANEL - INVERTER COMFORMITY CONTROL

Inverter Characteristics Properties

Max. Array Voltage	= N x Voc x [1-(KVoc x [Tmin-Ts]/100)]								
	= 22 x 39,1 x [1-(-0,3 x [-10 -25] / 100)]	=	769,9	V	<	1000	V	SUITABLE
Min. Array Voltage	= N x Vmpp x [1+(KVoc x [Tmax-Ts]/100)]								
	= 22 x 31,3 x [1+(-0,3 x [70 -25] / 100)]	=	595,6	V	>	150	V	SUITABLE
Max.Mppt Voltage	= N x Vmpp x [1+(KVmpp x [Tmin-Ts])/100]								
	= 22 x 39,10 x [1-(-0,38 x [-10 -25] / 100)]	=	745,8	V	<	800	V	SUITABLE
Max.Mppt Voltage	= N x Vmpp x [1+(KVmpp x [Tmax-Ts])/100]								
	= 22 x 31,3 x [1+(-0,38 x [70 -25] / 100)]	=	570,8	V	>	440	V	SUITABLE

Panel Temperature Coefficient. From Panel Cataloque.

MAXIMUM DC CURRENT CONTROL

Mppt A Array Max. Current	=	D x Impp	=	1 x 8,96	=	8,96 A	<	18 A	SUITABLE
Mppt B Array Max. Current	=	D x Impp	=	1 x 8,96	=	8,96 A	<	10 A	SUITABLE

Panel Characteristics Properties

Figure 4.15: Panel-Inverter conformity control.

4.2.2. HV - LV Cable Calculation

In this section we will talk about cable calculatıons which are cable sections control between SES MCM and Train Line Feeding Center in Fig. 4.16, cable sections control between SES MCM and Transformer in Fig. 4.17.

4.2.2.1. Cable Sections Control Between SES MCM and Train Line Feeding Center

Control Based on Loading Current

Voltage in cable when SES station work in optimum capacity;

$$I_G = \frac{S}{\sqrt{3} \times Un} = \frac{1 \times 50}{\sqrt{3} \times 27} = 1{,}069 \ A$$

Chosen Cable Type	:	3 x (1 x 50 / 16) mm² N2XSY
Voltage Capacity of Chosen Cable Type	:	**251 A**
Correction Parameter of Cable Quantity (ϒc)	:	**1**
Temperature Parameter (βc)	:	**35 °C => 0,8**

Voltage Capacity of Chosen Cable Type After Correction Parameter

$I_{dür.}$ = Icable x ϒc x βc

$I_{dür.}$ = 251 x 1 x 0,8

$I_{dür.}$ = **200,8 A**

I_G < $I_{dür.}$ => 1,069 A < 200,8 A chosen cable is appropriate to loading voltage according to calculations

Control Based on Decreasing Voltage:

Cable Dimension		=	**50**	mm²
Cable Length		=	**100**	m
Cable's AA resistance to 90 °C, the highest operation temperature	R	=	**0,193**	Ω/km-faz,
Cable's inductive resistance on flat installation	X	=	**0,192**	Ω/km-faz,
cosα		=	**0,95**	
sinα		=	**0,3**	

ΔV = √3 x I_G x L (R cosα + X sinα)

ΔV = √3 x 1,069 x 0,1 (0,193 x 0,95 + 0,192 x 0,3)

ΔV = 0,04462 V

ΔV% = (ΔV / Un) x 100

ΔV% = (0,045 / 34500) x 100

ΔV% = 0,0001 % Decreasing voltage is at ignorable level.

Figure 4.16: Cable sections control between SES MCM and train line feeding center.

4.2.2.2. Cable Sections Control Between SES MCM And Transformer

Control Based on Loading Current

Voltage in cable when SES station work in optimum capacity;

$$I_G = \frac{S}{\sqrt{3} \times Un} = \frac{1 \times 50}{\sqrt{3} \times 27} = 1{,}069 \quad A$$

Chosen Cable Type	:	3	x	(	1	x	50	/	16	)	mm²	N2XSY
Voltage Capacity of Chosen Cable Type	:	251	A									
Correction Parameter of Cable Quantity (ϒc)	:	1										
Temperature Parameter (βc)	:	35 °C	=>	0,8								

Voltage Capacity of Chosen Cable Type After Correction Parameter

$$I_{döz.} = I_{kablo} \times ϒc \times βc$$
$$I_{döz.} = 251 \times 1 \times 0{,}8$$
$$I_{döz.} = 200{,}8 \quad A$$

$I_G < I_{döz.}$ => 1,069 A < 200,8 A chosen cable is appropriate to loading voltage according to calculations

Control Based on Decreasing Voltage:

Cable Dimension		=	50	mm²
Cable Length		=	5	m
Cable's AA resistance to 90 °C, the highest operation temperature	R	=	0,193	Ω/km-faz,
Cable's inductive resistance on flat installation	X	=	0,192	Ω/km-faz,
cosα		=	0,95	
sinα		=	0,3	

$$\Delta V = \sqrt{3} \times I_G \times L \; (R \; \cos\alpha + X \; \sin\alpha)$$
$$\Delta V = \sqrt{3} \times 1{,}069 \times 0{,}005 \; (0{,}193 \times 0{,}95 + 0{,}192 \times 0{,}3)$$
$$\Delta V = 0{,}002231 \quad V$$

$$\Delta V\% = (\Delta V / Un) \times 100$$
$$\Delta V\% = (0{,}002 / 31500) \times 100$$

$\Delta V\%$ = 0,00001 % Decreasing voltage is at ignorable level.

Figure 4.17: Cable sections control between SES MCM and transformer.

4.2.2.3. Cable Calculations

In this section we will talk about cables calculatıons are between transformer and electric collection panel in Fig. 4.18, between electric collection panel and inverter 1 in Fig. 4.19, with the power loss and voltage drops calculations of all AC cables in Fig. 4.20.

CABLE CALCULATIONS BETWEEN TRANSFORMER AND ELECTRIC COLLECTION PANEL	
Selected cable type :	1 x (4 x 16 /) mm² NYY

Nk = 24 kW L = 5 m S = 16 mm^2 n = 1 piece K = 56 $m/\Omega.mm^2$ U = 380 V CosØ = 0,99	**CONTROL BY LOAD CURRENT** $I=(Nk)/(\sqrt{3}xU\ x\ Cos\text{Ø})$ $I = \frac{24000}{\sqrt{3} * 380 * 0{,}99}$ I = 36,83 A
	CONTROL POWER LOSS AND VOLTAGE REDUCTION POWER LOSS $p_K=(3\ x\ L\ x\ I^2)/(S\ x\ K)$ $P_k = \frac{3 * 5 * 36{,}83^2}{1 * 16 * 56}$ P_k = 22,71 Wp
	VOLTAGE REDUCTION $\%e=(\sqrt{3}\ x\ 100\ x\ L\ x\ I)/(S\ x\ U\ x\ K)$ $\%e = \frac{\sqrt{3} * 100 * 5 * 36{,}83}{1\ \ 16 * 380 * 56}$ %e = 0,094

Cable carrying capacity : 80 A (Appendix E and F)
Total cable carrying capacity : 1 x 80 A = 80 A
Cable multiplicity correction coefficient(Yc) : 0,8
Temperature coefficier 25 °C : 0,95
Ground thermal resistance for (K) 2.5K-m/w : 1

IEC 601364-5-52 STANDARD REFERENCE

The carrying capacity of cable when our consdered correction coefficient and temperature coefficient

80 A x 0,8 x 0,95 = 60,8 A
36,83 A < 60,8 A => Selected Cable **SUITABLE**
%e = 0,094 < 3 => Selected Cable **SUITABLE**

Figure 4.18: Between transformer and electric collection panel cable calculations.

CABLE BETWEEN ELECTRIC COLLECTION PANEL AND INVERTER-1

Selected Cable Type : (5 x 4 /) mm^2 NYY

Nk = 12 kW	**CONTROL BY LOAD CURRENT**
L = 5 m	$I=(Nk)/(\sqrt{3} x U x Cos\text{Ø})$ $I = \frac{12000}{\sqrt{3} * 380 * 0{,}99}$
S = 4 mm^2	I = 18,42 A
n = 1 piece	**CONTROL POWER LOSS AND VOLTAGE REDUCTION**
K = 56 m/Ω.mm^2	POWER LOSS
U = 380 V	$p_K=(3 x L x I^2)/(S x K)$ $P_k = \frac{3 * 5 * 18{,}42^2}{1 * 4 * 56}$
CosØ = 0,99	P_k = 22,71 Wp
	VOLTAGE REDUCTION
	$\%e=(\sqrt{3} x 100 x L x I)/(S x U x K)$ $\%e = \frac{\sqrt{3} * 100 * 5 * 18{,}42}{1 \quad 4 * 380 * 56}$
	%e = 0,187

Cable carrying capacity : 41 A

Total cable carrying capacity : 1 x 41 A = 41 A

Cable multiplicity correction coefficient(Yc) : 0,8

Temperature coefficier 25 °C : 0,95

Ground thermal resistance for (K) 2.5K-m/w : 1

IEC 601364-5-52 SSTANDARD REFERENCE

The carrying capacity of cable when our consdered correction coefficient and temperature coefficient

41 A x 1 x 0,95 = 31,16 A

18,42 A < 31,16 A => Selected cable **SUITABLE**

%e = 0,187 < 1 => Selected cable **SUITABLE**

Figure 4.19: Between electric collection panel and inverter 1 cable calculation.

THE POWER LOSS AND VOLTAGE DROPS CALCULATIONS OF ALL AC CABLES

AC Panel Name / Number	AC Installed Power (kWe)	Current (A)	Selected conductor: Cable number			Selected conductor: Section	Quantities	Power Loss (PL)	Power Loss (%Pk)	Voltage Reduction	Limit Value	Voltage Reduction Control	Warning and Cable Carrying Control
ECP-APU	24	36,83	1	4	x	16	5	22,71	0,095	0,094	3	Suitable	Suitable
INV-01	12	18,4	1	5	x	4	5	22,71	0,189	0,187	1	Suitable	Suitable
INV-02	12	18,4	1	5	x	4	5	22,71	0,189	0,187	1	Suitable	Suitable

Figure 4.20: The Power loss and voltage drops calculations of all AC cables.

4.2.2.4. IEC 601364-5-52 Standard Tables

Correction factors for applications on voltage capacities of cables in soil different from (20 ^{0}C), weakening factors for cables more than one circuit in soil, correction factors for applications on voltage capacities of cables in soil whose thermal resistance is different from 2.5 K-m/W for D method are given in Fig. 4.21.

TABLE A-1 (20 °C) CORRECTION FACTORS FOR APPLICATIONS ON VOLTAGE CAPACITIES OF CABLES IN SOIL DIFFERENT FROM (20 °C)

HEAT SOIL °C	INSULATION	
	PVC	XLPE-EPR
10	1,1	1,07
15	1,05	1,07
25	0,95	0,96
30	0,69	0,93
35	0,84	0,89
40	0,77	0,85
45	0,71	0,8
50	0,63	0,76
55	0,55	0,71
60	0,45	0,65
65	-	0,6
70	-	0,53
75	-	0,46
60	-	0,38

TABLE A-19 WEAKENING FACTORS FOR CABLES MORE THAN ONE CIRCUIT IN SOIL

MULTIPLE-VESSEL CABLES IN A SINGLE CELL				
CABLE NUMBER	GAP BETWEEN CELLS (a)			
	CELLS TOGETHER	0.25m	0.5m	1m
2	0,85	0,9	0,95	0,95
3	0,75	0,85	0,9	0,95
4	0,7	0,8	0,85	0,9
5	0,65	0,8	0,85	0,9
6	0,6	0,8	0,8	0,9

TABLE A-16 CORRECTION FACTORS FOR APPLICATION VOLTAGE CAPACITIES OF CABLES IN SOIL WHOSE THERMAL RESISTENCE IS DIFFERENT FROM 2.5K-m/W FOR D METHOD

THERMAL RESISTENCE 2.5K-m/W	1	1,5	2	2,5	3
CORRECTION FACTORS	1	1,5	2	2,5	3

NOTE:1- Correction factors are average of cable types and sizes of cables of table A.2-A.5. (+) (-) %5 is included in correction factors.
NOT:2- Correction factors are for cables through in-soil channel. For the cables directly in soil, thermal resistence will be bigger than resistences below 2.5K-m/W 2. More sensitive values can be calculated with methods id IEC 60287 if required.
NOTE:3-Correction factors are applicable for channels under 0.8 m deep soil.

Figure 4.21: IEC601364-5-52 Standard tables.

4.2.2.5. Cable Control Between Panel and Inverter

In this section catalogue information are given. They are as follows catalogue information of solar cables to be used in Table 4.3, correction factor table based on the method of cable installation in Table 4.4, permitted or suggested operation heat in Table 4.5.

Table 4.3: Catalogue information of solar cables to be used.

	Cable Dimention	Outer Diameter	Capacity	Resistance Value	Nominal Voltage	Operation Heat
	mm2	mm	A	Ω/Km	Vdc	°C
PV1-F	2,5	5,1	41	7,7	1000	-40 ...+90°C
PV1-F	4	2,8	55	4,75	1000	-40 ...+90°C
PV1-F	6	7	70	3,39	1000	-40 ...+90°C
PV1-F	10	8,2	98	1,91	1000	-40 ...+90°C

Table 4.4: Correction factor table based on the method of cable installation.

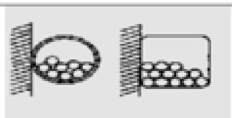
INSTALLATION METHOD	SYSTEM NUMBER														
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
	1,00	0,80	0,70	0,65	0,60	0,57	0,54	0,52	0,50	0,48	0,45	0,43	0,41	0,39	0,38
	1,00	0,85	0,79	0,75	0,73	0,72	0,72	0,71	0,70	0,70	0,70	0,70	0,70	0,70	0,70
	1,00	0,94	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90

Table 4.5: Permitted or suggested operation heat.

Environment Heat	40 °C	60 °C	70 °C	80 °C	85 °C	90 °C
30 °C	1	1	1	1	1	1
35 °C	0,71	0,91	0,95	0,95	0,95	0,96
40 °C	-	0,82	0,89	0,89	0,95	0,91
45 °C	-	0,71	0,84	0,84	0,90	0,87
50 °C	-	0,58	0,77	0,77	0,85	0,82
55 °C	-	0,41	0,71	0,71	-	0,76
60 °C	-	-	0,63	0,63	-	0,71
65 °C	-	-	0,55	0,55	-	0,65
70 °C	-	-	0,45	0,45	-	0,58
75 °C	-	-	-	-	-	0,50
80 °C	-	-	-	-	-	0,41
85 °C	-	-	-	-	-	0,29
90 °C	-	-	-	-	-	-
95 °C	-	-	-	-	-	-

4.2.2.6. Current Carrying Control For Number 01-1A Array

Current Carrying Control For Number 01-1A Array is calculated and is given in Fig. 4.22.

If cable's or channel's permanent current capacity is equal to or higher than Ik value under STC, PV arrays and PV partial generator cables/channels may not resist overload protection, according to VDE 0100 712 (IEC 60364-7). According to VDE 010 Chapter 712 Installation's being safe for short circuit and using protection modules group II will be enough to provide safety.

Iz range is needed to be ≥ 1,25 * Ik STC range.

Higher safety is needed to be provided in especially buildings or on flammable roof covering because there is always a fire risk due to static light arches. Malfunction may occur in case the facility works under overduration or bad environment and all current of the generator may flow in one arrays. Maximum current in module or arrays is equal to all arrays' short current (Ik arrays) minus short current of a arrays. In this case;

Imaks = 1,25 * [∑Ik arrays – Ik arrays] is the calculation.

Maximum current value in module value to be used and in Inverter 1 line is;

Imaks = 1,25 * [∑Ik arrays – Ik arrays] = 1,25 x **9,5** = **11,875** A o.

Based onone vessel-cable catalogue information in Table 1, current capacity of 6mm2 solar cable is **70A**.

When correction factor is used in one vessel-cables in Table 2, correction factor is **0,70** in the case of side by side or dense installation of cables in cable tray.

Correction factor for temperatures in Table 3; **55** °C permitted temperature for solar cable **90** °C

is the **0,76** is the value used,

6mm² is the current value of the solar cable;

I =Cable's current capacity * temperature factor * Correction factor based on cable installation method

I = 0 x 0,76 x 0,00 = **0** A.;

0 A ≥ **11,88** A Therefore, chosen cable's current capacity, temperature factor, Correction factor based on cable installation method and İnverter input are considered and all the parallel arrays are applicable for shortcut circuits.

Figure 4.22: Current carrying control for number 01-1A array.

4.2.2.7. Power Loss, Voltage Drop and Current Capacity

Power loss, voltage drop and current capacity for DC cables are calculated and located in Fig. 4.23.

(DC) POWER LOSS CABLE CALCULATIONS

$p_K = (2 \times L \times I_{sc}^2)/(S \times K)$

P_K	W	=	Module or arrays line's power loss
L	mt.	=	Module or arrays line's line length in one layer
S	mm^2	=	Cable dimention of module or arrays line
K	$m/\Omega.mm^2$	=	Conductivity (56 for copper, 34 for aluminium)
I_{sc}	A	=	Shortcut Circuit

POWER LOSS CALCULATION FOR THE LONGEST DC CABLE

L	=	4	mt.
S	=	6	mm^2
K	=	56	$m/\Omega.mm^2$
I_{sc}	=	9,5	A

(+ ve -) cable length should be multiplied by to in order to find DC cable length.

$$P_k = \frac{2 \times 4 \times 9{,}5^{2}}{6 \times 56} = 2{,}149$$ is the calculation.

CABLE CALCULATIONS FOR (DC) VOLTAGE DECLINE

$\%e = (2 \times 100 \times L \times I_{sc})/(S \times U_{MPPT} \times K)$

%e		=	Voltage decline rate
L	mt.	=	One layer's length of module or arrays line
S	mm^2	=	Cable dimention of module or arrays line
K	$m/\Omega.mm^2$	=	Conductivity (56 for copper, 34 for aluminium)
I_{sc}	A	=	Short Circuit Current
U_{MPPT}	V	=	Arrays Voltage
N		=	Serially connected module number in a range

DC VOLTAGE DECLINE CALCULATION FOR THE LONGEST CABLE

L	=	4	mt.
S	=	6	mm^0
K	=	56	$m/\Omega.mm^2$
I_{sc}	=	9,50	A
V_{MPPT}	=	31,30	V
N	=	22	adet

$U_{MPPT} = N \times V_{MPPT} = 22 \times 31{,}30 = 688{,}6$ V

$$\%e = \frac{2 \times 100 \times 4 \times 9{,}50}{6 \times 688{,}6 \times 56} = 0{,}033$$ is the calculation

Figure 4.23: Power loss, voltage drop and current capacity.

4.2.2.8. Power Loss For All Arrays and Voltage Drop Calculations

Power loss for all arrays and voltage drop calculations and array line Informatıon are given in Table 4.6.

Table 4.6: Power loss for all arrays and voltage drop calculations.

AC Panel Nr	Inverter Nr.	Array Nr.	Panel Quantity	Panel Power P (W)	Cable Length L (mt.)	Cable Dimention (S - mm2)	ARRAY LINE INFORMATION									
							Conductivity (m/Ω.mm^2)	Total Array Power P (W)	Current I_{sc} (A)	Voltage (Panel) V_{MPPT} (A)	Voltage (Array) U_{MPPT} (V)	Power Loss Pk (W)	Power loss %Pk (W)	Voltage Decline U_L (V)	Voltage Decline	Border Value (%)
1	01	A1	22	280	4	6	56	6160	9,5	31,3	688,6	2,149	0,035	0,226	0,033	1
		A2														
		B1	22	280	4	6	56	6160	9,5	31,3	688,6	2,149	0,035	0,226	0,033	1
		B2														
	02	A1	22	280	4	6	56	6160	9,50	31,3	688,6	2,149	0,035	0,226	0,033	1
		A2														
		B1	22	280	4	6	56	6160	9,5	31,3	688,6	2,149	0,035	0,226	0,033	1
		B2														

4.2.2.9. Cables Sections

All cables are used in the project is shown following tables; between transformer and MCM with train and line feeding center cable sections in Table 4.7, between ECP and transformer cable sections (4X) in Table 4.8, between ECP and inverter cable sections (5X) in Table 4.9 and AC cable sections in Table 4.10.

Table 4.7: Between transformer and MCM with train and line feeding center cable sections.

Between Transformer And SES MCM With SES MCM And Traın Line Feeding Center Cables					
Normally Section			Type	Current Carrying Capacity	
1	X	50	N2XSY	251	A
1	X	70	N2XSY	306	A
1	X	95	N2XSY	363	A
1	X	120	N2XSY	410	A
1	X	150	N2XSY	449	A
1	X	185	N2XSY	503	A
1	X	240	N2XSY	576	A

Table 4.8: Between ECP and transformer cable sections (4X).

Between ECP And Transformer Cables					
Normally Section			Type	Current Carrying Capacity	
4	X	50	NYY	185	A
4	X	70	NYY	228	A
4	X	95	NYY	275	A
4	X	120	NYY	313	A
4	X	150	NYY	353	A
4	X	185	NYY	399	A
4	X	240	NYY	464	A

Table 4.9: Between ECP and inverter cable sections (5 X).

Between ECP And Inverter Cables					
Normally Section			Type	Current Carrying Capacity	
5	X	10	NYY	78	A
5	X	16	NYY	101	A
5	X	25	NYY	131	A
5	X	35	NYY	157	A
5	X	50	NYY	185	A
5	X	70	NYY	212	A

Table 4.10: AC Cable sections.

AC Cables					
Normally Section			Type	Current Carrying Capacity	
1	X	50	NYY	230	A
1	X	70	NYY	282	A
1	X	95	NYY	336	A
1	X	120	NYY	382	A
1	X	150	NYY	428	A
1	X	185	NYY	483	A
1	X	240	NYY	561	A

4.2.3. TMS Thermal Magnetic Switch and Fuse Selection Calculations.

Thermal magnetic switch and fuse selectıon calculations and selections is given in Fig. 4.24.

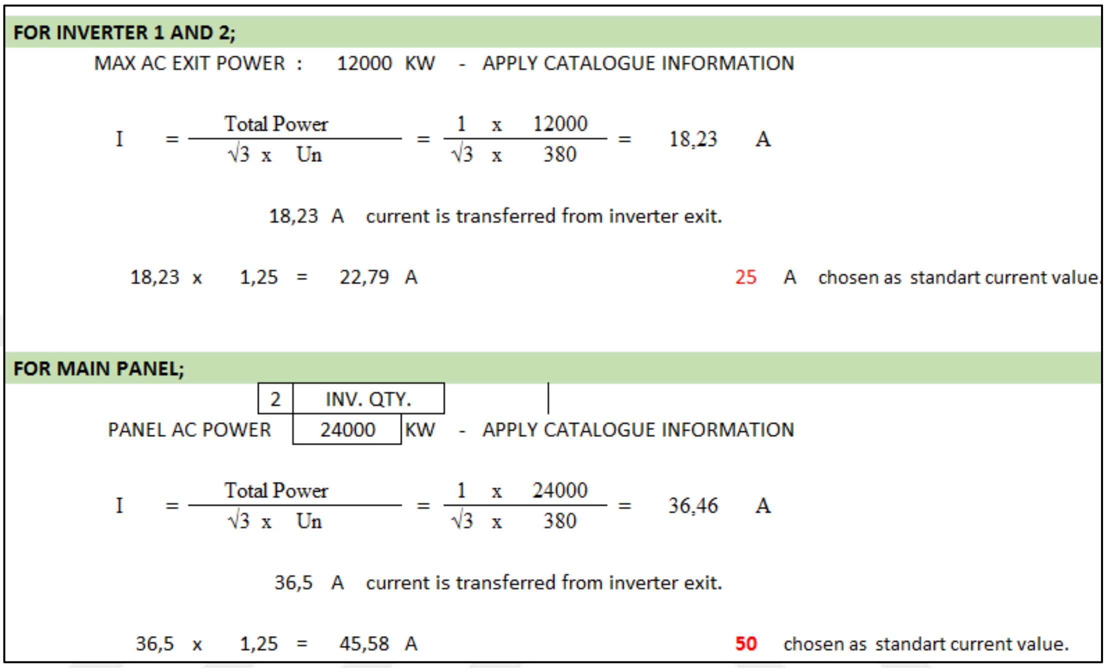


Figure 4.24: TMS and fuse selectıon calculations.

4.2.4. Bar Section Calculations

In the field distribution panels, the outputs of triple inverters are combined in copper bars. The triple cables coming from the field distribution boxes are also collected in the main distribution box with copper bars. Table 4.11 shows the current carrying capacities of the bars in various sizes.

Table 4.11: Continuous charging currents according to cross sections of copper bars.

Environment Temperature:25 °C Warming: 30 °C										
Sizes mm	**Dimension m m2**	**Weight kg/m**	**Continuing Load Current (A) - 50 Hz. A.C.**							
			Colored Bar Quantity				**Bare Bar Quantity**			
			I	**II**	**III**	**IIII**	**I**	**II**	**III**	**IIII**
12X2	24	0,21	125	250	-	-	110	220	-	-
15X2	30	0,27	155	270	-	-	140	240	-	-
15X3	45	0,40	185	330	-	-	170	300	-	-
20X2	40	0,36	205	350	-	-	185	315	-	-
20X3	0	0,54	245	425	-	-	220	380	-	-
20X5	100	0,89	325	550	-	-	290	495	-	-
25X3	75	0,67	300	510	-	-	270	460	-	-
25X5	125	1,12	385	670	-	-	350	600	-	-
30X3	90	0,80	350	600	-	-	315	540	-	-
30X5	150	1,34	450	780	-	-	400	700	-	-
40X3	120	1,07	460	780	-	-	420	710	-	-
40X5	200	1,78	600	1000	-	-	520	900	-	-
40X10	400	3,56	835	1500	2060	2800	750	1350	1850	2500
50X5	250	2,23	720	1200	1750	2300	630	1100	1500	2100
50X10	500	4,45	1025	1800	2450	3330	920	1620	2200	3000
60X5	300	2,67	825	1400	1980	2650	750	1300	1740	2400
00X10	0	5,34	1200	2100	2800	3800	1100	1860	2500	3400
80X5	400	3,56	1060	1800	2450	3300	950	1650	2200	2900
80X10	800	7,12	1540	2600	3300	4600	1400	2300	3100	4200
100X5	500	4,45	1310	2200	2950	3800	1100	2000	2600	3400
100X10	1000	8,90	1880	3100	4000	5400	1700	2700	3600	4800
120X10	1200	10,68	2200	3500	4600	6100	2000	3200	4200	5500
160X10	1600	14,24	2880	4400	5800	7800	2600	3900	5200	7000

Sample Calculation:

$$I = \frac{\text{Total AC power}}{\sqrt{3}\ \text{x Un}} = \frac{150000}{\sqrt{3}\ \text{x}\ 400} = 216.7\text{A}$$

For Main Panel:

Total power : 2 pieces of inverter

An inverter power : 12.000 W

$$I = \frac{24000}{\sqrt{3}\ \text{x}\ 380} = 36.5\ \text{A}$$

36.5 A x 1.25 = 45.6 A 45.6 A (from capable of current capacity)

One piece of 12 x 2 mm copper bar will be used.

NOTE: 40 x 5 mm Bar will be used SES MCM. Bars will be coloured.

Copper bars sections are located in Table 4.11.

4.2.5. Electrical Connection Stationary System Primer Equipment Calculations

Electrical connection stationary system primer equipment calculations section includes SES MCM breaker Input/Output cell, SES MCM primary equipment list, SES MCM Cells information and calculatıons which are given in Fig. 4.25 and Fig. 4.26.

SES MCM	BREAKER INPUT/OUTOUT CELL

Turn rate

Rated current of the transformer's MV winding:

Total connected power : **1 x 50 kVA**

Rated current of the transformer's MV winding:

$$I_{n\text{-}TR} = \frac{\text{Total Installed Power}}{\sqrt{3} \times \text{Un}} = \frac{1 \times 50}{\sqrt{3} \times 27} = 1{,}07 \ \text{A}$$

Current transformer ratio which is about the rated current

5 / 5A is the chosen value.

SES MCM PRIMARY EQUIPMENT LIST

TRANSFORMER

50 KVA TRANSFORMER

Quantity	:	1 pıece
Type	:	3 phase . Coiled and Hermetic
Nominal Power	:	**50** kvA
Nominal Voltage-HV	:	27 kV
Nominal Voltage-LV	:	0,38 kV
Nominal Frequency	:	50 Hz.
Connection Style	:	Dyn11

MV CELLS

GENERAL TECHNICAL INFORMATION

Nominal Voltage	:	36 kV
Lightning Strike Voltage	:	170 kV
Nominal Current	:	630 A
Nominal Short Circuit Open Current	:	16 kA

Figure 4.25: Electrical connection stationary system primer equipment calculations - 1.

SES MCM CELLS

Interrupted Input Output Cell (MCM Output)

Breaker	:	Air İnsulated 36kV. 630A. 16KA
Seperatör	:	36kV. 630A. 16kA
Current Transformer	:	3 piece, 100-200/5A , 15VA+15VA cl:1 Ith:16kA
Ground Seperatör	:	1 piece (3-phase), 36kV, 16kA
Surge Arresters	:	3 piece, 100-200/5A , 15VA+15VA cl:1 Ith:16kA
Protect Relay	:	ANSI50, ANSI51, ANSI50N, ANSI51N
Gerilim Göstergesi	:	3 piece, 100-200/5A , 15VA+15VA cl:1 Ith:16kA
Ammeter	:	3 piece, 100-200/5A , 15VA+15VA cl:1 Ith:16kA

Load Discvonnection, İnsured Transformer, Protection Cell

Load Disconnector	:	1 piece (3-phase), 36kV, 630A, 16kA
Ground Sepeatör	:	1 piece (3-phase), 36kV, 16kA
Voltage Indicator	:	3 piece
Fuse	:	3 piece, 36kV, 6A, 16kA

Figure 4.26: Electrical connection stationary system primer equipment calculations - 2.

4.3. Cost Calculation

In this section, we will talk about cost calculations for suburban train system in Table 4.12 and cost calculations for stationary system in Table 4.13.

4.3.1. Suburban Train System Cost Calculation

Table 4.12: It shows cost calculations for suburban train system.

Materials	Exposure Number	Type	Quantity	Unit	Unit Price	Total Amount
Inverter	Special-1	12 kW Inverter	2	Pieces	$2.400,00	$4.800,00
Panel	Special -1	280 W Panel	88	Pieces	$238,00	$20.944,00
DC Cables	Special -1	Solar Cable 6 mm^2 (Red)	30	Meter	2,42 TL	72,60 TL
	Special -2	Solar Cable 6 mm^2 (Black)	30	Meter	2,42 TL	72,60 TL
	Special -3	Connector (SET)	4	Set	10,00 TL	40,00 TL
AC Cables	Special -1	AC Cable 5x4mm2 NYY	15	Meter	23,79 TL	356,85 TL
	Special -2	AC Cable 4x16mm2 NYY	5	Meter	133,00 TL	665,00 TL
Cable Transport Materials	Special -1	Spiral Tube 32mm	30	Meter	0,85 TL	25,50 TL
Protection and Operating Grounding Materials	Special -1	Grounding Consumables Materials	1	Set	100,00 TL	100,00 TL
	Special -2	Galvanization Line 30X3,5 mm	15	Meter	3,75 TL	56,25 TL
	Special -3	1X16 mm^2 NYaF	50	Meter	4,21 TL	210,50 TL
Distribution Panel Materials	Special -1	Main Distribution Panel	1	Pieces	10.000,00 TL	10.000,00 TL
		Total TL	80.759,30 TL			
		Total (USD)	$25.744,00			
		General Total (USD)	$45.984,43			

4.3.2. Stationary System Cost Calculation

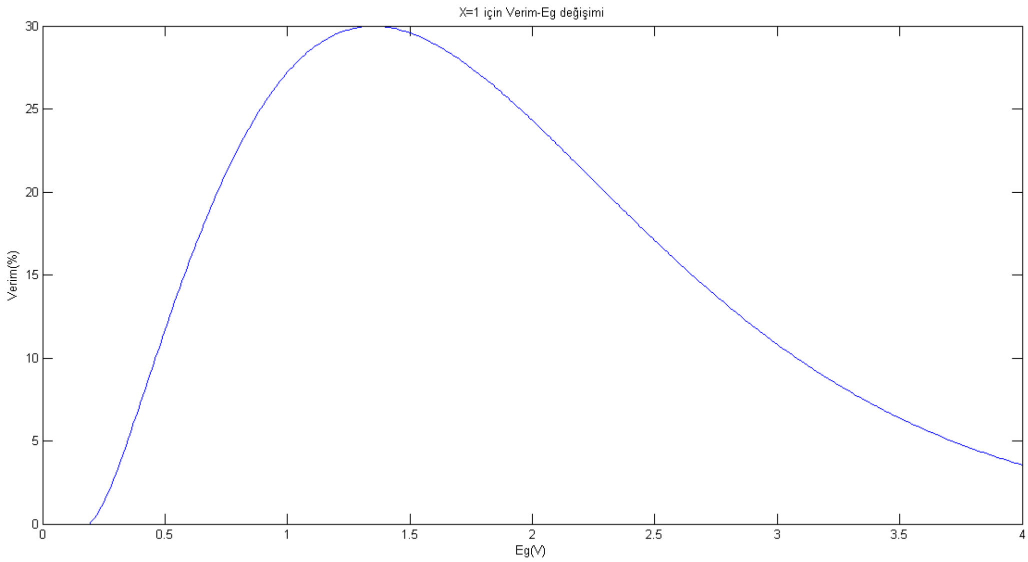
Table 4.13: It shows cost calculations for stationary system.

Materials	Exposure Number	Type	Quantity	Unit	Unit Price	Total Amount
Inverter	Special -1	12 kW Inverter	2	Piece	$2.400,00	$4.800,00
Panel	Special -1	280 W Panel	88	Pieces	$238,00	$20.944,00
Dc Cables	Special -1	Solar Cable 6 mm^2 (Red)	30	Meter	2,42 TL	72,60 TL
	Special -2	Solar Cable 6 mm^2 (Black)	30	Meter	2,42 TL	72,60 TL
	Special -3	Connector (SET)	4	Set	10,00 TL	40,00 TL
AC Cables	Special -1	AC Cable 5x4mm^2 NYY	15	Meter	23,79 TL	356,85 TL
	Special -2	AC Cable 4x16mm^2 NYY	5	Meter	133,00 TL	665,00 TL
MV Cables	Special -1	1x50/16 N2XSY	20	Meter	27,00 TL	540,00 TL
Cable Transport Materials	Special -1	Spiral Tube 32mm	30	Meter	0,85 TL	25,50 TL
Protection and Operating Grounding Materials	Special -1	Grounding Consumables Materials	1	Set	100,00 TL	100,00 TL
	Special -2	Galvanize Stick 30X3,5 mm	15	Meter	3,75 TL	56,25 TL
	Special -3	1X16 mm^2 NYaF	50	Meter	4,21 TL	210,50 TL
	Special -4	1X95 mm^2 NYY	60	Meter	45,30 TL	2.718,00 TL
	Special -5	Q20 mm 1,5 m Grounding Bar	24	Pieces	135,00 TL	3.240,00 TL
	Special -6	50mm^2 Copper	50	Meter	12,00 TL	600,00 TL
Distribution Panel Materials	Special -1	Main Distribution Panel	1	Pieces	10.000,00 TL	10.000,00 TL
Monoblok Concrete Mansion Building (MCM) Materials	Special -1	Monoblok Mansion (4350*2300*3550 mm)	1	Pieces	12.300,00 TL	12.300,00 TL
	Special -2	Battery Rectifier	1	Pieces	2.000,00 TL	2.000,00 TL
	Special -3	Interrupted Output Cell	1	Pieces	17.255,00 TL	17.255,00 TL
	Special -4	Load Separated TR Protection Cell	1	Pieces	7.900,00 TL	7.900,00 TL
	Special -5	50 kVA Transformer	1	Pieces	$2.500,00	$2.500,00
	Special -7	1x50/16 XLPE Cable Head	3	Pieces	60,00 TL	180,00 TL
Carrier System Materials	Special -1	Steel Construction	24,64	kWp	$ 91,70	$ 2.259,49
Workers Health and Safety Epuipments	Special -1	Isolated carpet	5	m^2	40,00 TL	200,00 TL
	Special -2	Isolated Table	2	Pieces	72,00 TL	144,00 TL
	Special -3	Isolated Glove	2	Pieces	288,00 TL	576,00 TL
	Special -4	Isolated Maneva Rope	2	Pieces	150,00 TL	300,00 TL
	Special -5	Label and Plates	2	Set	2.000,00 TL	4.000,00 TL
	Special -6	6 Kg Fire Extinguisher	2	Pieces	60,00 TL	120,00 TL
Other Expenses	Special -1	Shipping Costs	1	Set	30.000,00 TL	30.000,00 TL
	Special -2	Sand, Strip, etc. Consumables Materials	1	Set	10.000,00 TL	10.000,00 TL
		Total TL	175.332,30 TL			
		Total (USD)	$28.003,49			
		General Total (USD)	$71.946,42			

4.4. Matlab Application

<u>Model of a PN Junction PV Solar Cell</u>

```
Electron Load          ➔  q=1.6e-19A*sn;
Planck Static          ➔  h=4.14e-15eV*sn;
Boltzmann Static       ➔  kb=8.617343e-5eV/K;
Light Speed            ➔  c=2.9979e10cm/sn;
                          Sin(θs)=1/46000;
Solar Heat             ➔  Ts=6000K;
Battery Heat           ➔  Tc=300;
Sorption Parameter     ➔  α(ε)=10^4 cm^-1
For the Black Object   ➔  Pin=157,9mA are the assumed values.
```



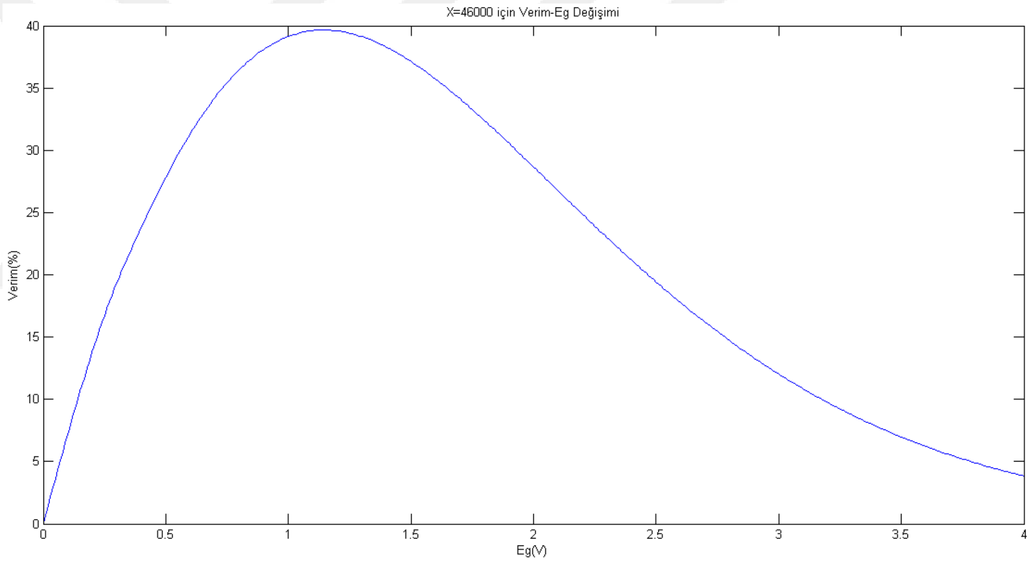
The highest efficiency was obtained when Eg = 1.34V. Semiconductors with 1 eV to 1 eV are more suitable for solar cell. The maximum yield at which P-N joints can be obtained is about 30%.

Source Code

```
Jsc=@(Ep)(Ep.*Ep)./((2.7183.^(Ep./a))-1); %Usedto determine functions
q = quad(fun,a,b); % Common descriptions for all codes:
clear all;
q=1.6e-19;
h=4.14e-15;
kb=8.617343e-5;
c=2.9979e10;
sin=1/46000;
K=(2*pi*q)/((h^3)*(c^2));
Ts=6000;
Tc=300;
a=kb*Ts;
b=kb*Tc;
```

Calculations for Kod-1: X=1

```
Pin=0.1579;
Jsc=@(Ep)(Ep.*Ep)./((2.7183.^(Ep./a))-1);
Jo=@(Ep)(Ep.*Ep)./(2.7183.^(Ep./b));
Eg=0:0.01:4;
for i=1:1:length(Eg)
    V=0:0.01:Eg(i);
    for j=1:1:length(V)
    J(i,j)=K*sin*quad(Jsc,Eg(i),10)-(2.71^((V(j))/b))*K*quad(Jo,Eg(i),10);
    P(j)=V(j)*J(i,j);
    Pm(i)=max(P);
    end
end
verim=Pm./Pin;
figure(1)
plot(Eg,verim*100)
title('X=1 için Verim-Eg değişimi');
xlabel('Eg(V)');
ylabel('Verim(%)');
```



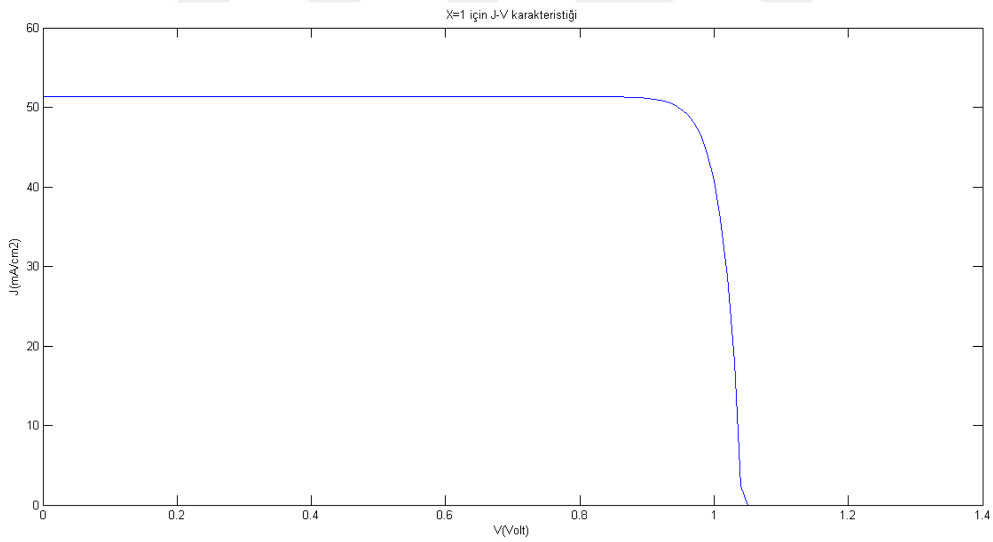
Using the black body composition and assuming that it is as thick as the pylon, yield = Eg change at X = 46000

The maximum yield that can be taken under the maximum solar concentration (X = 46000) with the P-N joint solar cell is around 40%.

Source Code for X=46000

```
X=46000;
Pincont=Pin*X;
Jsc=@(Ep)(Ep.*Ep)./((2.7183.^(Ep./a))-1);
Jo=@(Ep)(Ep.*Ep)./(2.7183.^(Ep./b));
Eg=0:0.01:4;
for i=1:1:length(Eg)
    V=0:0.01:Eg(i);
    for j=1:1:length(V)
    J(i,j)=X*K*sin*quad(Jsc,Eg(i),10)-
(2.71^((V(j))/b))*K*quad(Jo,Eg(i),10);
    Pcont(j)=V(j)*J(i,j);
    Pmcont(i)=max(Pcont);
    end
end
verimcont=Pmcont./Pincont;
figure(2)
plot(Eg,verimcont*100)
title('X=46000 için Verim-Eg Değişimi');
xlabel('Eg(V)');
ylabel('Verim(%)');
```

The J-V characteristic of the battery for maximum efficiency Eg = 1.34V



When Jsc = Jrad, then Δμ = Voc. However, Jsc = Jrad equations are never obtained because of the selected coefficients and the error share of the integral operation. For this reason, the point where J (V) = Jsc-Jrad is negative is taken as Voc. Voc <Δμ <Eg Jrad is too large and has opposite signs so that the parts where the current is negative are not shown in the drawing.

Open Circuit Voltage ➔ Voc =1.05V

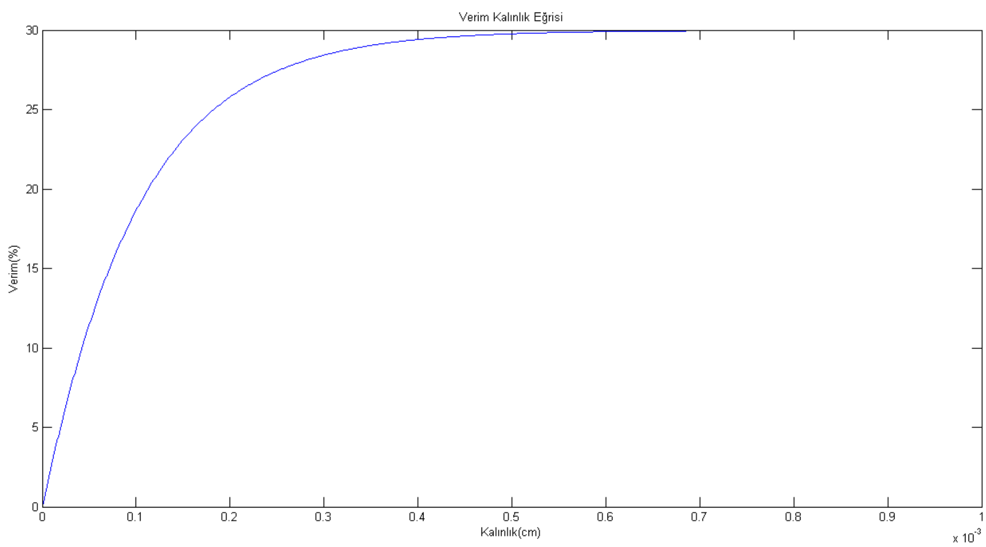
Short Circuit Current ➔ Jsc = 51.3mA/cm2

Feed Factor → FF = 0.8779

Efficiency → η=%30

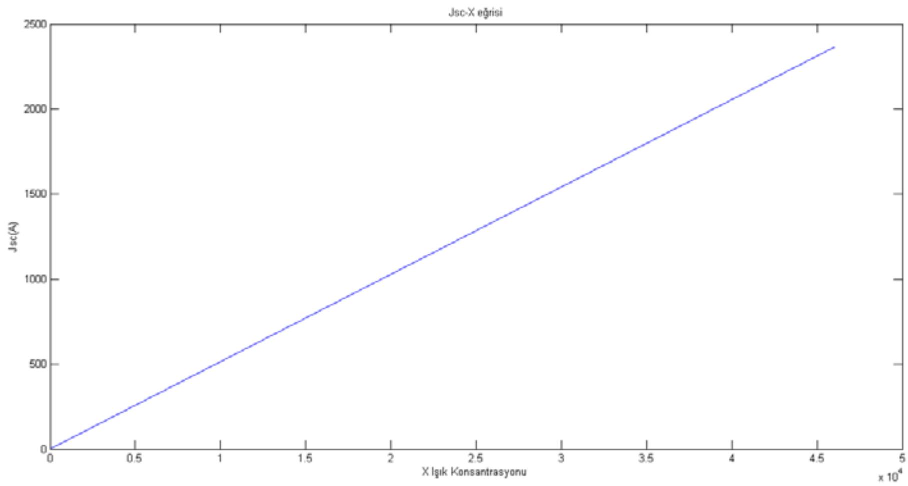
```
clear Eg;
Eg=1.34
V=0:0.01:Eg;
J=zeros(1,length(V));
for j=1:1:length(V)
    %
    J(j)=K*sin*quad(Jsc,Eg,10)-(2.7183^((V(j))/b))*K*quad(Jo,Eg,10);
    if J(j)<0
        J(j)=0;
        Voc=V(j);
        break
    end
end
figure(3)
plot(V,1000*J)
title('X=1 için J-V karakteristiği');
xlabel('V(Volt)');
ylabel('J(mA/cm2)');
Voc
Jscb=J(1)*1000
P=V.*J;
VmJm = max(P);
FF=VmJm/(Voc*Jscb)
verim=((Voc*Jscb*FF)/Pin)*100
```

To examine the thickness of the battery, select Thickness 0 <w <10 × 〖10〗 ^ (- 3) cm and select Yield-Thickness curve

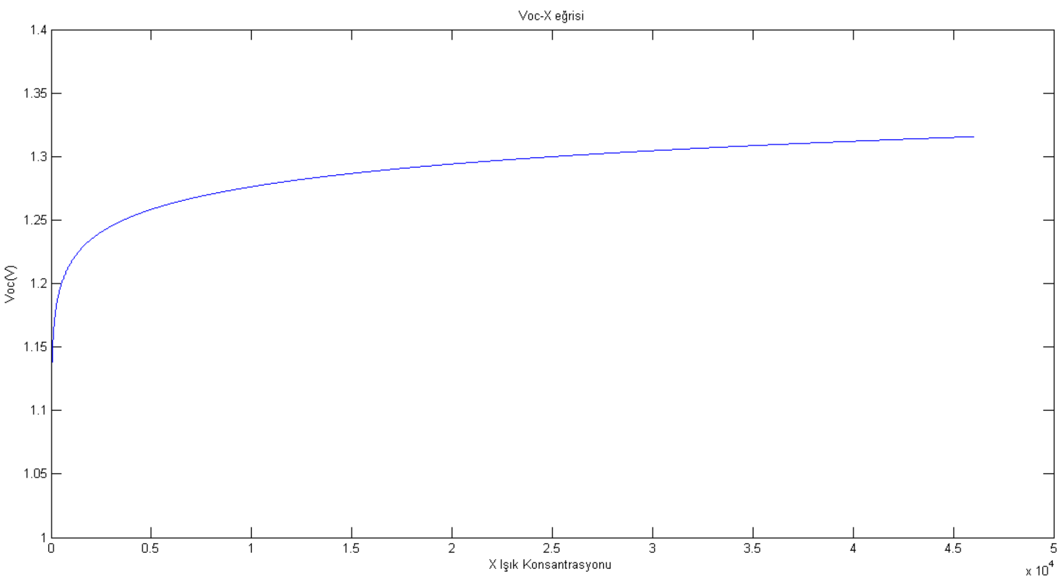


It was observed that some photons had passed without being cooled and the yield decreased when the material was not thick enough. When α (ε) * w product is 5, it can be said that approximately all the photons are absorbed. For the P-N joint pi, w = 5μm must not be selected small.

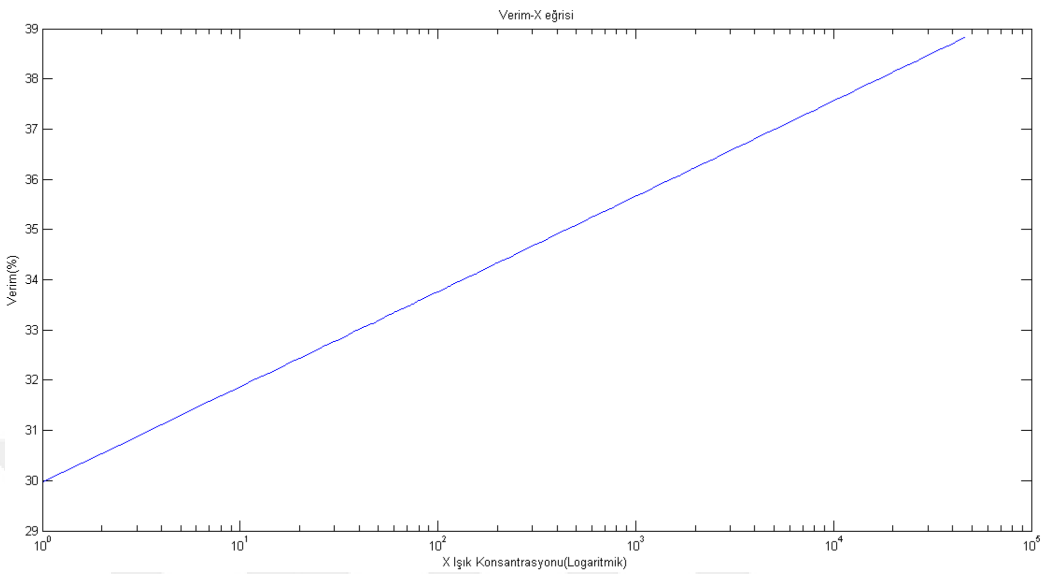
```
w=0:10e-7:10e-4;
for i=1:1:length(w)
    for j=1:1:length(V)
        Jc(i,j)=(1-(2.7183^(-10000*w(i))))*K*sin*quad(Jsc,Eg,10)-
(2.71^((V(j))/b))*K*quad(Jo,Eg,10);
        Pc(j)=V(j)*Jc(i,j);
        Pmc(i)=max(Pc);
    end
end
    verimc=Pmc./Pin;
    figure(4)
plot(w,verimc.*100)
title('Verim Kalınlık Eğrisi');
xlabel('Kalınlık(cm)');
ylabel('Verim(%)');
```



Yield-X, Jsc-X and Voc-X variations to investigate the effect of light concentration.



The J_{sc} current was found to increase linearly with light concentration and V_{oc} logarithmically. In high light concentration, P_{in} increases the linearity with X, so it takes effect of J_{sc}, the increase in front is obtained by the increase in V_{oc}.




```
clear Pincont;
X=1:1:46000;
for i=1:1:length(X)
Pincont(i)=X(i)*Pin;
Jscd(i)=K*sin*quad(Jsc,Eg,10)*X(i);
Vocd(i)=kb*Tc*log(Jscd(i)/(K*quad(Jo,Eg,10)));
for j=1:1:length(V)
    Jd(i,j)=X(i)*K*sin*quad(Jsc,Eg,10)-
(2.7183^((V(j))/b))*K*quad(Jo,Eg,10);
    Pd(j)=V(j)*Jd(i,j);
   Pmd(i)=max(Pd);
end
end
    verimd=Pmd./Pincont;
figure(5)
plot(X,Jscd)
title('Jsc-X eğrisi')
xlabel('X Işık Konsantrasyonu')
ylabel('Jsc(A)')
figure(6)
plot(X,Vocd)
title('Voc-X eğrisi')
xlabel('X Işık Konsantrasyonu')
ylabel('Voc(V)')
figure(7)
semilogx(X,verimd*100)
title('Verim-X eğrisi')
xlabel('X Işık Konsantrasyonu')
ylabel('Verim(%)')
```

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1. Results

This thesis proposes the solar PV panel placement on top of an electrical train. The implementation will be calculated for a case study, suburban rail way. The total capacity that is available for solar PV panels will be calculated. Note that it is known that this capacity would be a small portion of the train power. Nonetheless, this small portion would decrease the electricity cost as well as the carbon dioxide emission.

In the trains, wagon ceilings are free areas to set Solar PV panels. It is shown in Fig. 5.1. As seen in the previous chapter, it is not possible to use the Wagon 2. Therefore, the solar panel which is for 280 W_p monocrystalline solar module can only be placed on top of Wagon 1 and Wagon 3.

The sample of solar PV placement is given in Fig. 5.1. It is just only sample. It really does not exist.

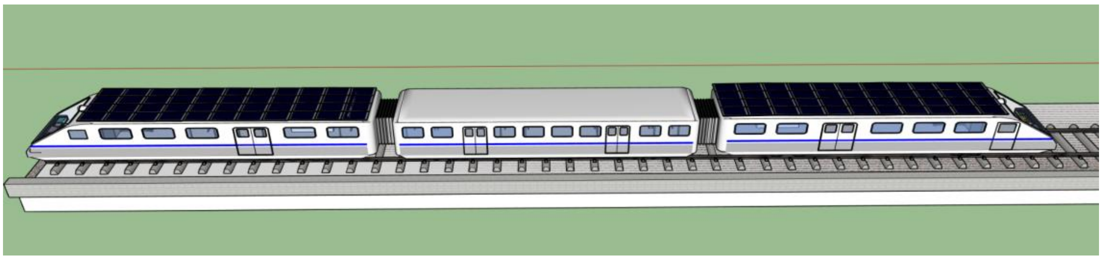


Figure 5.1: 1st and 3rd Wagons are free for solar PV panels.

Figure 5.1 1st and 3rd Wagons are free for solar PV panels

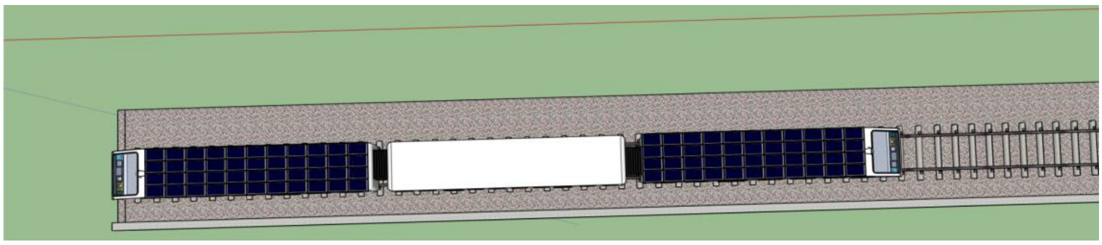


Figure 5.2: PV panel placement on top of a wagon.

The physical properties of the wagon 1 is given in Table 5.1. The physical properties of the solar panel are also given in Table 5.2.

Table 5.1: Wagon ceiling physical properties.

Wagon Ceiling	Free area (m)
Length	18
Width	4

Table 5.2: Solar panel physical properties.

Solar Panel	Free area (m)
Length	1.6
Width	1

By considering the physical properties of the train and the panel, number of panels that can be fitted to the train ceiling is given in Table 5.3.

Table 5.3: Panel placement results.

Panel Placement	Number of Panel
Column	4
Row	11

According to this calculation, one can place 44 solar panel on top of a wagon ceiling. By considering two wagons, the total panel number that a train can carry is found to be 88. Note that the panels are supposed to be placed on Wagon 1 and Wagon 3. The overall results are given in Table 5.4.

Table 5.4: Panel placement results for all wagons.

Wagon Number	Solar Panels
1	44
2	0
3	44
Total	88

The number of solar panels for a train is 88 and the corresponding power of solar panels are calculated in Table 5.5.

Table 5.5: Power calculation for solar panels.

Power	Wp
1 PV Panel	280
88 PV Panels	24640

Moreover, the solar system requires an inverter. However, the PV solar panels are distributed over two wagons. Here, there are two main options. One is choosing a central inverter. The other option is two inverters for each wagon. By considering the fact that the panels are placed on Wagons 1 and 3, connecting them to a central inverter would create higher cable losses. Therefore, two inverters are chosen for each wagon. The possible commercial inverters for such power levels are 10, 12 and 15 kW. Even though one wagon panel peak power is 12.32 kW, 12 kW inverter is appropriate for this application. For this purpose, SMA 12000TL three phase inverter can be chosen. Note that solar array should also be checked in this power.

These open-circuit and maximum power point tracking voltages are appropriate for the selected SMA 12000TL three-phase inverter [21]. Datasheet of the corresponding inverter is given in the Appendix C. Since the MPPT voltage is in between the allowed range, the inverter will be able to operate in the MPT point since there is an MPPT algorithm inside the inverter.

Table 5.6: Inverter selection.

1. inverter	12 Kw, 3 phase
2. inverter	12 Kw, 3 phase
Total	24 Kw, 3 phase

The results for inverter selection is given with Table 5.6. Construction of the train set is given in the Fig. 5.3. In this Figure, solar power system is also included.

By considering these information, the following calculations are obtained from the Solar System Program.

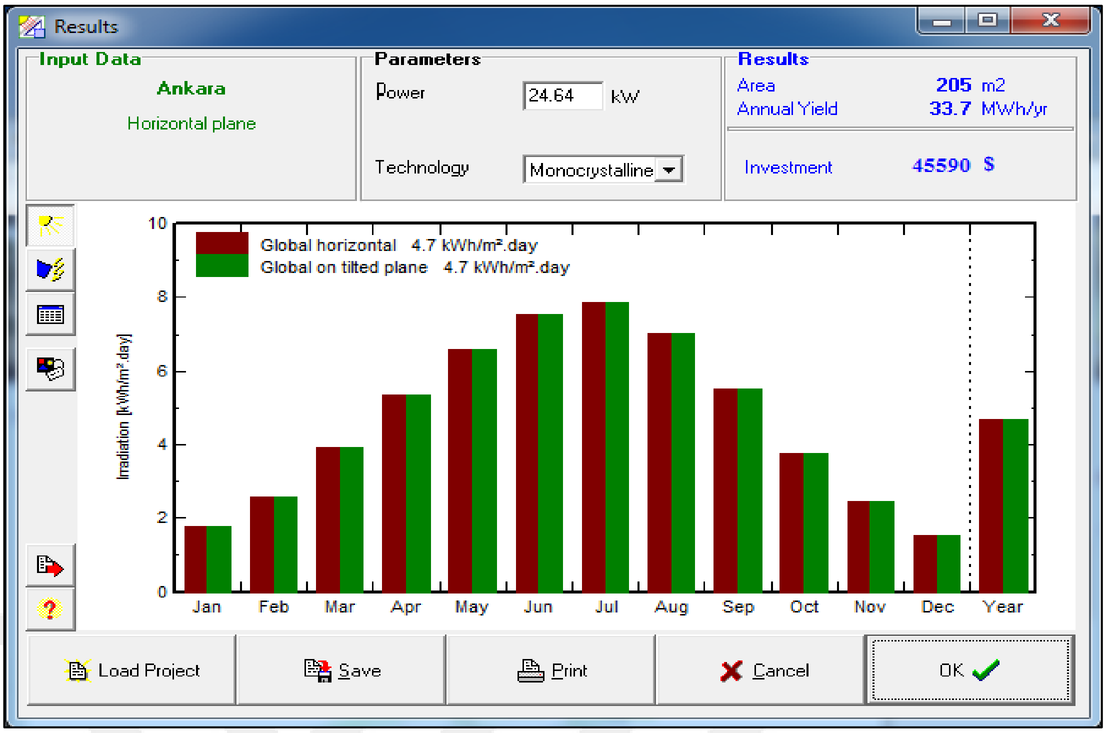


Figure 5.3: Seasonal irradiation.

Seasonal Irradiation is given in Fig. 5.3. Here, the location is given as Ankara and the horizontal placement is also declared to the program since the train goes from either East to West or West to East. The energy production for 24.64 kW peak power solar system is given in Fig. 5.4 for 12 months.

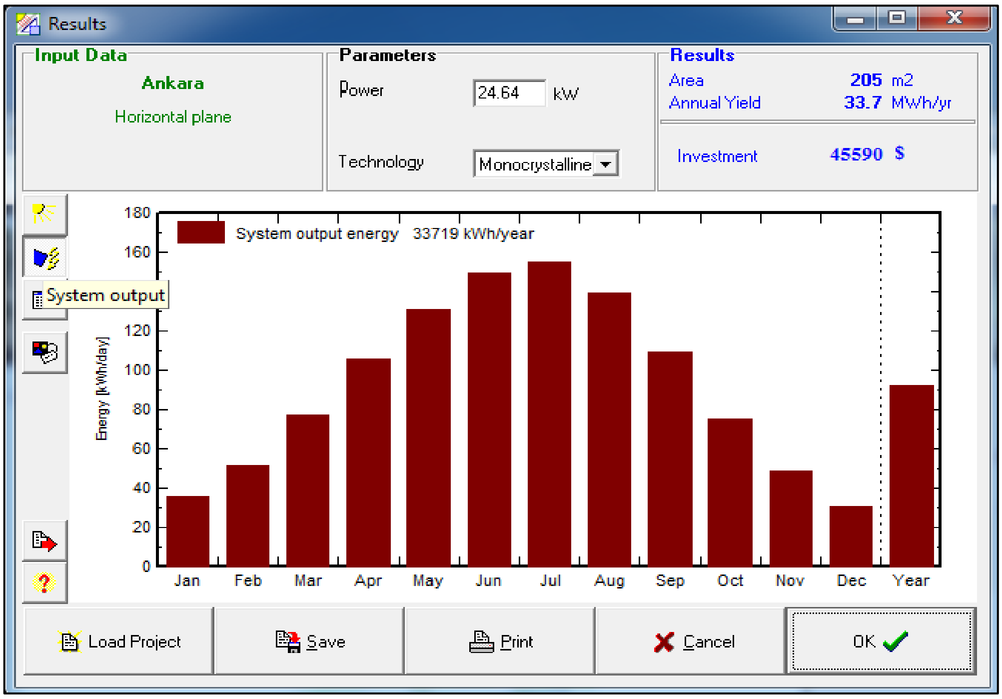


Figure 5.4: Seasonal energy production.

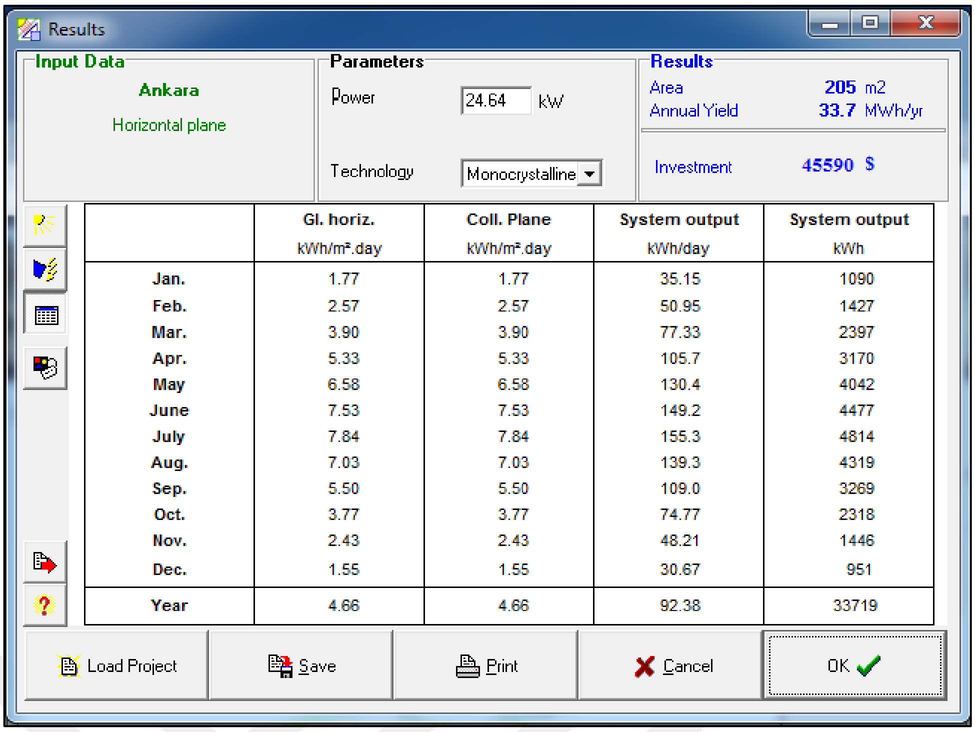


Figure 5.5: Monthly system output.

Seasonal energy production is also given monthly in Fig. 5.5. Total investment cost is given in Fig. 5.6. Total investment for the solar system 45.590 $. Note that almost half of the investment cost is the module cost.

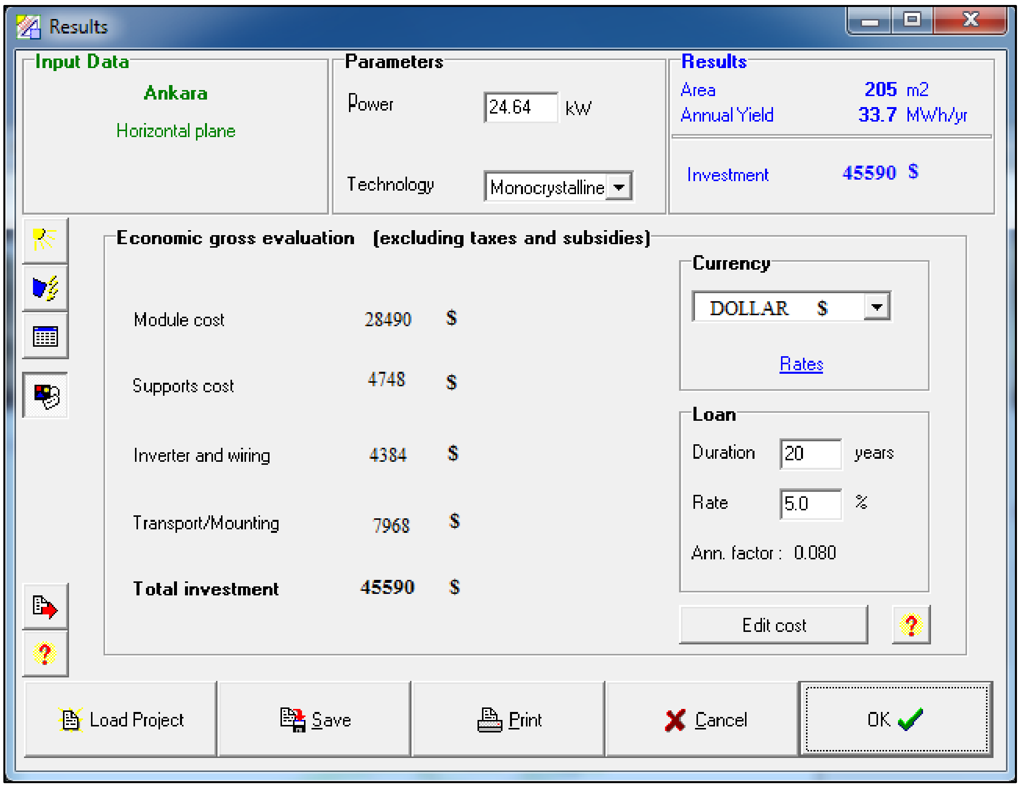
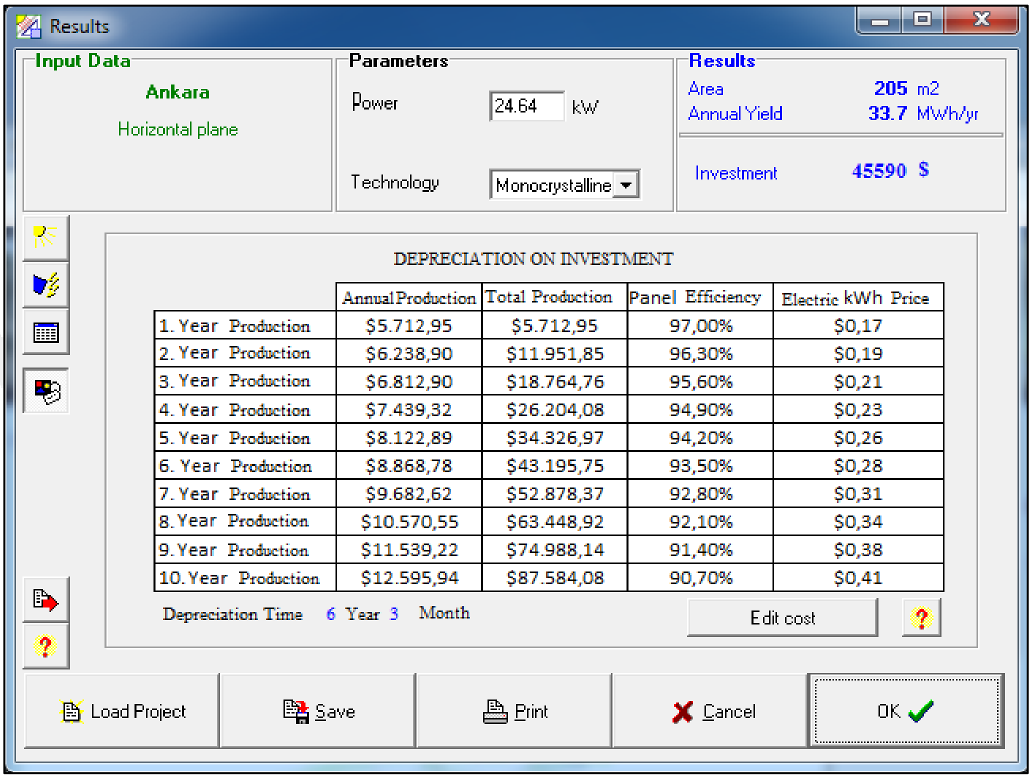


Figure 5.6: Total investment cost.

Yearly production is shown in Fig. 5.7. As it is seen from the figure, the decrease in panel efficiency is considered. The panel efficiency has decreased by 10% at the end of ten years. This is a realistic approach. Moreover, the electricity price is also changed yearly by estimation. The depreciation on investment is also shown in Fig. 5.8. As seen from the figure, depreciation time is 6 years and 3 months.



	Annual Production	Total Production	Panel Efficiency	Electric kWh Price
1. Year Production	$5.712,95	$5.712,95	97,00%	$0,17
2. Year Production	$6.238,90	$11.951,85	96,30%	$0,19
3. Year Production	$6.812,90	$18.764,76	95,60%	$0,21
4. Year Production	$7.439,32	$26.204,08	94,90%	$0,23
5. Year Production	$8.122,89	$34.326,97	94,20%	$0,26
6. Year Production	$8.868,78	$43.195,75	93,50%	$0,28
7. Year Production	$9.682,62	$52.878,37	92,80%	$0,31
8. Year Production	$10.570,55	$63.448,92	92,10%	$0,34
9. Year Production	$11.539,22	$74.988,14	91,40%	$0,38
10. Year Production	$12.595,94	$87.584,08	90,70%	$0,41

Figure 5.7: Yearly production.

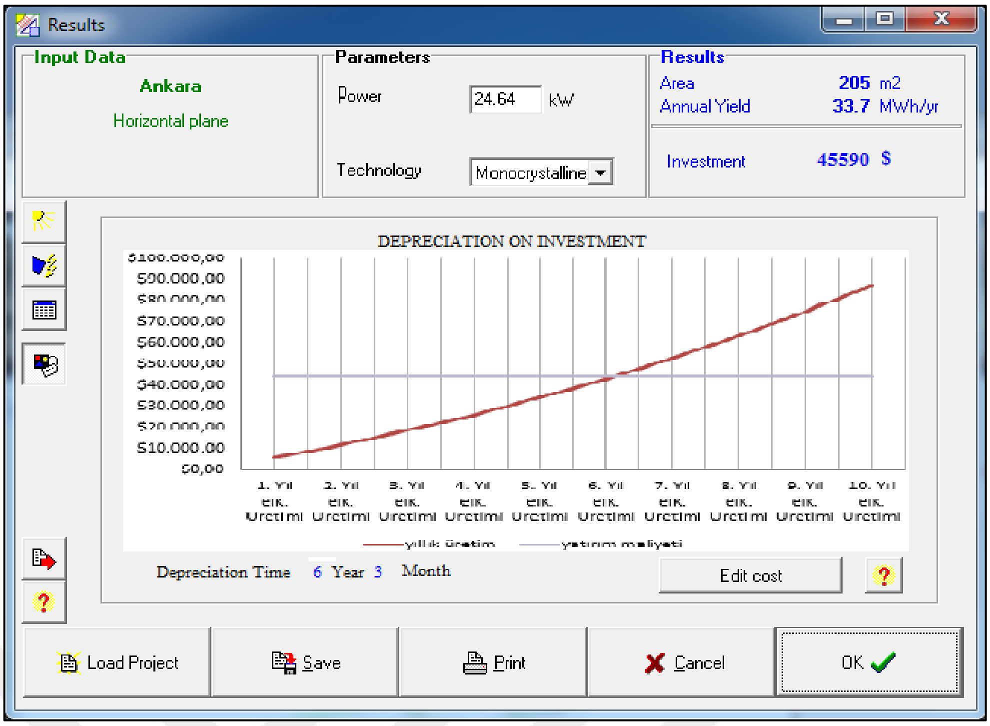
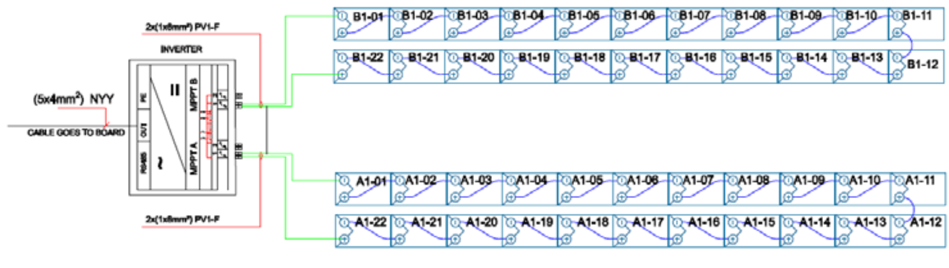


Figure 5.8: Depreciation on investment.

Consequently, it is not possible to produce all the power that the train needs, but it is possible to produce valuable power by this system. Another approach is setting up this system on the station instead of the train ceilings. In this case, one can set 88 panels to top of the roof of the station and we can use a 25 kW 3 phase inverter. Even though in this case it is possible to use one 25 kW and it would be cheaper than two 12 kW inverter, it would need 3 phase 400V – 1 phase 27 kV converter included transformer. Therefore, this choice is expensive than the other. Moreover, this case would cause much more loss in transformer and transmission line to supply train. This would increase depreciation time on investment and solar system gets meaningless.

5.2. Discussion

In this thesis work, the utilization of solar system on top of a train has been proposed. In order to evaluate feasibility, an implementation on the Suburban Rail Way is calculated.



INVERTER TECHNICAL SPECIFICATIONS						
1	DC POWER	AC POWER	NUMBER OF PANELS CONNECTED IN SERIES	SERIAL NUMBER CONNECTED IN PARALLEL	VOLTAGE	CURRENT
2	12,32 kWp	12 kWe	22	2	31.3x22=688.6	8.96x1=8.96 MPPT A 8.96x1=8.96 MPPT B

Figure 5.9: Simple diagram of inverter-panel.

Each inverter has 2 parallel arrays connected in parallel and 22 arrays of parallel solar arrays connected in series. Since each panel has a nominal voltage of 31.3 V, the DC voltage of the inverters connected to PV1-F cables is 22 x 31.3 V= 688.6 V. This is shown in Fig. 5.9 for the inverter.

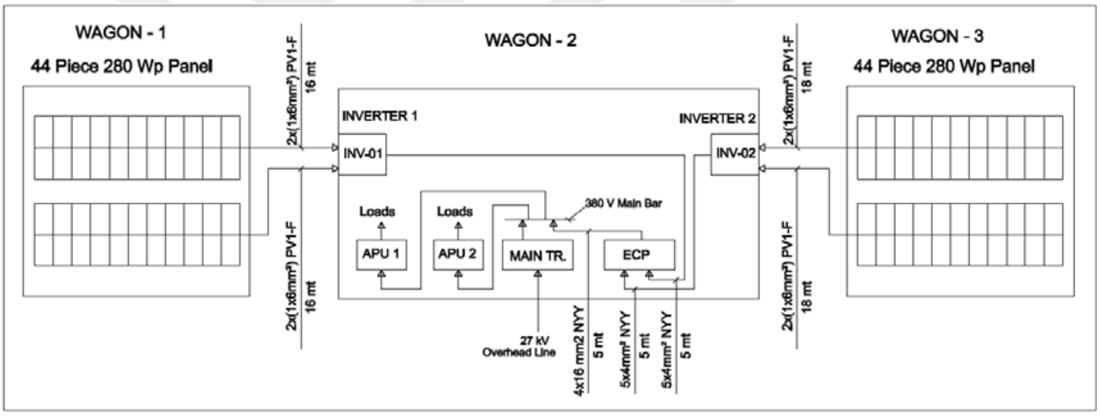


Figure 5.10: Suburban Train System SES With PV Block Diagram.

The working principle of our system in Fig. 5.10 as follows:

The DC voltage which is from the solar panel arrays on 1st and 3rd wagons, will be transformed to 380 V AC by the inverters located in 2nd wagon and transmitted to the main bar in 2nd wagon after passing through ECP Board in 2nd wagon.

380 V AC voltage will be transmitted to the APU1 and APU2 Units from the main bar and loads connected to these units will be supplied.

However, the total power of our 2 inverters will not be enough to feed these loads. Therefore, our Solar Energy Power Plant (SES) is a network-connected system.

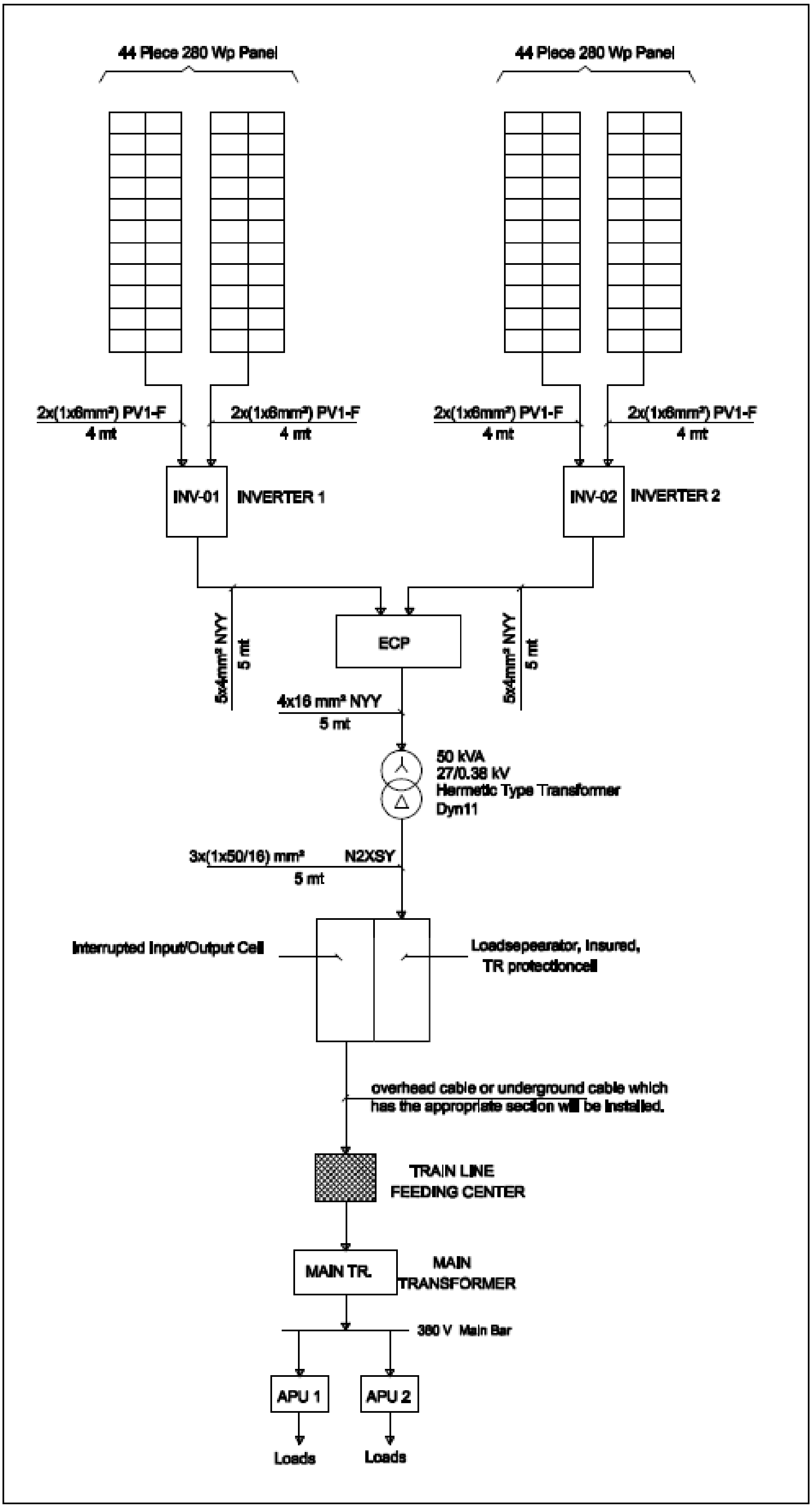


Figure 5.11: Stationary System SES With PV Block Diagram.

The working principle of our system in Fig. 5.11 as follows:

DC voltage which comes from solar panel arrays to inverters. It is converted to 380 V AC by the inverters sent to the LV side of the Hermetic Type Transformer after through the ECP

The MV side of the same transformer will be supplied with 27 kV AC voltage. The resulting 27 kV AC voltage will be transmitted to the Load Disconnection Fuse Transformer Protection Cell.

After it is through the Interrupted Output Cell will be transmitted to the Line Power Feeding Center.

27 kV AC voltage will be transmitted from the Train Line Feeding Center to the Main Transformer and the 380 V AC voltage will be reduced.

This means that the 380 V AC voltage will be transmitted to the APU1 and APU2 Units via the main bar and loads connected to these units will be supplied.

However, the total power of our 2 inverters will not be enough to feed these loads.

Therefore, Our Solar Energy System (SES) is a network-connected system.

According to the calculations, the solar system is not able to provide all the electricity of the train but it supplies a significant value of power. Obtaining this amount of power from solar PV panels also has significant importance on the electricity cost and the carbon dioxide emission.

Another possibility is that one can set up this system on a station instead of the train ceilings. However, it brings extra costs such as step-up transformer, monobloc transformer substation, workers health and safety equipment, protection and operating earthing materials MV cabling and transmission costs.

So when we place the panels on a station in our system, equipment and projecting up to the high voltage line will generate extra cost.

Because in the system after the point of connection from the high voltage line to the train the existing system is used.

When the cost study is examined, it is seen that the price of the material required for the stationary system SES installation is 71.946,42 Dollars, and the price of the material required for the suburban train system SES installation is 45.984,43 Dollars. In addition, this will require an extra cost since the stationary system will require site (land) for SES installation. Therefore, considering both the total cost and the site requirement, it is seen that the suburban train system SES installation is much more economical than the stationary system SES installation. It's shown graphically in Fig. 5.12.

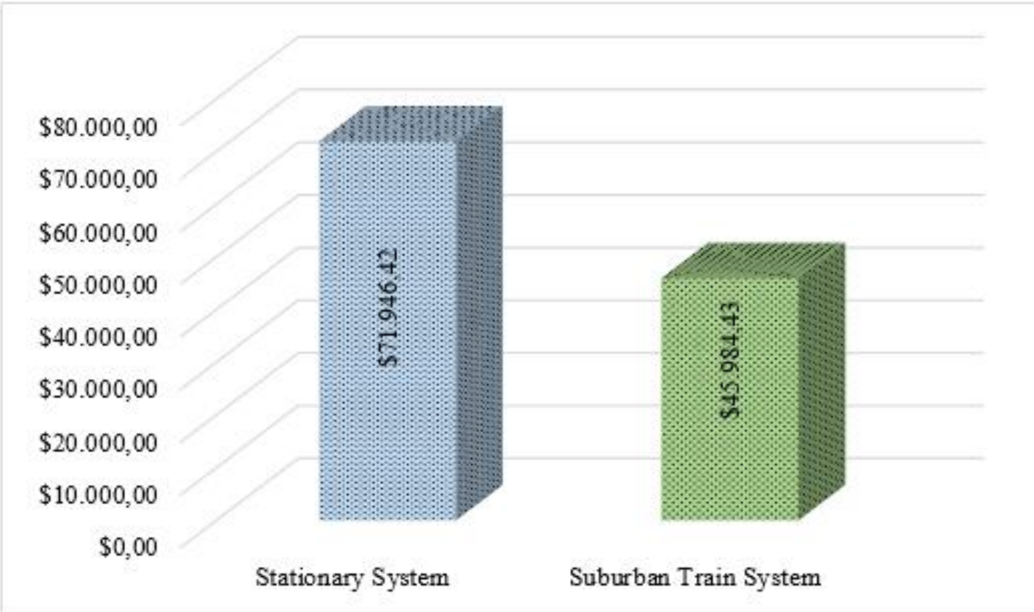


Figure 5.12: Comparison of the cost calculation suburban train system with stationary system.

With this system we can provide a portion of the energy consumed by the auxiliary power unit. In our system there are 2 auxiliary power units which are auxiliary power unit1 and auxiliary power unit2.

They provide the source of the illumination, illustration back up, ceiling heater, technical materials, door motor, horn mechanism etc., of the wagons. Each of them supplies the energy for 1,5 wagon's consumptions.

Total consumption of 2 auxiliary power unit is 41.606 kW x 2 = 83.212 kW from Table 4.1 and Table 4.2.

The results are shown graphically for 2 auxiliary power unit in Fig. 5.13. Therefore, the implementation on the train ceiling makes much more sense than the implementation of the station.

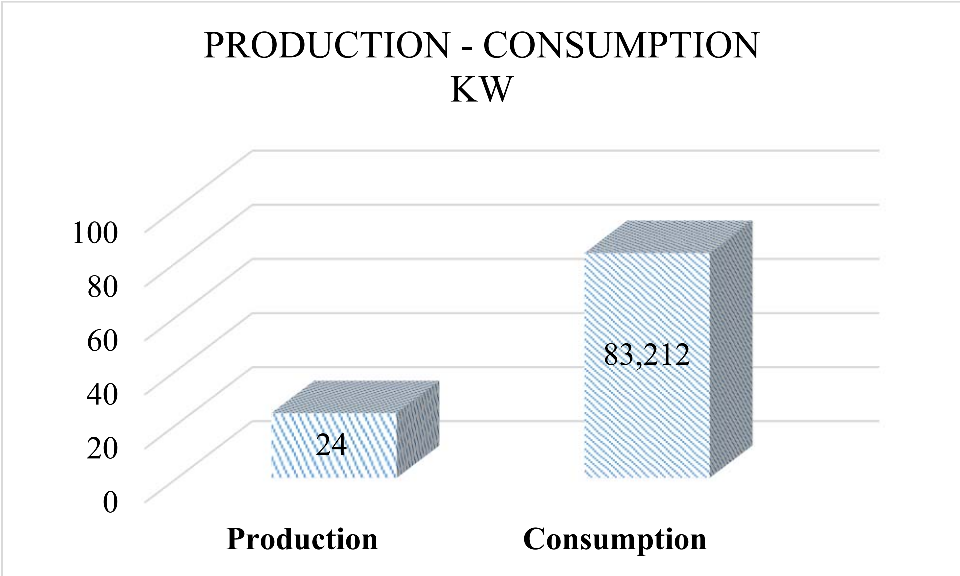


Figure 5.13: Production chart from 2 inverters and consumption chart of 2 APU.

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APPENDICES

Appendix A: Auxiliary Power Unit General Description

TOSHIBA SSD-DH-S-0157-R4

REPUBLIC OF TURKEY
GENERAL DIRECTORATE OF
STATE RAILWAYS

3 WAGON ELECTRICAL
SUBURBAN TRAIN SET

AUXILIARY POWER UNIT SYSTEM
GENERAL DESCRIPTION

TOSHIBA
TOSHIBA CORPORATION

TCDD Auxiliary Power System
April, 2007

- 1 -

GENERAL

Bu dokuman, Türkiye Cumhuriyeti Devlet Demiryolları'na (TCDD) ait doksan altı (96) çoklu elektrik ünitesi (AMU) için yedek güç sistemini (APU) tanımlamaktadır.

1. GENEL SİSTEM AÇIKLMASI

96 EMU, TCDD Sincan-Kinyas hattı için tasarlanmıştır.

Bu EMU treninin temel konfigürasyonu, üç (3) vagonlu Mc-T-Mc treni şeklindedir; Mc, makinist kabinine sahip motorlu bir vagon, T ise makinist kabini olmayan römork vagonudur. Tren setinin maksimum konfigürasyonu dokuz (9) vagondur; diğer bir deyişle Mc-T-Mc=Mc-T-Mc=Mc-T-Mc. Bir tren takımı çalışmaz hale geldiğinde, aynı nicelikteki tren takımından ibaret bir kurtarma treni çalışmayan treni en yakın istasyona itmek/çekmek üzere, elektriksel olarak bağlanmadan, sadece fiziksel olarak bağlanır.

Yedek Güç Sistemi, trenin kontrol yükü, kliması, ışıklandırması, fan ve vagonun diğer herhangi bir acil durum ihtiyacı için regüle edilmiş güç sağlayan, sabit gerilim ve sabit frekans tipi (CVCF) Redresördür.

1) IGBT'ler (Yalıtılmış Gate Bipolar Trasistör) makas ekipmanında kullanıldığı gibi, IGBT gate driver ünitesi basit ve daha güvenilirdir ve az güç kullanır.

2) Üç fazlı redresör kaynak ekipmanının ana özellikleri:

- Çok yüksek genel verimlilik
- Yüksek güvenilirlik
- Kompakt düzen
- Hafif
- Modüler tasarımı ile kolay bakım

3) Statik redresörün elektronik olarak regüle edilmesi, giriş geriliminden bağımsız olarak, sabit frekans (±1Hz) ve sabit gerilim (±%5) elde edilebilmesine izin verir.

4) Laptop PC ile diagnostic/izleme ve takip için kullanılan Hizmet Arayüzü RS232 ve LED lamba sinyal sağlanmıştır.

2. REYTİNG

Tanım		Reyting
Ana Devre		PWM Konvertör + Redresör
Kontrol Yöntemi		Dijital atım genişlik modülasyonu (PWM)
Soğutma Yöntemi		Isı alıcılı tahrikli hava soğutma
Kapasite		120 KVA
GİRİŞ	Değerlendirilmiş Gerilim	AC 404Vrms / 50Hz
	Çalışma Aralığı	AC 307Vrms ~ 444Vrms
AC ÇIKIŞ	AC Yükü	105kVA
	Çıkış Gerilimi Tipi	3 fazlı 4 hat tipi
	Gerilim Değeri	AC 380Vrms (3 Fazlı) /220Vrms
	Gerilim Regülasyon Toleransı	± 5%
	Frekans Değeri	50 Hz
	Frekans Regülasyon Toleransı	± 1Hz
	Harmonik Distorsiyon	%10'dan az
	Yük Güç Faktörü	0.85
	Garanti Performans için Yük Varyasyonu	0 ~ 100%
	Aşırı Yük	150%, 5 sec.
DC ÇIKIŞ	Gerilim Değeri	DC 110V
	Gerilim Regülasyon Toleransı	± 5%
	DC Yükü	15 KW
KONTROL GÜCÜ	Değerlendirilmiş Gerilim	DC 110V
	Kontrol Elektronikleri Kaynağı Gerilim Aralığı	DC 77 ~ 121V

Tanım	Reyting
Duyulabilir Gürültü (Gürültü Basıncı Seviyesi)	APS'den 15m uzakta maksimum 58dBA olarak ölçülmüştür
Çalışma Çevre Sıcaklığı	- 25 °C ~ + 45 °C

3. KONTROL

Statik redresörün kontrolü Dijital Sinyal İşlemci sistemi ile sağlanır.

Fonksiyonları şöyledir:

- Tek fazlı dalga formu oluşturmak üzere gate atımlarını sıraya dizmek

- Işık veren diyotlar (LED) ile ekipmanın durumunu göstermek

- Sistem arızaları ve aşırı çıkış yükü durumlarında hata koruması

- Bakım sırasında taşınabilir Note Book bilgisayarlar ile iletişim

- Mikroişlemci 32 bit dijital kontrol

- Arıza tanısı için otomatik veri kaydetme .

3.1. KONTRO TİPİ

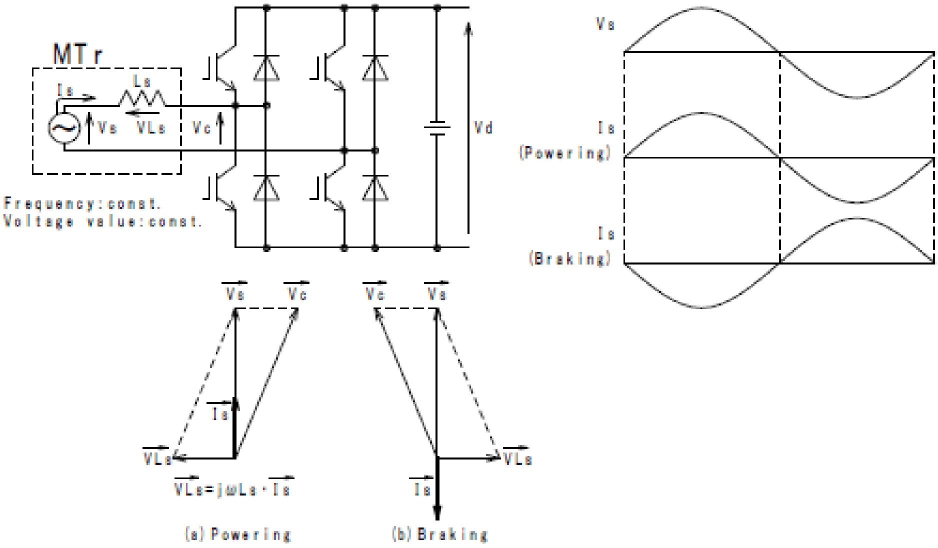
Yedek güç sistemi iki parçadan ibarettir; PWM konvertörü ve IGBT redresörü.

PWM konvertörü, AC gücü DC güce çevirmek için IGBT kullanan bir dönüşüm sistemidir.

PWM konvetörün özellikleri:

- Diyot köprüler ile karşılaştırıldığında IGBT, her diyota hem paralel hem de ters yönde bağlıdır. AC gücü DC güce çevirir.
- DC çıkış gerilimi, AC giriş gerilimi genliğinden daha fazla artar.
- AC devrede reaktans olsa bile, güç faktörü 1.0'da tutulabilir.
- AC güç kaynağı ve/veya DC yükü değiştiğinde bile DC çıkış gerilimi sabit tutulabilir.

Genelde, tek fazlı AC güç kaynağı demiryolu araçları için kullanılır ve önerilen EMU'de de tek fazlı PWM konvertör uygulamıştır. Basit diyot doğrultucu ile karşılaştırıldığında, PWM konvertörünün nasıl çalıştığı aşağıda açıklanmıştır:



Şekil 3.1

Şekil 3.1'de PWM konvertörünün temel devre şeması ve AC kısmında bireysel gerilim ve akım vektörleri ile ilişkisi görülmektedir.

Ana transformatörün birincil tarafının güç faktörünü 1.0'da tutmak üzere PWM konvertörü AC akım Is'ini, ana transformatörün ikicil gerilim Vs'i ile aynı fazda tutar. Is'i Vs ile aynı fazda tutmak için ise, giriş devresinin reaktansı Ls'e uygulanan gerilim VLs(=Vs-Vc) oldukça önemli bir faktördür. Is'in faz açısı VLs'in 90° gerisindedir. Is'in genliği VLs'in yüksekliğine ve Ls'in indüktansına bağlıdır.

Konvertör devre, filtre kapasitörün DC gücünü AC güce çevirir ve giriş terminaline veren bir AC-gerilim kaynağı olarak çalışır.

Konvertör giriş gerilimi Vc öyle kadar kontrol edilir ki, Is ana transformatörün ikincil gerilimi Vs ile aynı faza gelir.

IGBT redresörü, filtre kapasitörün her iki ucundaki DC-bağlantı geriliminden U, V ve W fazlarından yapılmış üç koldan ibarettir.

IGBT'nin çıkış gerilim kontrolü, ger bir IGBT anahtarının PWM kontrolü ile PI kontrol algoritması tarafından gerçekleştirilir.

Çalıştırma ve kapama, U, V ve W çiftleri arsında 120°'lik fark ile giriş gerilimince kapsanan “ON” atım genişliği altında tekrarlanır.

Redresör sisteminden elde edilen çıkış, üç fazlı çıkış oluşturmak amacıyla transformatör üzerinden birleştirilir.

3.2 GENEL GENİŞ TANIM

- Kontrolör giriş ve çıkış hallerini izler.
- Çıkış geriliminin gerçek zamanlı kontrolü.
- İletken durumunun gözlemlenmesi.
- Sitem Koruması
- Bakım için durum verisi sağlar.

Kontrol ünitesi koruma, sekans, hata bildirimi ve kayıt için 32-bir CPU’lar kullanır. Kontrol kartının fonksiyonları detaylı bir şekilde aşağıda gösterilmiştir:

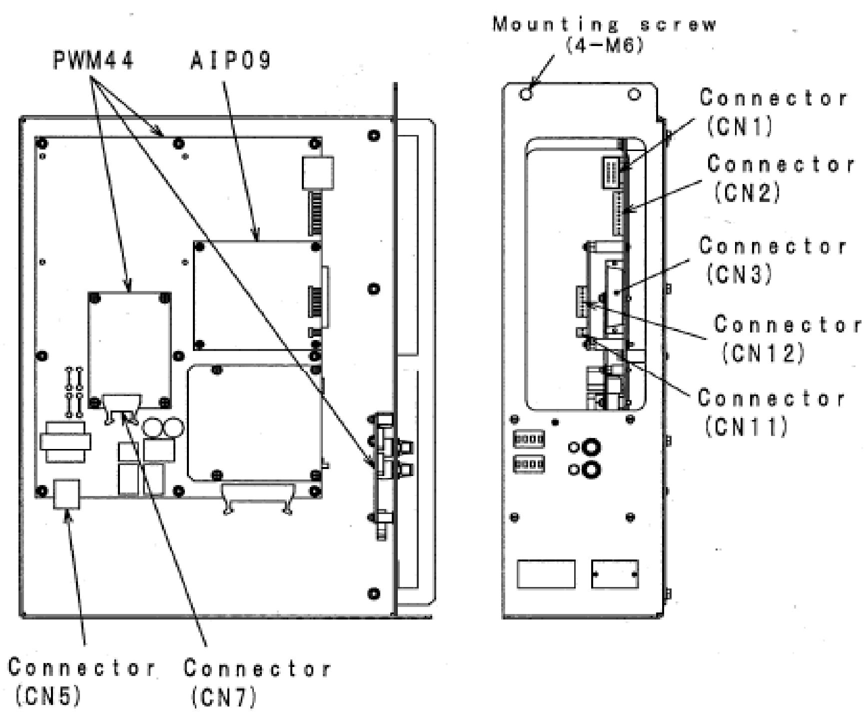


Figure 3.2 Kontrol Ünitesi

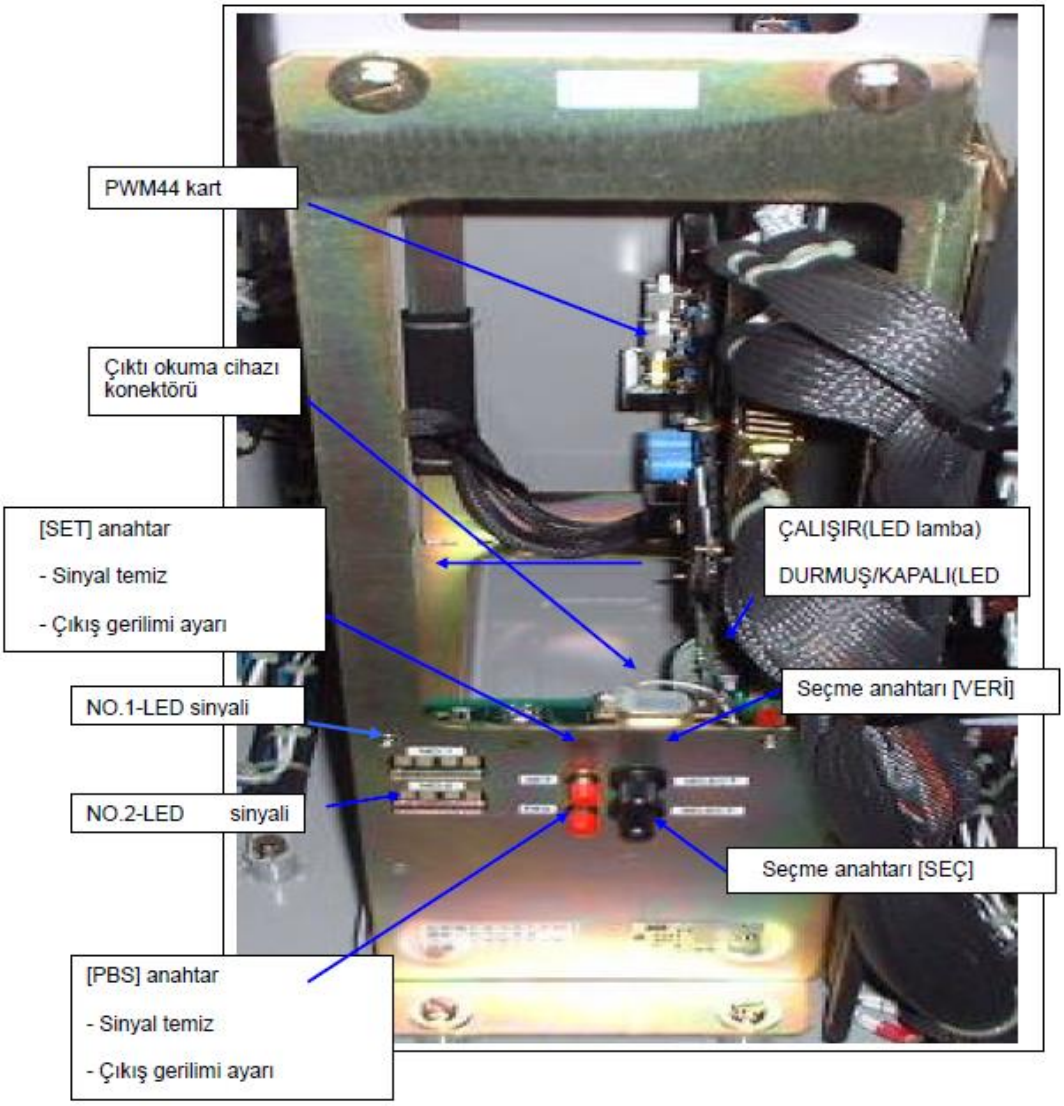
4. KORUMA VE BİLDİRİM

4.1 KORUMA

- Aşırı giriş gerilimi
- Düşük giriş gerilimi
- Aşırı giriş akımı
- Çıkış kısa devresi
- Aşırı sıcaklık
- Aşırı çıkış gerilimi
- Diğer

4.2 BİLDİRİM

APU'nun çalışma durumu LED sinyal ve LED lambalarla teyit edilebilir.



Kontrol kartı üzerindeki iki LED lamba APU durumunu göstermektedir.

Tablo 3-6 LED lambalar ve APU durumu

LED lamba	Kontrol gücü verildiğinde LED lamba sinyali	Tanımlar	APU Durumu	Kontrol ve ölçütler
ÇALIŞMA Yeşil (kontrol güç kaynağı olmaksızın)	Yanık	Sekans kontrol CPU'su normal olarak çalışıyor.	Normal	
	Sönük	Sekans kontrol CPU'su durmuş ya da gerilim 5V'un altında	Durmuş	Sürücü kabinindeki IVCN kapatılır ve açılır.
DURMUŞ/KAPALI Beyaz (kontrol güç kaynağı olmaksızın)	Yeşik Işık	Sekans kontrol CPU'su normal olarak çalışıyor. Ancak parlaklık CPU yüküne göre değişir.	Normal	
	Kırmızı Işık	Sekans kontrol CPU'su durmakta.	Durmuş	Sürücü kabinindeki IVCN kapatılır ve açılır.

5. ÇİZİMLER

Şemalar	7K3R7757-11	SIV ANA DEVRESİ
Çerçeve	3S3RH094	ÇERÇEVE,SIV,KUTU

Appendix B: Capacity Calculations for APU (Auxiliary Power Unit)

Rotem	Rotem Company R&D CENTER	Doc. No.	REDE101679
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TCDD EMU (Multiple Electric Railway Series)

Capacity Calculations for APU (Auxiliary Power Unit)

1. General

Measured capacity of APU has been defined by T.C.D.D. for T.C.D.D. EMU's. Total load will be calculated on both AC and DC loads.

Teklif edilen Yardımcı Güç Ünitesinin ölçülen kapasitesi TCDD EMU ları için TCDD nin istemine göre belirlenmiştir. Toplam yük AC ve DC yükleri üzerinden hesaplanacaktır.

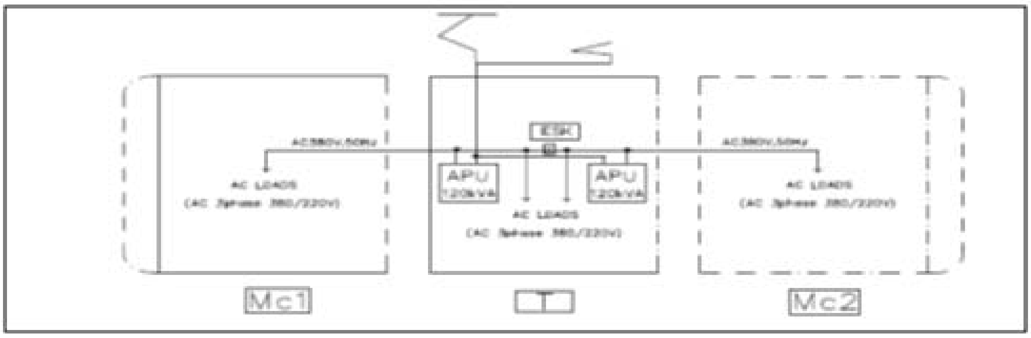
2. Capacity Calculation Conditions

-The load factor of Battery Charger Unit is defined 0.2C for charging batteries. (C: Stands for total capacity of battery)

-Logical function cyle control system is the 20% of usual conditions.

-Radio function cycle is 60% at activated capacity, 40% at inactivated capasity.

3. Regulation of Train and requirement of load balancing



Full Load: Normal operation: APU1, APU2 running.

With Auxilary Power Unit: APU1 or APU2 running.

Under usual conditions, the APU's which are assigned to T vagon, will be in charge of one and half vagon. Thus, APU1 and APU2 will supplying the full load of Mc, while T vagon is supplying the half load.

On one APU fault codition : APU capacity calculation is made by considering one APU fault on three vagon train series. Under this condition, the power factor of air conditioning and heating system will be 50% on prolonged supply.

09-01(Rev.1/2001.12.12) A4(210×297 mm) Rotem Company

4. APU loads calculation

4.1. Usual Operation

380V& 220V AC (Summer) [KVA]

NO	Load	Mc (APU1)	T (APU1)	T (APU2)	Mc (APU2)	Power Factor
3- Phase , AC 380V, 50Hz						
1	Passenger Section Air Conditioner					
	Compressor	25.37	12.68	12.68	25.37	0.82
	Condenser Fan Motor	4.29	2.14	2.14	4.29	0.7
2	Train Driver Cabin Air Conditioner					
	Compressor Motor	2.82	0.00	0.00	0.00	0.85
	Condenser Fan Motor	0.33	0.00	0.00	0.00	0.6
	Vaporizer Fan Motor	0.14	0.00	0.00	0.00	0.7
3	Air compressor Motor (VV80T)	6.32	0.00	0.00	6.32	0.74
4	Main Transformer Blower Fan	0.00	0.55	0.00	0.00	1
1- Phase , AC 220V, 50Hz						
5	CC TV	0.60	0.60	0.00	0.60	1
6	Defroster	0.40	0.00	0.00	0.40	1
7	Indoor Lights	0.83	0.45	0.45	0.83	0.95
8	Driver Cabin HVAC Control	0.08	0.00	0.00	0.00	1
	Total	41.69	16.43	15.78	38.30	

380V & 220 V AC(Winter) [KVA]

NO	Load	Mc (APU1)	T (APU1)	T (APU2)	Mc (APU2)	Power Factor
3- Phase , AC 380V, 50Hz						
1	Heater Section					
	Heater	12.00	6.60	6.60	12.00	1
	Electrical Heater (with passenger air conditioner)	24.00	12.00	12.00	24.00	1
2	Train Driver Cabin Heater					
	Ceiling Heater	3.00	0.00	0.00	0.00	1
	Vaporizer Fan Motor	0.14	0.00	0.00	0.00	0.7
3	Air compressor Motor (VV80T)	6.32	0.00	0.00	6.32	0.74
4	Main Transformer Blower Fan	0.00	0.55	0.00	0.00	1
1-phase, AC 220V, 50Hz						

5	CC TV	0.60	0.60	0.00	0.60	1
6	Defroster	0.40	0.00	0.00	0.40	1
7	Indoor Lights	0.83	0.45	0.45	0.83	0.95
8	Driver Cabin HVAC Control	0.08	0.00	0.00	0.00	1
	Total	47.88	20.20	19.55	44.65	

110V DC [KW]

Load	Mc	T		Mc
	APU1		APU2	
Indoor Lights	0.14	0.07	0.07	0.14
Train Driver Cabin Light	0.07	0.00	0.00	0.00
Train Driver Cabin Reading Light	0.02	0.00	0.00	0.00
Air Dryer Unit (LTZ011H)	0.03	0.00	0.00	0.03
Brake Control Unit	0.01	0.01	0.00	0.01
Magnetic Valve (A19)	0.01	0.00	0.00	0.01
Magnetic Valve (U15)	0.00	0.01	0.00	0.00
Blasting Heater , Indicator and Power Units	0.17	0.00	0.00	0.17
Magnetic Valve (F09)	0.02	0.00	0.00	0.02
Impulse Valve	0.01	0.01	0.00	0.01
Anti Slip Valve	0.01	0.01	0.01	0.01
Magnetic Valve for Stroke	0.03	0.00	0.00	0.00
Wiper Motor	0.03	0.00	0.00	0.00
Water Reservoir	0.03	0.00	0.00	0.00
Magnetic Valve for Coupling	0.01	0.00	0.00	0.01
Heater for Electric Header	0.05	0.00	0.00	0.05
Head Lamps	0.40	0.00	0.00	0.00
Stop Lamps	0.00	0.00	0.00	0.02
Signal Lamps	0.02	0.00	0.00	0.02
TMS				
Main Unit	0.07	0.00	0.00	0.07
Secondary Unit	0.00	0.05	0.00	0.00
Display Unit	0.03	0.00	0.00	0.03
PA/PIS				
AVAU	0.06	0.00	0.00	0.06
PAMP	0.05	0.05	0.00	0.05
DIF	0.11	0.00	0.00	0.11

PIB	0.56	0.28	0.28	0.56
Wireless Communication Device	0.09	0.00	0.00	0.06
ATS System	0.35	0.00	0.00	0.35
RC Casing	0.00	0.06	0.00	0.00
HVAC Control	0.80	0.40	0.40	0.80
Evaporator Fan Motor	1.48	0.74	0.74	1.48
APU Control Load	0.00	0.44	0.44	0.00
Main C/I Control Load	0.30	0.00	0.00	0.30
General Distribution Panel	0.10	0.10	0.00	0.10
PCT/Aux Control Box	0.00	0.10	0.10	0.00
Door Control	0.11	0.05	0.05	0.11
Door Motor	0.13	0.06	0.06	0.13
Battery Charger Unit	0.00	0.00	4.80	0.00
Subtotal	5.29	2.44	6.96	4.70

※ Note: The DC load in detail,will be given in a document entitled (REDE100361 Calculation of battery capacity) will be presented.

4.2. Extension Power Supply [In case of one API defective]

380V&220V AC (Summer) [KVA]

NO	Power	Mc	T	Mc	Power Factor
3- Phase , AC 380V, 50Hz					
1	Passenger Compartment Air Conditioner				
	Compressor	12.68	12.68	12.68	0.82
	Condenser Fan Motor	2.14	2.14	2.14	0.7
2	Train Driver Cabin Air Conditioner				
	Compressor Motor	2.82	0.00	0.00	0.85
	Condenser Fan Motor	0.33	0.00	0.00	0.6
	Evaporator Fan Motor	0.14	0.00	0.00	0.7
3	Air Compressor Motor (VV80T)	6.32	0.00	6.32	0.74
4	Main Transformer Blower Fan	0.00	0.55	0.00	1
1-phase, AC 220V, 50Hz					
5	CC TV	0.60	0.60	0.60	1
6	Defroster	0.40	0.00	0.40	1
7	Indoor Lights	0.83	0.91	0.83	0.95
8	Driver Cabin HVAC Control	0.08	0.00	0.00	1
	Total	26.86	17.39	23.48	

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※ Note: lima system and heater load factor will be 50 per cent in prolonged supply situation.

380V & 220 V AC(Winter) [KVA]

NO	Power	Mc	T	Mc	Power Factor
3- Phase , AC 380V, 50Hz					
1	Passenser Compartment Heater				
	Heater	6.00	6.60	6.00	1
	Electric Heater (with Passegger Compartment Air Conditioner)	12.00	12.00	12.00	1
2	Train Driver Cabin Heating				
	Ceiling Heater	3.00	0.00	0.00	1
	Evaporator Fan Motor	0.14	0.00	0.00	0.7
3	Air Compressor Motor (VV80T)	6.32	0.00	6.32	0.74
4	Main Transformer Blower Fan	0.00	0.55	0.00	1
1- Phase , AC 220V, 50Hz					
5	CC TV	0.60	0.60	0.60	1
6	Defroster	0.40	0.00	0.40	1
7	Indoor Lights	0.83	0.91	0.83	0.95
8	Driver Cabin HVAC Control	0.08	0.00	0.00	1
Total		29.88	21.16	26.65	

110V DC [KW]

Load	Mc	T	Mc
Indoor Lights	0.14	0.14	0.14
Train Driver Cabin Light	0.07	0.00	0.00
Train Driver Cabin Reading Light	0.02	0.00	0.00
Air Dryer Unit (LTZ011H)	0.03	0.00	0.03
Brake Control Unit	0.01	0.01	0.01
Magnetic Valve (A19)	0.01	0.00	0.01
Magnetic Valve (U15)	0.00	0.01	0.00
Blasting Heater , Indicator and Power Units	0.17	0.00	0.17
Magnetic Valve (F09)	0.02	0.00	0.02
Impulse Valve	0.01	0.01	0.01
Anti Slip Valve	0.01	0.01	0.01
Magnetic Valve for Horn	0.03	0.00	0.00
Wiper Motor	0.03	0.00	0.00
Water Reservoir	0.03	0.00	0.00

Magnetic Valve for Coupling	0.01	0.00	0.01
Heater for Electric Header	0.05	0.00	0.05
Head Lamps	0.40	0.00	0.00
Stop Lamps	0.00	0.00	0.02
Signal Lamps	0.02	0.00	0.00
TMS			
Main Unit	0.07	0.00	0.07
Secondary Unit	0.00	0.05	0.00
Display Unit	0.03	0.00	0.00
PA/PIS			
AVAU	0.06	0.00	0.06
PAMP	0.05	0.05	0.05
DIF	0.11	0.00	0.11
PIB	0.56	0.56	0.56
Wireless Communication Device	0.09	0.00	0.06
ATS System	0.35	0.00	0.35
RC Casing	0.00	0.06	0.00
HVAC Control	0.40	0.40	0.40
Evaporator Fan Motor	1.48	1.48	1.48
APU Control Load	0.00	0.44	0.00
Main C/I Control Load	0.30	0.00	0.30
General Distribution Panel	0.10	0.10	0.10
PCT/Aux Control Box	0.00	0.20	0.00
Door Control	0.11	0.11	0.11
Door Motor	0.13	0.13	0.13
Subtotal	4.89	3.76	4.25

※ Note: The battery charging load is taken into account in the DC load table. Because under normal conditions it is constantly fully charged battery .

Yet, the battery charger will supply power to ordinary DC load of the train . Because the battery voltage is higher than the battery charger volatj . Then the battery power of the charger is not only to meet the DC load to the battery using longer trains at the same time will also be used to charge the power .

5. AC and DC Loads Calculation Summary

5.1. AC Load Summary

Winter [KVA]

		Mc	T	T	Mc
		APU1		APU2	
Regular	Wagon	47.88	20.20	19.55	44.65
	Total	68.08		64.21	
Extension	Wagon	29.88	21.16		26.65
	Total	77.69			

Summer [KVA]

		Mc	T	T	Mc
		APU1		APU2	
Regular	Wagon	41.69	16.43	15.78	38.30
	Total	58.12		54.08	
Extension	Wagon	26.86	17.39		23.48
	Total	67.72			

5.2. DC Load Summary

[KW]

		Mc	T	T	Mc
Regular	Wagon	5.29	2.44	6.96	4.70
	Total	7.73		11.65	
Extension	Wagon	4.89	3.76		4.25
	Total	12.90			

6. Result

6.1. AC Capacity

As calculated in case 5.1 extended power supplying status (one APU fault) the total AC load is 77.69 KVA . Consequently , considering the total power of 105 KVA indicates that there are 26 percent excess power in this train.

6.2. DC Capacity

As calculated in case 5.1 extended power supplying status (one APU fault) the total DC load is 12.90 KVA . Consequently , considering the total power of 15 KVA indicates that there are 14 percent excess power in this train.

Appendix C: Datasheet of the SMA-1200TL Three Phase Inverter

SUNNY TRIPOWER
5000TL – 12000TL

Economical

- Maximum efficiency of 98.3 %
- Shade management with OptiTrac Global Peak
- Active temperature management with OptiCool

Flexible

- DC input voltage of up to 1,000 V
- Integrated grid management functions
- Reactive power supply
- Module-tailored system design with Optiflex

Communicative

- SMA Webconnect
- Sunny Portal communication
- SMA and SunSpec Modbus communication
- Simple country configuration
- Multifunction relay comes standard

Easy-to-Use

- Three-phase feed-in
- Cable connection without tools
- SUNCLIX DC plug-in system
- Integrated ESS (Electronic Solar Switch)
- Easy wall mounting

SUNNY TRIPOWER 5000TL – 12000TL

The Three-Phase Inverter – Not Only for Your Home...

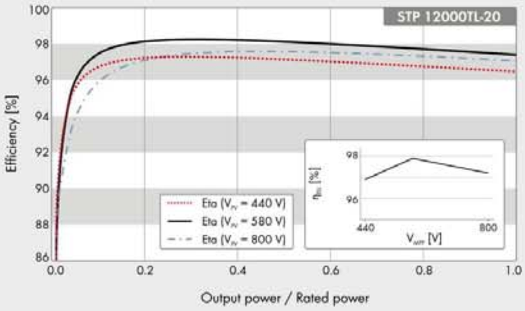
...but also perfectly suited to the design of the traditional residential PV system up to the higher power outage range. After all, with the addition of the new 10 kVA and 12 kVA versions to the portfolio, the Sunny Tripower product range covers a broad spectrum of applications. Users benefit from numerous tried-and-tested product features. Highly flexible with its proven Optiflex technology and asymmetrical multistring, it delivers maximum yields with a top efficiency rating and OptiTrac Global Peak. In addition to SMA and Sunspec Modbus communication, it also comes standard with a direct Sunny Portal connection via SMA Webconnect. Other standard features include integrated grid management functions, reactive power supply and suitability for operation with a 30 mA RCD. In summary, when it comes to system design in the 5 kW to 12 kW power classes, the Sunny Tripower is the optimum product solution – for applications ranging from use in your own home and larger PV rooftop systems to implementation of smaller-scale PV farms.

SUNNY TRIPOWER
5000TL / 6000TL / 7000TL / 8000TL / 9000TL / 10000TL / 12000TL

Technical Data	Sunny Tripower 5000TL	Sunny Tripower 6000TL
Input (DC)		
Max. generator power	9000 Wp	9000 Wp
Max. input voltage	1000 V	1000 V
MPP voltage range / rated input voltage	245 V to 800 V/580 V	295 V to 800 V/580 V
Min. input voltage / start input voltage	150 V / 188 V	150 V / 188 V
Max. input current input A / input B	11 A / 10 A	11 A / 10 A
Max. short-circuit current input A / input B	17 A / 15 A	17 A / 15 A
Number of independent MPP inputs / strings per MPP input	2 / A:2; B:2	2 / A:2; B:2
Output (AC)		
Rated power (at 230 V, 50 Hz)	5000 W	6000 W
Max. AC apparent power	5000 VA	6000 VA
Nominal AC voltage	3 / N / PE; 220 / 380 V 3 / N / PE; 230 / 400 V 3 / N / PE; 240 / 415 V	3 / N / PE; 220 / 380 V 3 / N / PE; 230 / 400 V 3 / N / PE; 240 / 415 V
Nominal AC voltage range	160 to 280 V	160 V to 280 V
AC grid frequency / range	50 Hz, 60 Hz / -5 Hz to +5 Hz	50 Hz, 60 Hz / -5 Hz to +5 Hz
Rated power frequency / rated grid voltage	50 Hz / 230 V	50 Hz / 230 V
Max. output current	7.3 A	8.7 A
Power factor at rated power	1	1
Adjustable displacement power factor	0.8 overexcited to 0.8 underexcited	0.8 overexcited to 0.8 underexcited
Feed-in phases / connection phases	3 / 3	3 / 3
Efficiency		
Max. efficiency / European efficiency	98 % / 97.1 %	98 % / 97.4 %
Protective devices		
DC disconnect device	●	●
Ground fault monitoring / grid monitoring	● / ●	● / ●
DC reverse polarity protection / AC short-circuit current capability / galvanically isolated	● / ● / –	● / ● / –
All-pole sensitive residual-current monitoring unit	●	●
Protection class (according to IEC 62103)/overvoltage category (according to IEC 60664-1)	I / III	I / III
General data		
Dimensions (W / H / D)	470 / 730 / 240 mm (18.5 / 28.7 / 9.5 inch)	470 / 730 / 240 mm (18.5 / 28.7 / 9.5 inch)
Weight	37 kg (81.6 lb)	37 kg (81.6 lb)
Operating temperature range	-25 °C to +60 °C (-13 °F to +140 °F)	-25 °C to +60 °C (-13 °F to +140 °F)
Noise emission (typical)	40 dB(A)	40 dB(A)
Self-consumption (at night)	1 W	1 W
Topology / cooling concept	Transformerless / Opticool	Transformerless / Opticool
Degree of protection (according to IEC 60529)	IP65	IP65
Climatic category (according to IEC 60721-3-4)	4K4H	4K4H
Maximum permissible value for relative humidity (non-condensing)	100 %	100 %
Features		
DC connection / AC connection	SUNCLIX / spring-cage terminal	SUNCLIX / spring-cage terminal
Display	Graphic	Graphic
Interface: RS485, Modbus, Speedwire / Webconnect	○ / ● / ●	○ / ● / ●
Multifunction relay / Power Control Module	● / ○	● / ○
Guarantee: 5 / 10 / 15 / 20 years	● / ○ / ○ / ○	● / ○ / ○ / ○
Certificates and permits (more available on request)	AS 4777.2:2015, CE, CEI 0-21:2016, C10/11:2012, DIN EN 62109-1, EN 50438[1], G59/3, G83/2, IEC 61727/MEA[2], IEC 62109-2, NEN EN 50438, NRS 097-2-1, PPC, PPDS, RD 661/2007, RD 1699:2011, SI 4777, UTE C15-712-1, VDE0126-1-1, VDE AR-N 4105, VFR 2013, VFR 2014	
Type designation	STP 5000TL-20	STP 6000TL-20

Sunny Tripower 7000TL	Sunny Tripower 8000TL	Sunny Tripower 9000TL
13500 Wp	13500 Wp	13500 Wp
1000 V	1000 V	1000 V
290 V to 800 V / 580 V	330 V to 800 V / 580 V	370 V to 800 V / 580 V
150 V / 188 V	150 V / 188 V	150 V / 188 V
15 A / 10 A	15 A / 10 A	15 A / 10 A
25 A / 15 A	25 A / 15 A	25 A / 15 A
2 / A:2; B:2	2 / A:2; B:2	2 / A:2; B:2
7000 W	8000 W	9000 W
7000 VA	8000 VA	9000 VA
3 / N / PE; 220 / 380 V 3 / N / PE; 230 / 400 V 3 / N / PE; 240 / 415 V	3 / N / PE; 220 / 380 V 3 / N / PE; 230 / 400 V 3 / N / PE; 240 / 415 V	3 / N / PE; 220 / 380 V 3 / N / PE; 230 / 400 V 3 / N / PE; 240 / 415 V
160 V to 280 V	160 V to 280 V	160 V ... 280 V
50 Hz, 60 Hz / -5 Hz to +5 Hz	50 Hz, 60 Hz / -5 Hz to +5 Hz	50 Hz, 60 Hz / -5 Hz ... +5 Hz
50 Hz / 230 V	50 Hz / 230 V	50 Hz / 230 V
10.2 A	11.6 A	13.1 A
1	1	1
0.8 overexcited to 0.8 underexcited	0.8 overexcited to 0.8 underexcited	0.8 overexcited to 0.8 underexcited
3 / 3	3 / 3	3 / 3
98 % / 97.5 %	98 % / 97.6 %	98 % / 97.6 %
●	●	●
● / ●	● / ●	● / ●
● / ● / –	● / ● / –	● / ● / –
●	●	●
I / III	I / III	I / III
470 / 730 / 240 mm (18.5 / 28.7 / 9.5 inch)	470 / 730 / 240 mm (18.5 / 28.7 / 9.5 inch)	470 / 730 / 240 mm (18.5 / 28.7 / 9.5 inch)
37 kg (81.6 lb)	37 kg (81.6 lb)	37 kg (81.6 lb)
-25 °C to +60 °C (-13 °F to +140 °F)	-25 °C to +60 °C (-13 °F to +140 °F)	-25 °C to +60 °C (-13 °F to +140 °F)
40 dB(A)	40 dB(A)	40 dB(A)
1 W	1 W	1 W
Transformerless / Opticool	Transformerless / Opticool	Transformerless / Opticool
IP65	IP65	IP65
4K4H	4K4H	4K4H
100 %	100 %	100 %
SUNCLIX / spring-cage terminal	SUNCLIX / spring-cage terminal	SUNCLIX / spring-cage terminal
Graphic	Graphic	Graphic
○ / ● / ●	○ / ● / ●	○ / ● / ●
● / ○	● / ○	● / ○
● / ○ / ○ / ○	● / ○ / ○ / ○	● / ○ / ○ / ○
AS 4777.2:2015, CE, CEI 0-21:2016, C10/11:2012, DIN EN 62109-1, EN 50438[1], G59/3, G83/2, IEC 61727/MEA[2], IEC 62109-2, NEN EN 50438, NRS 097-2-1, PPC, PPDS, RD 661/2007, RD 1699:2011, SI 4777, UTE C15-712-1, VDE0126-1-1, VDE AR-N 4105, VFR 2013, VFR 2014		
STP 7000TL-20	STP 8000TL-20	STP 9000TL-20

Efficiency curve



Accessories

Power Controle Module
PWCBRD-10

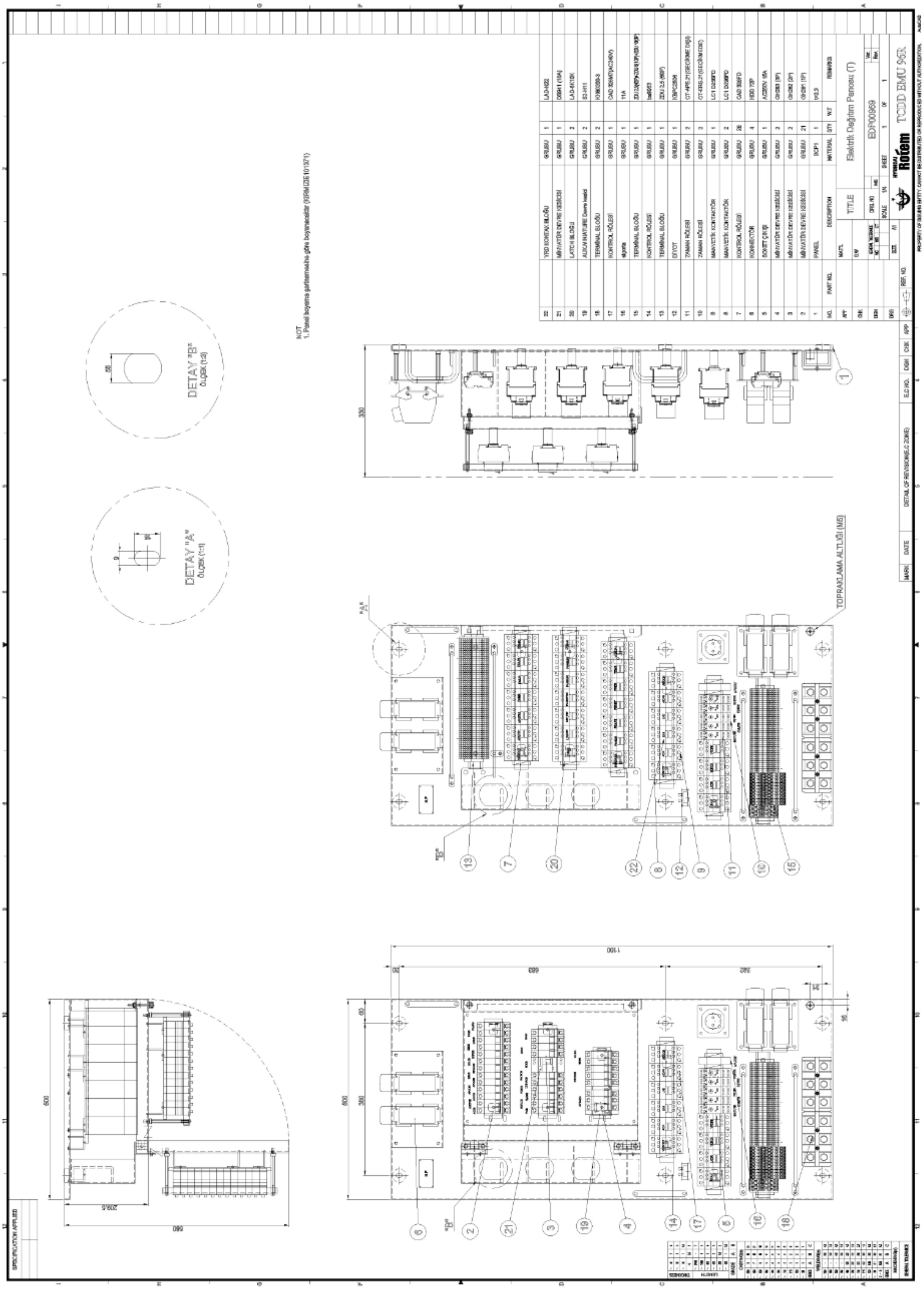
RS485 interface
485BRD-10

[1] Does not apply to all national appendices of EN 50438
[2] Only STP 9000TL-20

● Standard feature ○ Optional feature – Not available
Last updated: May 2017
Data at nominal conditions

Sunny Tripower 10000TL	Sunny Tripower 12000TL	
13500 Wp	18000 Wp	
1000 V	1000 V	
370 V to 800 V / 580 V	440 V to 800 V / 580 V	
150 V / 188 V	150 V / 188 V	
18 A / 10 A	18 A / 10 A	
25 A / 15 A	25 A / 15 A	
2 / A:2; B:2	2 / A:2; B:2	
10000 W	12000 W	
10000 VA	12000 VA	
3 / N / PE; 220 / 380 V 3 / N / PE; 230 / 400 V 3 / N / PE; 240 / 415 V	3 / N / PE; 220 / 380 V 3 / N / PE; 230 / 400 V 3 / N / PE; 240 / 415 V	
160 V to 280 V	160 V to 280 V	
50 Hz, 60 Hz / -5 Hz to +5 Hz	50 Hz, 60 Hz / -5 Hz to +5 Hz	
50 Hz / 230 V	50 Hz / 230 V	
14.5 A	17.4 A	
1	1	
0.8 overexcited to 0.8 underexcited	0.8 overexcited to 0.8 underexcited	
3 / 3	3 / 3	
98 % / 97.6 %	98.3 % / 97.9 %	
●	●	
● / ●	● / ●	
● / ● / –	● / ● / –	
●	●	
I / III	I / III	
470 / 730 / 240 mm (18.5 / 28.7 / 9.5 inches)	470 / 730 / 240 mm (18.5 / 28.7 / 9.5 inch)	
37 kg (81.6 lb)	38 kg / 84 lbs	
-25 °C to +60 °C (-13 °F to +140 °F)	-25 °C to +60 °C (-13 °F to +140 °F)	
40 dB(A)	40 dB(A)	
1 W	1 W	
Transformerless / Opticool	Transformerless / Opticool	
IP65	IP65	
4K4H	4K4H	
100 %	100 %	
SUNCLIX / spring-cage terminal	SUNCLIX / spring-cage terminal	
Graphic	Graphic	
○ / ● / ●	○ / ● / ●	
● / ○	● / ○	
● / ○ / ○ / ○	● / ○ / ○ / ○	
AS 4777.2:2015, CE, CEI 0-21:2016, C10/11:2012, DIN EN 62109-1, EN 50438[1], G59/3, G83/2, IEC 61727/MEA[2], IEC 62109-2, NEN EN 50438, NRS 097-2-1, PPC, PPDS, RD 661/2007, RD 1699:2011, SI 4777, UTE C15-712-1, VDE0126-1-1, VDE AR-N 4105, VFR 2013, VFR 2014		
STP 10000TL-20	STP 12000TL-20	

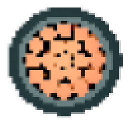
Appendix D: Electricity Distribution Board Detail



Appendix E: HES Cable NYY

HES KABLO

0.6/1 kV PVC izoleli, tek damarlı, bakır iletkenli kablolar



Kod
YVV-U,YVV-R, CU/PVC/PVC, NYY
U: Som iletken
R: Örgülü Rijit iletken

Standartlar

TS IEC 60502 -1, VDE 0276

Teknik Veriler
Maksimum çalışma sıcaklığı : 70 °C
Maksimum kısa devre sıcaklığı: (max. 5 sn.)
Kesit < 300 mm : 160 °C
Kesit > 300 mm : 140 °C
Anma gerilimi : 0.6/1 kV
Minimum bükülmeyarıçapı : 12 x D
D : Kablo çapı

Kullanıldığı Yerler

Güç merkezlerinde, şalt ve endüstritesislerinde, yerel enerji dağıtımında güç kablosu olarak; mekanik hasar riskinin olmadığı yerlerde hariçte, dahilde, toprak altında veya kablo kanallarında kullanılır.

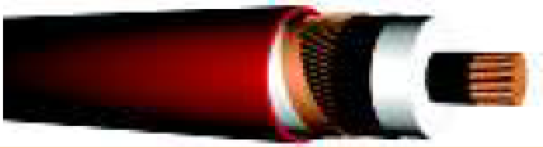
Yapısı

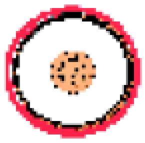
1. Bir veya çok telli bakır iletken.
2. PVC izole.
3. PVC dış kılıf.

BOYUT VE AĞIRLIKLAR			ELEKTRİKSEL ÖZELLİKLER					
Normal Kesit	Dış Çap (yaklaşık)	Net Ağırlık (yaklaşık)	Sevk Uzunluğu	İletken DC Direnci 20 °C' de max	Akım Taşıma Kapasitesi(A)			
					Toprakta 20 °C		Havada 30 °C	
mm²	mm	kg/km	m	ohm/km	***	***	***	***
1x1,5	5.8	50	1000	12.1	-	-	25	20
1x2,5	6.2	60	1000	7.41	-	-	34	27
1x4	7.0	85	1000	4.61	-	-	45	37
1x6	7.5	105	1000	3.08	-	-	57	48
1x10	9.0	160	1000	1.83	-	-	78	66
1x16	10.0	215	1000	1.15	127	107	103	89
1x25	11.5	320	1000	0.727	163	137	137	118
1x35	12.5	420	1000	0.524	195	165	169	145
1x50	14.0	570	1000	0.387	230	195	206	176
1x70	15.5	780	1000	0.268	282	239	261	224
1x95	18.0	1050	1000	0.193	336	287	321	271
1x120	19.5	1300	1000	0.153	382	326	374	314
1x150	21.0	1600	1000	0.124	428	366	428	361
1x185	23.5	1950	1000	0.0991	483	414	494	412
1x240	27.0	2550	1000	0.0754	561	481	590	484
1x300	30.5	3150	1000	0.0601	632	542	678	549
1x400	34.0	4200	1000	0.0470	730	624	817	657
1x500	39.0	5200	1000	0.0366	823	698	940	749
1x630	42.0	6450	500	0.0283	866	775	1108	920

Appendix F: HES OG Cable N2XSY

20.8/36 kV XLPE izoleli, tek damarlı, bakır iletkenli kablolar





Kod

YXC7V-R, N2XSY, CU/XLPE/CWS/PVC
R: Örgülü rijit iletken

Standartlar

TS HD 620 S2

Teknik Veriler

Maksimum çalışma sıcaklığı : 90 °C
Maksimum kısa devre sıcaklığı: 250 °C (max. 5 sn.)
Anma gerilimi : 20.8/36 kV
Minimum bükülme yarıçapı : 15 x D
D : Kablo çapı

Kullanıldığı yerler

Dielektrik kayıpları çok düşük olan bu kablolar, ani yük değişimlerinin olduğu şebekeler ile kısa devre akımlarının büyük olduğu yerleşim ve endüstri bölgelerinde, kablo kanallarında, toprak altında ve havada kullanılır

Yapısı

1. Çok telli bakır iletken
2. iç yarı iletken
3. XLPE izole
4. Dış yarı iletken
5. Yarı iletken bant
6. Bakır ekran
7. Polyester bant
8. PVC dış kılıf

BOYUT VE AĞIRLIKLAR				ELEKTRİKSEL ÖZELLİKLER								
Normal Kesit	Dış Çap (yaklaşık)	Net Ağırlık (yaklaşık)	Sevk Uzunluğu	İletken DC Direnci 20 °C' de max	İletken DC Direnci 90 °C' de max	Çalışma İndüktansı (yaklaşık)		İşletme Kapasitesi (yaklaşık)	Akım Taşıma Kapasitesi(A)			
mm²	mm	kg/km	m	ohm/km	ohm/km	••• mH/km	∴ mH/km	F/km	Toprakta 20°C •••	Toprakta 20°C ∴	Havada 30°C •••	Havada 30 °C ∴
1x25/16	33.5	1200	1000	0.7270	0.9306	0.711	0.486	0.105	-	-	-	-
1x35/16	34.5	1300	1000	0.5240	0.6707	0.685	0.464	0.115	214	192	233	202
1x50/16	36.0	1550	1000	0.3870	0.4954	0.659	0.444	0.125	251	226	279	241
1x70/16	37.5	1800	1000	0.2680	0.3430	0.628	0.420	0.140	306	276	348	299
1x95/16	39.5	2100	1000	0.1930	0.2470	0.604	0.402	0.153	363	329	421	362
1x120/16	41.5	2400	1000	0.1530	0.1958	0.585	0.388	0.165	410	373	483	416
1x150/25	43.0	2850	1000	0.1240	0.1587	0.567	0.376	0.178	449	415	540	469
1x185/25	44.5	3200	1000	0.0991	0.1268	0.551	0.365	0.191	503	468	615	536
1x240/25	47.5	3800	1000	0.0754	0.0965	0.531	0.351	0.209	576	541	718	630
1x300/25	49.5	4500	1000	0.0601	0.0769	0.514	0.341	0.226	641	608	812	717
1x400/35	53.0	5650	500	0.0470	0.0602	0.493	0.328	0.252	697	684	904	823
1x500/35	56.0	6700	500	0.0366	0.0468	0.477	0.318	0.274	768	762	1011	929
1x630/35	60.0	8000	500	0.0283	0.0362	0.460	0.308	0.300	858	847	1128	1043

Appendix G: Suburban Train System SES Principle Single Line Project

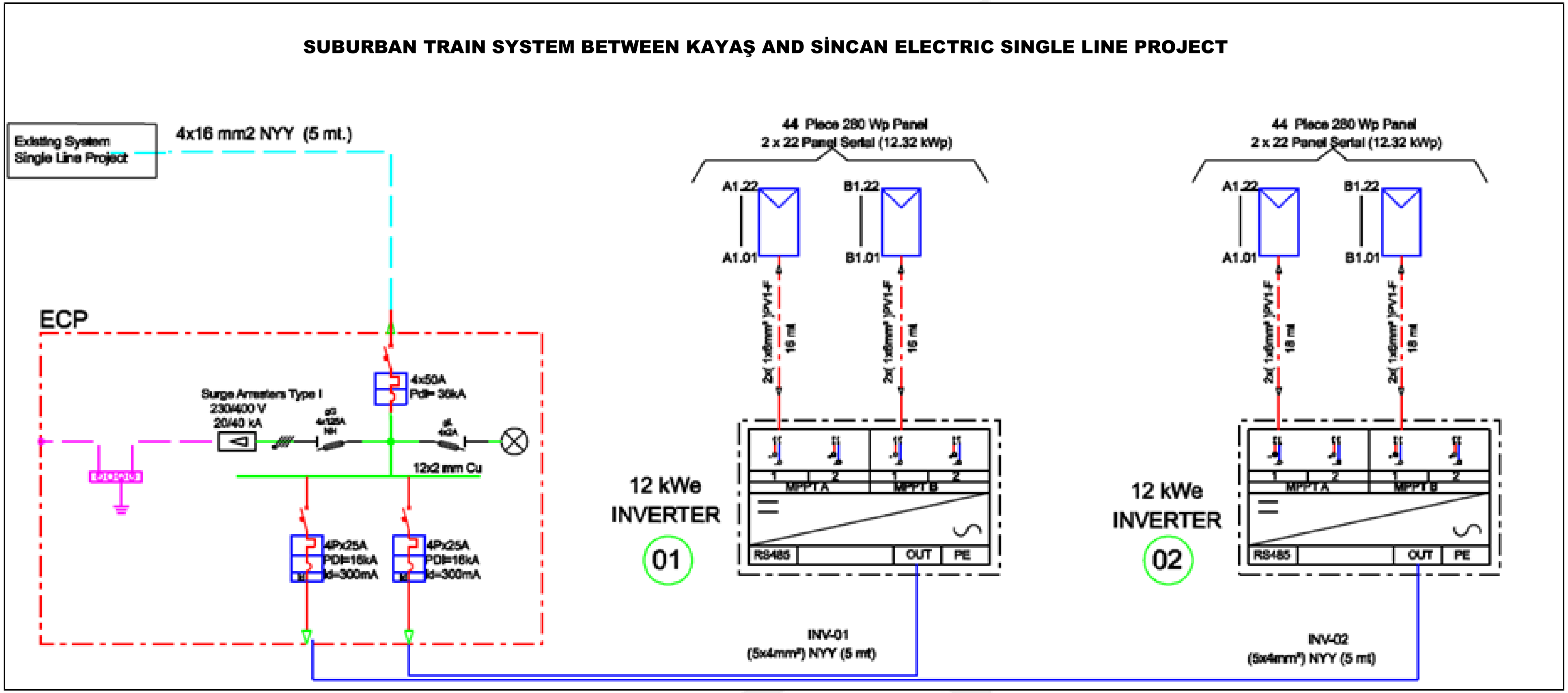


Figure 4.2: Suburban train system SES principle single line project.

CV

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Institution	University of Turkish Aeronautical Association
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Operating Systems	Windows, Android, iOS
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