Application of 30 MWp Grid-Connected Solar Photovoltaic Power Plant for Djibouti Vision 2035

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Abstract – Nowadays, like most of African countries, Djibouti is facing challenging energy access. The country was suffering a shortage of electricity for a long period until the government of Djibouti signed an agreement with the Ethiopia electric power cooperation (EEPCO) company in 2011. Thereby, the electricity consumption of the country is mainly from imported fossil fuels and the interconnection project. In order to realize Djibouti Vision 2035, the Republic of Djibouti signed an agreement with an Emirati company (AMEA) to build the first solar photovoltaic power plant in Grand Bara. In this paper, sizing, and simulation of the 30 MWp grid-connected solar photovoltaic power plant will be done using PVsyst 7.2 software. A 400 W bifacial monocrystalline panel and 160 kW string inverters are used in this study. The simulation results from PVsyst software are to acquire the system production, the performance ratio, and the various power losses such as losses due to irradiance level. The average global horizontal irradiance of the site is 2317.2 kWh/m^2 while the average ambient temperature is 25.75° C. About 59.6 GWh of electricity power is injected into the grid with an average performance ratio of 83.21% in the year. This study is an example in terms of solar energy application in Africa and also its contributions to the socio-economic development of African countries will be observed in the near future.

Keywords: Energy access, Djibouti Vision 2035, Grand Bara, grid-connected solar photovoltaic power plant, socio-economic development.

1. Introduction

Due to global warming, the United Nations presented seventeen global goals in the name of Sustainable Development Goals (SDGs) which were set up in 2015. While the main goal of SDGs is to protect the planet and to prevent climate change, they also encourage a better sustainable future in health, education, and well-being for the whole world around 2030 [1-4]. According to ref [5], the demand for electricity is continuously increasing because of the population growth (9.7 billion in 2050) around the world. Despite their environmental impact and their high price, fossil fuels which are the actual source of electricity production will dry up in the coming years. Hence renewable energy resources become the most widely used energy resources due to their fewer impact on the environment. Among the renewable energy sources, the photovoltaic system is the most used because it can produce nearly the whole energy demand around the world [6-9]. The total annual solar radiation received by the Earth from the sun is more than 7500 times 450 EJ (the total annual primary energy consumed around the world). The Grid-connected photovoltaic system is one of the most used applications for power generation as the cost of PV systems become very affordable [10-13]. According to ref [14], IEA's prognosis states that the production cost of large-scale PV power plants, in five coming years, will decrease by 36% which will result in the lowest cost of electricity generation in the world.

Djibouti, which is a small country of 23 000 km^2 with approximately one million inhabitants, located in the East of Africa is endowed with significant sources of renewable energy such as solar, wind, and geothermal energy sources. The increase in population and the demand for energy consumption is prompting the Republic of Djibouti to develop its renewable energy sources, to meet energy access and energy security. Like the majority of African countries, the Republic of Djibouti is facing numerous critical challenges with energy accessibility. The country is strongly dependent on Ethiopia and on imported fossil fuels in terms of energy consumption where 62% of the whole population has access to electricity. This has led to a pricey electricity bill for consumers, with an average of $0.28/kWh which is higher than the average of $0.14/kWh in Africa [15]. Due to the growing population and energy access challenge, Djibouti is planning to make Djibouti Vision 2035 a reality. This leads the Republic of Djibouti to build the first large-scale 30 MWp grid-connected photovoltaic power plant in Grand Bara (latitude: 11.25° N, longitude:42.61° E) by the Emirati company AMEA Power [16,17]. As stated in ref [18], Djibouti initiated in 2014 a long-term sustainable development, known as Vision 2035 which is to be a fully independent and “100% green” country by having energy access as well as energy security. The country also plans to join the East African Power Pool (EAPP) and be an important regional power supplier. Therefore, the 30 MWp solar grid-connected power plant in Grand Bara (south of Djibouti) will be the first solar farm built by an Emirati Independent Power Producer (IPP)AMEA Power and the second renewable energy project after the Ghoubet wind energy project (60 MW) [19]. The application of large-scale photovoltaic power plants is a pioneer study for the projection of Djibouti Vision 2035 as well as for the rest of African countries for better sustainable development. Hence its contributions in terms of the socio-economic aspect will be observed in the near future. This study will be carried out by the simulation of the 30 MWp solar grid-connected power plant in Grand Bara using PVsyst software.

The organization of this study is done as follows, the site selection and orientation are given in section 2. Section 3 presents the description of PV grid systems and Djibouti power system. And lastly, section 4 discusses the simulation analysis obtained after the simulation of the 30 MWp PV grid-connected system.

2. Site Selection and Orientation

The Grand Bara is a desert area located in the south of Djibouti. The geographical location of the site is 11.2466° North latitude, 42.6082° East longitude, and 556 m above sea level of altitude (as shown in figure 1). Almost no animals are living in this area because of its climate conditions.

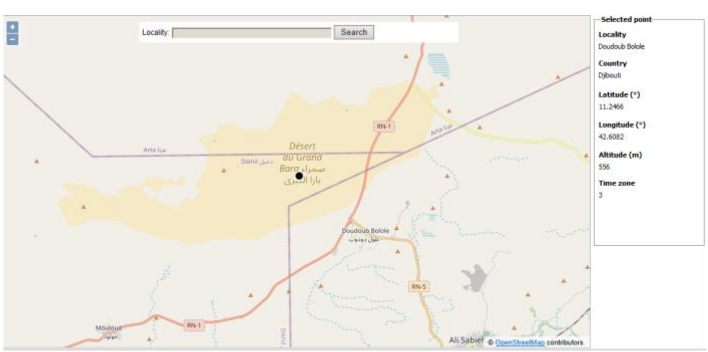

Fig. 1. Geographical data of Grand Bara (PVsyst software).

The orientation of the PV modules is different in the summertime and in the wintertime. The panels are oriented to the south (azimuth =180°) with a tilt angle of 12° in the summertime (from April to September). While the panels are oriented to the north (azimuth = 0.0°) with a tilt angle of 33°in the winter time (October to March). This difference in the orientation and tilt angles will improve the collection of PV solar irradiance which will result in better energy production.

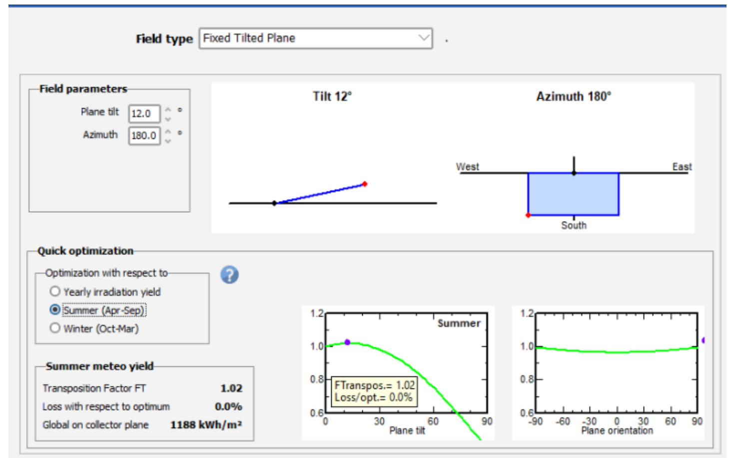

Fig.2. Solar Panel Orientation in the summertime.

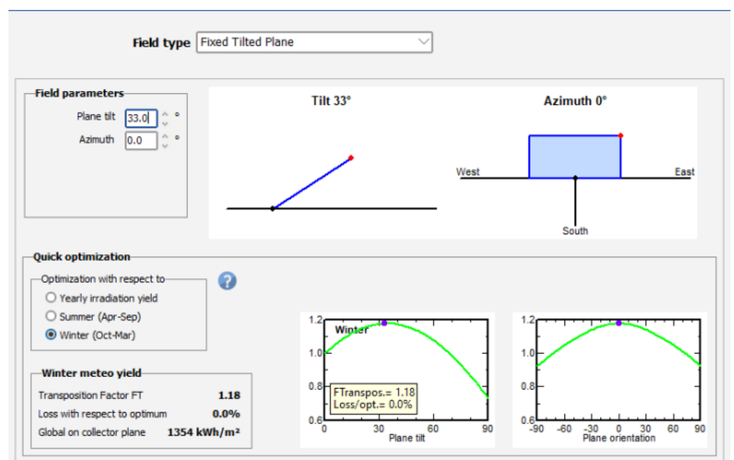

Fig.3. Solar Panel Orientation in the wintertime.

3. Description of PV-grid Systems and Djibouti Power System

PV grid-connected systems are generally composed of a PV array, inverters, and a grid. In this study, a 30 MWp solar grid power plant was sized using PVsyst software. Fig. 4 illustrates the simplified sketch of the PV grid-connected system given by PVsyst software.

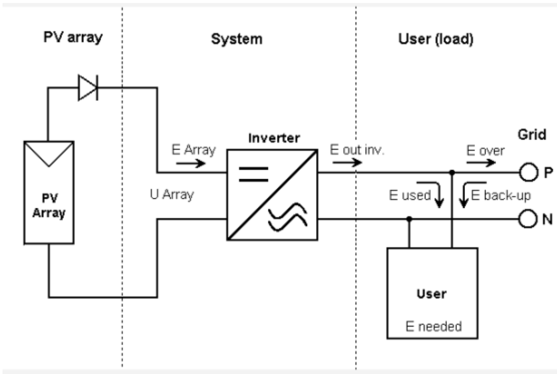

Fig.4. Simplified sketch of PV grid-connected system.

3.1. PV Array Layout

While designing the PV grid-connected power plant, the selection of the PV module is one of the hardest decisions to take because the solar power plant depends on the characteristics of the module such as power output and efficiency [20]. In this study, the selected PV module is a bifacial monocrystalline model (JKM400M-72H-BDVP-Bifacial) of 400 W and 19.55 of efficiency. The bifacial module is selected because it has better efficiency than the mono facial. It uses both sides to capture the sunlight to produce electricity thus the efficiency can be 5% higher than the conventional module (mono facial). The electrical parameters of the module are given in Table 1. The total PV modules required to produce 30MWp are 25 panels connected in series and 3000 connected in parallel with a total area of 153544 m^2.

Table 1. Module datasheet

Maximum Power	400 W
Cells per module	144
Open circuit voltage V_{oc}	48.8 V
Short-circuit current Isc	10.24 A
The voltage at maximum power point V_{mp}	41 V
Current at maximum power point Imp	9.76 A
Temperature coefficient of V_{oc}	-0.142 %/deg. C
Temperature coefficient of I_{sc}	0.05%/deg. C

3.2. Inverter

The inverters are the key role device performing the grid-connected PV power plant as it is the device that converts the DC produced by the PV array to AC to inject it into the grid. Despite their conversion role, inverters control the output voltage and frequency as well as regulate the power quality. The selection of an inverter depends on the specifications of the PV module used thus it should be compatible with the PV module for better system efficiency [21]. In this study, 160 kW$_{ac}$ string inverters (Huawei Sun2000-185KTL-INH0-50C) with MPPT (Maximum Power Point Tracking) technology are selected (Table 2). The total number of inverters for this solar power plant is 160 string inverters.

Table 2. Electrical data specification of Huawei Sun2000-185KTL-INH0-50C

Input side (DC PV field)	
Minimum MPP voltage	600 V
Maximum MPP voltage	1500 V
Maximum DC current	225 A
Output side (AC grid)	
Triphased	50 Hz
Grid voltage	1000 V
Nominal AC Power	160 kVA
Maximum AC Power	185 kVA
Maximum AC current	135 A
Maximum efficiency	99.00%

3.3. Djibouti Power System Layout

As the population of Djibouti is continuously increasing, the demand for energy consumption also soared which led the electricity of Djibouti (EDD) to sign an agreement with Ethiopia electric power cooperation (EEPCO) company. The interconnection line has been established in October 2011 [15]. Approximately 70% of the electricity consumption comes from this interconnection and the lasting 30% is generated domestically from diesel fuel generators. Therefore, the price of electricity in Djibouti is extremely high, and also the electrification rate is very low. This is one of the reasons, the government of Djibouti is working to achieve its Vision 2035 by the means of renewable energy sources [22].

The transmission line voltage of the interconnection line is 230 kV double line (HURSO and ADIGALA) by overhead lines with a total length of 296 km from HURSO to DJABAN'AS. Then there are two step-down transformers (230kV/63kV and 63kV/20kV/11kV) at DJABAN'AS. The 63 kV voltage is redistributed to Boulaos, Marabout, Doraleh, and Al Bawadi Mall to distribute to the consumers. Whereas the 11 kV is used to feed the DJABAN'AS substation and the neighborhoods around this substation. The connection point of the PV solar power plant is at the 63 kV transmission line voltage of the Ali-Sabieh substation as illustrated in Fig. 5. The full single-line diagram is shown in Appendix A.

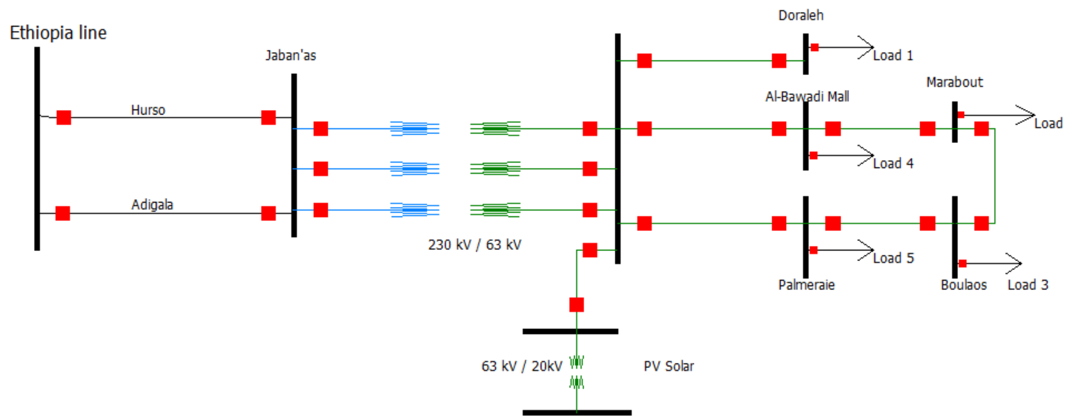

Fig.5. Simplified single-line diagram of Djibouti power grid.

4. Simulation Analysis

The main simulation results given by PVsyst software version 7.2 explain the monthly normalized productions, the performance ratio of the system, the energy produced by the PV array, the energy injected into the grid, and the loss diagram. Fig. 6 shows the monthly normalized productions which included three data (PV array losses, system loss, and the inverter output). It is illustrated from the figure that the produced useful energy is higher in the wintertime than in the summertime. For example, the useful energy produced in April is around 6.1 kWh/kWp/day while the useful energy produced in July is around 4.7 kWh/kWp/day and this is due to the higher ambient temperature in July than in April.

Figure 7 contains the monthly performance ratio of the PV system. The performance ratio provides valuable information about the quality of the system such as the efficiency and reliability of the PV power plant. The performance ratio is the ratio of the energy effectively produced (Y_F) over the energy that would be produced (Y_R) if the system was operating at STC efficiency (1000 W/m^2 & 25°C) [23]. Its formula is given in equation (1). In this simulation, the average performance ratio is 0.832 in the year while the highest performance month is in December with PR=0.846.

$$PR = \frac{Final\ energy\ Yield}{Reference\ energy\ Yield} = \frac{Y_F}{Y_R} \quad (1)$$

Different data such as global horizontal irradiation, ambient temperature, effective energy at the output of the PV array, energy injected into the grid, and performance ratio are represented in Table 3. In this study, Meteonorm 8.0 database which is an international weather data has been used. The yearly average global horizontal irradiation received by the PV array is 2317.2 kWh/m^2, the yearly average ambient temperature is 25.75 °C and the average diffuse horizontal irradiation is 773.19 kWh/m^2. As a result, the effective energy produced by the PV array is 60.7 GWh in a year therefore 59.6 GWh is injected into the grid, taking into account the inverter losses.

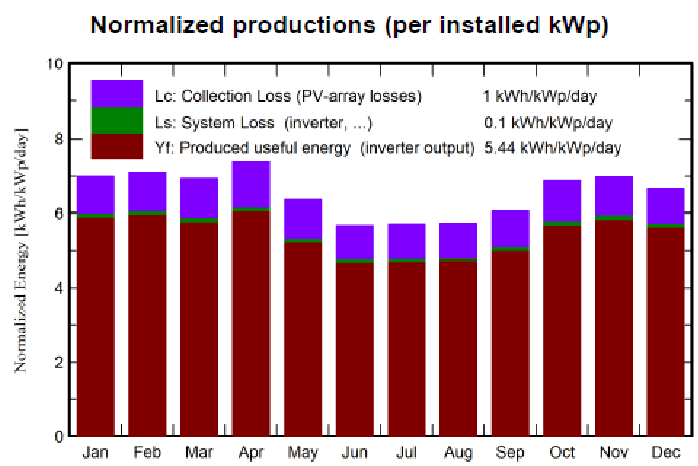

Fig.6. Normalized production (per installed kWp).

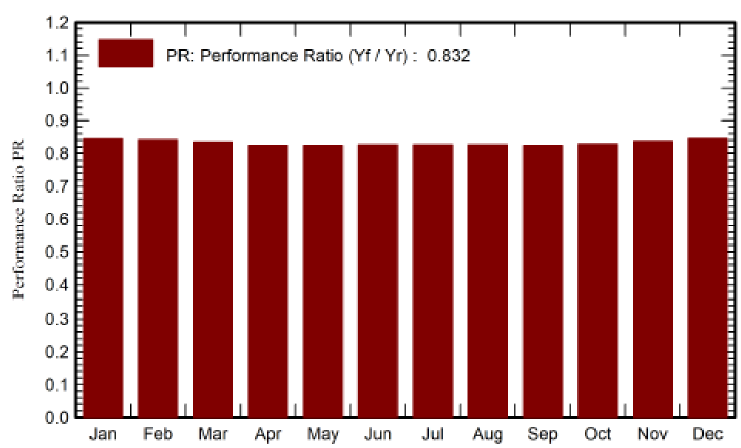

Fig.7. Monthly performance ratio of the PV grid system.

Table 3. Balances and main results of the PV grid system

Month	Global horizontal irradiation (kWh/m^2)	Horizontal diffuse irradiation (kWh/m^2)	Ambient temperature (°C)	EArray (GWh)	E_Grid (GWh)	PR ratio
January	191.3	39.0	20.6	5.60	5.49	0.84
February	182.5	46.8	21.2	5.11	5.02	0.84
March	208.7	65.5	23.4	5.49	5.39	0.83
April	225.2	53.2	25.5	5.57	5.47	0.82
May	209.0	73.6	28.4	4.98	4.88	0.82
June	181.3	88.6	29.8	4.30	4.22	0.83
July	187.0	93.5	30.4	4.47	4.38	0.83
August	182.7	95.3	30.2	4.49	4.41	0.83
September	180.6	78.2	28.7	4.60	4.51	0.82
October	200.6	59.1	25.8	5.40	5.30	0.83
November	187.6	40.1	23.1	5.36	5.26	0.84
December	180.7	40.4	21.5	5.34	5.25	0.85
Year	**2317.2**	**773.3**	**25.7**	**60.71**	**59.58**	**0.83**

In fig. 8, the annual loss diagram is shown in detail. The highest loss is from the PV loss due to temperature at an average of 11% while the minor losses are from the IAM factor on global, ohmic wiring losses, and inverter loss during operation. 70.2 GWh is the produced PV array nominal energy under the standard test conditions (1000 W/m^2 and 25°C) but 60.7 GWh is the produced PV array energy at MPP due to PV system losses such as the PV loss due to irradiance variability as well as the temperature flicks, mismatch loss, modules, and strings losses, etc.

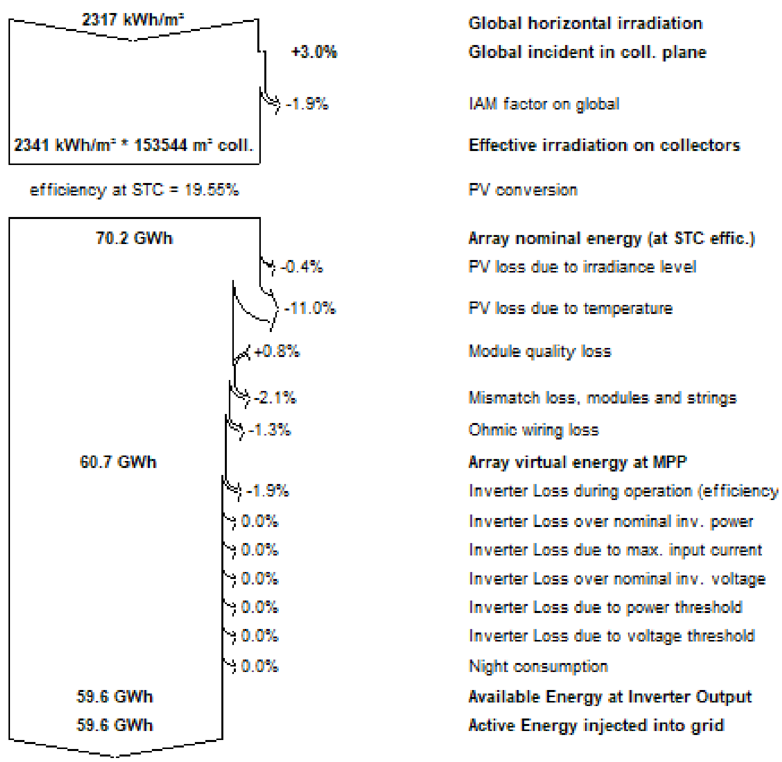

Fig.8. Yearly loss diagram for the Grand Bara site.

5. Conclusions and Discussions

A 30 MWp PV grid-connected power plant in Grand Bara is designed and sized using the PVsyst software version 7.2. A 400W bifacial monocrystalline PV panel with a total number of 75000 PV panels connected in series and parallel with 160 x 160 kW string inverters is selected for this study. The maximum power produced by the PV array is 30 013 kW_{dc} but with the losses of the PV system and inverters, only 25600 kW_{ac} is injected into the grid. It has been observed that the PV loss due to temperature is more severe than the loss due to irradiance level which results in low power generation during the summertime. The performance ratio of the system is 83.21% in a year. Hence, the average daily produced useful energy is 5.44 kWh/kWp and 59.6 GWh is the yearly energy injected into the Djibouti grid. The application of this 30 MWp photovoltaic grid-connected power plant is a contribution to attain Vision 2035 and thus access to energy as well as becoming a “100%” green country. Hence, the Republic of Djibouti will achieve one of the main sustainable development goals. Furthermore, this case study can be considered as a sample for other African countries in terms of the contribution of renewable energy sources to a higher electrification rate as well as to their socio-economic development.

Acknowledgment

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APPENDIX

A. Djibouti Single-line Diagram

The full single-line diagram of the Djibouti power grid is shown in the below figure.

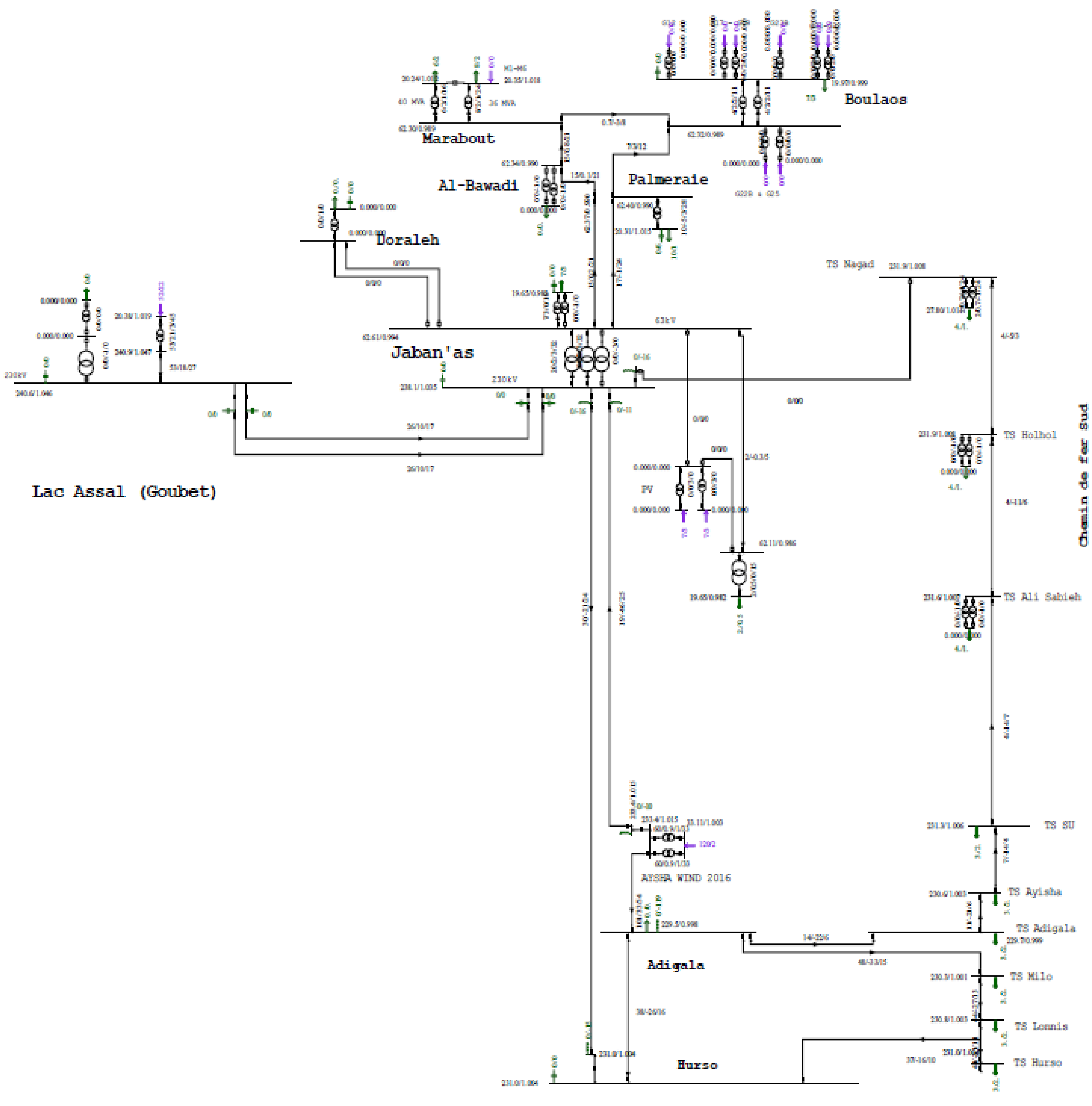

Figure A.1: Single-line diagram of the Djibouti power system.