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Simulation and analysis of the distributed photovoltaic generation systems based on DIgSILENT power factory

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ABSTRACT

The voltage stability of the system has become an important component for the steady and dependable functioning of the power system as a result of multiple blackouts around the world (particularly in Iraq). Distributed photovoltaic systems are a subset of decentralized power generating systems that generate electricity using renewable energy sources like solar cells, wind turbines, and water power plants. In order to size a solar-grid-connected home system properly and to confirm the impact of photovoltaics on the system, this article will also do a steady-state analysis. The heating and cooling loads were taken into account when evaluating the residential load profile. With the help of predicted energy use, the photovoltaic (PV) system was sized. The solar system's power output was calculated, and the key variables affecting system performance were examined. The DigSilent power factory 15.2 was used to simulate all of the investigations. This article achieves better system stability outcomes.

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1. INTRODUCTION

Photovoltaic systems that are connected to the grid are often built to run concurrently with the grid. The inverter is a key component of photovoltaic systems that are connected to the grid. The inverter converts the direct current (DC) power to alternating current (AC) electricity to meet the utility grid's standards for voltage and power quality, and when the utility grid is not in use, it automatically cuts off power to the grid. The distribution panel is typically where a two-way communication interface is created between the utility grid and the AC output circuits of the photovoltaic (PV) system. When the PV system's capacity exceeds the site's load requirement, the AC generated by the PV system can either power the site's electrical loads or be sent back to the grid [1]-[10]. The grid provides the necessary electricity when the electrical loads exceed the output of the PV system. These systems' power is immediately shut off and removed from the grid the moment the grid goes offline [11]-[16].

Because this type of power system information is difficult to get by adding new parameters to any of the power combinations is difficult and time-consuming. On the other hand, it frequently leads to the discovery of fictitious networks, reducing the significance of the analysis. The chosen network should be able to record the change from low to high RES penetration rates while also allowing for full deployment. New technologies, such as energy storage and demand response systems, should be included. It should be flexible enough to represent a meaningful challenge while remaining stable under steady-state conditions. Finally, in terms of the line's capabilities, the reference system must incorporate some limits in terms of noting congestion, potential contingencies, and so on. It must also include some minimal structural capacity via keys, as well as the ability to realistically modify the structure [17]-[22].

Other research focuses on electric vehicles (EV) charging methods to prevent LV grid congestion and overloading. Vehicle to grid (V2G) technology was proposed by Shokrzade *et al.* [23] as a method to prevent grid asset overloading, such as transformers [23]-[25]. To alleviate congestion, Zhao *et al.* [26] developed a charging algorithm for electric vehicles (EVs) and a coordinated control method for EV and PV systems [26], [27]. Caramanis and Foster [28] developed a decision method for coordinated EV charging, which has an impact on feeder prices and congestion [28], [29].

Using various optimization and control methodologies, the influence of large-scale penetration and power production from various types of variable renewable energy sources on the system stability and dependability of distribution and sub-transmission networks is explored in [30]-[35]. Propose a stability index based on the voltage stability operation region that considers both active and reactive load depicts the voltage stability index in three dimensions, taking into account voltage instability as a function of active and reactive load/voltage [36]-[41]. The structure of the paper is as follows: Section 2 presents the main study of this paper, while section 3 describes the data repository by using DigSILENT power factory. Then, section 4 presents the studied grid along with the most relevant results. Finally, section 5 concludes the study of this work.

2. MAIN STUDY OF THIS PAPER

This report was prepared by a study of the static stability of the 15 bus system. The modelling and calculation process is carried out using the DigSilent software and includes:

a) A vital tool for diagnosing issues with the power systems network or grid is load flow analysis, commonly referred to as power flow analysis. A load flow analysis is performed to determine the equipment's condition and ensure that it is operating within the predetermined parameters.
b) Short circuit calculation: a short-circuit study is an electrical system examination that identifies the number of currents flowing during an electrical fault. The first step in verifying that the power system is safely protected is to compare these estimated values to the equipment ratings.
c) Voltage drop: voltage drop is the reduction in electrical potential along a current's course in an electrical circuit. Voltage drops in the source's internal resistance, across conductors, across contacts, and across connections are undesirable because some of the energy supplied is wasted.
d) Voltage angle: power factor, where I and V are the magnitudes of the RMS current and voltage values, determines the phase angle between the current and voltage waveforms. It is crucial to keep in mind that the phase angle which is the difference between current and voltage or between voltage and current must be the same.

3. MODELLING PROCEDURE IN DIGSILENT POWER FACTORY

Fifteen bus systems were modelled in DigSilent power factory. The solar PV system is connected to eachbus bar and Static loads are connected to each bus bar. The grid utility is connected to distribution point. Parameters of the inverters were obtained during the data collection phase, summarized in Table 1. The city-distributed system modelled in DigSilent is shown in Figure 1.

Table 1. Parameters of the PV plants

Parameters	Input values
Voltage, kV	0.22
Installed capacity, MVA	0.02
Power factor	0.9

3.1. PV plant data

Determining the size of a PV system connected to the grid begins with an estimate of the home's energy consumption. The summarized information of one solar PV system is provided in Figure 2. The estimated load profiles of a home’s energy consumption are provided in Table 2. The maximum active power for each home for the PV system and load is shown in Figure 3, Figure 3(a) presents the PV system maximum active power of each home.

3.2. Load data

Loads at bus bars are selected as per home electricity demand which includes TV, computer, refrigerator, and washing machine. The maximum electricity consumption is in house 1, which is 20 kW, while the minimum electricity consumption is 3 kW in house 15. In the simulation phase, the power consumption of each house is connected to the bus bars as a static load. All the data for load profiles are summarized and provided in Table 3. and load active power was obtained during the data collection phase shown in Figure 3(b).

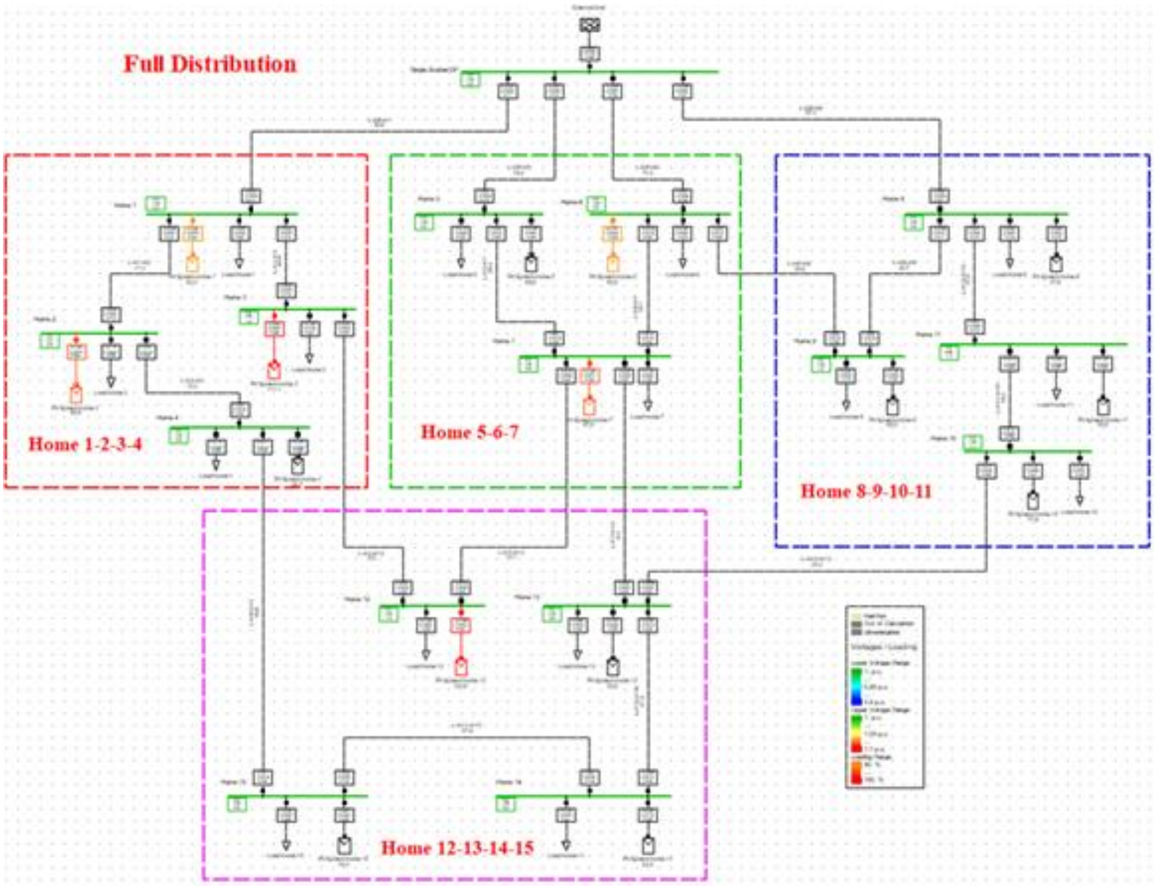


Figure 1. Distributed models in the city

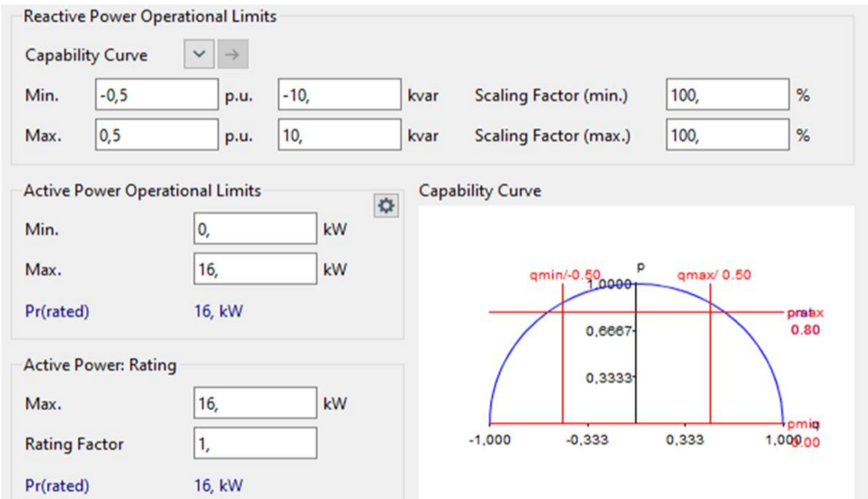
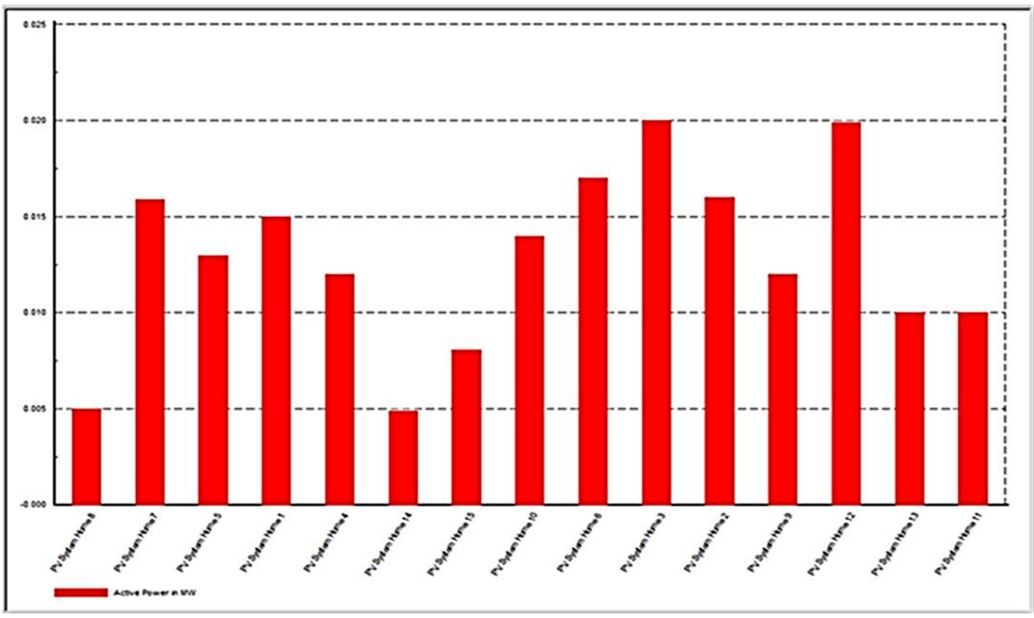


Figure 2. Parameters of one home connected solar PV

Table 2. The estimated load profiles of a home's energy consumption

PV System Home No.	Active power KW	Reactive power Kvar	Power factor
PV System Home 1	15	7.3	0.9
PV System Home 2	16	7.6	0.9
PV System Home 3	20	9.7	0.9
PV System Home 4	12	5.8	0.9
PV System Home 5	13	6.3	0.9
PV System Home 6	17	0	1
PV System Home 7	16	7.8	0.9
PV System Home 8	5	2.4	0.9
PV System Home 9	12	0	1
PV System Home 10	14	6.8	0.9
PV System Home 11	10	0	1
PV System Home 12	20	9.7	0.9
PV System Home 13	10	4.8	0.9
PV System Home 14	5	2.4	0.9
PV System Home 15	8	0	1



(a)

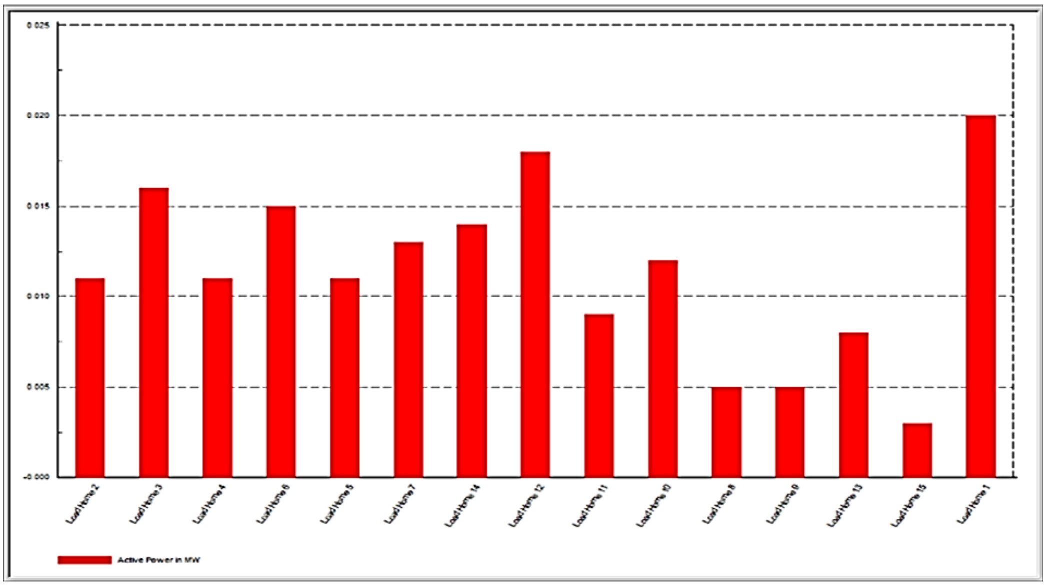


Figure 3. Maximum active power for each home (a) PV system and (b) load

Table 3. The estimated load profiles of a home's energy consumption

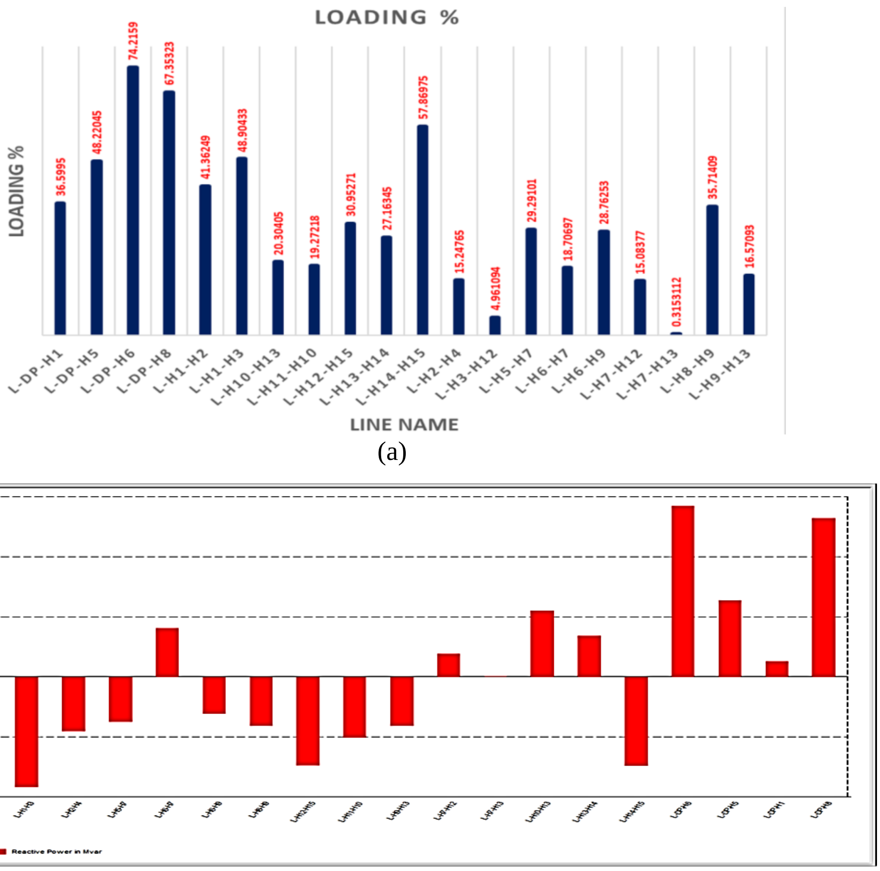
Load Home No.	Active power MW	Reactive power Mvar
Load Home 1	0.02	0.004
Load Home 2	0.011	0.006
Load Home 3	0.016	0.013
Load Home 4	0.011	0.006
Load Home 5	0.011	0.006
Load Home 6	0.015	0.006
Load Home 7	0.013	0.006
Load Home 8	0.005	0.003
Load Home 9	0.005	0.003
Load Home 10	0.012	0.007
Load Home 11	0.009	0.005
Load Home 12	0.018	0.006
Load Home 13	0.008	0.004
Load Home 14	0.014	0.007
Load Home 15	0.003	0

4. ANALYSIS AND RESULTS

The steady-state analysis is calculated using DidSilent power factory software. Provided in the section below. In this section the following cases will be discussed, load flow analysis, voltage drop and short circuit calculation.

4.1. Load flow analysis and voltage drop

A load flow study is an analysis of the steady stats of the power system grid is shown in Figure 4. Figure 4(a) carrying out a load flow study determines the operating state of the system for a given load. Phase angle voltage and phase angle, real and reactive power (on both sides in each line), line losses, and sag bus power are the results of the load flow analysis. Load flow analysis was carried out. Results of active power generation, reactive power generation, and power factor are summarized in Figure 4(b).

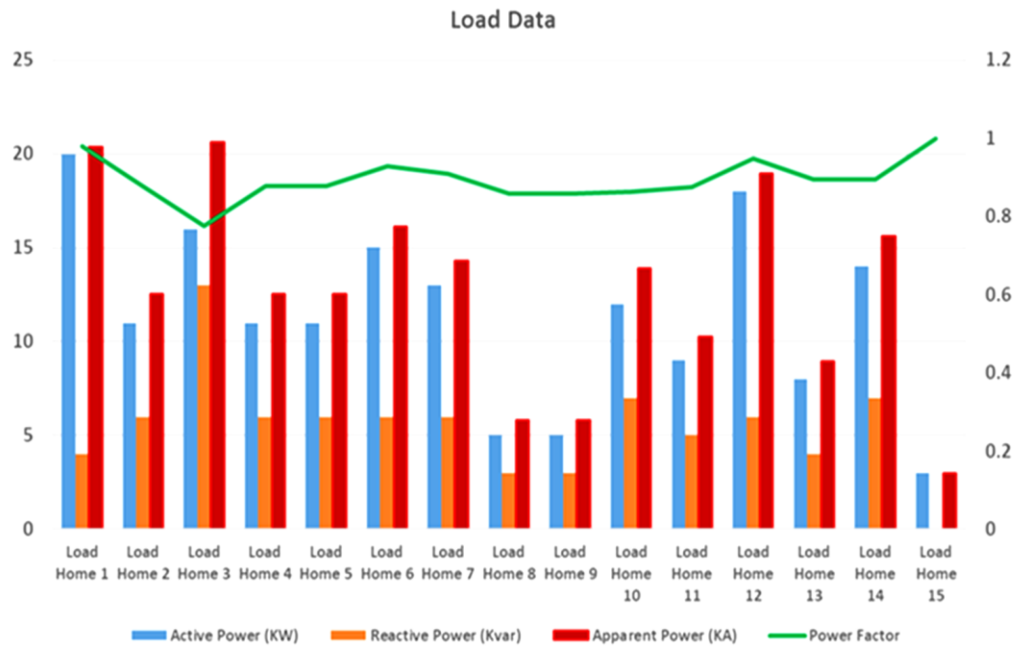


(a)

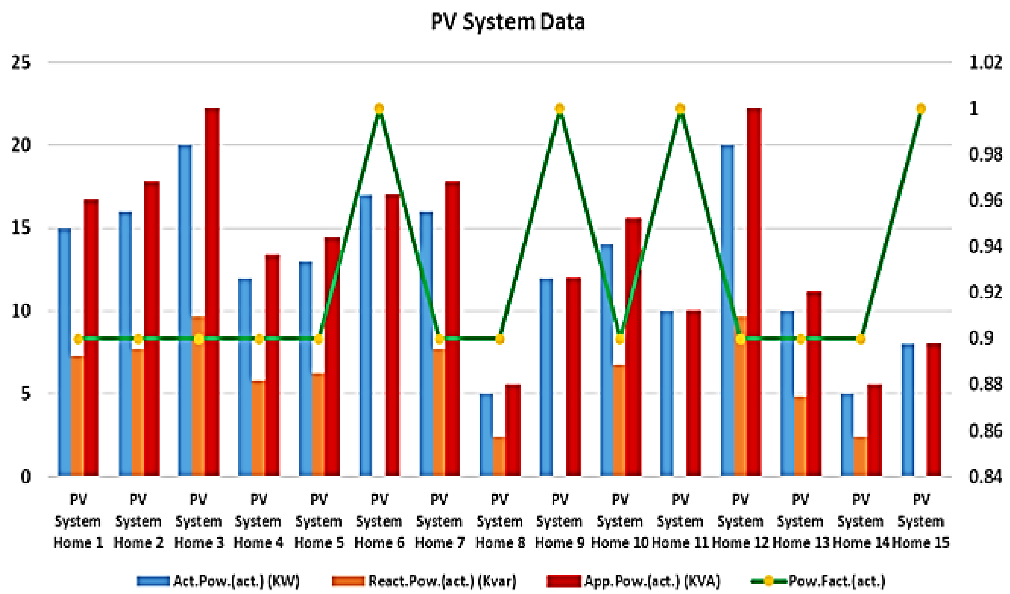
(b)

Figure 4. Loading values of (a) transmission lines and (b) transmission lines active power flow in MW

The objective of load flow calculation: the purpose of the load flow analysis is to identify the steady-state performance of the power system for a specified load and generator of real power and voltage conditions. To evaluate the loading of the power system equipment (transformers, cables, and OHTL) to make sure it is within acceptable limits. Load flow calculations were provided using DigSilent power factory software and obtained results are shown in Figure 5, for loads are provided in Figure 5(a) and for PV systems in Figure 5(b).



(a)



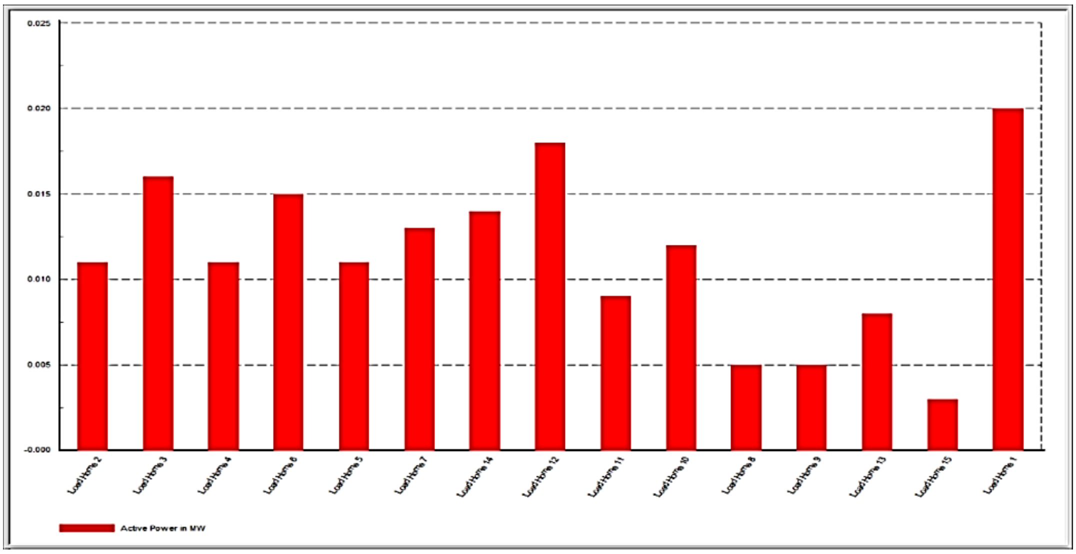
(b)

Figure 5. Load flow results by using DigSilent power factory for (a) load and (b) PV systems

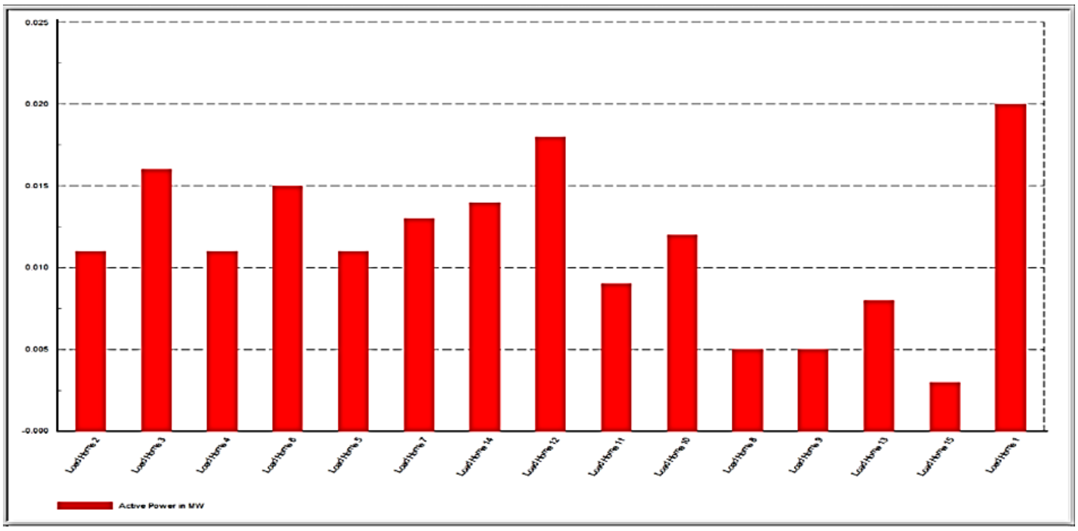
The PV system connected to home 3 is generating more power to keep the voltage within the accepted limits. The loading of transmission lines is provided in Table 4. According to the calculated results in Table 4, all data is within the accepted limits. Load flow results are provided in Figure 6. Load results: Figure 6(a) present the load active power and Figure 6(b) present the reactive power flow results.

Table 4. Loading of transmission lines data

Name	Terminal I Bus bar	Terminal j Bus bar	Loading %
L-DP-H1	Home 1	DP	36.5995
L-DP-H5	Home 5	DP	48.22045
L-DP-H6	Home 6	DP	74.2159
L-DP-H8	Home 8	DP	67.35323
L-H1-H2	Home 1	Home 2	41.36249
L-H1-H3	Home 1	Home 3	48.90433
L-H10-H13	Home 10	Home 13	20.30405
L-H11-H10	Home 10	Home 11	19.27218
L-H12-H15	Home 8	Home 11	30.95271
L-H13-H14	Home 13	Home 14	27.16345
L-H14-H15	Home 14	Home 15	57.86975
L-H2-H4	Home 2	Home 4	15.24765
L-H3-H12	Home 3	Home 12	4.961094
L-H5-H7	Home 5	Home 7	29.29101
L-H6-H7	Home 6	Home 7	18.70697
L-H6-H9	Home 6	Home 9	28.76253
L-H7-H12	Home 12	Home 7	15.08377
L-H7-H13	Home 7	Home 13	0.315311
L-H8-H9	Home 8	Home 9	35.71409
L-H9-H13	Home 4	Home 15	16.57093



(a)



(b)

Figure 6. Load results (a) active power flow results and (b) reactive power flow results

4.2. Voltage drop

A decrease in voltage is a decrease in the electrical potential in the current flow path of an electrical circuit. The drop in voltage on the source's internal resistance, on the conductors, on the contacts, and the connectors is not desirable because some of the energy input is wasted. Electrical load voltage drop is proportional to the power which can be converted into some other useful form of energy in that load.

The main objectives of voltage drop calculation to: i) evaluate the level of voltage during steady-state analysis to ensure that voltage drop is within the ±5% according to IEEE standard and ii) take actions (install reactive power compensators, change the position of the TAP) if voltage drop is not within the limits.

Figure 7 present the relation between the Bas bar voltage and angle. To prevent damage to the refrigerator, TV, air conditioning and, the home voltage level should be within the accepted limits. Voltage drop calculation results are provided in Table 5. As per the calculations in Table 5, It appears that the voltage drop on all bus bars is within the required limits. The voltage drop must be within ±5% in a normal regime according to IEEE standards. Voltage is the main indicator of power quality in-home electricity demand.

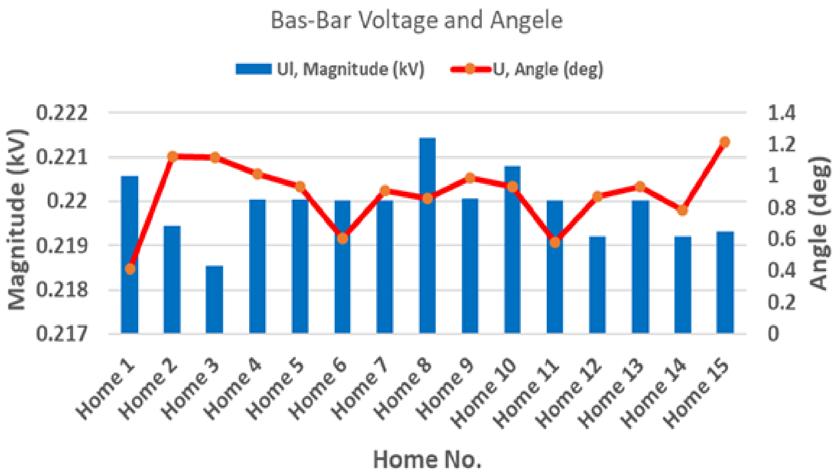


Figure 7. The bas bar voltage and angle

Table 5. Full system voltage drop results

Home No.	Nom. L-L Volt. KV	VI, Magnitude KV	U, Magnitude P. U.	U, Angle P. U.
DP	0.22	0.22	1.00	0.00
Home 1	0.22	0.22	1.01	1.97
Home 2	0.22	0.22	1.00	1.13
Home 3	0.22	0.23	1.03	2.91
Home 4	0.22	0.23	1.04	3.31
Home 5	0.22	0.22	1.01	1.32
Home 6	0.22	0.22	1.00	2.47
Home 7	0.22	0.22	1.00	2.53
Home 8	0.22	0.22	1.02	1.70
Home 9	0.22	0.23	1.04	3.41
Home 10	0.22	0.23	1.03	2.92
Home 11	0.22	0.23	1.04	3.15
Home 12	0.22	0.22	1.02	1.33
Home 13	0.22	0.23	1.04	3.36
Home 14	0.22	0.22	1.01	2.15
Home 15	0.22	0.23	1.03	2.30

4.3. Short circuit calculation

Short circuit protection is almost always required in electrical installations wherever there is an electrical breakdown. Most often this corresponds to the points where there is a break in the conductor cross-section. It is necessary to calculate the short-circuit current at every level of the electrical system to specify the characteristics of the installation required to withstand or trip the short-circuit current.

The main objectives of short circuit's current calculation: i) providing adequate overcurrent protection equipment in the distribution system that will prevent injury to personnel, minimize component damage, and limit the extent and duration of maintenance interruptions in the event of equipment failures; and ii) checking power distribution system facilities (circuit breakers, bus bars) to determine their ability to withstand short-circuit current.

IEC standard is selected to calculate short circuit current. Short circuit currents were calculated using DigSilent power factory software and obtained results are provided in Table 6. As per the short circuit current calculation, provided in Table 6, the three-phase short circuit current is around 1.72 kA and peak short circuit current is 3.28 kA. The following circuit breakers should be selected to withstand short circuit current and clear at:

- Distribution point: 2 kA circuit breaker with 5 kA peak current.
- Each home part: 4 kA circuit breaker with 10 kA peak current.

Table 6. Short circuit current results analysis results

Home No.	SKss" (MVA) KW	IKss" KA	Ip KA
DP	2.0	5.25	12.96
Home 1	0.6	1.614	3.07
Home 2	0.4	0.963	1.77
Home 3	0.5	1.3	2.42
Home 4	0.31	0.8	1.146
Home 5	0.6	1.65	3.15
Home 6	0.7	1.86	3.58
Home 7	0.7	1.72	3.29
Home 8	0.6	1.67	3.19
Home 9	0.5	1.32	2.46
Home 10	0.4	0.97	1.79
Home 11	0.4	1.06	1.96
Home 12	0.5	1.41	2.64
Home 13	0.4	1.18	2.19
Home 14	0.3	0.86	1.57
Home 15	0.3	0.81	1.48

RMS symmetrical short circuit current is equal to 1.414 times the maximum peak current at the moment of short circuit and gets normal in less than 0.1 sec (5 cycles). Fault clearing time should be equal to or less than 0.2 sec (10 cycles). In the end, the final summary of the results of the studied system can be seen in Figure 8.

```
| Load Flow Calculation                                                      Total System Summary |
| AC Load Flow, unbalanced, 3-phase (ABC)          | Automatic Model Adaptation for Convergence    No      |
| Automatic Tap Adjust of Transformers      No     | Max. Acceptable Load Flow Error for                    |
| Consider Reactive Power Limits            No     |   Nodes                                      1.00 kVA |
|                                                  |   Model Equations                            0.10 %   |

| Total System Summary                  | Study Case: Study Case           | Annex:              / 1 |
|
| No. of Substations    1     No. of Busbars     16     No. of Terminals      15     No. of Lines            20 |
| No. of 2-w Trfs.      0     No. of 3-w Trfs.    0     No. of syn. Machines  0      No. of asyn.Machines    0  |
| No. of Loads          15    No. of Shunts       0     No. of SVS            0                                |
|
| Generation        =     0.19  MW       0.07  Mvar      0.20  MVA |
| External Infeed   =    -0.02  MW       0.01  Mvar      0.03  MVA |
| Load P(U)         =     0.17  MW       0.08  Mvar      0.19  MVA |
| Load P(Un)        =     0.17  MW       0.08  Mvar      0.19  MVA |
| Load P(Un-U)      =    -0.00  MW      -0.00  Mvar                 |
| Motor Load        =     0.00  MW       0.00  Mvar      0.00  MVA |
| Grid Losses       =     0.00  MW       0.00  Mvar                 |
| Line Charging     =                     0.00  Mvar                 |
| Compensation ind. =                     0.00  Mvar                 |
| Compensation cap. =                     0.00  Mvar                 |
|
| Installed Capacity  =     0.24  MW |
| Spinning Reserve    =     0.00  MW |
|
| Total Power Factor:
|   Generation        =        0.94  [-] |
|   Load/Motor        =  0.90 / 0.00  [-] |
```

Figure 8. The final summary of the system

5. CONCLUSION

In this paper, a system consisting of 15 Bas bars with a photovoltaic system installed on each one is selected. The loads on the bus bars are chosen according to the power demand of the house. Since there are some problems with power quality and overloading in the real power system. The necessary calculations have been presented in this work so that everyone can understand the problems. For Steady study analysis, active and reactive power losses are very low which is acceptable, and As per the calculations, the voltage drop on all bus bars is within the required limits. The voltage drop must be within ±5% in a normal regime according to IEEE standards. For Short circuit current calculation, As per the short circuit current calculation, The phase short circuit current is around 1.72 kA and peak short circuit current is 3.28 kA. The following circuit breaker (CB) should be selected.

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