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Modeling of a Low Voltage Power Distribution Network of a University Campus

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Abstract

The use of renewable generation and demand response programs become a reality in the nowadays electricity markets and distribution networks. An intelligent energy management system is required in all levels of electricity supply chain, in order to efficiently profit from the distributed energy sources. However, before the implementation of the business models, the mathematical and simulation models should be well surveyed and verified. This paper presents a model of low voltage distribution network of a university campus developed in MATLAB/Simulink tools. Several types of resource modelings have been used in order to develop a reliable distribution network model. In the case study of this paper, the real consumption profiles of the buildings located in the university campus are provided to the developed model and the behaviors of the network components are surveyed.

Keywords: demand response programs, low voltage network modeling, microgrids, simulink

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1. Introduction

Nowadays, the network operators are forced to use efficient solutions for renewable energy sources due to the daily increment of energy demand [1]. Demand Response (DR) programs and Distributed Renewable Energy resources (DRERs) are two main concepts, which are appeared with the implementation of smart grids and microgrids. DR programs can be defined as altering the consumption profile of customers in response to the price variations or financial profits paid by the DR managing entity, namely aggregator [2]. This means the DR programs would aid the two sides of the network, including demand sides and network operators. There are two classifications for the DR programs: price-based and incentive-based [3][4].

The demand side customers utilize DR programs for reducing their electricity costs, and the network operator employs DR program to reduce the congestion of the grid and reduce the peak consumptions [5]. The integration of the DR programs with DRERs is the hot topic of research society since they can provide flexibility for the market negotiations [6]. However, the consumers should have enough capacity for consumption reduction in order to participate in the DR programs. This means the small and medium consumers should be aggregated and participated in the electricity markets as a unique resource [7][8]. Therefore, the role of this small and medium consumers should be well tested and validated through several models in order to identify future problems [9][10].

This paper presents a modeling of low voltage distribution network of a university campus considering DR programs and DRERs. The model is implemented in MATLAB/Simulink tools. Three types of loads has been tested in this model: A Series RL load, a Parallel load, and Dynamic load. Through several studies, it is found out that dynamic load is the best choice for network modeling of a university campus, somehow each building of the university is simulated by a dynamic load block. The model developed in MATLAB/Simulink is based on the real architecture of the transmission lines implemented in the area of the university, and all power loses, and impedances are considered in the model. In the case study of this paper, at first, the behavior of one specific bus in the network is surveyed while several load modelings are implemented in order to validate and select the best approach, considering response time and accuracy of the simulation. In the second stage, several scenarios investigate the reaction of the entire network in various conditions. The real consumption profile of each building is presented to the load model associated with that building, and the simulation results regarding the entire network as well as each consumer will be surveyed.

After this section, Section 2 presents the real university network and the developed Simulink model. Section 3 focuses on the case study description, and its results are provided in Section 4. Finally, the main conclusions of the work are explained in Section 5.

2. University Campus Modelling

The low voltage distribution network considered in this paper is related to a university campus in Porto, Portugal. This network consists of 21 buses, one bus for each building, connected via underground electrical lines with a total length of 3.350 km. There is an MV/LV transformer in BUS 21, which connects the campus network to the external supplier with the following features: 15kV / 400V-230V, 2050 kVA. Fig. 1 illustrates the network architecture indicating the location of the buildings, buses, and transmission lines. Also, Table 1 provides the electrical characteristics of the distribution network.

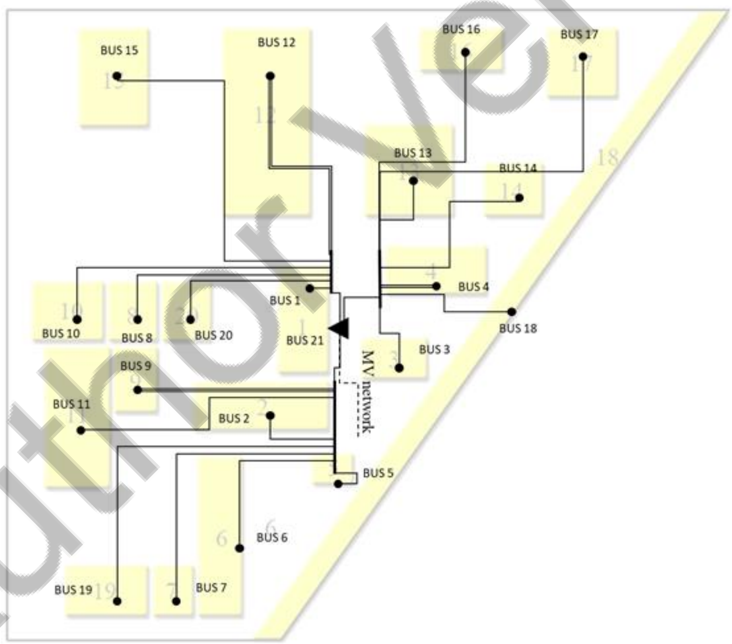

Fig. 44: Internal low voltage distribution network of the university campus.

Fig. 2 illustrates the setup of the network in the Simulink tool. As it was mentioned, the distribution network contains 21 buildings, which each building is modeled as a load. All the loads are connected through a branch that has resistance and an inductance value, as shown in Table 1. The three-phase loads provide the information regarding the voltages and currents, and therefore, the model would be able to calculate the number of power losses in the branches for different buildings of the university.

The network model is operated as 400 V and 1000 VA at a frequency of 50 Hz. Also, the source of the network is modeled as a three-phase source providing 400 V and 1000 VA at 50 Hz, which are based on the real data in the current form of the network. Moreover, as it can be seen in Fig. 2, the entire network buses are modeled with three-phase loads. BUS #18 that is the most distant bus from the supply, is surveyed with two different load models, including a series and a dynamic load. By this way, the most suitable load model is determined and used for the entire model.

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Table 13: Electrical charactriscits of university campus distribution network.

Line	Bus	Distance (km)	R (p.u)	X (p.u)	Maximum Power Limit (kVA)
1	21 – 1	0.04	1.67×10^{-4}	2.00×10^{-5}	121
2	21 – 2	0.07	6.96×10^{-5}	3.50×10^{-5}	276
3	21 – 3	0.08	2.47×10^{-4}	3.50×10^{-5}	143
4	21 – 4	0.135	4.16×10^{-4}	5.90×10^{-5}	133
5	21 – 4	0.135	4.16×10^{-4}	5.90×10^{-5}	133
6	21 – 5	0.080	1.97×10^{-3}	4.00×10^{-5}	37
7	21 – 6	0.085	6.79×10^{-5}	3.71×10^{-5}	316
8	21 – 7	0.155	2.26×10^{-3}	7.75×10^{-5}	52
9	21 – 8	0.135	2.89×10^{-4}	5.90×10^{-5}	170
10	21 – 9	0.170	5.24×10^{-4}	7.44×10^{-5}	133
11	21 – 9	0.170	5.24×10^{-4}	7.44×10^{-5}	133
12	21 – 10	0.175	1.37×10^{-4}	8.75×10^{-5}	251
13	21 – 11	0.115	3.54×10^{-4}	5.03×10^{-5}	143
14	21 – 12	0.195	2.39×10^{-4}	9.75×10^{-5}	240
15	21 – 12	0.195	2.39×10^{-4}	9.75×10^{-5}	240
16	21 – 13	0.105	1.28×10^{-4}	5.25×10^{-5}	238
17	21 – 14	0.215	1.98×10^{-3}	1.08×10^{-4}	69
18	21 – 15	0.245	2.25×10^{-3}	1.23×10^{-4}	69
19	21 – 16	0.255	7.86×10^{-4}	1.12×10^{-4}	133
20	21 – 17	0.240	1.88×10^{-4}	1.20×10^{-4}	251
21	21 – 18	0.085	1.24×10^{-3}	4.25×10^{-5}	52
22	21 – 19	0.155	6.47×10^{-4}	7.75×10^{-5}	121
23	21 – 20	0.115	1.06×10^{-3}	5.75×10^{-5}	78

As can be seen in Fig. 2, each load of the network is modeled by a group of three blocks. The blocks are a three-phase series branch, a three-phase measurement block, and three-phase series load. Also, the three-phase source located in BUS #21 supplies the loads and a three-phase V-I measurement block measures the main power input of the whole network.

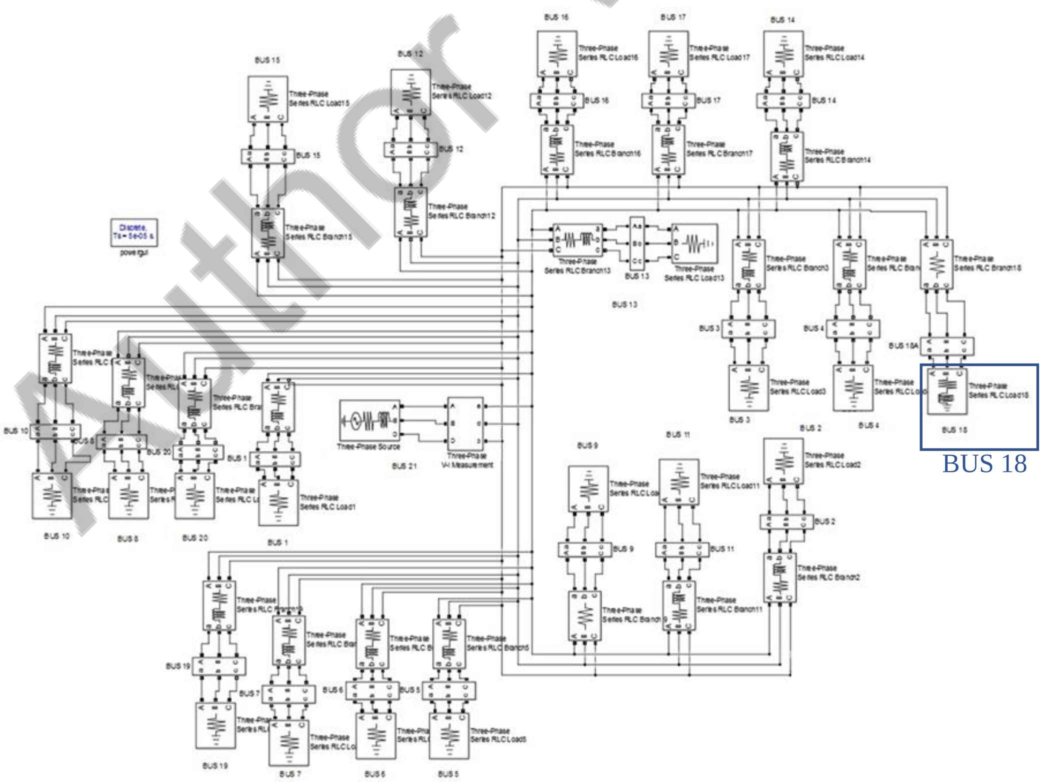

Fig. 2: Simulink model of the distribution network of the university campus.

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3. Case Studies

In this section, several case studies are implemented in order to test and validate the proposed network modeling. For this purpose, the behavior of the network will be surveyed in different conditions considering various rates of consumption.

At the first stage, the focus is given to BUS #18, which is the most distant bus from the power source. Three types of load modelings are considered for BUS #18 in order to survey the behavior of this specific bus. In the first test, a dynamic load is considered for BUS #18 while the rest of the loads are modeled as series loads consuming 100 kW, and in the second and third tests, a series and a parallel load is associated respectively for BUS #18 while the conditions are as same as the first test. The results of these three experiments would be illustrated and surveyed in the next section.

The second part of the case study is related to validate the performance of the developed model, while all the loads are modeled by dynamic loads. Three scenarios are considered for this section:

1. **Winter profiles**: the real consumption profile of each building on a winter day is considered for the network model;
2. **Summer profiles**: the real consumption profile of university on a summer day is considered;
3. **Off-peak**: the profiles would be as same as scenario 1, however, it is considered that the three most consuming buildings are not participating in the consumption profiles, since it is a public holiday and there are no classes in the faculty.

Fig. 3 shows the real consumption profiles of each bus (each building) considered for three scenarios. All the charts are stacked lines, which means the last line presents the total consumption of the network.

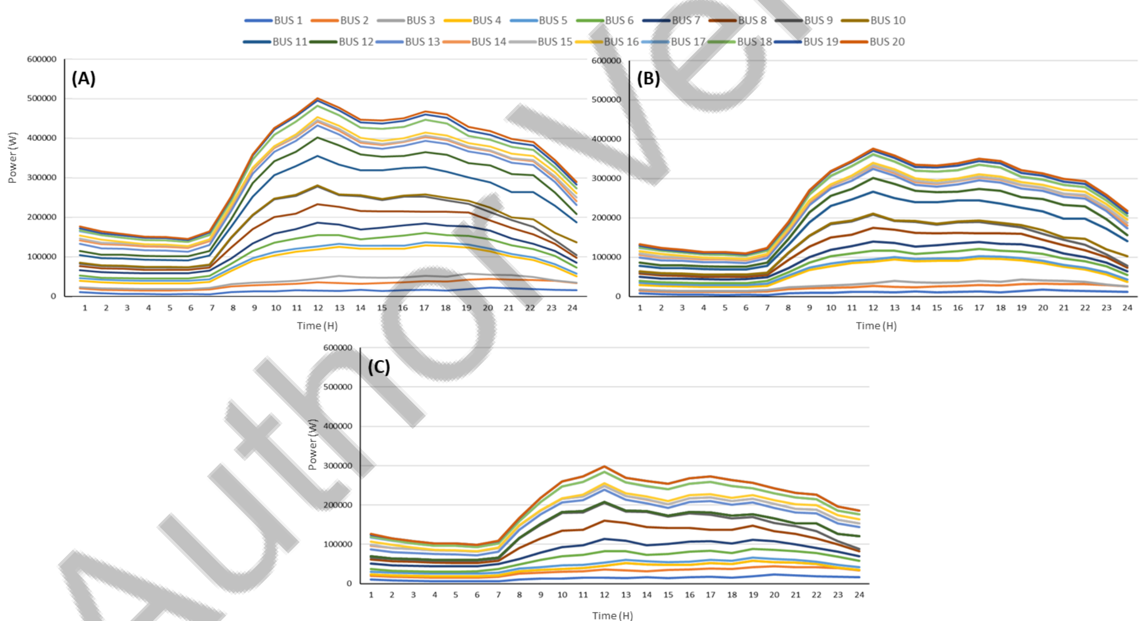

Fig. 3: The real consumption profiles of university considered for the case study in three scenarios: (A) winter profiles, (B) summer profiles, (C) off-peak.

As Fig. 3 shows, the profiles are for one day with a 1-hour time interval. The simulation is set to run each hour period values in a fixed-step size of 30 seconds. Therefore, the outcomes of simulations would be obtained in 12 minutes after it starts running.

4. Results

The present section shows the results obtained from the simulation described in the previous section. The first gained results are related to the performance of BUS #18 with three different load models. Fig. 4 shows the behavior of these load models in the first second of the simulation while there is 100 kW active power and 40 kVAR reactive power demand in BUS #18.

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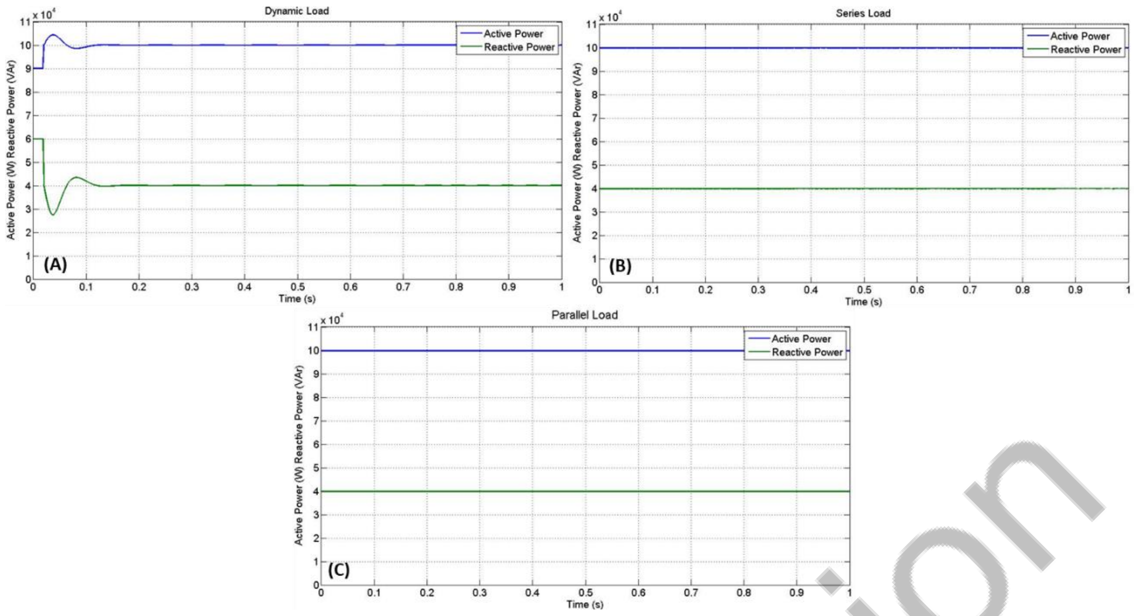

Fig. 45: Behaviour of BUS #18 in the first second of the simulation with three different loads modeling: (A) Dynamic load, (B) Series load, (C) Parallel load.

As Fig. 4 shows, the response of the dynamic load is slower to reach to its permanent state comparing to the other two load models that have similar behaviors. In the dynamic load, it takes 0.15 seconds for the reaching to the permanent state while the other two load models immediately reached the desired rate. Furthermore, Table 2 presents the power consumptions of loads and branches in BUS #18 at the end of the simulation. As it can be observed from Table 2, there are some internal losses in the series and parallel load model somehow, they do not allow the consumption rate to be as same as the desired rate. Also, the losses in the branch of the dynamic load are slightly higher than the rest of the loads.

Table 2: Power measurement regarding BUS #18.

	Measured Power		**Branch Power**		**Total Consumption**	
	P (W)	Q (VAR)	P (W)	Q (VAR)	P (W)	Q (VAR)
Dynamic Load	100000	40000	145,4	0	100145,4	40000
Series Load	99641,805	39857,541	144,5	0	99786,3	39857,54
Parallel Load	99642,372	39856,817	144,5	0	99786,87	39856,82

Another important difference between these models is to set the desired power rate. In Series and Parallel loads, the power consumption rate can only be set before starting the simulation, however, in the dynamic load model it can be changed throughout the simulation. These differences between the load modelings, especially the dynamic load, are due to the nature of the type of loads and blocks that are being used for the testing in the Simulink tool.

Regarding the results of the whole network, Fig. 5 shows the overall consumption of the network simulated by the developed model for the university campus distribution network in three scenarios mentioned before. In all three scenarios, the loads are modeled using dynamic load, since its outputs are closer to a realistic load and also it allows to change the power input while the simulation is running.

The results shown in Fig. 5, are for 12 minutes in total, which means each 30 seconds a new power consumption rate is transmitted to all loads and therefore, they react and try to reach the favorable consumption rate. Also, in the same figure, while the consumption rate is changed, there is a peak in active power, which is due to the nature of the dynamic load, as it was discussed in Fig. 4.

Based on the results shown on this section, it can be concluded that the developed Simulink model has adequate and acceptable performance in simulation, and the obtained results validated the functionalities of that in different conditions with the various rate of consumption.

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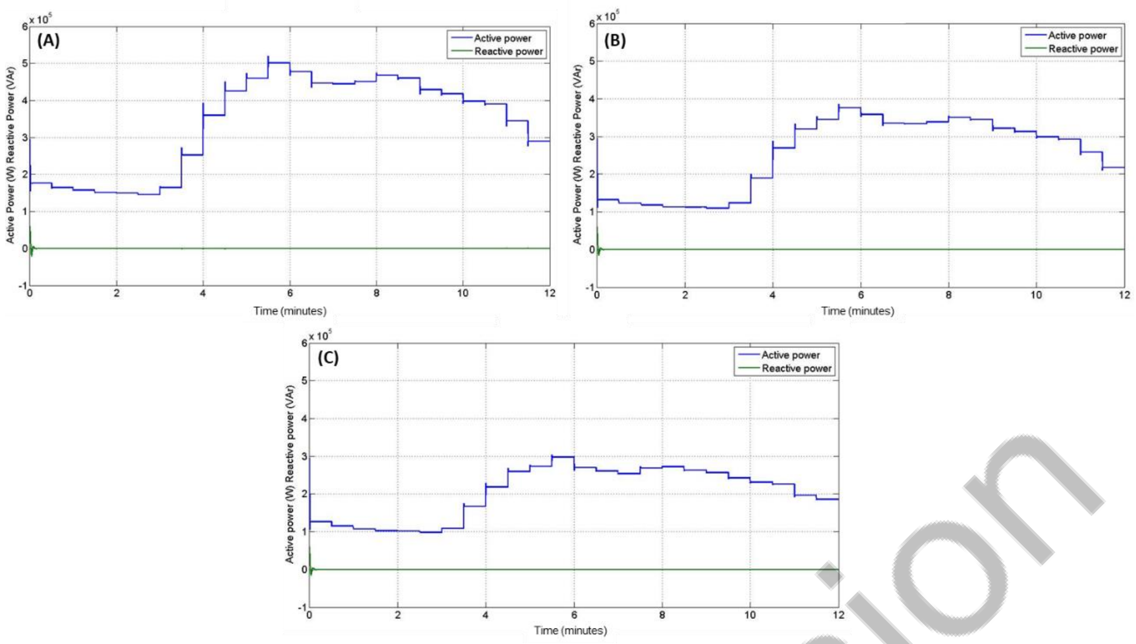

Fig. 5: Overall consumption of university campus network simulated by the developed Simulink model: (A) winter profiles, (B) summer profiles, (C) off-peak.

5. Conclusions

This paper presented a MATLAB/Simulink model of a low voltage distribution network of a university campus. Several load modelings have been surveyed and their performances in various conditions were demonstrated. The real consumption profiles of the university campus were used for the case studies through different scenarios. In the model, each building of the university was considered as a dynamic load for simulating the consumption rate. The results of the simulation show that three-phase dynamic load is the best approach for modeling the consumption of each building since it reacts closer to a realistic load. Moreover, the dynamic load model allows the user to modify and change the rate of consumption while the simulation is running, which this is not possible to implement using other types of load modelings.

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